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Engineering Analysis Report

Photographic Payload and Related Support and Test Equipment for MOL/DORIAN System

Volume I

Prepared by

EASTMAN KODAK COMPANY
Kodak Apparatus Division
Rochester, New York 14650

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J G Maher

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In addition see Volume II, [redacted]

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LIST OF ABBREVIATIONS*

AAC	Automatic Alignment Control
ATS	Acquisition telescope
ATF	Acoustic test facility
ACO	Administrative contracting officer
AS	Aerospace Corporation
AFE	Aerospace flight equipment
AGE	Aerospace ground equipment
ASE	Aerospace support equipment
AIM	Aerial image modulation
ADC	Airborne digital computer
AF	Air Force
ACS	Alignment control system
AMS	Alignment monitoring system
AO	American Optical
BIMAT	Bimat film
CATS	Camera assembly test sets
COA	Camera optical assembly
cg	Center of gravity
CM	Compatability model
CITE	Computer integrated test equipment
CDS	Command definition specification
CCN	Contract change notice
CDP	Contract definition phase
Hz	Cycles per second
DCU	Data conversion unit
DMS	Data management system

* The following listed abbreviations are not necessarily used in this report.

LIST OF ABBREVIATIONS (Continued)

DRV	Data re-entry vehicle
DRC	Data return container
DD	Department of Defense
DCCB	Design change control board
DCO	Design change order
EKC	Eastman Kodak Company
ETD	Edge thickness difference
EMC	Electro magnetic compatability
EMI	Electro magnetic interference
EMISM	Electro magnetic interferences safety margins
EDCTU	Electronic development compatability test unit
EAR	Engineering Analysis Report
EM	Engineering model
ECS	Environmental control system
FHE	Film handling electronics
FDR	Final design review
FVTL	Flight vehicle timeline
FCE	Focus control electronics
FCP	Focus control preamplifier
FS	Formula sample
FPDA	Fraction of planned data acquired
GE	General Electric Company
GFE	Government furnished equipment
H/SLS	Hardware/software limitations specification
IMC	Image motion compensation

LIST OF ABBREVIATIONS (Continued)

IVS	Image velocity sensor
IFOT	In-flight on time
ICN	Interface change notice
IP	Instrumentation processor
ITCPS	Integrated testing computer programming specification
KAD	Kodak Apparatus Division
LM	Laboratory module
LMCU	Laboratory module control unit
LMPU	Laboratory module power unit
LMQTV	Laboratory module qualification test vehicle
LMQM	Laboratory module qualfication model
LMTS	Laboratory module thermal simulator
LOCTP	Launch operations crew training plan
LV	Launch vehicle
M/A	Manned/Automatic
MOL	Manned Orbiting Laboratory
MDR	Major design review
MDAC-WD	McDonnell Douglas Astronautics Company-Western Division
MDAC-ED	McDonnell Douglas Astronautics Company-Eastern Division
MTTF	Mean-time-to-failure
MCC	Mission control center
MDAU	Mission data adapter unit
MM	Mission module
MMAS	Mission module aft section
MMA	Mission module assembly

LIST OF ABBREVIATIONS (Continued)

MMCU	Mission module control unit
MMFS	Mission module forward section
MMIP	Mission module instrumentation processor
MMPU	Mission module power unit
MMQM	Mission module qualification model
MMSE	Mission module simulation equipment
MMTS	Mission module test set
MPS	Mission payload system
MPSS	Mission payload system segment
MES	Mobile environment shelter
MTF	Modulation transfer function
NASA	National Aeronautics and Space Administration
NPC	National Photocolor Corporation
n mi	Nautical miles
NAA	North American Aviation
OCTOPUS	Operational computer programming specification
OA	Optical assembly
OAT	Optical assembly test
OQF	Optical quality factor
OV	Orbiting vehicle
PP	Photographic payload
PPS	Photographic payload system
PTE	Photographic test equipment
PM	Primary mirror
PDR	Preliminary design review
PLOT	Probable-launch-on-time

LIST OF ABBREVIATIONS (Continued)

PRL	Project requirements list
PCM	Pulse code modulation
QM	Qualification model
QC	Quality control
RFD	Reference focal distance
RC	Reliability components
STC	Satellite Test Center
SAFSP	Secretary of the Air Force Special Projects
STS	Sensor test system
SW	Sensor worth
SRC	Slant range compensation
SSB	Source selection board
SGLS	Space ground-link subsystem
SIR	Special industrial requirements
STE	Special test equipment
ST	Special tooling
SLS	Static load structure
SDM	Structural development model
SM	Support module
SEL	Systems engineering laboratories
SSE	System safety engineer
TA	Technical advisor
TEM	Technical exchange meeting
TIM	Technical interface meeting
TC	Thermal components
TDMS	Thermal data management system

LIST OF ABBREVIATIONS (Continued)

THM	Thermal model
TCA	Time of closest approach
TBD	To-be-determined
TBR	To-be-resolved
TM	Tracking mirror
ULE	Ultra-low expansion
VAFB	Vandenberg Air Force Base
VO	Visual optics
VOA	Visual optics assembly
VOAC	Visual optics assembly control
XEPS	Xenon energy projection system
X-IMC	Across-the-format Image Motion Compensation
ZI	Zone of the interior

INTRODUCTION

This is the third in a series of engineering analysis reports prepared in accordance with paragraph 3.12.7 of SAFSP Exhibit 11-22, Phase II Work Specification, F-004953-IH, dated 20 July 1966, as amended and line item 7 SAFSP Exhibit A, Revision 4, DD Form 1423 to Contract AF 18(600)-2864. The report presents an analysis of the design for the photographic payload (PP) and related support and test equipment for the Manned Orbiting Laboratory (MOL)/Dorian System as of 1 September 1968. The PP is the Eastman Kodak Company (EKC) furnished portion of the aerospace vehicle equipment for the MOL/Dorian Program.

Section 1 of the report describes the PP flight configuration and mission. Sections 2 and 3 discuss system requirements applicable to the PP and define interfaces with other contractors respectively. Hardware design and justification for selected approaches are covered in Section 4. Automatic mode concepts are discussed in Section 5. Section 6 discusses test methods and facilities, aerospace support equipment (ASE) and developmental models. A discussion of reliability is contained in Section 7 and system safety engineering is discussed in Section 8. A detailed numerical summary appears in Section 9 and several appendices provide supplemental information to the report.

The primary mission of the MOL System is the MOL/Dorian mission which is to perform high-resolution photographic intelligence gathering against specific targets of interest.

The PP is designed in two configurations, manned/automatic mode and automatic mode. The manned photographic mission, designated manned/automatic (M/A) mode, is being designed, and will be qualified, for a 30-day mission duration. EKC is conducting a study of the unmanned configuration, designated automatic mode. Automatic mode hardware configuration and design consideration will be included in future issues of the engineering analysis report.

SECTION 1

FLIGHT CONFIGURATION AND MISSION DESCRIPTION

1.1 MANNED ORBITING LABORATORY (MOL)/DORIAN FLIGHT VEHICLE CONFIGURATION

The flight vehicle consists of the Titan III-M (TIII-M) and the orbiting vehicle (OV). The manned/automatic (M/A) configuration is shown in Figure 1.1-1.

1.1.1 Titan III-M

The TIII-M launch vehicle consists of a two-stage liquid-propellant core vehicle, two 120-inch-diameter strap-on solid-propellant rocket motors and a liquid-fueled transtage.

1.1.2 Orbiting Vehicle

In the M/A mode, the OV consists of a Gemini B, flight-crew equipment, and a laboratory vehicle (LV). In the automatic mode, the OV consists of a support module (SM) and the LV.

1.1.2.1 Gemini B. The Gemini B consists of a re-entry module, adapter and blast shield. The Gemini-B re-entry module is a National Aeronautics and Space Administration (NASA) Gemini spacecraft with minimum modification and has a 30-day orbital capability as an integral part of the OV. The Gemini B is capable of controlled earth orbit, loiter, re-entry, and water landing as an autonomous spacecraft.

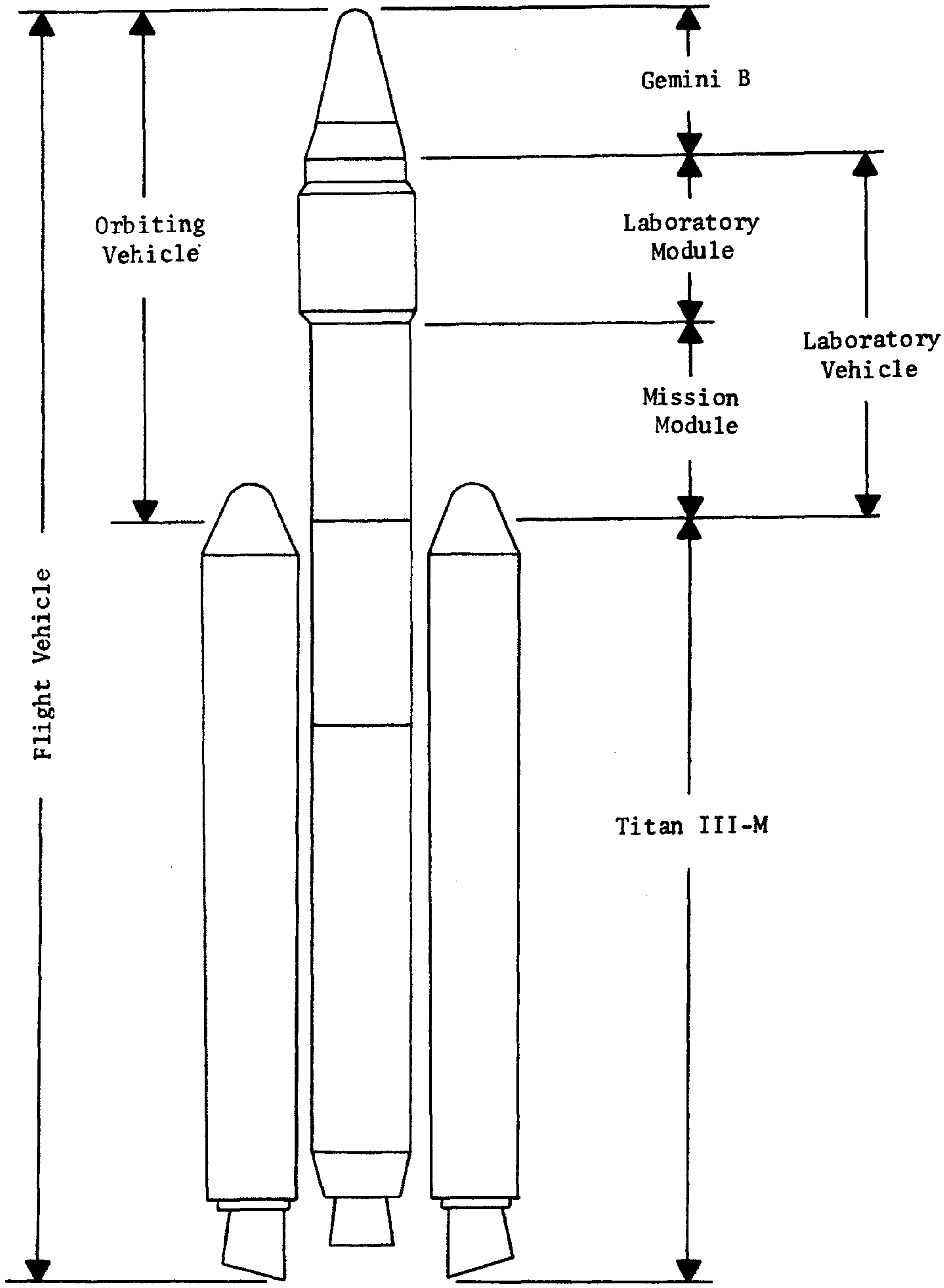

Figure 1.1-1. MOL/Dorian Flight Vehicle Configuration - Manned/Automatic Mode

1.1.2.2 Support Module (SM). In the automatic mode, the Gemini B is replaced by a SM. The SM consists of a tank section module [which is part of the laboratory module (LM)], a recovery section which includes the data re-entry vehicles (DRV's), film handling system, and fairing section.

1.1.2.3 Laboratory Vehicle. The LV consists of two modules; the mission module (MM) and the laboratory module (LM).

a. Mission Module. The MM contains the following major photographic payload (PP) equipment:optical assembly (OA), tracking mirror (TM) and mount, and the camera optical assembly (COA) mount set. The MM also contains the following major equipment provided by the associate contractor: TM gimbals and drive, TM enclosure, and TM-enclosure thermal control.

b. Laboratory Module. The LM contains environmental control, life support, attitude control, power generation, communications, vehicle-status monitoring, and photographic mission equipment.

1.2 OBJECTIVE AND MISSION DESCRIPTION

1.2.1 Objective

The principal objective of the MOL/Dorian reconnaissance system is to provide the capability for obtaining stereo photography with [redacted] ground resolution or better under certain specified conditions in a manned or unmanned configuration.

1.2.2 Sequence of Major Mission Events

In the M/A mode, the MM is assembled at Eastman Kodak Company (EKC) and shipped to the LV integrating contractor for mating to the LM, thereby forming the LV. The LV is then shipped to the pad for mating with the Gemini B and the TIII-M. The flight vehicle will be launced from the Western Test Range into an orbit which will be selected for maximum reconnaissance information while respecting program constraints. During the ascent to orbit and the early revs, the flight crew will be in the Gemini B. Later, the flight crew will transfer to the LM by way of a pressurized tunnel. The flight crew will assist in the performance of the photographic mission from the LM.

After the flight crew enters the LM, the OV will be controlled by commands from the Mission Control Center (MCC) supplemented by flight-crew-initiated over-ride controls. The MCC will be at the satellite test center (STC) in Sunnyvale, California, and will exercise control over all aspects of the mission.

After the photographic mission, the flight crew will return to the Gemini B, separate the Gemini B from the LM, de-orbit, re-enter, and be recovered. Photographic film is returned with the Gemini B.

1.2.3 Mission Requirements and Constraints

The PP is designed to photograph targets anywhere on earth between 80° North and 80° South latitude where sufficient illumination is available. Targets can be photographed on northbound and southbound passes.

The PP is capable of operating within the following mission constraints:

a. Mission Duration. The PP is capable of performing missions of 30-days duration either with a two-man flight crew or with automatic equipment without flight crew. Orbit sustenance is provided to achieve the required orbit lifetime.

b. Photographic Altitude. Photographic altitude will range from 70 to 230 nautical miles (n mi). Nominal altitude is 80 n mi perigee and 180 n mi apogee. Perigee altitude can range from 70 to 85 n mi; apogee will be less than or equal to 230 n mi. Nominal perigee location will be 55 degrees N latitude. The eccentricity will not exceed 0.0225.

c. Orbit-Plane Inclination. Operation is required for orbit-plane inclinations ranging from 80 to 100 degrees. The nominal is 90 degrees for the M/A mode.

d. Sun-Elevation Angle for Photography. The minimum acceptable sun-elevation angle at the target is 5 degrees.

e. Beta Angle. The PP is designed to operate within a beta-angle range of ±60 degrees. The beta angle can vary within this range during the mission. The beta angle is the angle between the earth-sun line and its projection in a plane perpendicular to the orbital plane.

1.3 DESCRIPTION OF THE PHOTOGRAPHIC PAYLOAD

The PP includes a 70-inch-diameter aperture, [redacted] focal-length optical assembly, a TM which reflects light rays from the ground scene into the optical assembly, a frame camera to record the image, associated film handling, automatic optical alignment, camera focus control, camera control functions, visual optics, processor, and viewer. During photography, the

TM is initially driven by ground commands and updated by the image velocity sensor (IVS)* (with flight-crew inputs for partial correction of rate errors if required) to follow a ground target so that the target image in the camera focal plane remains virtually stationary at the format center. The tracking control system is the responsibility of an associate contractor. The camera has a focal plane shutter of variable slit width for controlling exposure and the capability for partial off-axis image motion compensation (IMC). The camera is used to perform a sequence of exposures at commanded times.

The camera contains a secondary platen in the M/A mode. The prime purpose of this secondary platen is to use special film types (that is, black-and-white for on-board processing, color, infrared color, high-speed black-and-white). Film type selection is controlled by a crewman, but only one secondary film type can be used during a photographic pass. The secondary platen is not required to have off-axis IMC.

The PP includes variable magnification visual optics (VO) which allow a crewman to view the ground target through the primary optics. The VO enable a crewman to detect residual image motion (tracking-rate error) at the center of the optical field and reduce this error by manually fine-tuning the TM rate.

An on-board processor is provided to process a limited quantity of film for flight-crew evaluation on the on-board viewer.

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* The IVS is the responsibility of an associate contractor.

Figure 1.2-1 shows the MM, LM, and Gemini B configuration for the M/A mode.

The MM in the automatic mode is the same as the MM in the M/A mode. The LM in the automatic mode differs from the LM in the M/A mode by the deletion of the VO, processor, viewer, secondary platen, and associated electrical equipment; and by the addition of film handling equipment to transport film from the camera to the DRV's in the SM and of appropriate electrical equipment.

Figure 1.2-2 shows the MM, and a typical LM and SM configuration for the automatic mode.

1.3.1 Mission Module Assembly (MMA)

The MMA consists of the following major assemblies:

a. MM Structure Assembly.

b. Optical Assembly (OA). When the camera is mounted to the OA, the combination is called the COA. However, only the OA is located in the MM.

c. COA Mount Set.

d. Tracking Mirror (TM) Assembly.

1.3.1.1 MM Structure Assembly. The MM structure assembly is a cylindrical shell structure consisting of two major assemblies joined at the assembly break at station (Sta) 345. The two major assemblies are the mission module forward section (MMFS) assembly and the mission module aft section (MMAS) assembly. The forward end of the MM interfaces with the LM and the aft end of the MM interfaces with the TIII-M.

1.3.1.1.1 Mission Module Forward Section. The MMFS is furnished to EKC with the TM drive, thermal coatings and blankets, view-port door, and associated mechanisms. EKC assembles the TM to this assembly before mating the MMAS and MMFS.

1.3.1.1.2 Mission Module Aft Section. The MMAS consists of a thermally finished MM structure, flight instrumentation, and the OA attached to the MM structure by A-frame mounts.

1.3.1.2 Optical Assembly. The OA consists of the lens assembly, thermal control components, electrical control equipment and instrumentation, and cabling.

The lens assembly consists of the primary mirror, diagonal mirror, Ross-corrector lens assembly, alignment assembly, COA structure assembly, and the primary mirror launch locks (see Figure 4.2-1). The function of the lens assembly is to form an image of the ground scene at the film plane. Light rays pass from the ground scene to the tracking mirror, then to the primary mirror and return to the Newtonian diagonal mirror; from the Newtonian diagonal mirror the light rays go to the Ross folding mirror, and then through the Ross-corrector elements to the image plane (see Figure 4.1-1). The alignment equipment is included in the optical assembly to correct optical misalignment while on-orbit. Optical misalignment is corrected by actuating servos which move the primary mirror and/or the Ross folding mirror as required. Primary mirror launch locks support the primary mirror so that stresses on the mirror during launch are within the design tolerance.

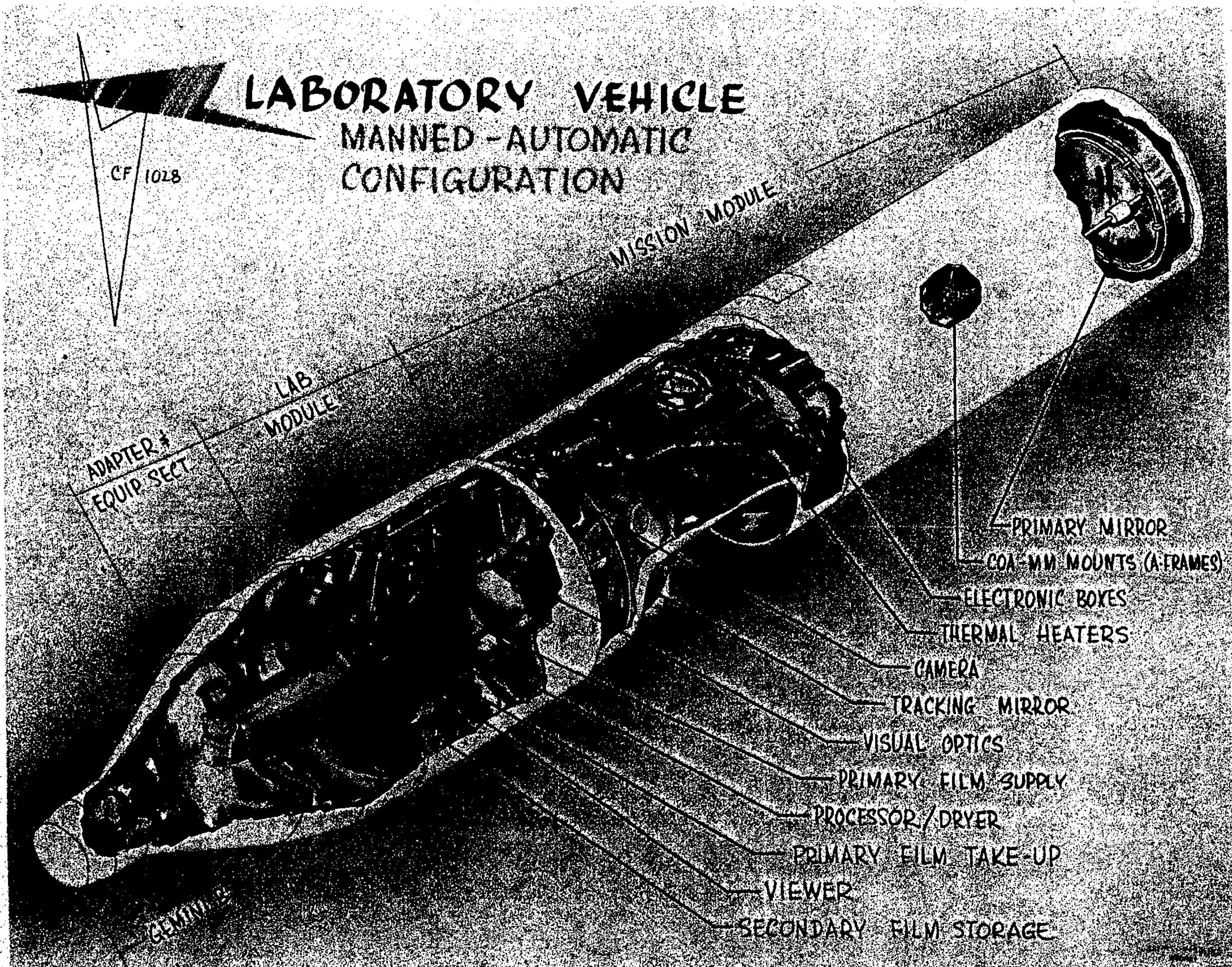


Figure 1.2-1. Orbiting Vehicle M/A Mode

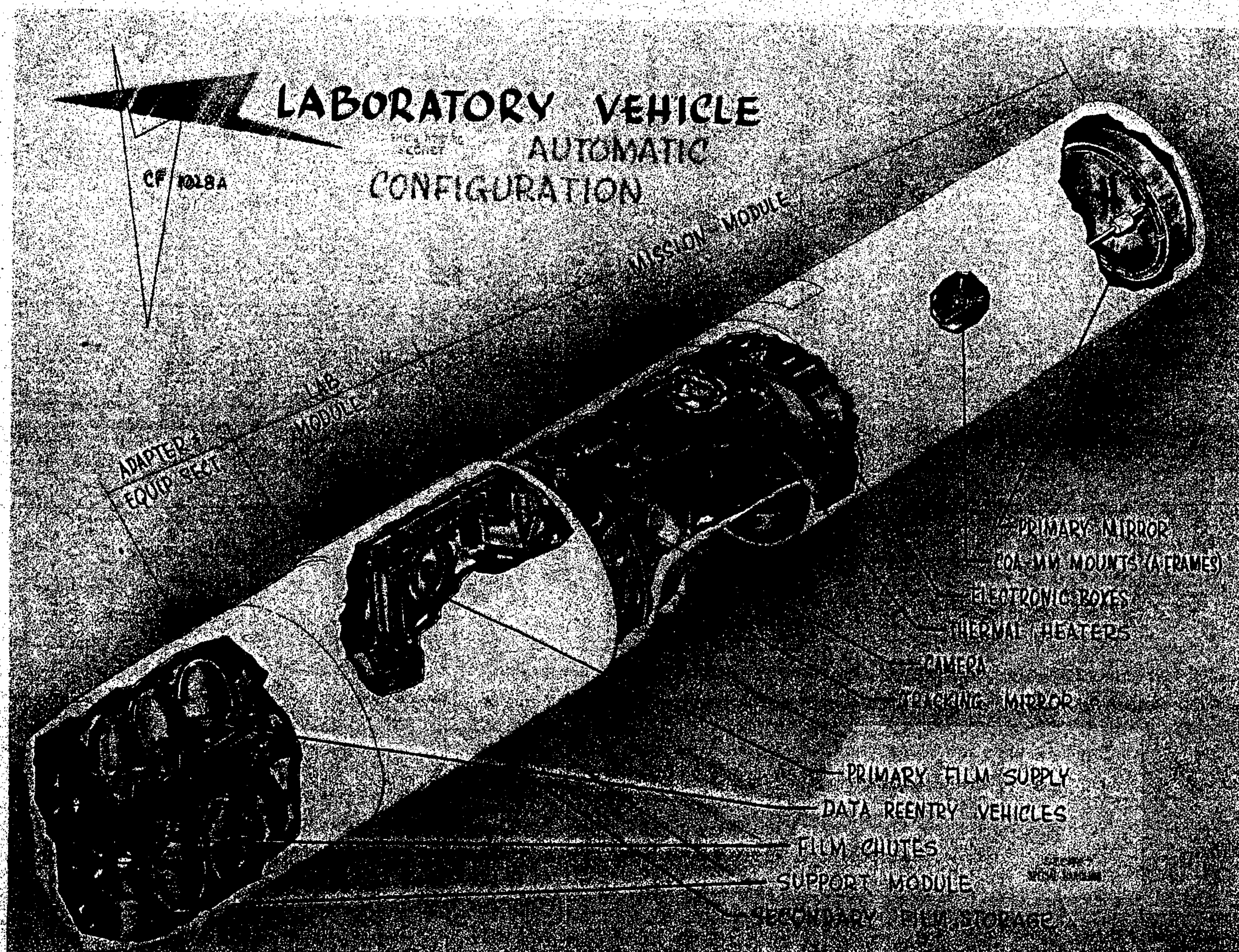


Figure 1.2-2. Orbiting Vehicle-Automatic Mode (Typical)

Accurate thermal control is included in the OA because the imaging properties of the lens components are sensitive to temperature variations. The thermal control components consist of heaters, heater controllers, insulation, and surface coatings.

Electrical control equipment is included in the OA to provide the necessary controls for operation of the lens assembly and launch-lock assemblies.

Instrumentation is provided in the optical assembly both for use by the flight crew and for telemetry to the ground.

Cabling is provided in the OA to support OA control and instrumenation requirements.

1.3.1.3 <u>The Camera Optical Assembly Mount Set.</u> The COA is supported within the MM structure assembly by means of a set of three Unibal mounts. The primary function of the COA mounts is to hold the COA in such a manner that deformations of the MM shell cannot produce strain in the optical assembly structure. The mounts also carry the COA load through the launch environment without permanent deformation of the COA, the MM shell, or the mounts themselves. Thermal conductance of the COA mounts is designed to be low to limit the heat transfer from the MM shell to the COA.

1.3.1.4 <u>Tracking Mirror Assembly</u>. The TM assembly includes the TM, TM mount, and launch locks. The TM is a 70-inch-diameter plano mirror. The TM assembly is mounted to a TM drive mechanism supplied by an associate contractor.

1.3.2 Laboratory Module (LM) Assemblies

The LM contains the following major assemblies and related electronics:*

a. Film handling

b. Processor

c. Viewer

d. Visual optics

e. Camera assembly

1.3.2.1 Film Handling. Film handling consists of the film supply, take-up cassettes, and equipment required to supply film to the camera assembly and to transport and store film when it is not in the camera assembly. Film chutes, drives, control and logic, cutters and splicers are also included.

One supply cassette contains the primary film. Three take-up reels are used sequentially to receive the exposed, primary film. A data return container (DRC) is used to store and house each reel of exposed primary film through the balance of the orbital, re-entry, and retrieval phases of the mission.

Secondary film is supplied in five supply cassettes. Three of the cassettes could contain special infrared color, high-speed black-and-white, or color film. The secondary film to be processed on-board will be supplied in the other two cassettes. Three take-up cassettes store and house the exposed special secondary film until completion of its use. Two DRC's are used to store and house secondary films for recovery.

* LM assemblies for the M/A mode only are described in this paragraph.

1.3.2.2 Processor. The on-board processing equipment includes the processor which processes batches of 9½-inch-wide High-Definition Aerial black-and-white film. When the film is ready for processing, it is drawn from the processor supply cassette and is laminated to Kodak BIMAT film. After the correct contact period, the BIMAT film is stripped from the processed photographic film and is fed onto a take-up reel as waste. The processed negatives advance through a drying chamber to attain correct relative humidity level. After drying, the negatives are wound onto a core to await use by a crewman.

1.3.2.3 Viewer. The on-board viewer is used to evaluate the film which has been processed on-orbit. An illuminated table, a comparison microscope, and a manually operated film advance mechanism comprise the viewer system.

1.3.2.4 Visual Optics. The VO assembly is basically an optical relay which presents an aerial image formed by the primary optical assembly to the flight crew for visual inspection. The VO equipment includes variable (fixed step) magnification assemblies, image derotation prisms, an eyepiece at each of two viewing stations, and an alignment reticle. The purpose of the VO assembly is to enable centering and tracking of targets, visual reconnaissance and optical alignment.

1.3.2.5 Camera Assembly. The purpose of the camera assembly is to place film at the image plane and provide selected exposure, focus and IMC to accomplish the recording of a high-resolution optical image with a maximum of fidelity within the allotted time. In the M/A mode, the camera can handle either of two strands of film (primary or secondary), as commanded.

will, on command, perform appropriate positioning to place the mirror in the correct optical location for focus monitoring. The focus drive assembly consists of drives and controls which, upon command, position the film plane with respect to the optical image plane by movement of the platen for correct focus.

1.3.2.5.5 Data Recording Assembly. The data recording assembly consists of a programmable array of light sources capable of recording, on command, numerical and digital data in a data-block format on the film.

1.3.3 Support Module Assemblies

The EKC provided assemblies in the SM consists of film handling equipment; film chutes, DRV take-ups, and film cutters/sealers.

SECTION 2
SYSTEMS CONSIDERATIONS

This section presents a discussion of the factors which influence the performance of the photographic payload (PP) and thereby form the basis for hardware and software requirements.

2.1 REQUIREMENTS OF THE PHOTOGRAPHIC MISSION

2.1.1 General Requirements of the Dorian System

The PP will be compatible with the following Dorian system objectives:

a. High reliability and safety

b. Nadir, on axis ground resolution of [redacted] under the following conditions:

   1. apparent contrast ratio of 2:1
   2. 80 nautical miles (n mi) altitude
   3. using a film having the resolving power of Type 3404 Film and an exposure index of 6.
   4. average minimum scene luminous emittance of 890 foot-lamberts.
   5. focus error of 0.001 inches (1 σ).
   6. angular smear rate of [redacted]/sec.
   7. using D-19 single-level equipment processing.

Unless specifically stated otherwise, all references to resolution in this report will be under these conditions.

c. Total capacity of 15,000 frames (primary and secondary frames) of specified targets in the manned/automatic (M/A) mode during a 30-day mission life.

d. The capability for exposing special films including color, infrared color, and high-speed black-and-white in the M/A mode.

e. On-board processing and viewing of black-and-white film in the M/A mode.

f. Photographic film return by data re-entry vehicles (DRV's) in the automatic mode and by the Gemini B capsule in the M/A mode.

g. High-magnification visual system incorporating the large aperture of the photographic system in the M/A mode.

2.1.2 Requirements for Major Photographic Payload Functions

The following paragraphs present an over-all view of the major requirements of the PP. In addition, each hardware and system description section of the report details many more specific requirements and the approaches being used to implement them.

2.1.2.1 Photo-Optical Quality. The on-axis static nadir resolution requirement for the lens and tracking mirror (TM) combined is [redacted] geometric mean, to meet the system resolution objective.

2.1.2.2 Camera Operations.

2.1.2.2.1 Frame Sequencing. The frame camera and film handling equipment must permit a sequence of up to 10 frames to be made of a target, at a frequency as high as one frame per second. Film recharge and camera setup operations must permit photography to be started for a new target within 5 seconds of completion of the last frame of the prior target.

A dual platen assembly in the M/A mode camera is used to interchange film so that either of two strands can be selectively registered to the image plane. Capability must exist to interchange strands such that the time between exposure start of a primary frame and exposure start of a succeeding secondary frame (and vice versa) will not exceed two seconds.

2.1.2.2.2 Off-Axis Image Motion Compensation (IMC). Residual off-axis image motion is present in the field even when the target is perfectly tracked on-axis. This off-axis motion is partially compensated in the camera through the use of a linear platen jog and synchronized shutter motion. Compensation is provided for the primary platen only.

2.1.2.2.3 Focus Control. A focus sensor is used to sense errors in the position of the platen with respect to the focus plane and also to provide the resulting signals to a display for possible corrective action. Focus sensing will be accomplished during nonphotographic periods.

The focus sensor and the control of focus-error-inducing contributors permit the over-all focus error to be held within ±0.002 inch. The on-board computer will be programmed to initiate platen adjustments to compensate for varying slant range, with an adjustment granularity of 0.0006 inch.

2.1.2.2.4 Exposure Control. A wide latitude of exposure modulation is provided by the camera to permit acceptable photography under the diverse luminance conditions expected during the mission. Exposure time is selectable for each frame from a set of eight values over a range of 0.0025 to 0.04 seconds.

2.1.2.2.5 Edge Data. Data defining the operational parameters are photographically encoded on each frame to aid the user in identifying and interpreting the photographs. Quantitative data are encoded within a rectangular format and consist of both binary-coded information and numerics. During the mission, these quantitative data are also fed to an associates equipment for recording on magnetic tape and subsequent transmission to the ground by telemetry.

Fiducial marks are used to delinlate the circular image boundary to establish an angular reference datum and to enable the user to establish the format center location of each photograph.

Interframe marks registers the midpoint between frames.

2.1.2.3 Visual Optics (VO). The VO provides one crewman at a time with the capability of viewing a target while it is being photographed. Separate stations are provied for each crewman. Magnification from the VO will be variable in four fixed steps over a range from [redacted] Magnification is held fixed during a photographic sequence to control power consumption and to avoid dynamic disturbances.

The angular resolution requirement is 2.0 arc-minutes or better within the central part of the field for the primary station, and 2.4 arc-minutes or better for the secondary station.

2.1.2.4 <u>On-Orbit Optical Alignment</u>. An alignment control system is provided to sense and correct on-orbit optical misalignment between the Ross-corrector optical axis and the primary mirror optical axis. The system permits this misalignment to be reduced to less than 14 arc-seconds equivalent primary mirror tilt error. The Ross-mirror drive must be capable of moving the edge of the Ross mirror 0.1 inch. The primary mirror drive must be capable of moving the edge of the primary mirror 0.3 inch.

2.1.2.5 <u>Launch Locks</u>. Launch locks provide a means for supporting the primary and tracking mirrors and the VO in the one-g state and during launch.

2.1.2.6 <u>Instrumentation and Command Requirements</u>. The PP has adequate instrumentation to reliably monitor the functional status of the payload components. Redundant instrumentation is provided for mission-critical functions to ensure that no single instrumentation failure could cause a curtailment of the mission or reduction in flight crew safety.

Uplink commands are generated at the mission control center (MCC). These commands are then transmitted to one of the tracking stations for subsequent transmittal to the orbiting vehicle (OV). Commands transmitted to the OV will either be executed when received (real-time commands) or stored in the memory of the on-board computer for execution at a later time (stored-program commands). Stored-program commands are executed when the vehicle-clock time coincides with the time label assigned to the command word.

Normal operation of PP equipment requires that some commands transmitted from the ground be augmented by commands which are generated from pre-stored routines in the on-board computer. Manual controls, including a computer keyboard control, are provided on-board to enable the flight crew to control selected PP functions.

2.1.2.7 On-Board Processing Requirements. The processor is designed to process batches of 9.5-inch-wide High-Definition Aerial Film with an ESTAR thin base (TB) or ultra thin base (UTB) support. The resolution of each negative exposed by the secondary camea and processed on-board is expected to be no more than 15 percent lower than that of a negative exposed by the same camera under the same conditions and BIMAT processed on the ground. Control of the processor is completely in the hands of the flight crew and the processor electronics logic.

2.1.2.8 Film Handling. The film handling system transports film to and receives film from the camera assembly at controlled rates and tensions. The film handling equipment must also, in general, provide for the storage and protection of the photographic record throughout the mission.

2.2 MODES OF OPERATION

The PP is designed in two configurations, manned/automatic (M/A) and automatic. In the M/A mode, a flight crew is aboard to assist in photographic operations, supplementing automatic control equipment. No flight crew is flown in the automatic mode; all control operations are fulfilled with automatic equipment under the direction and monitoring of the Mission Control Center (MCC) at the Satellite Test Center (STC).

2.2.1 Manned/Automatic Mode.

A primary duty of the flight crew during a photographic pass is to enhance the technical intelligence value of photography through a target selection process utilizing the acquisition telescope (ATS). This selection process allows the crewman to interdict the preprogrammed path of the primary optics if weather or target activity increases the intelligence value of an alternate target. The flight crew will have the responsibility for checking out the operation of the automatic equipment, such as the image velocity sensor (IVS), thereby assisting in the early development of an automatic system. As a backup to automatic equipment, the flight crew can assist in tracking, centering, or other functions. During nonphotographic portions of the orbit, the flight crew will be responsible for activities such as handling film, processor operations, and evaluation of on-board processed photography. On-board displays and controls are provided for checking and assisting in correction to optical alignment and focus, and monitoring payload equipment status.

Film handling equipment is designed for an optimum blend of mechanical and manual transport features. Primary film is automatically fed from a single supply reel to and from the camera and onto a take-up reel. The flight crew transports reels of exposed film, in special containers, to the Gemini-B module for data return. Secondary film is automatically transported within the camera and manually handled to load/unload, change film types or place in containers for data return.

An on-board processor and viewer provide the crewmen with the capability for viewing processed film. Telemetry exchange is used for two-way ground-command/flight-crew verbal communication.

2.2.2 Automatic Mode

The orbiting vehicle (OV) in the automatic mode consists of the same mission module (MM) as used for the M/A mode, a modified laboratory module (LM) and a support module (SM). Sensors are provided to enable lens alignment and focus adjustment to be made by remote control from the ground. The image velocity sensor (IVS) is used in closed loop as a fine control of tracking rate to reduce on-axis smear to acceptable levels.

Film handling is based on reliable mechanical transport of film from a single supply roll through the camera into data re-entry vehicles (DRV's) in series. The DRV's can be ejected from the OV to permit periodic return of the film.

2.2.3 Operational Capabilities

The PP is versatile in terms of operational use. During a given pass, up to 10 frames of each target can be exposed at frame intervals as short as 1-second. This permits stereo views to be acquired and permits exposure bracketing. Effective resolution is improved by making possible simultaneous viewing of several photographs of the same target. Versatility in target programming is enhanced by the short (5 second) time required to set up the camera and film supply for photographing a new target.

The primary film used in both the M/A and automatic modes is high-resolution black-and-white film. In the M/A mode, exposures on special film (color, infrared-color, or high speed black-and-white) can be made during the same target sequence in which high-resolution black-and-white exposures are made. Only one special film type can be used to supplement the high-resolution black-and-white film in a given photographic pass because of the time required to change from one special type to another.

A possible single-target 10-frame sequence is shown in Figure 2.2-1. The figure shows the Dorian use of exposure bracketing in frames 4 through 6, with one-stop under nominal exposure, nominal exposure, and one-stop over nominal exposure (see paragraph 2.4.2.3). Frame 5, which occurs at the nadir look position, provides [redacted] ground-resolution under the conditions specified in paragraph 2.1.1. Frame 10 depicts the versatility of using special films during a 10-frame sequence. Pairs of photographs from a sequence can be combined to provide a stereo view of the target (the minimum acceptable stereo convergence angle is generally considered to be about 15 degrees). This stereo view will have the resolution of the better frame of the pair. Thus, for example, frames 5 and 10 of Figure 2.2-1 could be combined to provide a high-resolution color/black-and-white stereo pair.

Versatility of use of the PP is provided with regard to target coverage. It is a system requirement that all targets between 80° N latitude and 80° S latitude be accessible at least three times in a 30-day mission. An additional coverage feature in the M/A mode is the ability of the flight crew to exercise visual surveillance of target areas.

Focus adjustment to accommodate slant range changes permits correct focus for all permissible viewing angles within an altitude span of 70 to 230 n mi. An exposure-time range is provided by the camera to permit photography with the high-resolution black-and-white film at solar altitudes as low as 5 degrees.

2.3 MISSION OPERATIONS (MANNED/AUTOMATIC MODE)

This section describes the mission phases which affect PP operations and provides information concerning the necessary functions which must be performed for initiation and maintenance of high-resolution photography.

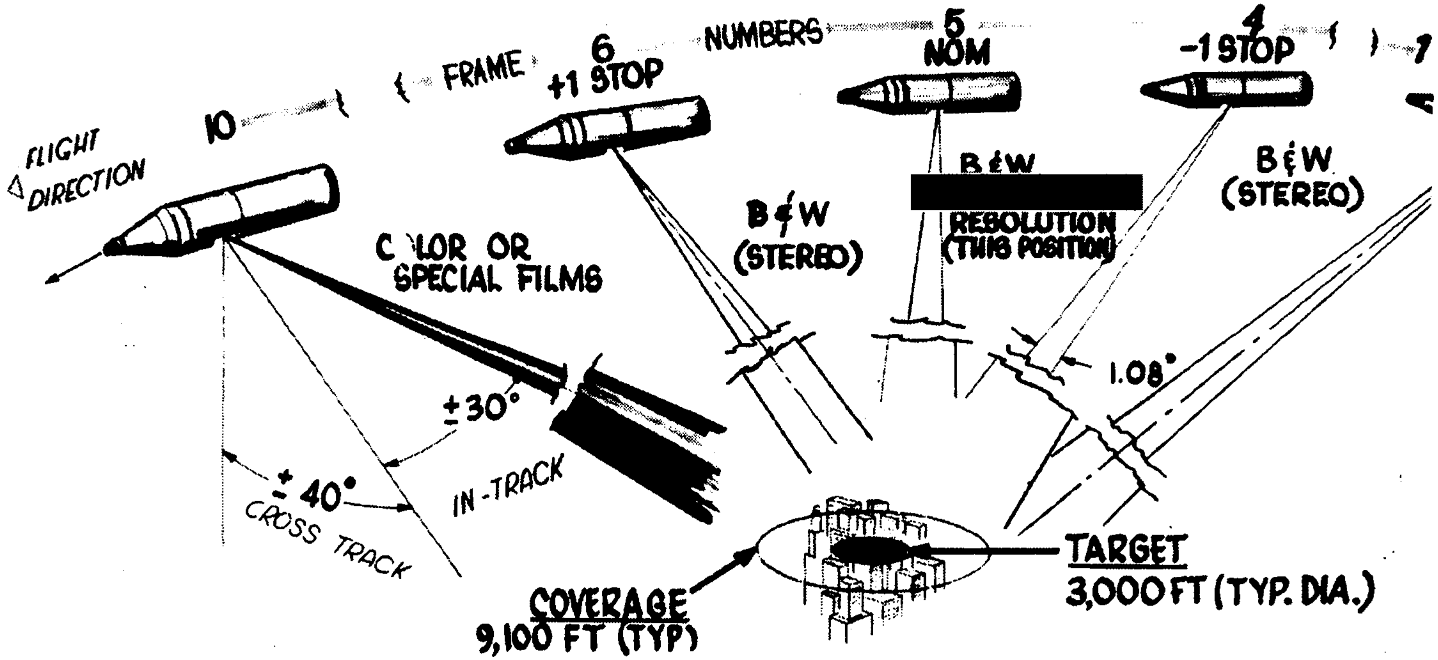


Figure 2.2-1. Dorian Objectives (Photographic Operations)
(M/A Mode)

2.3.1 Mission Operational Phases

2.3.1.1 Pre-Launch Phase. The period from arrival of Aerospace Flight Equipment (AFE) at Vandenberg Air Force Base (VAFB) to start of countdown. This phase includes assembly of the flight vehicle (FV) at the launch pad where checkout and countdown will be performed.

2.3.1.2 Launch Phase. The period from start of countdown to FV liftoff (exclusive).

2.3.1.3 Ascent Phase. The period from FV liftoff to initiation of OV separation from launch vehicle.

2.3.1.4 Early Orbit Phase. The period from the initiation of separation to closing of the LV hatch by the second crewman following transfer from the Gemini B.

2.3.1.5 Orbit Phase. The period from closure of LV hatch (exclusive) to the opening of LV hatch for final transfer of the first crewman to Gemini B.

Active PP operations occur only during the early orbit and orbit phases of the mission. However, during the launch and ascent phases the PP will require monitoring of unique launch and ascent instrumentation (vibration points, for example) and certain PCM telemetry (thermal points, launch lock status, etc.) via ground support to provide information on the functional status of various PP components and equipment. The primary purpose of these data is to ascertain payload health.

During on-orbit operations the PP is set-up, checked out and calibrated, and targets are acquired and photographed. The exact sequence of operations required in performing the initial set-up, check-out, and calibration (that is, initialization) of the PP is a function of the flight-vehicle launch date and launch hour, ephemeris (including resultant land-mass over-flights, sun altitude, and remote tracking station (RTS) availability), weather conditions at the land masses overflown, associates hardware considerations, and the AF requirements/philosophy governing early photo-graphy. Some operations, such as release of launch locks, are performed on a once-per-mission basis during initialization; other operations, such as optical alignment checks and focus sensing, are repeated routinely to ensure optimum PP performance throughout the mission.

Target photography includes all operations of the PP which are necessary for selection, acquisition, centering, tracking, and photography of a target. In the normal operating mode of the M/A configuration, the flight crew assists in target selection and all other photographic operations are performed automatically. A detailed description of target-selection procedures is given in paragraph 2.3.4.1.

Additional PP operations using the flight crew are required to support photography. These operations fall into the following functional categories.

a. Primary film handling operations

b. Secondary film handling operations

c. Processor operations

d. Viewer operations

e. Equipment-status monitoring

2.3.2 Operational Sequences and Scheduling Considerations

Operational sequences which are required prior to initial photography and/or routinely thereafter to optimize photographic performance are outlined in the following paragraphs. Some scheduling considerations are also discussed.

2.3.2.1 Launch Locks.

a. Mirror Launch Locks - Launch locks are provided for both the primary and tracking mirror to prevent damage during launch and ascent. The launch locks must be released prior to aligning the primary optics, making focus adjustments or initiating photography. It is anticipated that the launch locks will be released in the early orbit phase of the mission, before flight-crew transfer, via pad-loaded commands. Because of power considerations, the launch locks on the two mirrors must be released serially.

b. Visual Optics Assembly (VOA) Launch Locks - The VOA is supported by launch locks to prevent damage during launch and ascent. During this phase the VOA is structually independent of the primary optical assembly and must be manually unlocked after flight-crew transfer to allow the spring-loaded assembly to move into its operating position.

2.3.2.2 Primary Optics Alignment. Optical misalignment of the primary optics assembly on-orbit may occur because of stresses encountered during launch and ascent, including the change from one-g to zero-g loading, and effects of the vehicle's orbital environment. This misalignment, which must be detected and corrected prior to initial primary optics focus sensing or photography, can be represented as an equivalent primary mirror decentering error and an equivalent primary mirror tilt error. These errors are detected by an electro-optical alignment sensor and corrected by an appropriate primary optics alignment check and adjustment sequence in one of the following three modes of control.

a. Remote - In the remote mode of alignment control the alignment errors, detected by the alignment sensor, are read out via telemetry, analyzed by ground support personnel, and corrected via ground command.

b. Automatic - In the automatic mode of alignment control the alignment sensor, upon flight-crew or ground command, detects the alignment errors. The sensor electronics corrects the misalignment by a closed-loop system which is repeated once. Automatic alignment is expected to be the primary mode of control after confidence in its operation in an orbital environment has been established.

c. Manual - In the manual mode of alignment control the alignment errors are viewed through the VO by a crewman and corrected by a crewman using manual controls on panel 1-C. The alignment errors, detected by the alignment sensor, are also displayed on panel 1-C.

2.3.2.3 Focus Compensation. Displacement of the film emulsion plane from the primary optics plane of best focus is called focus error and will result in degraded photography. Focus errors may arise as a result of the following:

a. Inability to accurately establish orbital focus on the ground.

b. Stresses on the primary optics and/or camera during launch and ascent, including the change from one-g to zero-g loading.

c. Long-term orbital environmental effects (thermally induced structural bending for example).

d. Short-term orbital environmental effects (that is, distortion of optical elements during door-open periods).

e. Target slant-range changes during a target sequence.

Focus compensation, designed to eliminate focus errors resulting from the above causes (except item 4) is provided by two methods:

a. Focus Sensing and Correction - Used before a target sequence to initiate focus and to correct focus errors resulting from stresses and environmental effects.

b. Slant-Range and Film-Type Compensation - Used during a target sequence to compensate for slant-range and film-type changes.

2.3.2.3.1 Focus Sensing and Correction - This method of focus compensation involves the measurement of the location of the primary optics plane of best focus (PBF) using a focus sensor which is hard-mounted to the camera platen-drive assembly. A mirror is inserted into the optical path to divert the image from the film plane to the focus sensor. Focus errors are corrected by either (1) physically adjusting the location of the primary optics PBF by moving the primary mirror in translation along the optical axis until the PBF coincides with the film emulsion plane, or (2) instructing the on-board computer to assign a new reference focal distance (RFD) which, indirectly, causes the film platen to be driven along the camera optical axis so that the film emulsion plane is coincident with the primary optics PBF. Primary mirror movement will probably only be required for focus correction during PP initialization, if at all;platen movement will generally be used for focus correction after initialization.

Focus Sensing Sequence - The focus sensing sequence must be initiated by (stored) ground command and requires that the tracking mirror be pointed at a predetermined ground path. One of the acquisition telescopes should be programmed to allow the flight crew to evaluate and annotate scene content and weather conditions during the focus-sensing operation. The annotation of scene content and weather condition is made through the flight-crew voting logic buttons and the voice recorder. The flight crew should also be free to observe the focus-error displays on panel 1-C, to annotate focus data, and to make focus corrections if instructed to do so.

Modes of Focus Correction - Focus correction is an open-loop operation which can be controlled in two modes.

a. Remote Mode - In the remote mode of control, ground support personnel analyze telemetered focus-sensor data; after analysis, focus correction instructions are sent to the vehicle either via the command link or by voice. In the case of voice instructions, the focus corrections are performed by the flight crew using the airborne digital computer (ADC) keyboard. The remote mode of control will be the mode normally used during a mission.

b. Manual Mode - In the manual mode of control the flight crew evaluates the focus sensor readings displayed on panel 1-C, and initiates the necessary corrective operations (either primary mirror movement or updating of computer RFD) via the ADC keyboard.

2.3.2.3.2 Slant-Range and Film-Type Compensation - The on-board computer automatically calculates slant ranges (from ephemeris and tracking-mirror-position data) and the shift in the PBF resulting from slant-range and film-type changes for each frame of photography during a target sequence. This computer calculation results in the generation of a command to drive the film platen to the correct position along the camera optical axis so that the film emulsion plane coincides with the PBF for each photographic exposure. This command is executed between exposures so that the film platen is stationary in the direction of the camera optical axis during the actual shutter travel. Focus corrections (from analysis of focus sensor data) which result in updating the computer RFD, change the base to which compensation for slant range is added.

2.3.2.4 Visual Optics (VO) Assembly Focus. VO focus adjustments must be made before the VO can effectively be used for visual reconnaissance, image tracking and centering, or primary optics alignment. The sequence of operations required is as follows:

a. Check VO eyepiece for correct focus setting.

b. Manually focus the VO on the VO reticle.

c. Manually focus the VO reticle on a ground scene by appropriate use of control on panel 1-C.

Eyepiece settings should remain stable during the mission and probably will not need readjustment. Focus on the reticle should remain relatively stable and will require infrequent adjustments. Focus of the VO on a ground scene will need to be checked periodically, particularly whenever the primary mirror is moved during alignment or focus adjustments.

2.3.2.5 Zone of the Interior (ZI) Photography. After primary optics alignment and focus, and VO set up, a series of primary and/or secondary frames can be exposed and processed to check the performance of the photographic system. For maximum effectiveness, this photography should be over the ZI and should include CORN targets if time-line requirements permit.

2.3.2.6 PP Health Checks. The following functions should be included in health checks performed routinely to ensure optimum photographic performance:

a. PP instrumentation readout

b. PP electro-mechanical equipment checks

The frequency with which these functions should be checked during a mission will depend on how these parameters actually vary in an orbital environment.

2.3.3 Photographic Operations

This paragraph contains a brief discussion of the current operational concepts for target selection in the M/A mode. It further describes a set of photographic sequences typical of the type which might be used for the MOL/Dorian mission.

2.3.3.1 Target Selection. Target selection is normally accomplished through a combination of ground-based mission-planning software and flight-crew inputs to the on-board computer. The target path of the primary optics is generated by the mission-planning software, based on factors such as user requirements, OV operational status and capabilities, specific intelligence requirements, and weather in the area of interest. Those targets which lie on the programmed path of the primary optics are called primary targets. In addition, the mission planning software selects a series of alternate targets for each primary target based on their geometric relationship to the primary optics path, expected value of mission enhancement, and specific user requirements. Each primary target and its associated set of secondary targets are called a target group. The function of the flight crew, when all automatic systems are operating correctly, is to view the primary and alternate targets in each group using the two acquisition telescopes (ATS). The flight crew will then make one of four possible inputs to the ADC for each of the targets viewed in the group. These inputs to the computer are:

a. REJECT - used to denote any undesirable condition (such as clouds) which would prohibit satisfactory photography of a target.

b. INACTIVE - denotes that the target is visible, but that no activity indicators are present.

c. ACTIVE - denotes that the target is clear and that the predefined activity indicators are present.

d. OVERRIDE - used to denote unusually high intelligence value in a target. This input will cause the computer to commit the primary optics to that target without regard to any flight-crew inputs for other targets in the group.

If the primary target is not viewed by the flight crew, the computer will assume it to be clear and inactive. If an alternate target is not viewed, the computer will automatically reject it. The ATS will slew to the next target scheduled for viewing within a target group only after one of the four possible flight-crew inputs is made to the ADC. Associated with each target group is a decision time, which is generated by the mission-planning software. When the decision time is reached, the flight-crew inputs are polled by the ADC and, based on on-board decision logic, a decision is made whether to interdict the primary optics path in favor of an alternate target. Once the decision time is reached, the ATS's will automatically step to the next target group (unless the flight crew intervenes). Thus, photography of the selected target will occur simultaneously with viewing of the next target group.

In the event of a malfunction in the automatic systems, it will be necessary for one or both of the flight crew to assist, in some way, to accomplish successful photography. These malfunctions may involve automatic functions such as tracking and centering of the target or on-axis image motion compensation (IMC). In these situations the ability of the flight crew to view alternate targets may be severely limited.

2.3.3.2 Target Sequences. Each target selected for photography by the flight crew/computer is photographed using a preprogrammed sequence. The nature of the sequence for each target is determined from considerations such as user requirements (expressed as target priorities) and specific intelligence requirements (for example, desired stereo convergence angles and exposure bracketing). It is also possible for the flight crew to inhibit part or all of the preprogrammed sequences and to initiate exposures of the planned target from panels 2 and 8.

Table 2.3-1 gives a list of 5 exposure sequences. These sequences represent preliminary Eastman Kodak Company (EKC) thought on the general type of sequences which might be used for the MOL/Dorian mission. Included in the information for each sequence is the type of target for which the sequence could be used. The sequences in Table 2.3-1 are given in terms of time from the time of closest approach (TCA) to the target. The first two sequences are intended for use on targets which contain little or no significant stereo information. Therefore, targets of this type should be photographed at or near the maximum rate (1 photograph/second) with as many photographs as possible in the region zero degrees $\geq \Sigma \geq$ -15 degrees. The last three sequences are intended for use on targets where stereo viewing will significantly enhance the intelligence value of the photographs. Because the rate of change of stereo angle ($\Delta\Sigma/\Delta t$) can vary between approximately 1.5 degrees/second and 3.2 degrees/second (depending

TABLE 2.3-1

TYPICAL EXPOSURE SEQUENCES FOR A MOL/DORIAN MISSION

USE	TIME (sec. from TCA (*1)	EXPOSURE (Stops from Nominal)
Low-priority targets (8-9) with no significant stereo information	-1, 0, +1	+1, 0, -1
High-and medium-priority targets (0-7) with no significant stereo information.	-1.3, 0.0, +1.3, +2.7, +4.0, +5.3	+1.0, -1, -1, 0, +1
Low-priority targets (8-9) with significant stereo information (*3).	-5.2 (*2), -2.4, 0, 2.4, 4.8	0, +1, 0, -1, 0
Medium-priority targets (2-7) with significant stereo information (*3).	-6.0 (*2), -2.0, 0, 2.0, 4.0, 6.0, 8.0	0, +1, 0, -1, -1, 0, +1
High-priority targets (0-1) with significant stereo information (*3).	-6.4(*2), -3.2, -1.6, 0, 1.6, 3.2, 4.8, 6.4, 8.0, 9.6.	0, 0, +1, 0, -1, 0, -1, 0, +1, 0

(*1) Time of closest approach

(*2) Either primary camera black-and-white or secondary camera color photography can be taken.

(*3) A multiplicative correction factor (which is a function of vehicle altitude, vehicle velocity, and obliquity angle) should be applied to all of the photography times in this sequence.

on slant range and vehicle velocity), it is necessary to apply a multiplicative correction factor (in the mission-planning program and the on-board computer) to the last three sequences in order to ensure that minimum convergence-angle requirements are met at high slant ranges, and to prevent a loss in target coverage at low slant ranges.

2.4 PHOTOGRAPHIC PERFORMANCE CONSIDERATIONS

For reconnaissance photography from a satellite, ground resolution is a function of many factors such as target geometry, vehicle altitude, contrast, scene luminous emittance, lens optical quality and magnification, film characteristics, image smear, lens alignment, focus error, and atmospheric conditions. It should be noted that some of these factors (for example, contrast, scene luminous emittance and atmospheric conditions are not subject to control during a mission.

2.4.1 Ground Test Object

Resolution is a measure of the ability to distinguish between closely spaced objects under specific viewing conditions. For the Dorian Program, photographic performance evaluation is based on resolving tri-bar patterns, a group of three bars having a length-to-width ratio of 5:1 when the space between adjacent bars is equal to the width of the bars. For example, a [redacted]

2.4.2 Contrast

The apparent contrast between portions of a ground object or objects that have different inherent reflectances, as observed from an orbiting satellite, is primarily a function of solar altitude, look angle and prevailing weather conditions at the time of observation. For this reason, contrast at the lens entrance pupil cannot be controlled by human intervention. Based on post experience, a baseline apparent contrast of 2:1 at the lens entrance pupil, is assumed for the purpose of photographic performance predictions.

Further, the effective contrast at the photographic image plane is assumed to be equal to the 2:1 contrast at the lens' entrance pupil for the purpose of current performance predictions. However, this assumption is not strictly true for the following reasons:

a. Apparent contrast at the entrance pupil is related to the eye as the detector, whereas the effective image plane contrast is related to the spectral sensitivity of the photographic film being used.

b. As seen from the entrance pupil of the orbiting lens, the apparent contrast of the ground target is affected by back-scattered haze light from the atmosphere. A portion of this nonimage-forming haze light, is removed by the inherent spectral filtering action of the Ross-corrector lens elements, thereby slightly increasing the effective contrast at the photographic image plane.

The effect of contrast enhancement is to improve resolution capability; hence the current prediction contains an element of conservatism in this regard.

A study is being performed by EKC to determine a more exact value for effective film-plane contrast. This study also considers contrast enhancement which can be obtained by coating a minus-blue filter on one of the Ross-lens surfaces.

2.4.3 Lens Quality

Basically, the optical assembly transfers information from an object (ground target) to a photographic film where the information is stored and later recovered and evaluated. In common with all such systems, the amount of usable information transferred by the optical system depends on spatial frequency bandwidth, signal distortion, and noise. For any optical system, the spatial frequency bandwidth is limited by the diffraction of the light rays, signal distortion is caused by wavefront aberrations, and noise is caused by nonimage-forming light rays produced within the lens.

2.4.3.1 Diffraction. An important component of information contained in the input signal to a lens is the spatial frequency spectra of the objects being viewed. The ability of the Dorian lens to faithfully transfer the spatial-frequency-dependent modulation in the input signal to the film affects the sharpness and rendition of fine detail in the final image.

2.4.3.1.1 Cutoff Frequencey. In general, a lens acts as a low-pass filter because its finite aperture (entrance pupil) samples only a small portion of a wavefront surface radiated by the object. The maximum spatial frequency, in angular units, which a lens can pass is directly proportional to the ratio of the aperture diameter to the radiation wavelength. For photographic systems, it is convenient to convert this cutoff frequency from angular units to linear units on the image plane by including the lens focal length:

$$\upsilon_{co} = \frac{1}{f}\left[\frac{D}{\lambda}\right],$$

where: υ_{co} = cutoff spatial frequency (cycles/millimeter),
f = focal length (inches),
D = aperture diameter (inches), and
λ = radiation wavelength (m μ).

The cutoff spatial frequency for the Dorian photographic optics varies with azimuth on the focal plane because the lens aperture, established by the tilted tracking mirror, is elliptical. The maximum cutoff frequency, associated with the 70-inch-diameter major-axis of the aperture and a nominal wavelength of 587.6 mμ is [redacted] This means that the highest tri-bar target frequency which could be resolved by an ideal receptor at the Dorian focal plane, in any orientation, is [redacted] a fundamental limit imposed by the diffraction of light.

Ground resolution (Rg) at nadir is the reciprocal of the product of film resolution and optical magnification where magnification is the ratio of lens focal length to the orbital height (h):

$$Rg \text{ (nadir)} = \frac{1}{(f/h)\upsilon}.$$

Diffraction-limited ground resolution is associated with the cutoff spatial frequency υ_{co}, thus:

$$Rg_{max} = \frac{h}{D}\lambda.$$

This expression shows that the diffraction-limited ground resolution of a passive reconnaissance system can only be improved by getting closer to the target or taking a larger sample of the radiated wavefronts by increasing the sensor aperture.

The resolving power of the Dorian reconnaissance system does not approach the diffraction limit resulting from manufacturing tolerances on the system and information storage limitations of the photographic film. The required resolution of [redacted] which corresponds to [redacted] ground resolution from 80 n mi, is [redacted] of the maximum diffraction-limited cutoff frequency.

2.4.3.1.2 The Modulation Transfer Function (MTF). The spatial frequency filtering characteristic of an image-forming optical assembly is described by its MTF. The MTF defines a surface such as the example sketched in Figure 2.4-1. The relative modulation at the spatial frequency of zero cycles per millimeter is normalized to a value of 1.0. For a diffraction limited lens, the MTF surface has a finite height within the two-dimensional spatial frequency bandwidth determined by the limiting-aperture dimensions of the lens assembly; and the contour of the MTF surface is determined by the lens-aperture shape. In qualitative terms, image sharpness is proportional to the volume under the MTF surface and the rendition of fine detail occurring at a given spatial frequency is roughly proportional to the height of the MTF surface at that frequency.

The optical performance of the Dorian lens is rated in terms of the geometric mean value of limiting resolution for two tri-bar test objects (described in paragraph 2.4.1), one oriented parallel to the lens aperture

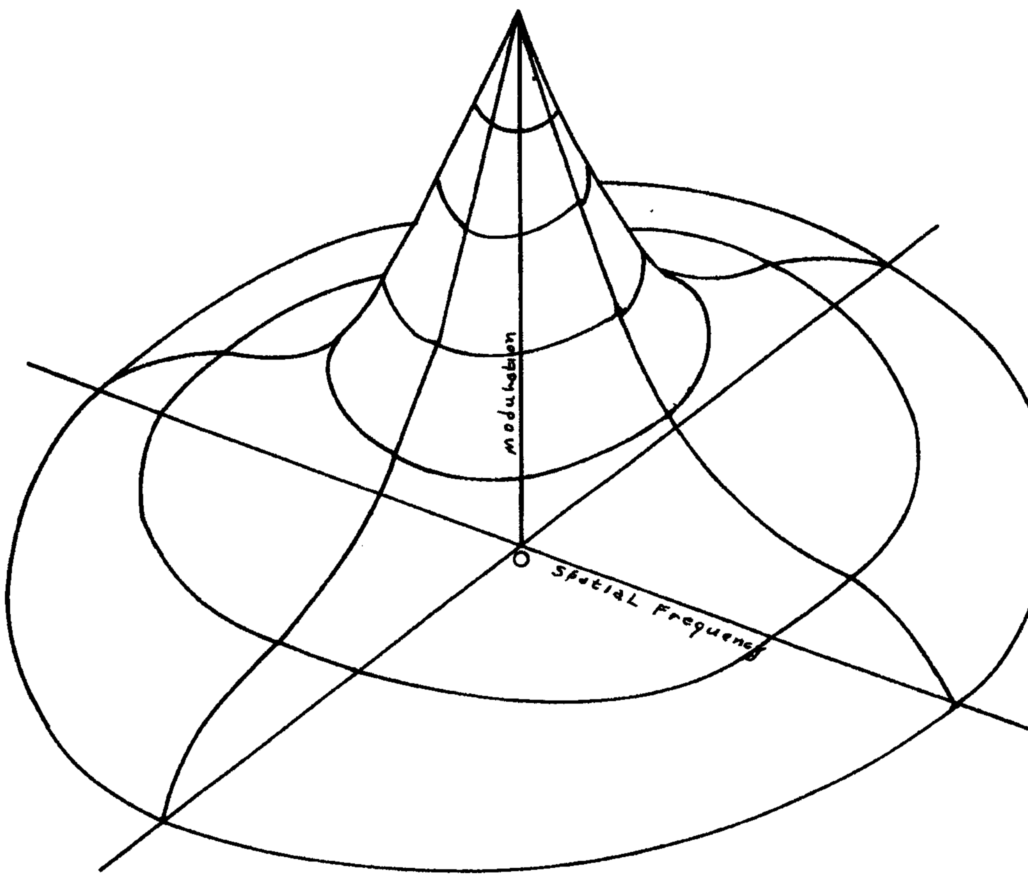


Figure 2.4-1. Surface Representation of a Normalized Modulation Transfer Function

major axis and the other oriented parallel to the aperture minor axis. For this reason, knowledge of the entire MTF surface is not needed for performance predictions, only the values associated with the major- and minor-axis azimuths of the lens aperture. Major-axis and minor-axis monochromatic (602.2 mμ) MTF related to a nadir line-of-sight are shown in Figures 2.4-2 and 2.4-3, respectively (Curve A in each figure).

2.4.3.1.3 Effect of Aperture Vignetting and Obstructions. The limiting aperture of the Dorian photographic optical assembly is the projection of the tracking-mirror aperture on a plane normal to the primary mirror optical axis. This projection forms an elliptical aperture which has a major axis diameter of 70 inches. The minor axis diameter depends on the stereo angle being used and the optical axis cant angle. For the established cant angle of 2 degrees and a zero-degree stereo angle, the minor-axis diameter of the limiting aperture is 48.6 inches. Because the tracking-mirror roll axis coincides with the optical axis, the limiting aperture size is independent of the obliquity angle. Table 2.4-1 contains the tracking-mirror projection for various stereo angles.

Further reduction of the lens aperture area is caused by obstructions from the Newtonian folding-mirror assembly and its mounting supports. The folding mirror assembly obstructs 12.7 percent of the 70-inch-diameter circular aperture of the lens assembly (this ratio excludes tracking-mirror vignetting). Adding the mounting structure (ringo) obstruction increases the total to 17.2 percent. These lens obstructions are shown in Figure 4.1-3.

The combined effect of aperture vignetting and obstructions on the lens MTF is shown in Figures 2.4-2 and 2.4.3. (Curve B in each figure).

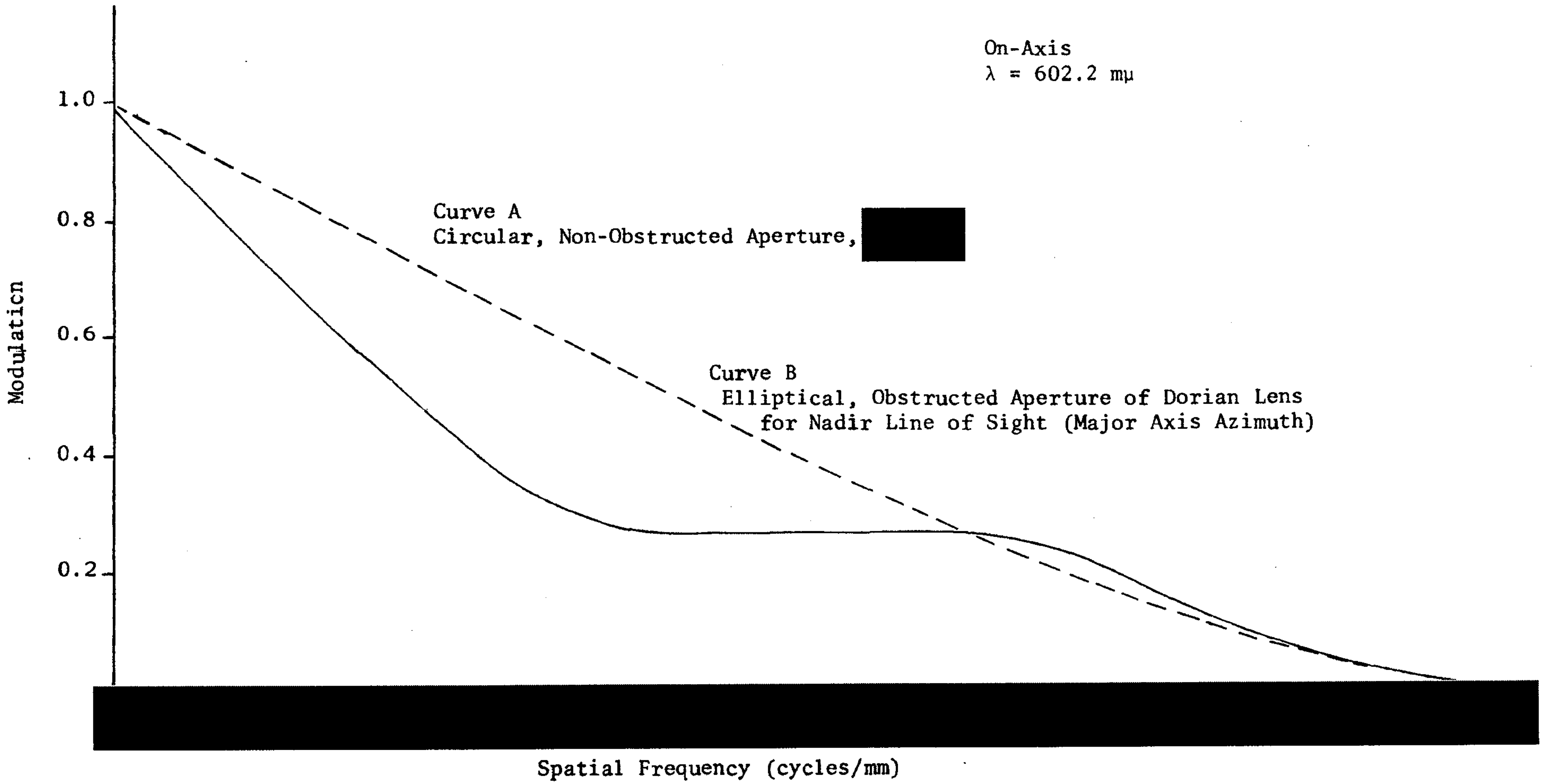


Figure 2.4-2. Effect of Aperture Vignetting and Obstructions Upon Monochromatic MTF (Major Axis Azimuth)

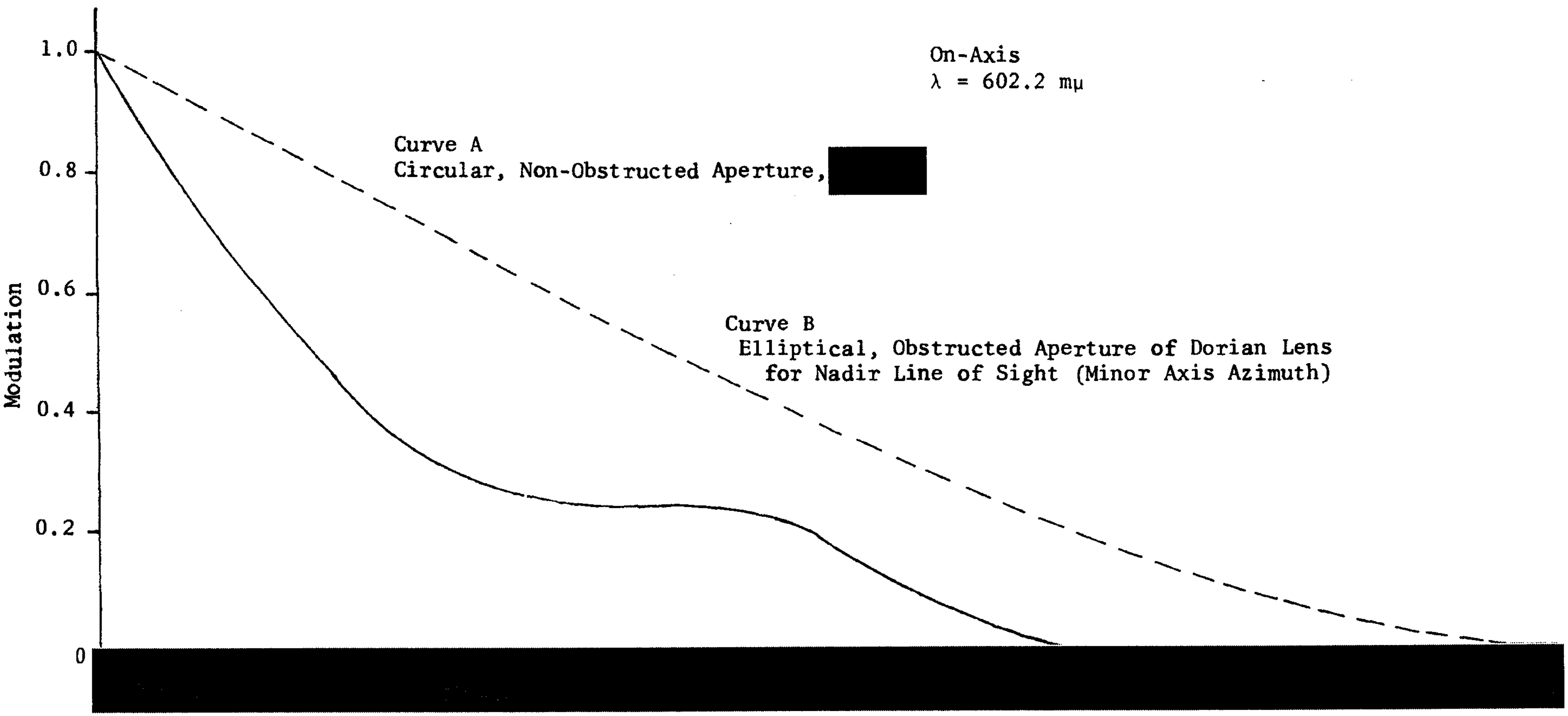


Figure 2.4-3. Effect of Aperture Vignetting and Obstructions Upon Monochromatic MTF (Minor Axis Azimuth)

TABLE 2.4-1

TM PROJECTION RELATIVE TO OPTICAL AXIS

Stereo Angle	Major Axis Radius (in)	Minor Axis Radius (in)	Offset (in)
+30°	35.00	16.97	-2.38
+20°	35.00	19.57	-2.13
+10°	35.00	22.03	-1.85
0°	35.00	24.31	-1.53
-10°	35.00	26.41	-1.19
-20°	35.00	28.32	-0.81
-30°	35.00	30.00	-0.42
-40°	35.00	31.46	0.0

Figure 2.4-2, related to the major-axis diameter of the lens aperture, compares the monochromatic diffraction-limited MTF of the vignetted and obstructed Dorian aperture with the MTF of a lens having a circular 70-inch-diameter nonobstructed aperture. Because the major axis diameter of the Dorian lens is also 70-inches, the cutoff frequency for both MTF curves is [redacted] for 602.2 mμ wavelength light. As shown in the figure, the central obstruction reduces modulation transfer at low spatial frequencies and enhances the MTF at higher frequencies. The loss in low frequency modulation results in a loss of sharpness in the image formed by the obstructed lens. For this reason, the size of the Dorian central obstruction was minimized.

The MTF related to the minor axis of the Dorian aperture is compared to the MTF of a 70-inch-diameter nonobstructed aperture in Figure 2.4-3. This figure shows that tracking-mirror vignetting for a nadir line-of-sight has reduced the lens cutoff frequency from [redacted] The resultant loss in high-frequency response reduces the ability of the lens to resolve fine detail along the minor-axis azimuth. The central obstruction causes an additional loss at low frequencies, as shown.

2.4.3.2 Wavefront Aberrations. The fundamental operation of an image-forming optical system is to convert an expanding spherical wavefront centered on an object point into a contracting spherical wavefront centered on a specific image point. Asphericity of the image-forming wavefront is termed an optical aberration. Aberrations can be caused by inherent limitations of the optical design, by manufacturing variations, focus error, and optical misalignment.

2.4.3.2.1 Residual Aberrations. In general, lens aberrations cannot be completely eliminated; instead, the lens designer attempts to balance the residuals for a best compromise based on the requirements and constraints of the system. In the case of the Dorian lens formula, the existence of on-axis aberrations results from the requirement for a finite usable field (of ±0.54 degree). That is, to reduce off-axis aberrations, some finite amount of on-axis residual aberration must be accepted. In addition, the degree to which these residual on-axis aberrations can be reduced toward zero is limited by design constraints such as requirements on maximum physical length of the lens and on minimum back focal distance. The optical design considerations related to residual aberrations are described in Paragraph 4.1.1.1.

Figure 2.4-4 and 2.4-5 give static on-axis heterochromatic MTF curves related to azimuths along the major and minor axes of the lens aperture respectively. Each figure shows two MTF curves, the upper curve includes only the effect of diffraction and the lower curve includes the losses resulting from aberrations as well as diffraction. The reduction in modulation from the upper curve to the lower; therefore, is caused by the residual on-axis aberrations. The seven wavelengths and weights used for generating these heterochromatic curves are given in Table 2.4-2.

2.4.3.2.2 Manufacturing Variations. Aberrations in the image-forming wavefront can be caused by manufacturing variations such as optical surface imperfections, refractive index inhomogeneity, partial dispersion variations, power, and thickness tolerances. The effect of these variations on the lens MTF is described by an optical quality function.

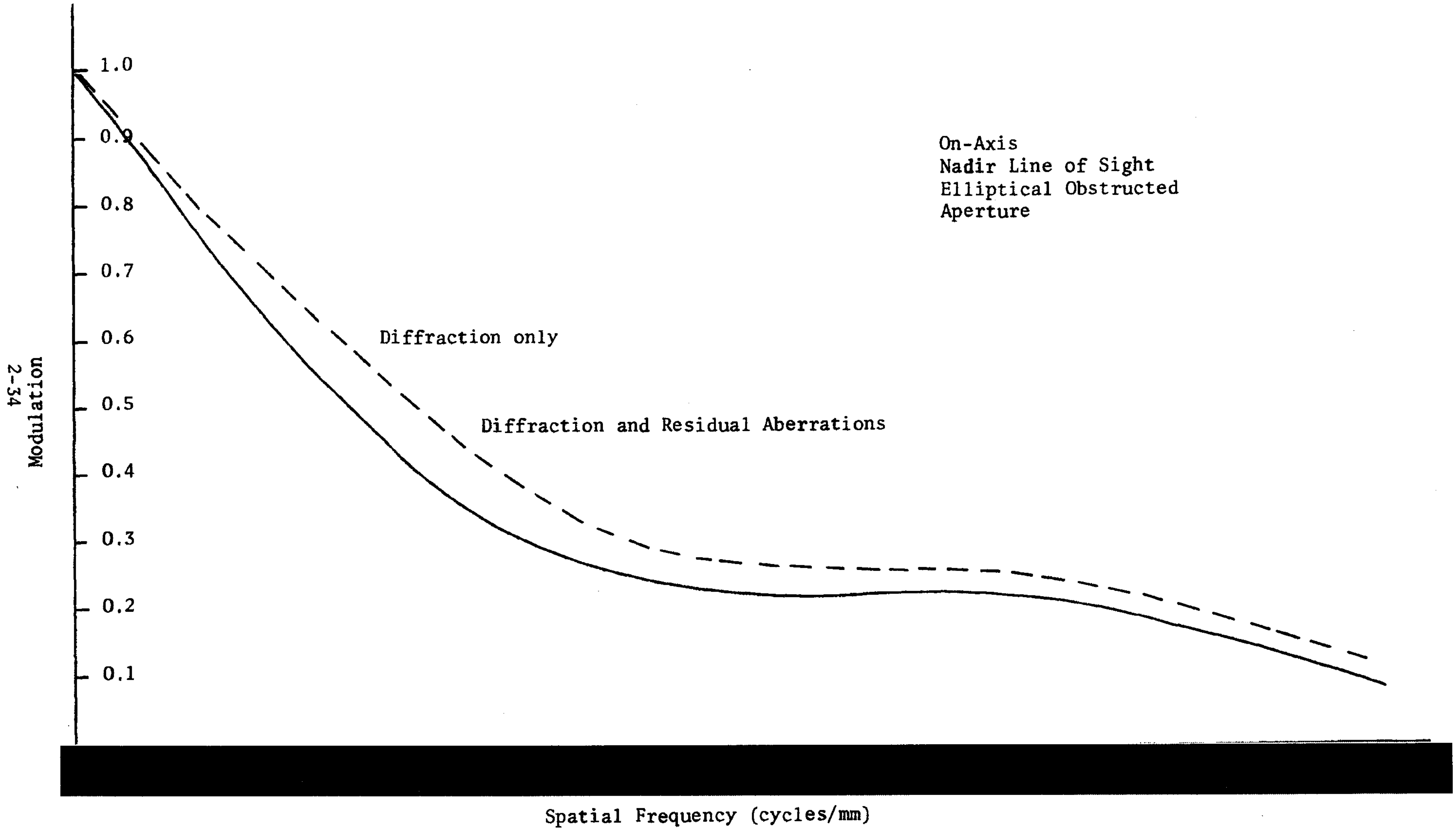


Figure 2.4-4. Effect of Residual Aberrations Upon Heterochromatic MTF (Major Axis Azimuth)

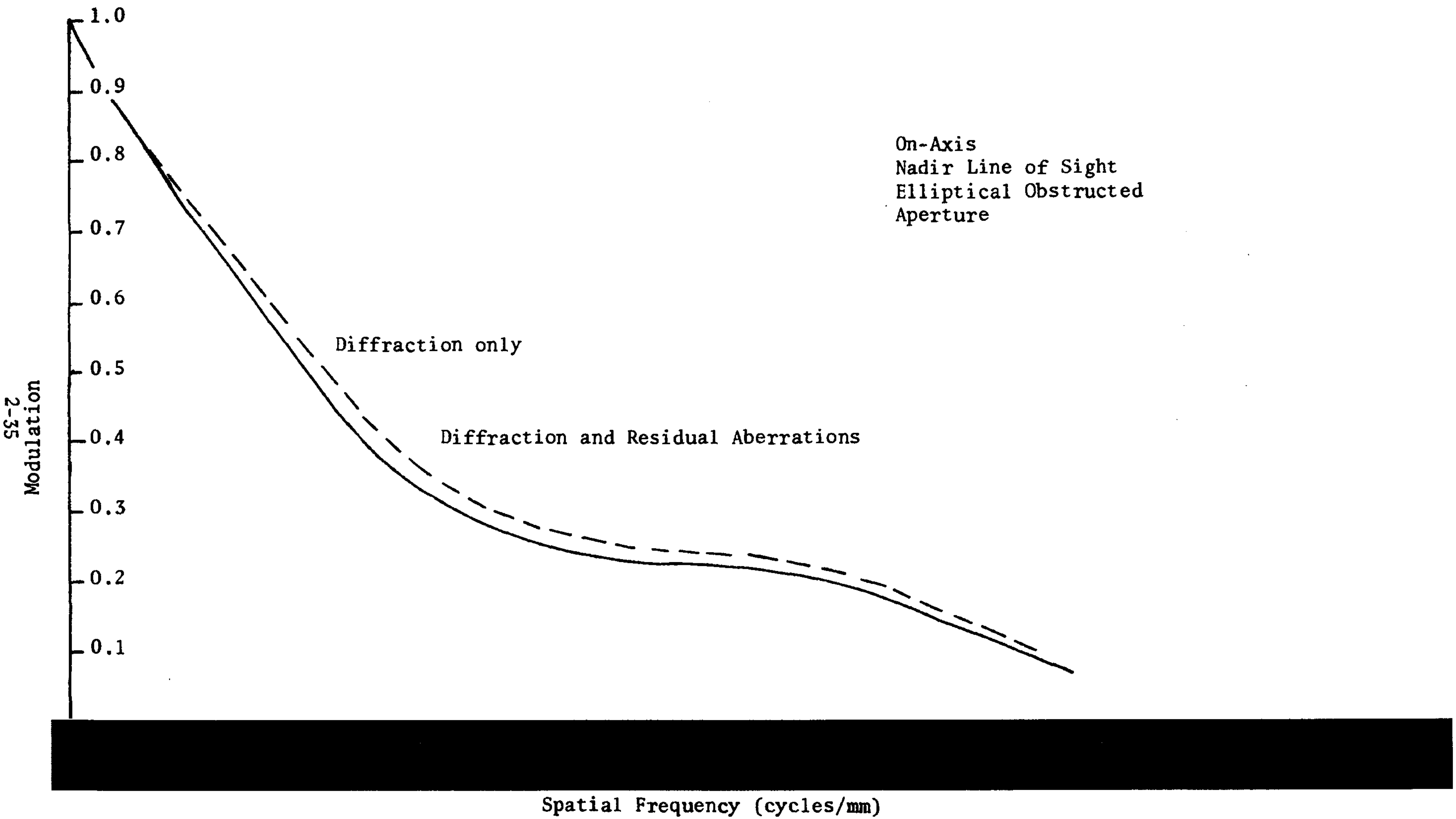


Figure 2.4-5. Effect of Residual Aberrations Upon Heterochromatic MTF (Minor Axis Azimuth)

TABLE 2.4-2

Current Weighting Factors
Used on Heterochromatic MTF Analyses

Wavelength (microns)	Weight
0.46554	0.09490
0.51615	0.12849
0.54357	0.13173
0.57084	0.12982
0.60221	0.16153
0.64411	0.13203
0.68950	0.22151

This function is defined as the ratio of the MTF of a lens manufactured in accordance with the assigned tolerances to the MTF of an ideally manufactured lens. Optical quality is a complex function of spatial frequency, for which function a shape must be assumed. The assumption is that the residual aberrations are small. A property of a very small aberration is that its degradation of the optical image is related to the root-mean-square (RMS) wavefront error, and is independent of the shape of the aberrated wavefront. Losses in image quality caused by spherical aberration, coma, focus error, and random error, etc., are nearly identical for a given small RMS wavefront error. The shape of the function, $OQF(\nu)$, therefore, is based on the effect of a random wavefront error. The OQF for a random wavefront error is given by:

$$OQF(\nu) = e^{-\left[\frac{2\pi}{\lambda}\right]^2 [\sigma^2 - S(\nu)]},$$

where:

σ = RMS wavefront error,

$S(\nu)$ = Autocorrelation function,

ν = Spatial frequency, and

λ = Wavelength.

This expression shows that the autocorrelation function causes optical quality to be spatial frequency dependent. Assuming that the autocorrelation function rapidly decreases to zero, the $OQF(\nu)$ becomes essentially independent of spatial frequency as shown in Figure 2.4-6.

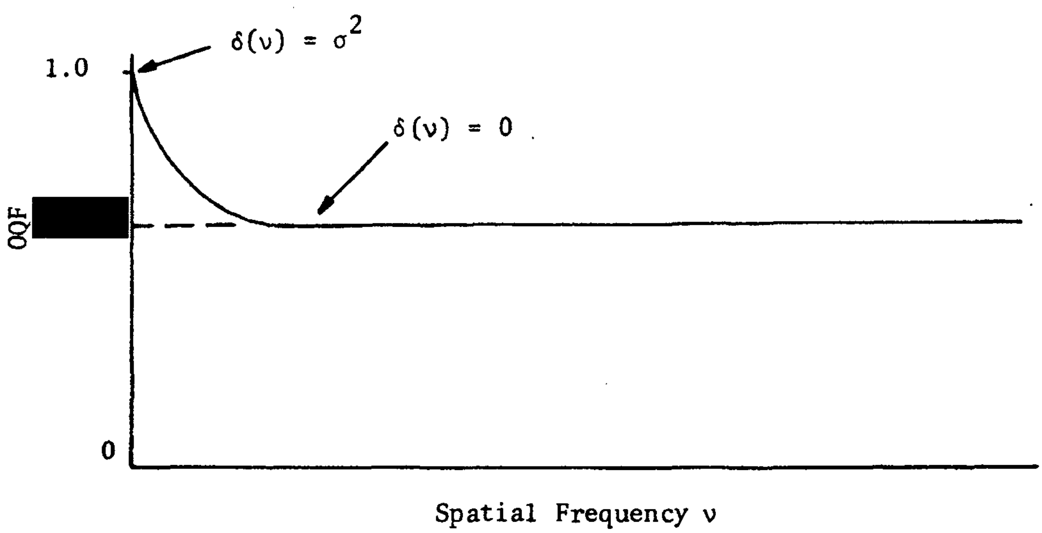


Figure 2.4-6. Optical Quality Factor

For prediction of photographic performance, the OQF(ν) is assumed to have the same value for all spatial frequencies of interest. This constant value is defined as the optical quality factor (OQF). The specification OQF for the photographic optics is [redacted] percent and the goal OQF is [redacted] percent. These values are used in the calculation of photographic performance described in paragraph 2.5-3.

The OQF requirement was also used as a criterion in assigning manufacturing and test tolerances to the photographic optical assembly. This tolerancing effort is described in Paragraph 4.1.2.

2.4.3.3 Veiling Glare. The veiling glare ratio is defined as the amount of nonimage-forming light rays at the lens focal plane divided by the total amount of light rays (image forming plus nonimage forming). For the Dorian photographic optical assembly, the veiling glare ratio will be no greater than 1 percent when the tracking mirror is in the nadir position.

The effect of veiling glare is to reduce image modulation by a factor which is independent of spatial frequency. This modulation transfer factor for veiling glare is given by the expression

$$G_F = \frac{1}{1 + R},$$

where: G_F = veiling glare MTF, and
R = veiling glare ratio (decimal).

The veiling glare MTF corresponding to a 1 percent ratio is 0.99. This value is used in the calculation of photographic performance as described in Paragraph 2.5.3.

2.4.4 Focus

To achieve high-resolution photography, the optical image must be accurately focused on the film surface (see Figure 2.4.7). A 95 percent confidence level of 0.002 inch or less focus error was established as the tolerable focus-error limit. This corresponds to 1/5 wave (λ) optical path difference on the major aperture axis which is tighter than the classic λ/4 Rayleigh criterion.

The focus of the Dorian optical system is sensitive to small changes in slant range. This sensitivity results from the extreme focal length of the lens. Together with the tracking mirror causing the slant range to change quickly over a short period of time, this necessitates that focus must be readjusted prior to nearly all exposures (see Figure 2.4.8).

Within focus control, provision must also be made for sensing the correctness of focus settings in order to provide the final focus adjustment to the COA after orbit is achieved and also to compensate for possible long-term focus drifts which might occur during a mission. Final focus adjustments after orbit is achieved will be necessary because gravitational and launch effects on a system of this size preclude factory prefocusing to an accuracy sufficient for high-resolution performance.

These two needs are satisfied through a formalized procedure for focus control.

2.4.4.1 Functional Description. Focus will be controlled by driving the platen toward or away from the lens by command from the on-board computer. The computer will calculate the optimum platen position based on information

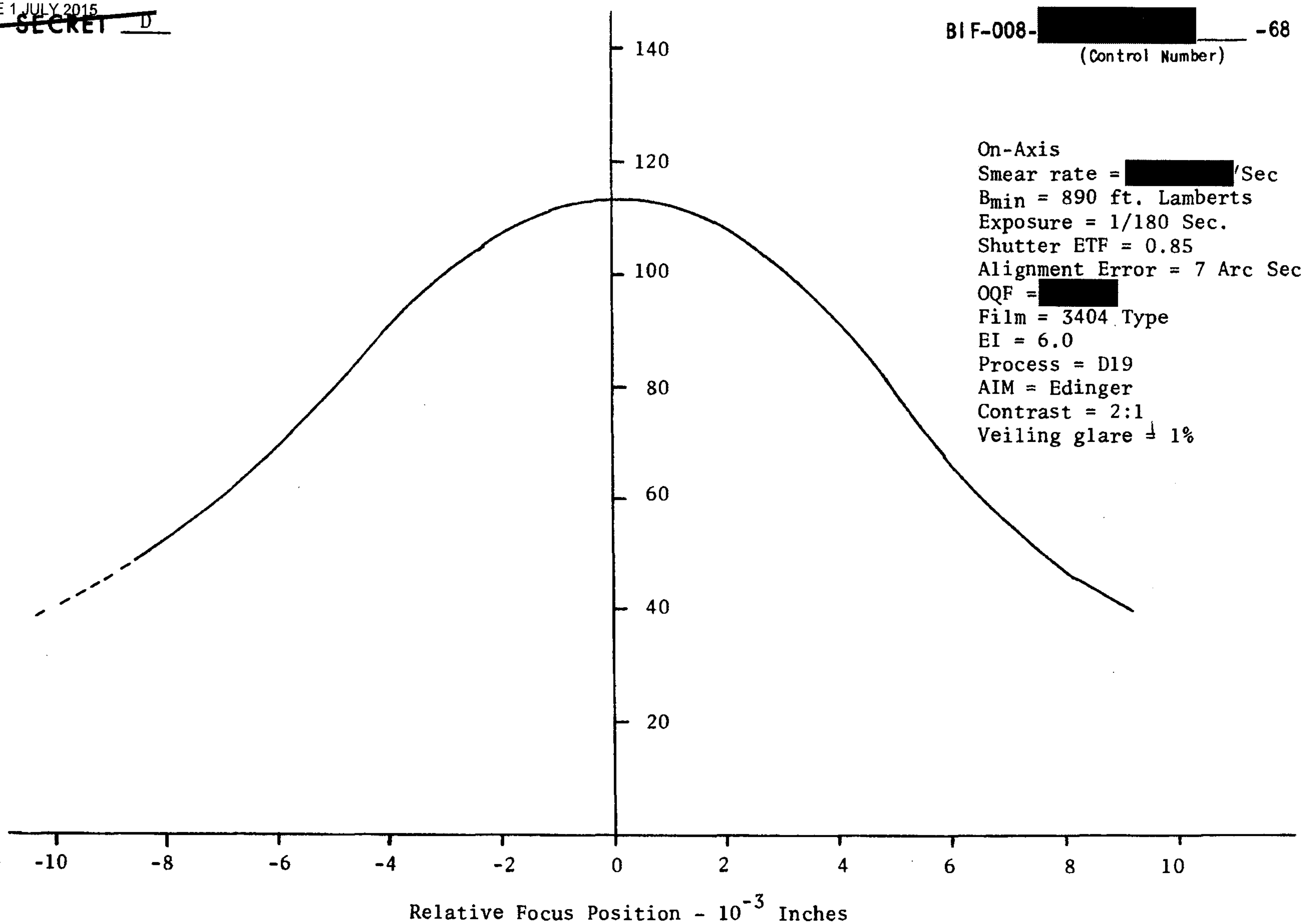


Figure 2.4-7. Effect of Focus on Resolution

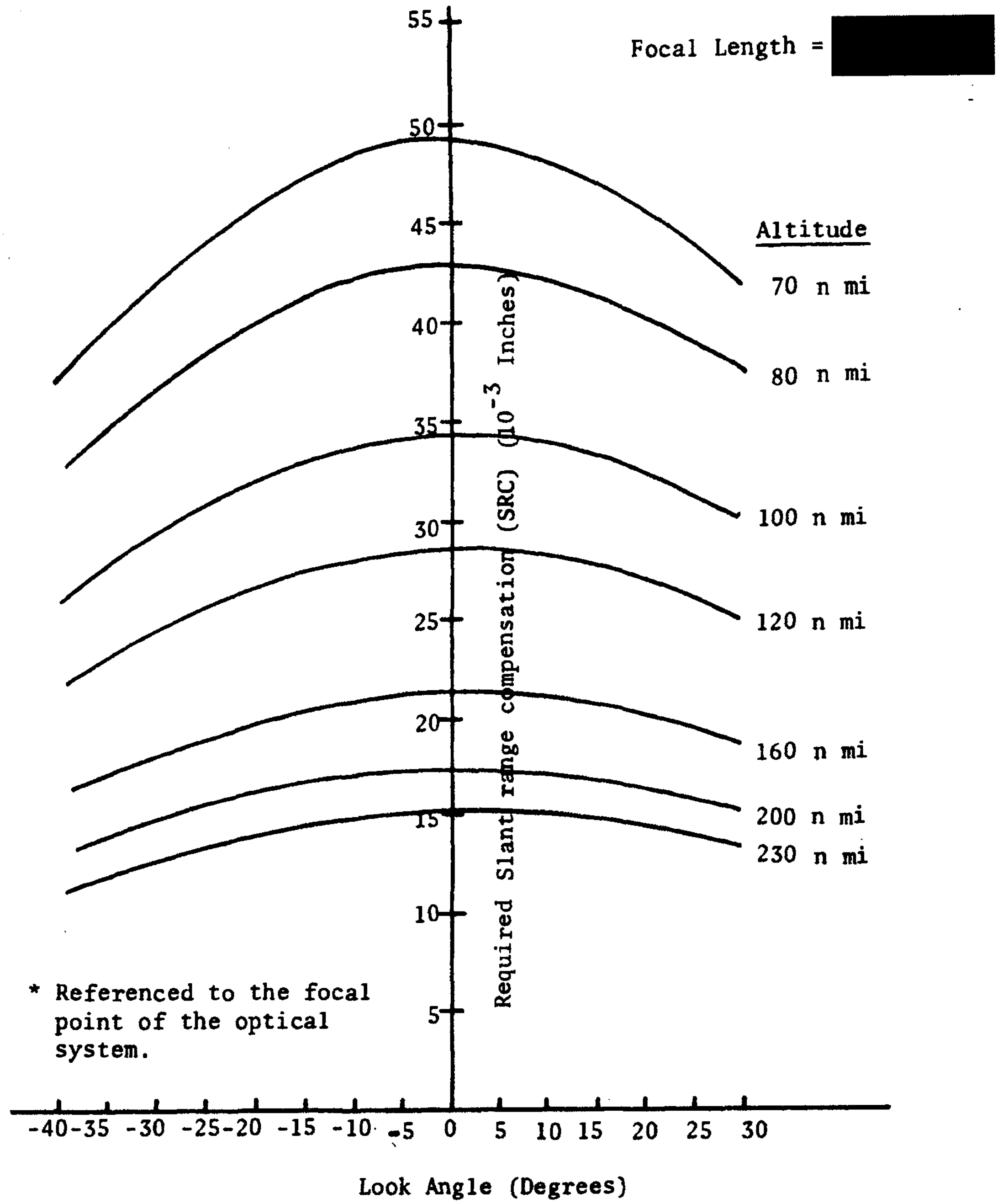


Figure 2.4-8. Focus Position vs Altitude and Look Angle*

* Combination of stereo and obliquity angles

regarding target altitudes, vehicle ephemeris and attitude, look angle, and information regarding the location of the focal point of the lens. The platen can be positioned in 0.0006 inch increments over a range of 0.1 inch. Adjustments to focus as needed for pre-launch uncertainty and long-term variation in the location of back focus will be determined using a focus sensor and implemented by updating computer data or translating the primary mirror.

2.4.4.1.1 Focusing Equations. The correct location for the platen is determined by first determining the distance (ΔZ) from the forward-most platen position (closest to the lens) to best focus using the following equation:

$$\Delta Z = \frac{f^2}{a} + RFD,$$

where: a = slant range to the target (in inches),
f = focal length (in inches), and
RFD = reference focal distance (see text).

Once the location of best focus is identified, the computer then identifies the platen position which is closest to this position and issues commands accordingly.

This equation is derived from the simple lens equation

$$\frac{1}{i} + \frac{1}{a} = \frac{1}{f}\text{ , where: } i = \text{image distance,}$$

which is sufficiently accurate for the Dorian system. Solving for i,

$$i = \frac{fa}{a-f}\text{ .}$$

The distance i is measured from the principal plane of the lens to the plane of best focus. (The principal plane can be thought of as the plane at which a single thin lens of focal length f would be located to provide the same focal point.)

The image distance measured from the focal point (position where rays from an infinitely distant source would come to focus) is given by,

$$\Delta\ i = i - f = \frac{fa}{a-f} - f = \frac{f^2}{a-f} \simeq \frac{f^2}{a} .$$

The parameter Δ i represents the correction needed to focus for a finite slant range a and often referred to as the slant range compensation term. The focal point is a property of the lens and is not mechanically identified with the camera. A computer stored parameter called the reference focal distance (RFD) defines for the computer, the location of the lens focal point with respect to a mechanical reference in the camera. For software convenience, this mechanical reference is chosen to be the forward-most platen position (see Figure 2.4.9). As will be discussed below, focus sensing will be used to define and/or verify the correctness of the RFD.

Therefore, the distance between the front platen position and best focus is given by

$$\Delta Z = \frac{f^2}{a} + \text{RFD}$$

2.4.4.1.2 Focus Control During Photography. During photographic periods the optimum platen position will be computed automatically by the on-board

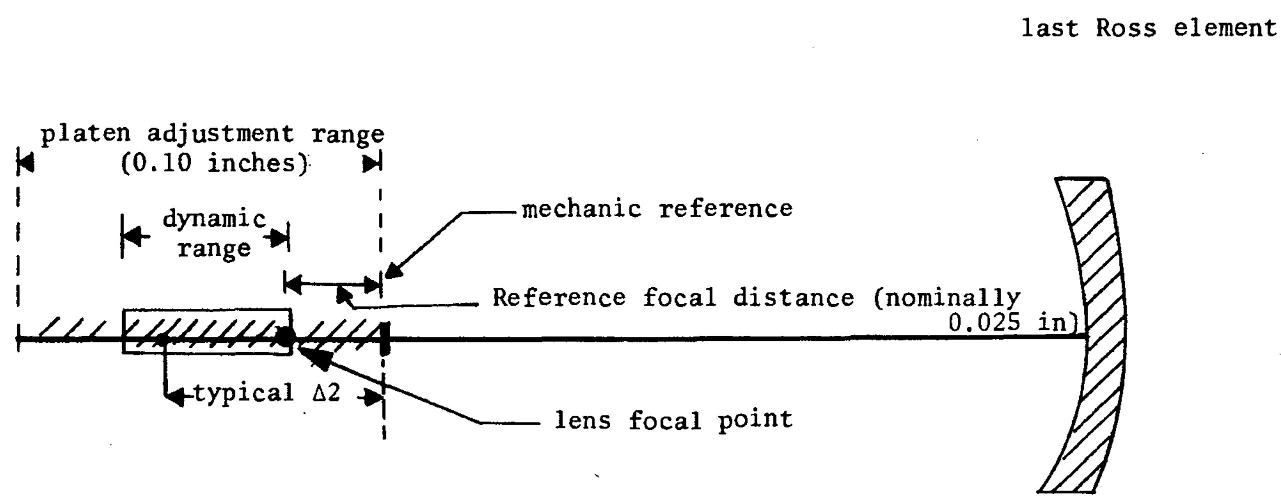


Figure 2.4-9. Meaning of Focus Control Terminology

computer prior to each exposure. This process, generally referred to as the slant range compensation process will need no attention during this time. Slant range is computed using target, ephemeris, and look-angle data already available to the computer.

2.4.4.1.3 Focus Sensing and Control of RFD. The computer operation described above cannot accurately determine focus until the correct RFD is established. The focus control system includes a procedure for updating this parameter and involves the use of a focus sensor (see paragraph 4.4.8).

The focus sensor is mechanically tied to the platen and moves with it for focus changes at all times. The device "sees" the same focus as does the film emulsion. To perform focus sensing, the camera will be maintained in focus using the same computer software used for focus control during photography, and using a predefined value for RFD. The focus error, if one exists, will then be detected by the sensor the outputs of which are monitored either by the flight crew or by ground personnel. Because slant range compensation will have been provided, a focus error must be attributed to an error in the location of the focal point as defined by the RFD. Compensation for this detected error can be provided by either commanding a change to the value of the RFD stored in the computer or by translating the primary mirror, thus also translating the focal point to the location defined by the computer. The latter capability is to be used only if the required slant range compensation range does not lie within the 0.1 inch platen positioning range.

In updating the RFD the change should equal the sensed error. In updating the primary mirror the change should equal 0.765 times the sensed error.

By iterative procedure, the correct value of RFD can be established without accurate prelaunch focus set-up efforts. In practice, however, the camera will be mounted to the optics so that the focal point to be desired will lie 0.025 inch into the range of available platen positions corresponding to an RFD of 0.025 inches.

Periodic updates as may be needed after the initial focusing exercise will be made through the RFD.

2.4.4.2 Focus Budget. The focus sensing and correction exercise is intended to remedy systematic or at least slowly varying effects. Short term or random variations in focus cannot be detected and compensated for by focus sensing and thus will not only affect the accuracy of focus during photography but also the accuracy by which errors in RFD can be detected during focus sensing.

To establish the required focus tolerance, the accuracy of focus sensing, together with these random factors were toleranced in a focus budget; see Table 2.4-3.

The budget is divided into two sections, considering individually errors which occur during focus sensing and errors which occur during photographic activities. The budget includes all factors which affect focus except door-open effects.

2.4.5 Primary Optical System Alignment

Alignment between the individual optical elements of the Ross-corrector assembly is discussed in paragraph 4.1.4. In this paragraph, optical misalignment is defined as the noncoincidence of the Ross-corrector-assembly optical axis with the primary mirror optical axis.

TABLE 2.4-3

DORIAN FOCUS BUDGET (ON-AXIS, REMOTE RECORD MODE)

A. Total Budget for Focus Sensing — 0.0016 inch (2 σ)

Contributor	Type of Distribution	Tolerance (inches)	2 σ Allotment (inches)	
1. Focus sensor accuracy	Normal	±0.0015		0.001
2. Focus sensor-camera interface				0.00094
a. FS - platen alignment accuracy	Constant Bias	±0.0002	0.0002 (95.5%)*	
b. FS mirror assembly runout	Normal	±0.0003	0.0002	
c. Platen tilt at FS	Normal	±0.00075*	0.0005	
d. Platen reference stability	Normal	±0.00045	0.0003	
e. Platen drive accuracy	Normal	±0.00045	0.0003	
f. Vibration (X-axis)	Normal	±0.00075	0.0005	
3. Software				0.00045
a. Platen position granularity	Uniform	±0.0003	0.00035	
b. Computer calculation accuracy	Normal	±0.0003	0.0002	
c. Ephemeris and terrain elevation accuracy	Normal	±0.6 n mi	0.0002	
4. Thermal focus shift**	Normal	±0.001		0.0007

* An error in the alignment of the focus sensor to the film platen will be a constant error contributor throughout each mission, although the amount of the error will vary from mission to mission. The expected 2 σ value of this alignment error is included in the budget so that 95 percent of all missions will have biases less than this amount.

** excluding door open effects.

TABLE 2.4-3 (continued)

B. Total Budget for Photographic Operations 0.0012 inch (2 σ)

Contributor	Type of Distribution	Tolerance (inches)	2 σ Allotment (inches)	
1. Camera				0.00065
a. Platen reference stability	Normal	±0.00045	0.0003	
b. Platen drive accuracy	Normal	±0.00045	0.0003	
c. Vibration (X-axis)	Normal	±0.0006	0.0004	
d. Film clamping variations	Normal	±0.00045	0.0003	
e. IMC effects on focus	Normal	±0.00015	0.0001	
2. Software				0.00042
a. Platen position granularity	Uniform	±0.0003	0.00035	
b. Computer calculation accuracy	Normal	±0.0003	0.0002	
c. Ephemeris and target-elevation accuracy	Normal	±0.2 n mi	0.0001	
d. Look-angle uncertainty	Normal	± 6 minute of Arc	0.0001	
3. Thermal focus shift*	Normal	±0.001		0.0007
4. Miscellaneous and Contingency				0.00064
a. Film thickness variations	Normal	±0.0003	0.0002	
b. Alignment perturbations to focus	Normal	±0.00035	0.00035	
c. Miscellaneous	Normal	±0.00045	0.0003	
d. Contingency	Normal	±0.0006	0.0004	

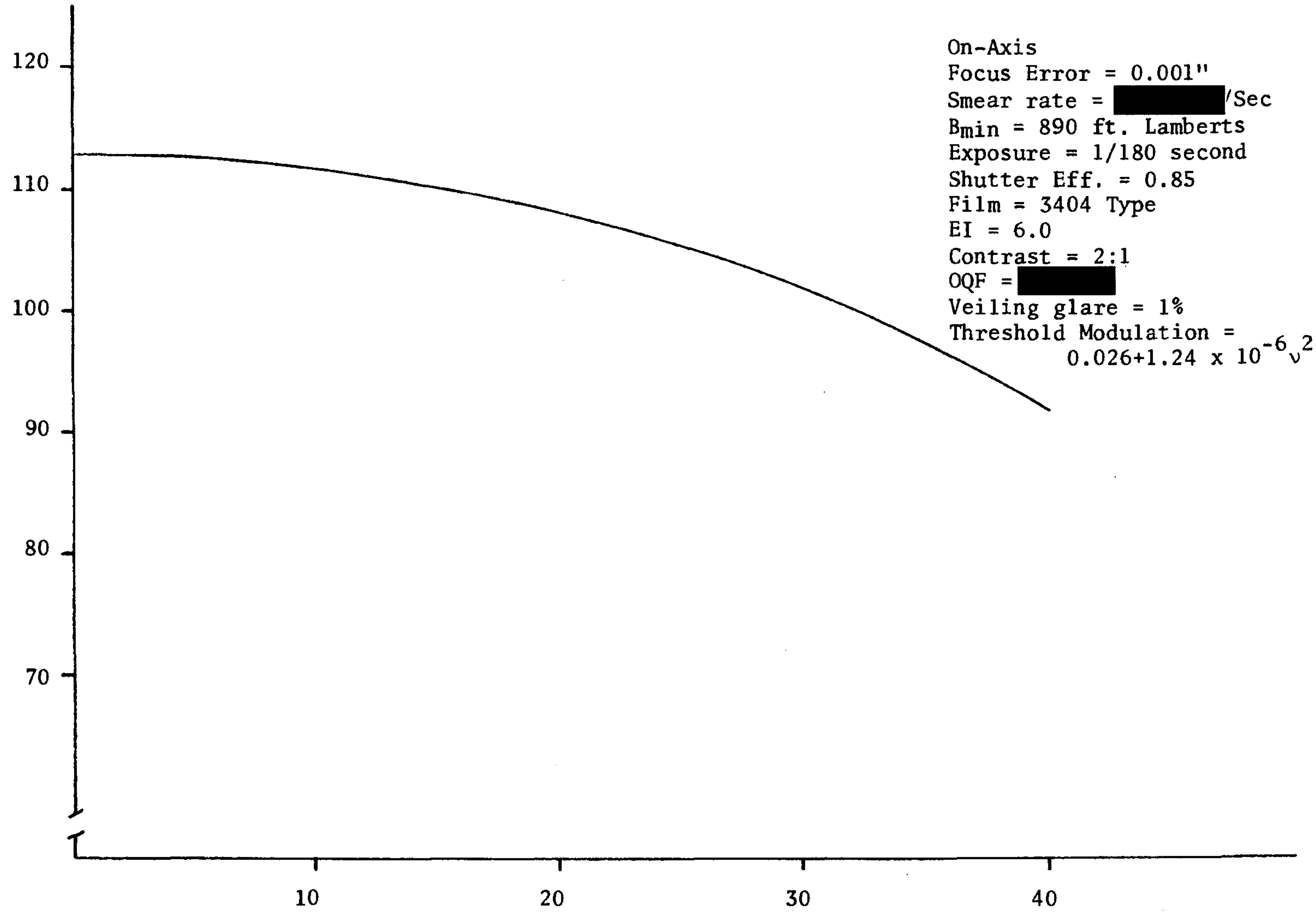
C. Over-all Focus Budget (combined effects of A & B above) 0.002 inch (2 σ)

* exluding door open effects.

2.4.5.1 Equivalent Primary Mirror Tilt. Misalignment between the optical axes of the Ross-corrector assembly and the primary mirror results from two contributors: tilt and decentering. The combined effect of these two contributors on optical performance is described by a single quantity termed equivalent primary mirror tilt. This equivalent tilt error will cause a loss in modulation transfer which is equal to the loss associated with the combined tilt and decentering components.

2.4.5.2 COA Alignment Control. The alignment sensor (described in paragraph 4.1.4.2) is accurate to 5 arc seconds, measured at the sensor, when sensing PM tilt and 0.009 inch when sensing PM decentering. The alignment control sequentially corrects the decentering errors before correcting tilt errors to minimize the cross-coupling of decentering to tilt errors. The Ross-mirror servos, which are used to correct the apparent decentering of the PM, tilts the Ross mirror in steps of 3.3 arc seconds in one axis and 1.96 arc seconds in the other. These steps result in a decentering granularity of 0.011 inch and 0.005 inch respectively. The PM servos tilt the PM in increments of 3.3 arc seconds in one axis and 1.96 arc seconds in the other axis. The combined effect of these residual tilt and decentering errors along with the expected thermal change of camera optical assembly (COA) alignment results in an equivalent primary mirror tilt error of 14 arc seconds (2 σ).

2.4.5.3 Resolution Loss Related to Equivalent Primary Mirror Tilt. The relationship between resolution and equivalent primary mirror tilt is shown in Figure 2.4-10. This figure shows, for the conditions stated on the curve, that the on-axis geometric mean resolution loss resulting from a one-sigma alignment error of 7 arc seconds is approximately 1 cycle/mm.



Equivalent Primary Mirror Tilt - (Arc Seconds)

Figure 2.4-10. Resolution vs Equivalent Primary Mirror Tilt

2.4.6 Image Motion Compensation (IMC)

For optimum quality photography, motion in the image should be minimal during exposure. Efforts to reduce or eliminate the motion in the image are termed IMC. The tracking-mirror drive acts as the primary IMC device by pointing the COA. Ideally, it completely stops the motion at mid-field by correctly aiming the optical line-of-sight.

Because of the changing geometric relationship between the OV and the ground target, the TM drive is capable of stopping the motion at only one point in the field. In general, the scene appears to expand and turn about this nulled point (tracked point) as the target is approached. As the OV leaves the target the image appears to shrink while still turning about the nulled point. This type of image motion is generally termed off-axis geometric image motion. At extreme look-angles and low altitudes, geometric image motion near the periphery of the format can be as much as 10 times the budgeted on-axis smear rate of 4.2×10^{-5} radian/sec.

With a focal plane shutter, only a narrow strip of the format is exposed at a given instant. If the image motion in the portion of the field encompassed by this strip can be matched by moving the film, the smear can be minimized. This technique is called across-the-format IMC (X-IMC). Because the film is rigid in its own plane, it can be moved laterally only by translation of all points at the same rate and in the same direction. The geometric image velocity, on the other hand, varies from point to point even within the slit area. Consequently, the X-IMC technique cannot completely compensate for all geometric smear.

2.4.6.1 Selection Ground Rules and Approach to X-IMC. Four basic ground rules were established for judging the acceptability of possible X-IMC methods:

a. The method should not excessively degrade on-axis performance.

b. No optical zooming of the image would be permitted because of the complexity and weight required by such a method.

c. Mechanical motions should be simple in nature and in implementation.

d. Designs should be based on linear geometric image-motion equations. (derived in Appendix A.)

The approach used in selecting the X-IMC method was to optimize a method originally suggested by Aerospace Corporation (AS). The method would be capable of significantly improving ground resolution.

2.4.6.2 X-Format Image Motion Compensation Concept. The Eastman Kodak Company (EKC) method requires that the rectangular exposure slit traverse the format at an angle corresponding to the line of maximum linear geometric image motion. As this traverse occurs, the platen and film are moved at a linearly changing velocity so as to match the geometric image motion along the line of maximum linear image motion. The platen motion required is a single reciprocating motion (jog) during each frame exposure. The speed of the platen is synchronized with the slit position. It is maximum at the time the exposure silt enters the field, zero when the centerline of the slit crosses the optical axis, reverses direction, and again reaches maximum when the slit leaves the field. The maximum speed and direction of the jog are fixed for a given frame. Three parameters, shutter orientation (S), jog orientation (J) and inital platen velocity (V_{Max}), are used to specify the camera X-IMC settings for a frame. Each of the three are functions of the changing stereo and obliquity angles to the target, and will vary from one frame to the next.

2.4.6.3 Requirements. Equations for computing the three X-IMC parameters are derived in Appendix A in terms of tracking-mirror gimbal angles and vehicle attitude. Camera assembly range requirements and tolerances are shown in Table 2.4-4.

2.4.6.3.1 Shutter Rotation-Rate Considerations. The maximum practical change in shutter orientation angle between consecutive frames at a one frame per second frame rate is 55 degrees. Time, inertia, power, vibration, angular impulse, and loss in effectiveness of X-IMC were factors considered in determining this limit. The 55-degree turning limit between frames was found not to appreciably degrade the X-IMC effectiveness except when tracking near nadir where certain tracking sequences called for a shutter rotation change exceeding the 55-degree design limit. If, for example, the obliquity angle were to change sign during a tracking sequence (as a result of earth rotation), an approximately 180-degree change in angle S between consecutive frames is possible. To avoid the necessity for inhibiting the X-IMC in this situation, the shutter-orientation range was made sufficiently wide, so that instead of having to turn almost 180 degrees, the shutter assembly could turn (in an opposite sense) to the very small supplement of the angle S.

2.4.6.3.2 Platen/Jog Synchronization. The platen velocity at the instant the slit centerline passes the optical axis is currently toleranced at zero

TABLE 2.4-4

X-IMC CAMERA ASSEMBLY REQUIREMENTS
FOR THE LINE-OF-SIGHT REGION

$-40 \text{ degrees} \leq \Omega \leq +40 \text{ degrees}, -40 \text{ degrees} \leq \Sigma \leq +30 \text{ degrees}$

$70 \text{ n mi} \leq h \leq 230 \text{ n mi}$

Control Parameter	Range	Step Size (degrees)	Accuracy Including Granularity and location (degrees)
Shutter orientation	±111 degree sector measured about X-axis with respect to +Y-axis	3	±3
Platen jog orientation	±60 degree sector measured about X-axis with respect to +Z-axis	4	±3
Maximum platen velocity	$-0.24 \frac{\text{inch}}{\text{sec}} \leq V_{max} \leq +0.24 \frac{\text{inch}}{\text{sec}}$	$0.016 \frac{\text{inch}}{\text{sec}}$	$\pm 0.014 \frac{\text{inch}}{\text{sec}}$

± 0.002 inch/second. Factors considered in establishing this synchronization tolerance were the degree of control complexity and accuracy required and the amount of performance degradation induced on-axis.

2.4.6.3.3 Parabolic Smear. Because the exposure slit width is finite, the image velocity at a point on the edge of the slit is not matched perfectly with the velocity imparted to the film (as determined by requirements at the centerline of the slit). This is a degrading effect inherent to all X-IMC methods. It is termed parabolic smear because the smear rate varies linearly during the exposure time and gives a total smear (resulting from this effect) which is proportional to the square of the local exposure time.

2.4.6.4 Implementation and Control. To control the X-IMC, shutter and jog orientation angles, and V_{Max} are determined by the on-board computer using values predicted to exist at the time the slit centerline will pass the on-axis point.

2.4.6.4.1 Shutter Rotation Control. In those situations where the shutter could be oriented to either of two rotational positions 180-degrees apart, the computer will determine which position can be attained more quickly and command the least time-consuming setup.

2.4.6.4.2 Inhibit Control. Inhibiting of the platen jog will be automatic to meet the requirements of paragraph 2.4.6.3.1 and 2.4.6.3.3. In addition, the flight crew will have the capability to inhibit the platen jog.

2.4.6.5 Factors Degrading X-IMC Effectiveness. X-IMC is designed to partially compensate for only the linear geometric image rates. Because the total image motion at any point in the field is the vector sum of the predictable geometric rates plus random tracking-rate error (including off-axis nulling) and vibration induced image motion, the effectiveness of the X-IMC in reducing smear is inherently limited by the relative magnitude of the uncompensated random image motion.

In addition, the X-IMC equipment will provide its own vibrational inputs to the optics and the platen which would not be present if X-IMC were not used.

2.4.6.6 X-IMC Inhibit Criteria. X-IMC should be inhibited when its use would increase the expected value of average smear in the central half-field (0.27 degree) of the format. For a perfect X-IMC device, (no induced vibration and zero servo inaccuracy) and no random image motion, the X-IMC equipment would be inhibited only for nadir photography, where the linear geometric image rates vanish. With a nonperfect IMC device and nonzero random image motion, a region exists around nadir where X-IMC should be inhibited. This region is convenriently defined by inhibiting X-IMC for jog velocities at the edge of the format which are less than 0.04 inch/sec. The operational software requirements were updated to this criterion.

2.4.7 Time-Dependent Factors.

The need for a finite exposure time when recording an image on film causes the performance of a photographic system to be time-dependent. The three principal time-dependent factors are: optimum exposure time, image smear rate, and shutter efficiency.

2.4.7.1 Exposure Time. Optimum resolution is dependent on correct exposure. In this paragraph, exposure criteria, exposure times for the Dorian system, and exposure optimization are discussed.

2.4.7.1.1 Film Exposure Index Criteria. The optimum exposure time for high-altitude reconnaissance photography is defined as the exposure time required to make the average-minimum apparent scene luminous emittance correspond to the 0.6-gamma (speed) point on the black-and-white aerial film characteristic curve (density vs log exposure).

The average-minimum apparent scene luminous emittance (B_{min}) varies with solar altitude, haze level, atmospheric transmittance, and scene content. For purposes of performance prediction and design a nominal B_{min} of 890 foot-lamberts is specified in the Phase II Work Specification and MOL System Specification, SS-MOL-1A (integrated).

2.4.7.1.2 Scene Luminous Emittances. The solar altitude depends on target location on the earth, and the time of day and year at the target. The following equations were used to describe the dependence of B_{min} on solar altitude:

$$\log B_{min} = 2.903 \text{ for solar altitudes } (\alpha_s) \text{ between 60 and 90 degrees, and}$$

$$\log B_{min} = 1.897 + 2.741\,(10^{-2}\alpha_s) - 1.736\,(10^{-4}\alpha_s^{\,2}) \text{ for 5 degrees} \le \alpha_s \le 60 \text{ degrees.}$$

These equations (plotted in Figure 2.4-11) may be refined as more scene luminous emittance data from satellite systems become available to the AF. The ground computer will be programmed to solve equations of this type. It is planned that the operational software will be capable of handling third-and fourth-order terms in solar altitude and also that the effect of aiming angles on the lens transmittance will be factored in.

2.4.7.1.3 Effective Lens Transmittance. The effective on-axis lens transmittance (T) of the photographic optical assembly is defined by the expression:

$$T = \left[\frac{A_{tm}}{A_L} - \frac{A_o}{A_L}\right] \frac{\int_0^\infty T_L(\lambda) W(\lambda) S(\lambda) d\lambda}{\int_0^\infty W(\lambda)\ S(\lambda)\ d\lambda} ,$$

where:

A_{TM} = projected area of the tracking mirror on a plane normal to the optical axis,

A_L = area of the 70-inch-diameter-lens circular aperture,

A_O = area of the Newtonian mirror and Newtonian-mirror spider-mount obstruction,

$T_L(\lambda)$ = on-axis transmittance of the optical elements (products of mirror reflectances, glass transmittances, and main pellicle transmittance) relative to equal energy sources,

$S(\lambda)$ = spectral sensitivity of the film, and

$W(\lambda)$ = apparent radiant emittance from the scene, including haze.

The first factor in this expression contains the projected area (A_{TM}) of the tracking mirror and causes the effective lens tramsittance to be dependent on the line-of-sight of the reconnaissance satellite. When the tracking mirror is positioned for nadir line-of-sight, the ratio A_{TM}/A_L is

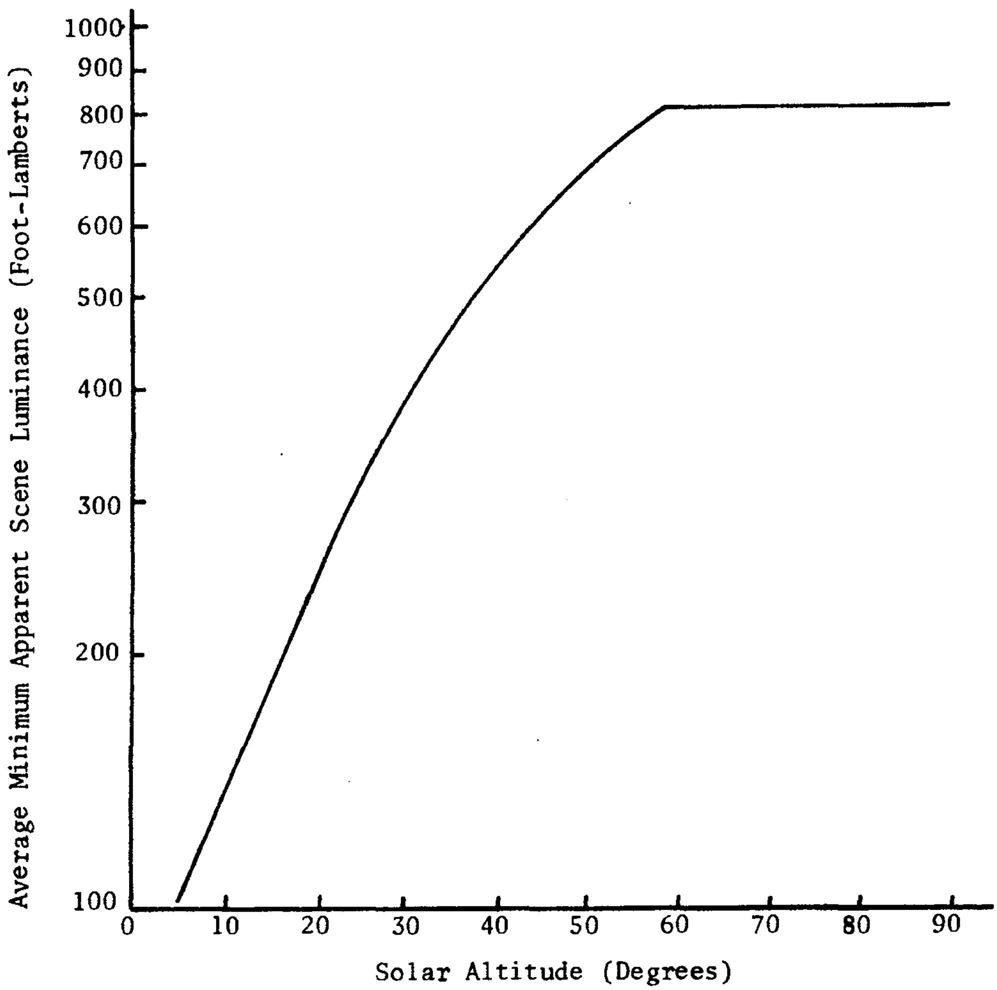


Figure 2.4-11. Relationship between Average-Minimum Apparent Scene Luminous Emittance and Solar Altitude

0.695. The ratio of the Newtonian mirror and mount area to the lens circular aperture area (A_O/A_L) is 0.172. The value for the first factor in the transmittance expression, therefore, is 0.52.

The on-axis spectral transmittance of the lens, $T_L(\lambda)$ is given in Figure 2.4-12. These data include an average pellicle transmittance of 0.875. Pellicle transmittance was reduced from the 0.93 value reported previously because of a decision to eliminate the anti-reflection coating.

Scene-radiance conditions used in determining W (λ) include:

a. Sunlight and skylight irradiance corresponding to a solar altitude of 30 degrees.

b. Scene reflectance - neutral target having a 10-percent reflectance.

The upper and lower limits of integration in the second factor of the transmittance expression correspond to the wavelengths where film sensitivity and lens transmittance, respectively, go to zero. Evaluation of this integral for the Dorian system yields a value of 0.56 for this second factor.

The effective on-axis transmittance, T, for a nadir line-of-sight is the product of these two factors, and

$$T = (0.52)(0.56) = 0.29.$$

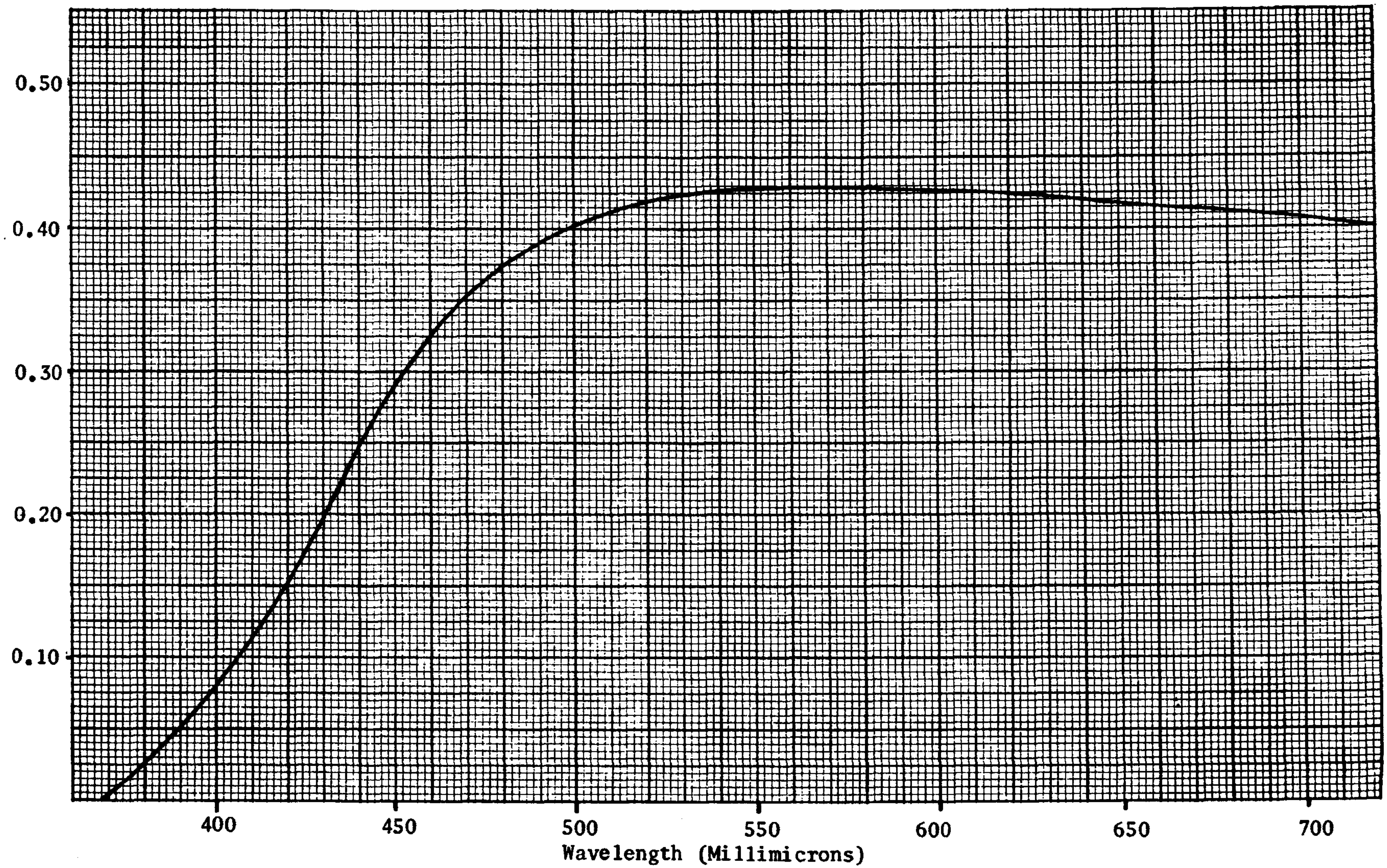


Figure 2.4-12. Spectral Transmittance of the Primary Optics for an Equal Energy Source and Independent of Film Sensitivity (Nadir Position)

2.4.7.1.4 Range of Exposure Times. The optimum exposure time for the Dorian system for targets having an average-minimum apparent scene luminous emittance of 890 foot-lamberts is 1/165 second based on the following parameters:

a. Lens transmittance including vignetting and obstructions = 0.29 (see paragraph 4.1.2).

b. F-number = [redacted]

c. Aerial exposure index (AEI) of primary film = 6.0

The equation used to determine exposure time after B_{min} was established is as follows:

$$t = \frac{4(N)^2}{10.76(2AEI)\ T(B_{min})},$$

where:

t = exposure time (seconds),

N = F-number,

$AEI = 1/(2E_{sp})$,

E_{sp} = Exposure at 0.6-gamma speed point in meter-candle-seconds,

T = Lens transmittance, including the central obstruction and on-axis vignetting for nadir view, and

B_{min} = Average-minimum apparent scene luminance (foot-lamberts).

The range of local exposure times needed to meet the expected range of B_{min} values and AEI values for the Dorian system is:

t_{max} = 0.04 second, and

t_{min} = 0.0025 second.

This range of exposure times is provided by including in the camera a focal plane shutter with a slit whose width can be varied in 8 discrete steps.

2.4.7.1.5 Exposure Optimization. One unique feature of the Dorian camera is that up to 10 frames of a single target can be obtained during a pass over the target. In the 10-frame exposure sequence the camera can be programmed to provide one-stop over nominal, nominal, and one-stop under nominal exposures. Exposure bracketing in this manner will provide maximum resolution for most luminances within the target area. Also, multiple frames of the same target will provide a choice of base-to-height ratios for stereo viewing. Should a particular frame be of lower resolution, it can be combined with a higher resolution frame of the same target to make a stereo pair in which the resolution will be that of the better frame.

Data relative to exposure bracketing are given in Figure 2.4-13. Curve (A) gives relative resolution values for an $f/4$ lens plotted against the average log exposure for a tri-bar target of a 2:1 contrast. A similar curve will exist with a Dorian lens. The maximum resolution corresponds to a density of 1.0 on the characteristic curve of the film. The film in this example is KODAK High-Definition Aerial Film, Type 3404 (ESTAR Thin Base) processed to an exposure index of 3.6. The apparent-scene luminous emittance values which correspond to nominal exposure and to plus and minus one-stop exposure are given on the lower part of Figure 2.4-13.

In a typical scene, about 95 percent of the recorded luminances are in a band having extremes in the ratio of 5:1. There are many local areas of specific interest whose contrast may be on the order of 2:1 but whose absolute-luminance levels may be anywhere within the overall 5:1 luminance

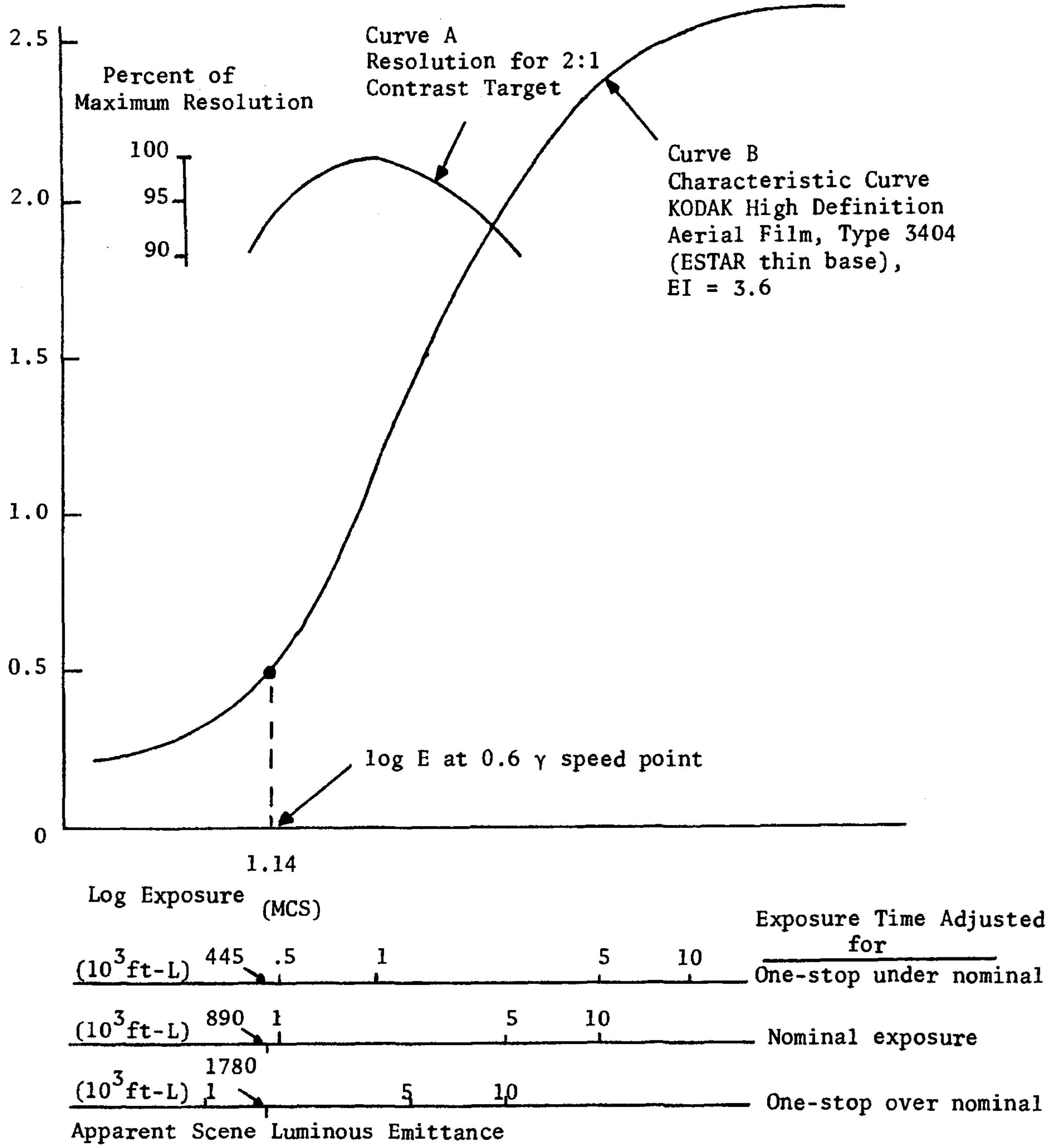


Figure 2.4-13. Relationship of Log Exposure to Resolution and Density

band. Experience has shown that the distribution of the absolute levels of the 2:1 local contrast areas is approximately log-normal within the 5:1 range. If exposure is set to equate the average-minimum scene luminous emittance to the 0.6-gamma speed point of Type 3404 Film, then the average 2:1 scene will occur at a luminance level which corresponds approximately to a density of 1.0 in the negative.

Bracketing the exposure increases the probability, compared to a single exposure, that many scene elements will be close to 1.0 density where maximum resolution occurs.

A simulation was prepared to illustrate the gain from exposure bracketing. The basic technique used to make the simulation is diagrammed in Figure 2.4-14. In Figures 2.4-15 and 2.4-16 there is a set of gray patches. The darkest patch, which has a reflectance of four percent measured on the ground, was used as a control for the simulation. 400 foot-lamberts of haze was added to simulate the haze expected at 40-degrees solar altitude. On the normally exposed Type 3404 Film simulation negative the apparent scene luminous emittance from the four-percent reflectance patch (haze included) was made to correspond to the 0.6-gamma speed point. The one-stop over and one-stop under exposures were adjusted accordingly.

A comparison of the gantry shadow areas of the two photographs in Figure 2.4-15 shows that in the shadow areas more detail and information can be seen in the one-stop overexposure photograph. A similar comparison of exposure photograph in Figure 2.4-15 with the same areas in the one-step underexposure photograph shows that underexposure photograph in Figure

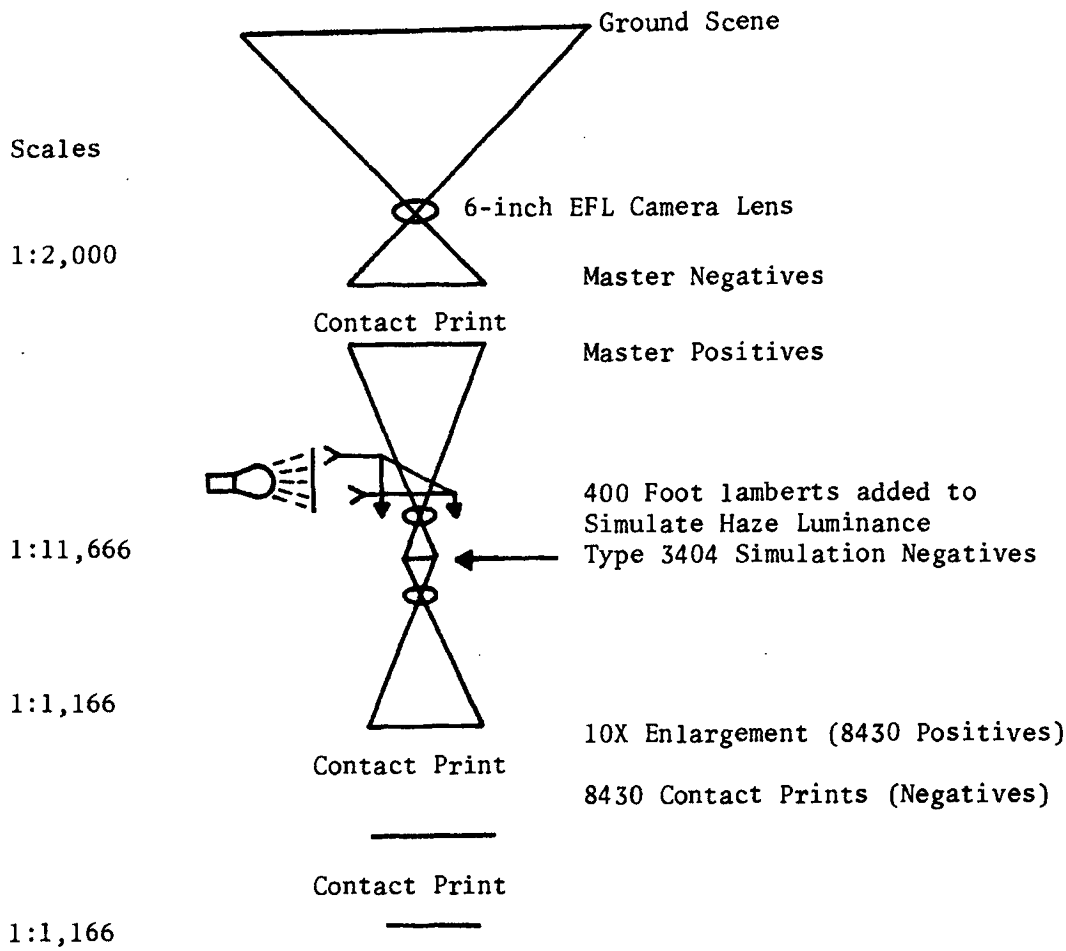


Figure 2.4-14. Procedure Used to Make Stereo-Pair Simulation

2.4-16 is preferred when recording detail in high-luminance areas. For mid-scale luminances the nominal exposure is best. This conclusion is illustrated by the fact that the other two photographs have poorer resolution on the low-contrast tri-bar target than does the nominal exposure. The low-contrast target is located adjacent to the large tri-bar target near the center of the scene.

These simulations demonstrate that the use of exposure bracketing will provide significantly more information than one correctly exposed frame.

2.4.7.1.6 Stereo and Quality Simulation. Figure 2.4-17 shows a stereo pair of prints made by combining a nominal exposure photograph with a one-stop overexposure photograph taken at a different angle of view. The resolution of the nominally exposed photograph is about [redacted] The original Type 3404 Film simulation negative had [redacted] quality, but three printing steps from the simulation negative have caused some resolution loss. Because the original negatives were taken from a helicopter using a hand-held camera, there is a slight difference in scale in the two views. However, scale differences among photographs taken with the Dorian system will normally occur because of the continuously varying slant range. It has been demonstrated experimentally that scale variation of the magnitude expected in Dorian does not interfere with the fusion of stereo pairs in a viewer. The photographs in Figure 2.4-17 are 10X enlargements from Type 3404 Film negatives made at a scale of 1:11,700.

2.4.7.2 Smear. When the image of an object being photographed moves with respect to the film during the exposure, the resultant photograph of the object is reduced in sharpness. The photograph is then said to be smeared. If the smear-free, or static, resolution of the system is better than the

[redacted]

Nominal Exposure on 3404
Simulation Negative

One-Stop Over Exposure on
3404 Simulation Negative

Figure 2.4-15. Simulation Showing Results
of Exposure Bracketing

[redacted]

One-Stop Under Exposure on
3404 Simulation Negative

Figure 2.4-16. Simulation Showing Results
of Exposure Bracketing

specified dynamic resolution, smear can be tolerated (budgeted) up to that point where the dynamic (with smear) resolution equals the specification. The smear budget for the OV, and the PP contributors to smear are presented in Table 2.4-5. Estimates of PP smear rate motions are pending receipt of associate contractor predicted OV vibrations in the form of time history of the camera and optical elements.

Off-axis points, especially in nonvertical photography are smeared by apparent changes in the target geometry (geometric smear) during the exposure interval. X-format image motion compensation (X-IMC) is used to reduce the smear arising from geometric image motion (see paragraph 2.4-6). Evaluation of the effectiveness of the X-IMC can be measured by comparing the average smear over a single frame with and without X-IMC. Table 2.4-6 shows the average smear (without X-IMC/with X-IMC) in microns as a function of the target acquisition parameters. The average is taken by equally weighting the resultant smear levels at 37 equally spaced points throughout the central 4.7 inch diameter of the format. The improvement in smear is even greater than that shown if the average is taken over the entire format. Smear reduction ratios for negative stereo and negative obliquity angles are approximately equal to their positive stereo and positive obliquity counterparts respectively.

2.4.7.3 Shutter Efficiency. For a focal plane shutter, shutter efficiency is equal to the time that an image point would be exposed if the shutter plane were coincident with the film plane divided by the overall time the image point is actually exposed. This ratio is a function of slit width, shutter-to-film separation, and lens f-number (see Figure 2.4-18). The shutter-to-film separation for the Dorian camera varies with focus adjust-

TABLE 2.4-5

ON-AXIS SMEAR BUDGET

	Budgeted Smear Rate (μ rad/sec) (2-sigma)
PP vibration	[redacted]
Camera* (preliminary)	
Film handling (preliminary)	
VO (preliminary)**	
Root Sum Square (RSS)	
Associate contractor vibration	
Contingency (all contractors)	
Total System Vibration (RSS)	
Associate contractor tracking rate error	
Total Dorian smear rate RSS	

* Without X-IMC (see paragraph 2.4.6.6 for X-format inhibiting criterion)

** Without magnification changes

[redacted]

Figure 2.4-17. Stereo Pair Showing Dorian System Image Quality

TABLE 2.4-6

Smear Without/With X-IMC

(Average Smear Throughout Central 4.7-inch Diameter of format)

(microns)

	Obliquity Angle (degrees)				
	0	+10	+20	+30	+40
Stereo Angle (degrees)					
+15	5.0	5.2	5.5	5.9	6.4
	3.1	3.0	2.8	2.7	2.7
+10	3.9	4.1	4.6	5.3	6.1
	2.8	2.7	2.7	2.6	2.6
+5	2.9	3.1	3.9	4.7	5.8
	2.6	2.6	2.6	2.6	2.6
+0	2.6	2.8	3.6	4.6	5.6
	2.6	2.6	2.6	2.6	2.6

Assumptions:

Stable orbit

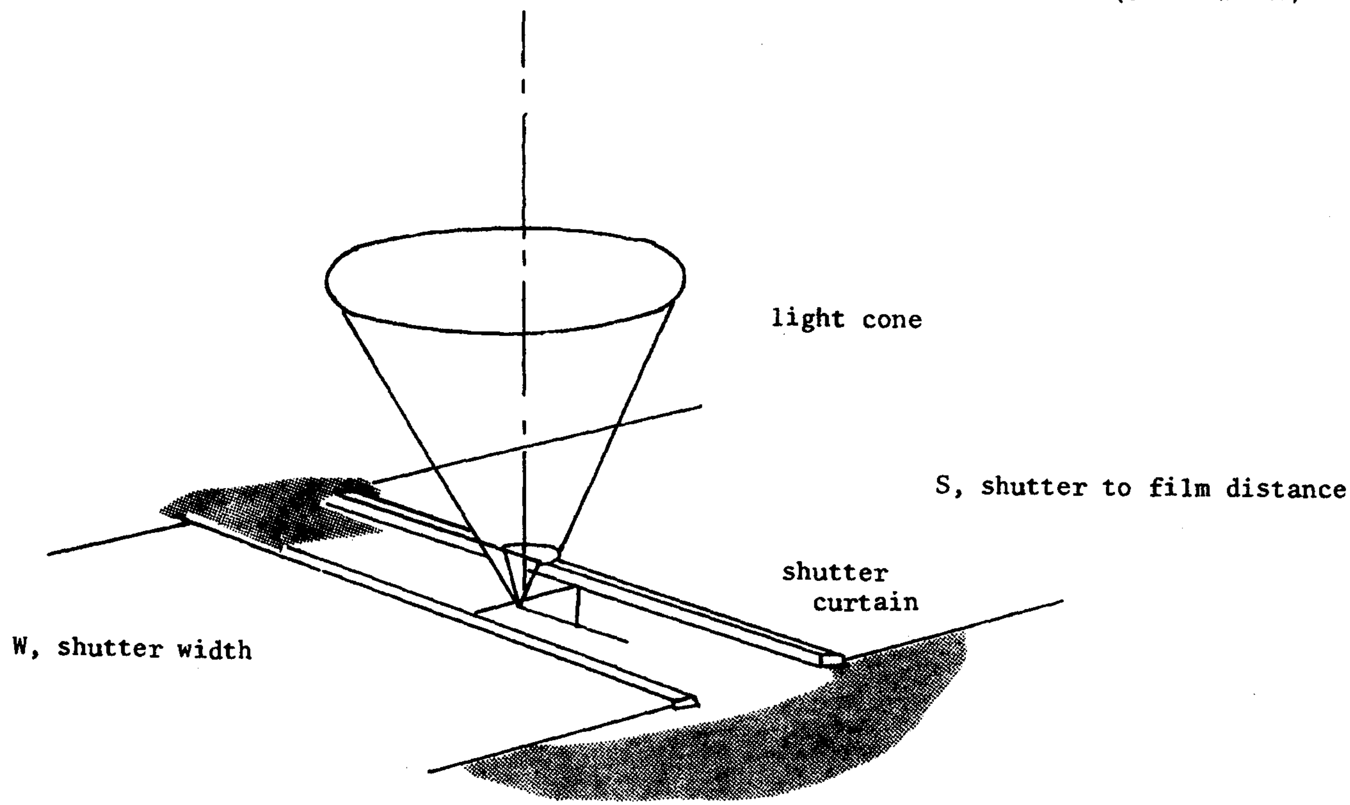
No error in programmed V/h, Σ, and Ω used for set up of X-IMC parameters

No errors in X-IMC set-up parameters

Slit velocity = 50 inches/sec

Local exposure = 1/200 second

[redacted] of random smear rate included both with and without X-IMC, neglecting any additional random smear caused by actuating X-IMC.



$$Eff = \frac{W}{W + S/f^{\#}}$$

Figure 2.4-18. Shutter Efficiency

ment. Based on a reference exposure time of 0.005 second, the shutter efficiency for the current camera design will vary from 85 percent to 90 percent as the platen is moved over its entire adjustment range. The system requirement that shutter efficiency shall not be less than 85 percent will, therefore, be met for all focus positions of the camera.

Optical performance predictions given in Paragraph 2.5.3 are based on a fixed shutter efficiency of 85 percent, which is a conservative approach because the camera will always exceed this value.

2.4.7.4 Effect of Time-Dependent Factors on Performance. The effect of shutter in efficiency and image motion during exposure is to degrade the MTF of the photographic system. This degraded MTF can be determined by cascading the MTF of the lens with the transfer functions for image motion and exit-pupil shuttering:

$$G_E(\nu) = G_L(\nu) \cdot G_S(\nu) \cdot G_I(\nu),$$

where $G_E(\nu)$ is the transfer function for the exposed image, $G_L(\nu)$ for the lens, $G_I(\nu)$ for image motion, and $G_S(\nu)$ for the shutter; ν is the spatial frequency at which the MTF is evaluated. These time-dependent MTF's are described in Appendix B.

2.4.8 Film Threshold Modulation

The limiting tri-bar resolution of the Dorian photographic system is the spatial frequency at which the available modulation in the aerial image just equals the threshold modulation required by the film. The previous paragraphs in this section describe factors related to the available image modulation; this paragraph considers the modulation needed by the film to form a just-resolved photographic image.

The threshold modulation curve, formerly called the aerial image modulation (AIM) curve, is empirically generated by photographing controlled tri-bar target arrays with a lens having known optical properties onto the photographic film which is being evaluated. The film is then processed under controlled conditions and the limiting resolution of the photographic images are visually determined by experienced readers. These limiting resolution data, combined with the measured target and test lens characteristics, are mathematically reduced to a threshold modulation curve for the film-process combination.

The threshold modulation curve used for photo-optical performance predictions is given by the following expression:

$$\text{Threshold modulation} = 0.026 + 1.24 \times 10^{-6}\nu^{2},$$

where: ν = spatial frequency (cycles/millimeter).

This new threshol modulation curve, which replaces the AIM curve reported in the 1968 EAR, was derived from improved tri-bar test targets and incorporates improved data-reduction methods. The new test targets have a series of tri-bar patterns separated by twelfth-root-of-two spatial frequency steps instead of the sixth-root-of-two steps used previously.

2.4.9 Dynamic Film-Resolution Prediction (Baseline)

Figure 2.4-19 shows the intersection of the film threshold modulation curve with the incident modulation (IM) curve for the exposure image and gives the baseline nadir on-axis dynamic resolution prediction of [redacted] millimeter.

The curve defines the threshold modulation characteristics of Type 3404 Film with D-19 single-level equivalent processing (see paragraph 2.4.8).

The IM curve defines the modulation available in the exposure image. This curve, which is a function of spatial frequency (ν) is given by the expression:

$$IM\ (\nu) = G_c \cdot G_s\ (\nu),$$

where: G_c is the effective scene modulation, 0.333, which corresponds to the effective image plane contrast of 2.00:1 (see paragraph 2.4.2).

$G_s\ (\nu)$ is the dynamic MTF for the photographic system. This system MTF is given by

$$G_s\ (\nu) = G_L\ (\nu) \cdot OQF \cdot G_F \cdot G_I\ (\nu) \cdot G_s\ (\nu).$$

$G_L\ (\nu)$ is the static on-axis heterochromatic MTF curve which includes the effects of diffraction, residual aberrations, focus error, and optical misalignment. The effects of diffraction and residual aberrations are

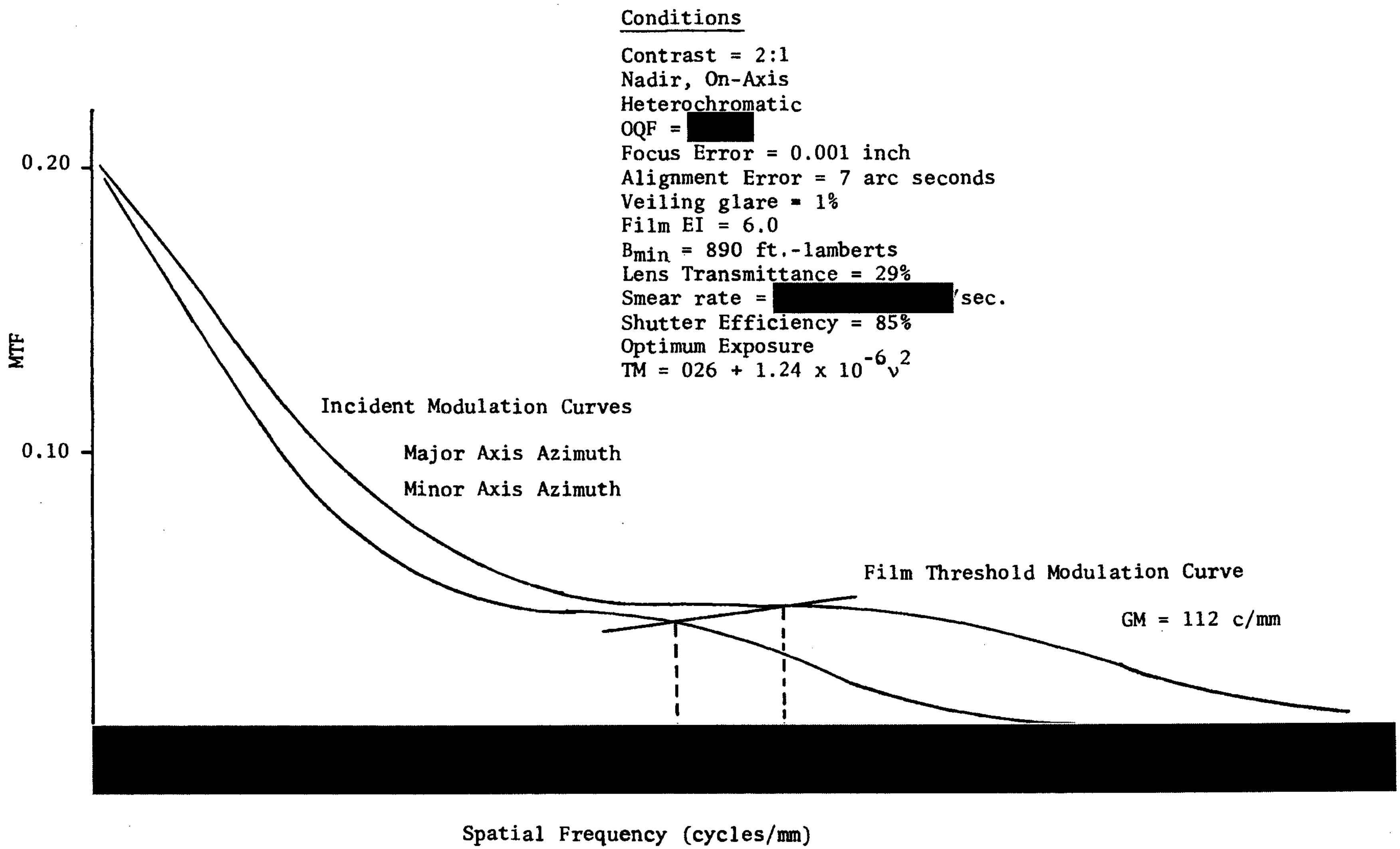


Figure 2.4-19. Baseline Dynamic Film Resolution Prediction

described in paragraphs 2.4.3.1 and 2.4.3.2.1 respectively. Focus error is discussed in pargraph 2.4.4 and optical misalignment in paragraph 2.4.5. The value of focus error used for this baseline performance prediction was 0.001 inch and the amount of misalignment between the optical axes of the primary mirror and Ross corrector assembly was 7 arc seconds. Both are equivalent to 1 standard derivation and, therefore, closely approximate the "expected" values.

The lens-aperture function, which describes the image-forming wavefront's extent and aberrations, is defined by a 70 by 70 array of data generated by ray tracing. This aperture function is numerically transformed into an optical transfer function (OTF) by the convolution method. Monochromatic OTF data for seven wavelengths of light are generated in this manner and are then vectorially summed, using appropriate weighting factors. The modulus of this complex function is the heterochromatic MTF, $G_L (\nu)$.

OQF is the Optical Quality Factor for the lens assembly and is related to manufacturing variations and test uncertainty (see paragraph 2.4.3.2.2). The specification OQF value of [redacted] was used for this baseline analysis.

G_F is the veiling glare factor which is described in paragraph 2.4.3.3. The system requirement for veiling glare is that it shall not exceed one percent of the total incident light on the lens focal plane. The veiling glare factor which corresponds to this requirement is 0.99.

$G_I (\nu)$ and $G_s (\nu)$ are the MTF's related to image smear and shutter efficiency. These functions are derived in Appendix B.

The baseline conditions used for smear calculations are:

a. Angular smear rate = [redacted] per second (1 sigma)

b. Average-minimum scene luminous emittance = 890 ft. lamberts

c. Aerial exposure index = 6.0

The baseline values for scene luminous emittance and film exposure index given above require an exposure time of 1/165 second. This exposure time combined with the baseline angular smear rate yields an image-smear value of [redacted] The direction of this smear is assumed to be 45 degrees to the flight direction. The component smear values, therefore, are [redacted] along the lens aperture major axis and [redacted] along the aperture minor axis. The value for shutter efficiency used for this baseline performance prediction is 85 percent. These time-dependent factors are described in paragraph 2.4.7.

Optical performance in terms of ground resolution is presented in paragraph 2.5.3.

2.5 PHOTOGRAPHIC OUTPUT

2.5.1 Film Format

Figure 2.5-1 is an illustration showing the approximate size of the film format. The scale of the simulated scene is 1 to 12,000; however, the contrast and resolution on an actual photograph will be much better than shown. The major portion of the format consists of the photographic image of the ground target area. Four fiducial marks are located on the periphery

[redacted] -68
Number)

[redacted]

of this image to provide orthogonal reference coordinates for measurement. The two diameters denoted by these marks enable the format center to be determined. The pitch between centers of frames is 10.400 ± 0.125 inches. Two rectangular interframe marks are exposed on either side of the imaginary line separating frames. These marks denote the beginning and end of each frame. An example of a data block containing pertinent information for each frame of photography is also exposed on each format. Simulated smear-slit tracks are also shown in Figure 2.5-1. Smear slits are discussed in paragraph 2.5.5. The sizes and locations of the interframe marks, the data blocks and the fiducial marks are given in Figure 2.5-5a and b along with the direction of film advance for both the primary and secondary film.

2.5.2 Image Size and Scale of Photography

The main image on the film is a 9.4-inch-diameter circle. The image scale will range from 1:52,800 to 1:10,200 depending on the altitude and look angle. For the nominal conditions of nadir photography from 80 n mi, the scale will be 1:11,700.

The current ground-resolution capability of the Dorian photographic system is [redacted] This estimate is based on the baseline conditions defined in Table 2.5-1. The dependence of ground resolution on each of these conditions is shown in a series of graphs which are identified in Table 2.5-1 and current design status and are subject to slight changes as the design progresses and more data become available. For each of these performance curves, baseline conditions are used except for the variable being evaluated.

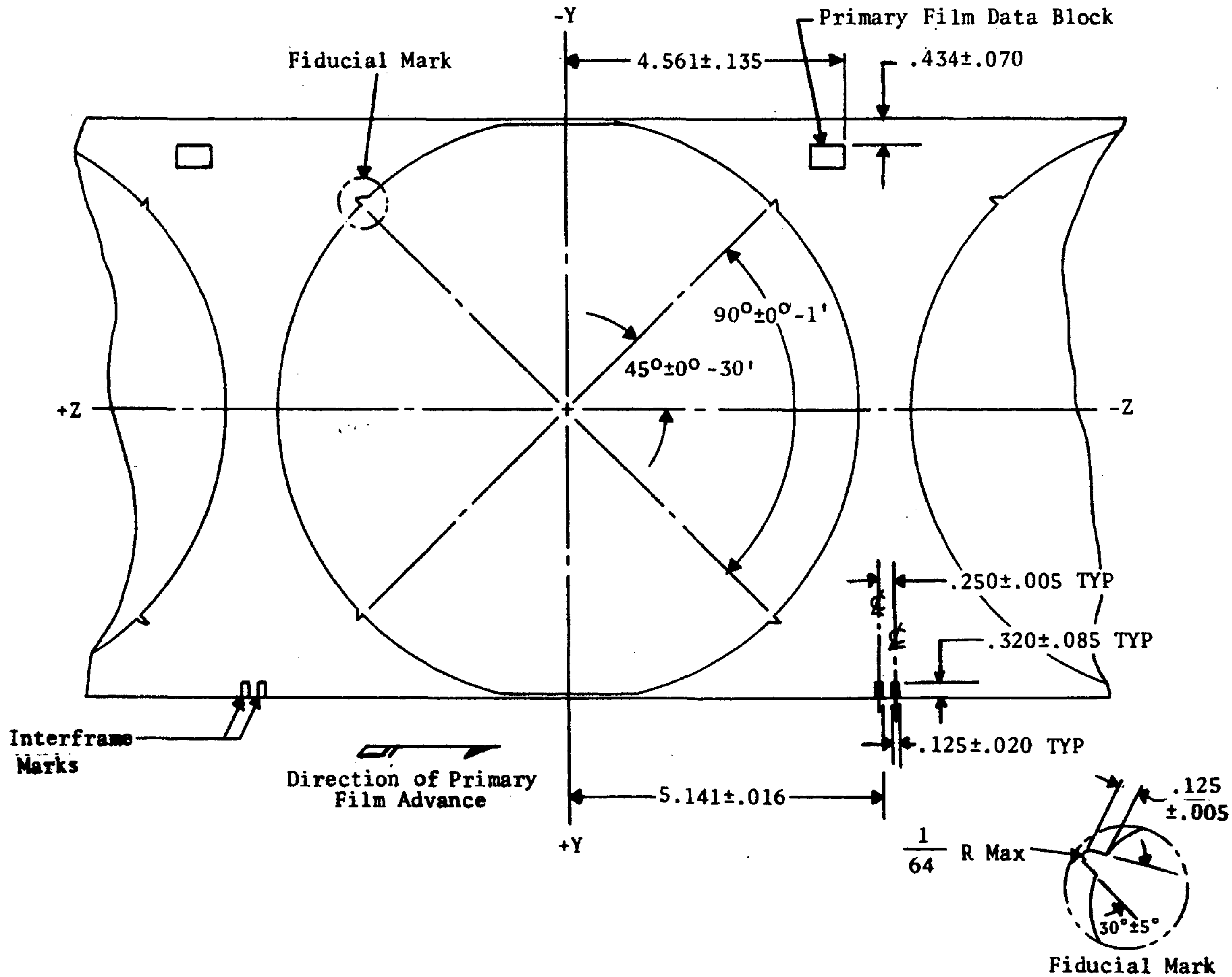


Figure 2.5-2a. Primary Film Format Location of Data Blocks, Interframe Marks, and Fiducial Marks as Viewed from Emulsion Side of Film

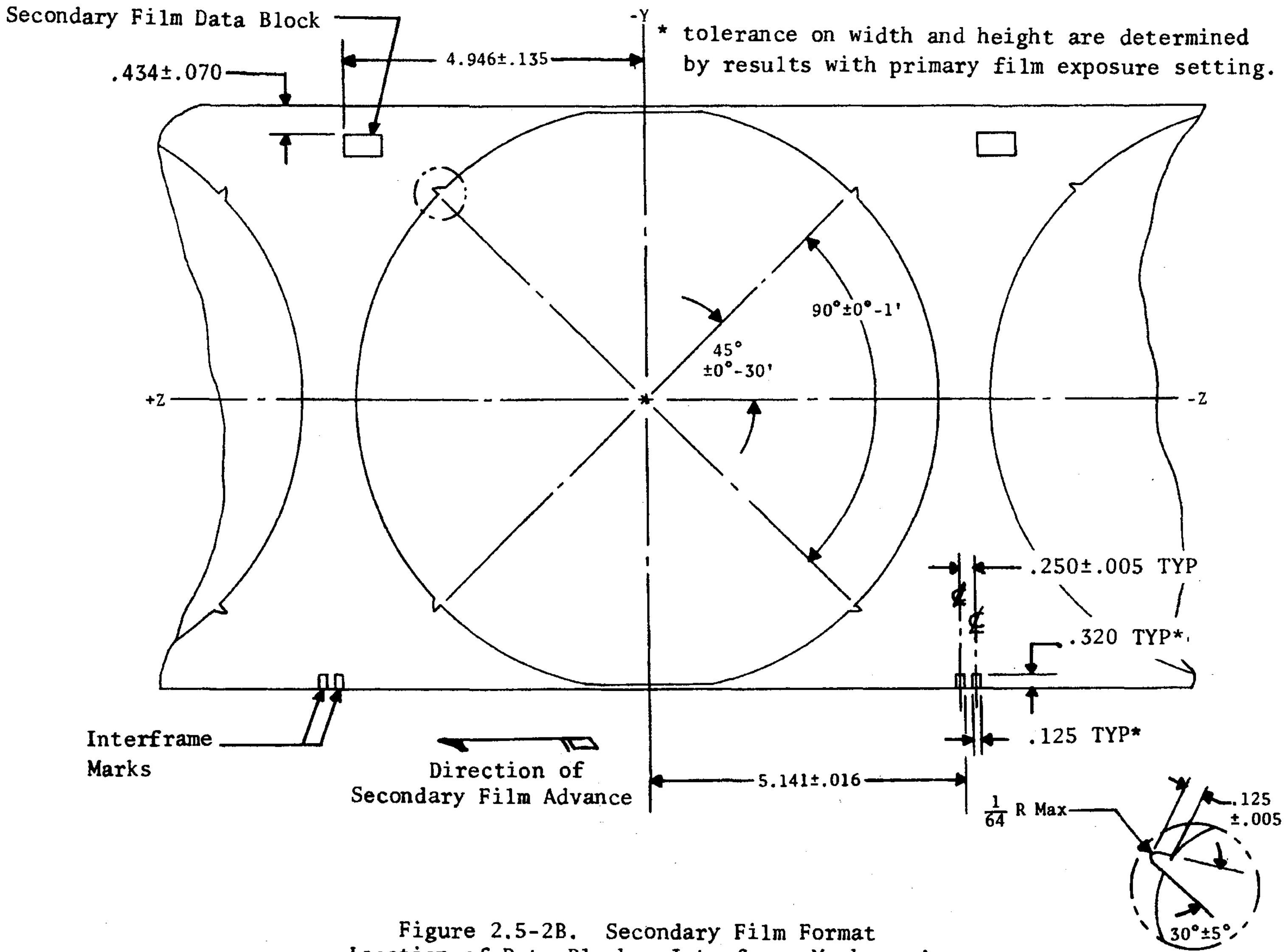


Figure 2.5-2B. Secondary Film Format
Location of Data Blocks, Interframe Marks and
Fiducial Marks as Viewed from Emulsion Side of Film

TABLE 2.5-1

BASELINE CONDITIONS USED FOR PERFORMANCE ESTIMATE

Condition	Baseline Value	Resolution Dependency
Vehicle altitude	80 n mi	Figure 2.5-3
Contrast at film plane	2:1	Figure 2.5-4
OQF	[redacted] percent	Figure 2.5-5
Focus error (1 σ)	0.001 inch	Figure 2.5-6
Image smear rate (1 σ)	[redacted]/sec.	Figure 2.5-7
Optical misalignment (1 σ)	7 arc seconds	Figure 2.5-8
Veiling glare ratio	1 percent	Figure 2.5-9
Shutter efficiency	85 percent	
Scene luminous emittance	B_{MIN}=890 foot-lamberts	
Exposure	Optimum	
Field angle	Zero degrees (On-Axis)	Figure 2.5-10
Pointing angle	Nadir	
Film threshold modulation	FTM = $0.026+1.24 \times 10^{-6} \upsilon 2$	
Film aerial exposure index	AEI = 6.0	

[redacted]

Figure 2.5-3. Dynamic Ground Resolution Related to Vehicle Altitude

[redacted]

Figure 2.5-4. Dynamic Ground Resolution Related to Image Plane Contrast

[redacted]

Figure 2.5-5. Dynamic Ground Resolution Related to Optical Quality Factor

[redacted]

Figure 2.5-6. Dynamic Ground Resolution Related to Focus Error

[redacted]

Figure 2.5-7. Dynamic Ground Resolution Related to Image Smear Rate

[redacted]

Figure 2.5-8. Dynamic Ground Resolution Related to Optical Misalignment

[redacted]

Figure 2.5-9. Dynamic Ground Resolution Related to Percent Veiling Glare

[redacted]

Figure 2.5-10. Dynamic Ground Resolution Related to Field Angle

The current baseline resolution estimate, however, is conservative for the following two reasons:

a. The apparent contrast at the entrance pupil is assumed also to be present at the film plane. Effective scene contrast, as seen by the film will be slightly higher than the 2:1 apparent contrast at the lens entrance pupil, (see paragraph 2.4.2).

b. The minimum shutter efficiency value of 85 percent is used as a baseline condition. Based on a reference exposure time of 0.005 seconds, the current camera design provides a shutter efficiency which will vary from 85 percent to 90 percent as the platen is moved over its entire adjustment range. The shutter efficiency which corresponds to a vehicle altitude of 80 n mi will be substantially higher than the 85-percent baseline value, (see paragraph 2.3.7.3).

c. The estimate is based on a nadir look angle whereas the current design yields slightly better resolution at an aft look angle of about 8 degrees.

Studies are currently being performed to determine more exact values for effective film plane contrast and for shutter efficiency based on the current camera design.

Resolution is predicted for a specific set of conditions, and it must be remembered that during orbital operations, variations in mission conditions beyond the control of EKC may cause the ground resolution to deviate from the predicted value.

2.5.3 Data Block Format

The on-board computer will be used to implement the formation of the data block. The control of data-block recording is discussed in paragraph 4.8.5. The arrangement of data block content was assigned to an associate contractor. The contractor is to ensure that numeric data, such as frame sequence number, will be readable without magnification and will be right-reading when viewed from the base side of the original negatives of the primary and secondary film.

The signals energizing individual data lamps are partially controlled by associate contractor equipment. The EKC camera equipment provides a block of data lamps and places the film in an appropriate position for recording the data. The functions of other EKC equipment in the control of data block recording are discussed in paragraph 4.8.5.

2.5-4 Smear Slits

It is desirable to incorporate into the camera design a means for evaluating the presence of smear. At the smear limits specified for the Dorian System, however, a quantitative measurement of the actual smear is not anticipated. However, useful analysis of gross smear can be performed. One method for recording photographic smear is by the use of smear slits. Smear slits amplify the smear by exposing the same scene twice in a small portion of the image area. The two exposures are separated by a known time interval which is large compared to the exposure time. If smear is present, the image will shift between the two exposures, and a discernible double image may result on the film. The displacement between the images can be measured and converted to equivalent main-image smear.

The double-image technique is limited by the ability to measure the distance between two images of the same object. Current measurement methods are capable of resolving image displacements of approximately 0.0005 inch depending on the quality of the images being used. An additional limitation is the ability to remove geometric smear and platen-jog-induced displacements from the smear record by computation. The accuracy of this computation is restricted by the error in measurement of each parameter (thus by the instrumentation accuracy).

The smear-slit record may be used during post-flight analysis to assist in determining sources of gross image smear (in particular, degrading dynamics) and to assist in evaluating malfunctions which are detectable by the presence of serious image degradation resulting from smear.

Figure 2.5-11 presents the smear-slit layout on the shutter curtain of the Dorian camera. The dimensions of the labeled quantities of Figure 2.5-11(a) and the associated tolerances are presented in Table 2.5-2.

Table 2.5-2

Smear Slit Tolerances

Quantity	Value	Manufacturing Tolerance	Allowable Error in Knowledge
Separation R S	(0.062±.0007)Vs (0.095±.0007)Vs	±0.1% of R	Minimum of ±0.1% of R or ±0.005 inch
Length L	0.1 inch	±0.005 inch	±0.005 inch
Width W-one slit -other slit	(0.005±.00015)Vs W/2 inch	±3%	±1%
C	4.3 inches	±0.01 inch	±0.1%

Vs = shutter curtain velocity in inches/second. Nominal exposure assumed to be 0.005 second.

VsTexp = width of main exposure slit for nominal exposure. Meaningful smear record analysis cannot be conducted for W > 0.5 inch.

The quality of photography in the smear-slit record is degraded by the double exposure. This degradation is not considered a serious problem for two reasons: (1) the area of the degraded image will be small, and (2) the smear-strip orientation varies with shutter orientation so that each frame of a target will have a different smear-strip orientation (see Figure 2.5-4(b)).

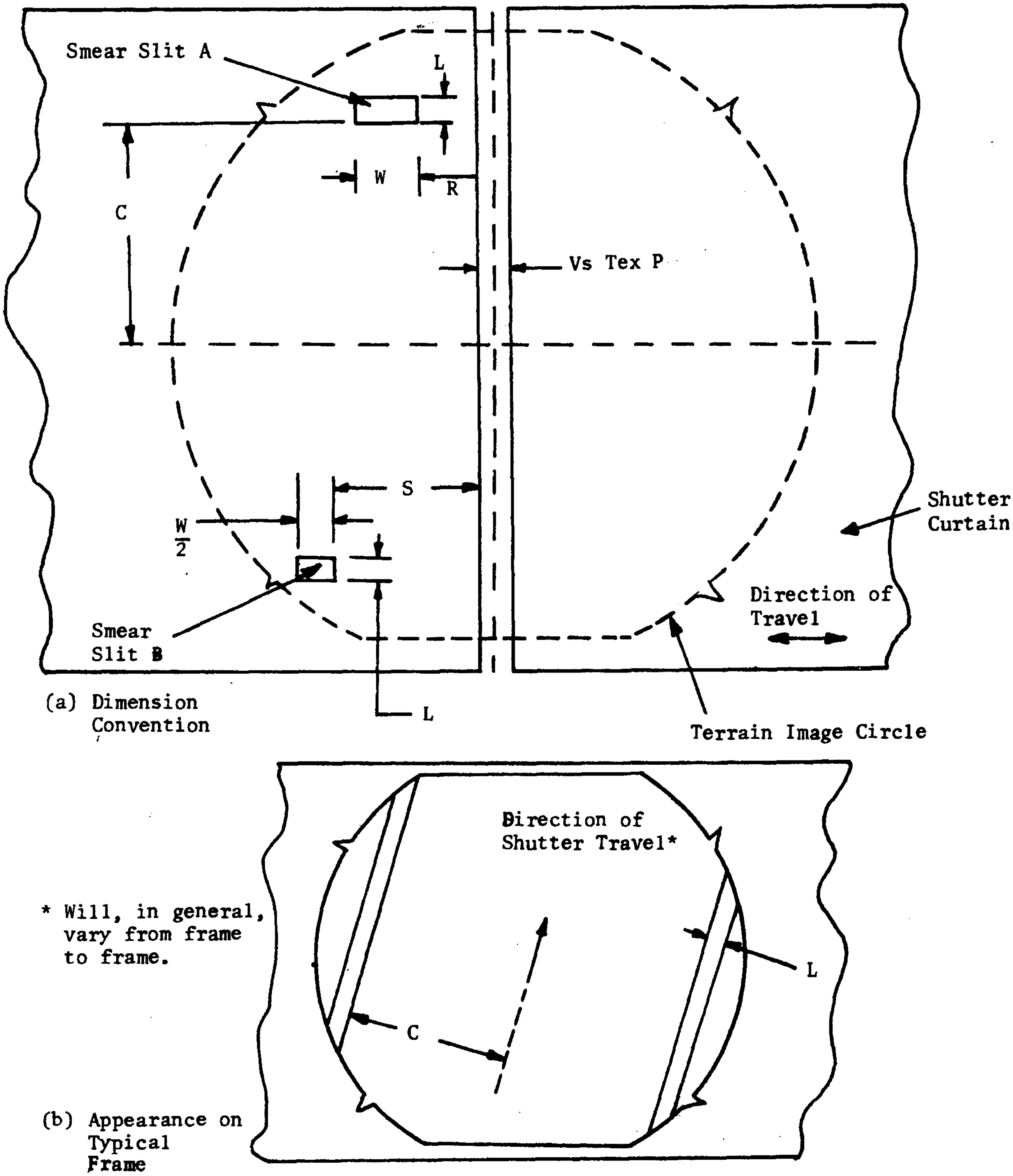


Figure 2.5-11. Smear Slit Layout

2.6 DATA RETURN

2.6.1 Manned/Automatic (M/A) Mode

Information on the photographic record is obtained by ground personnel by two methods in the M/A mode of operation. The principal mode of return of information on both the primary and secondary film types is in the Gemini B at the end of the mission. The flight crew also has the option of processing up to 20 pounds of secondary film and relaying the information contained on this film to the ground stations by verbal descriptions.

2.6.1.1 Return of Primary Film*. The exposed primary film is spooled onto the film reel of the primary film take-up assembly. When the film reel is nearly full (approximately 60 pounds of film), the film is cut and several layers of opaque material are spooled over the exposed film. The reel is then removed from the primary film take-up assembly housing, placed in a lighttight, cylindrical container called a data return container (DRC) and hand carried into the Gemini B and stowed. An identical, empty film reel is placed in the primary film take-up assembly and threaded.

2.6.1.2 Return of Secondary Film. The information from the BIMAT-processed black-and-white secondary film can be returned by verbal communication and by return of the film in the Gemini B. Other secondary film types will be returned in the Gemini B and processed on the ground. Figure 2.6-1 shows the flow taken by on-orbit-processed secondary film.

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* A small quantity of primary film can be processed on-board and returned with the secondary films in the Gemini B.

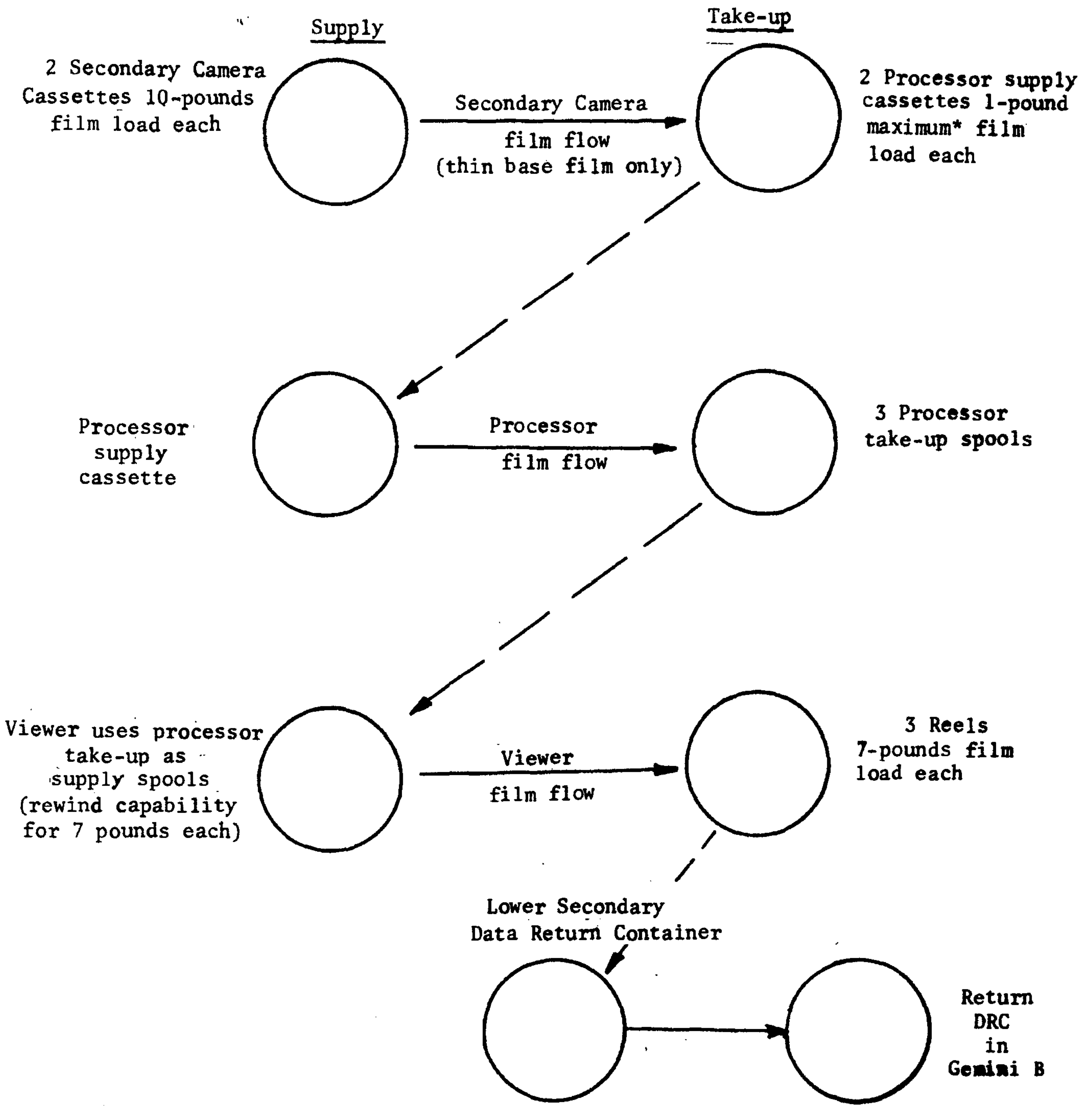


Figure 2.6-1. Secondary Film Flow (processed film only)

* Processor supply cassettes. These two cassettes are reused for several batches to handle the total 20 pounds of film.

2.6.1.3 Data Return Containers for Data Return in Gemini B. The DRC's are containers which support, protect, and store exposed film after removal from the primary and secondary take-up assemblies. The DRC's are designed to minimize the possibility of film damage resulting from handling, contamination, light leaks and excessive temperature excursions. In the Gemini B, the DRC's are capable of protecting and supporting the film for environmental conditions which include pressures from zero to 14.7 psia and the g loads encountered in splashdown.

2.6.1.4 Data Return Container Film Loads. The nominal DRC film-weight breakdown is as follows:

Data	DRC's	Film Weight
Primary film	3	60 pounds/DRC
Secondary film	2	50-pounds total

The secondary film weight breakdown is as follows:

Data	Film Weight (pounds)
Processed film	20
Color film*	10
Infrared color film*	10
High-speed black-and white-film*	10

2.6.1.5 Type and Quantity of Data Returned. In the M/A mode, five film types (1 primary, 4 secondary) are expected to be used, each type being chosen to broaden the information content which is realized from the

* The AF will select from these film types prior to launch preparations.

mission. The primary black-and-white film is to be chosen to provide high resolution of targets in order to gain the most detailed information. The nominal supply load of primary film is 190 pounds. This quantity, together with the 50 pound supply of secondary films, is sufficient to provide a total of 15,000 usable primary and secondary frames. Primary film-return capability in the three primary DRC's is approximately 11,400 usable frames of photography assuming that it is possible during the mission to provide full loading of each DRC. A small amount of the balance of primary film which cannot be used for return in the primary DRC's will serve for on-board photographic health checks.

The secondary black-and-white film of a type similar to Type 3404 Film was chosen so that the flight crew could process and view photographic frames. Ten pounds of color film are included in the payload to give an added dimension in interpretation of the scene content. The infrared color film will permit the detection of heat producing sources and the high-speed black-and-white film will permit night [redacted] photography. Figure 2.6-2 shows the length of film versus nominal weight for different film types. The secondary-film load will permit approximately 2600 usable frames to be returned.

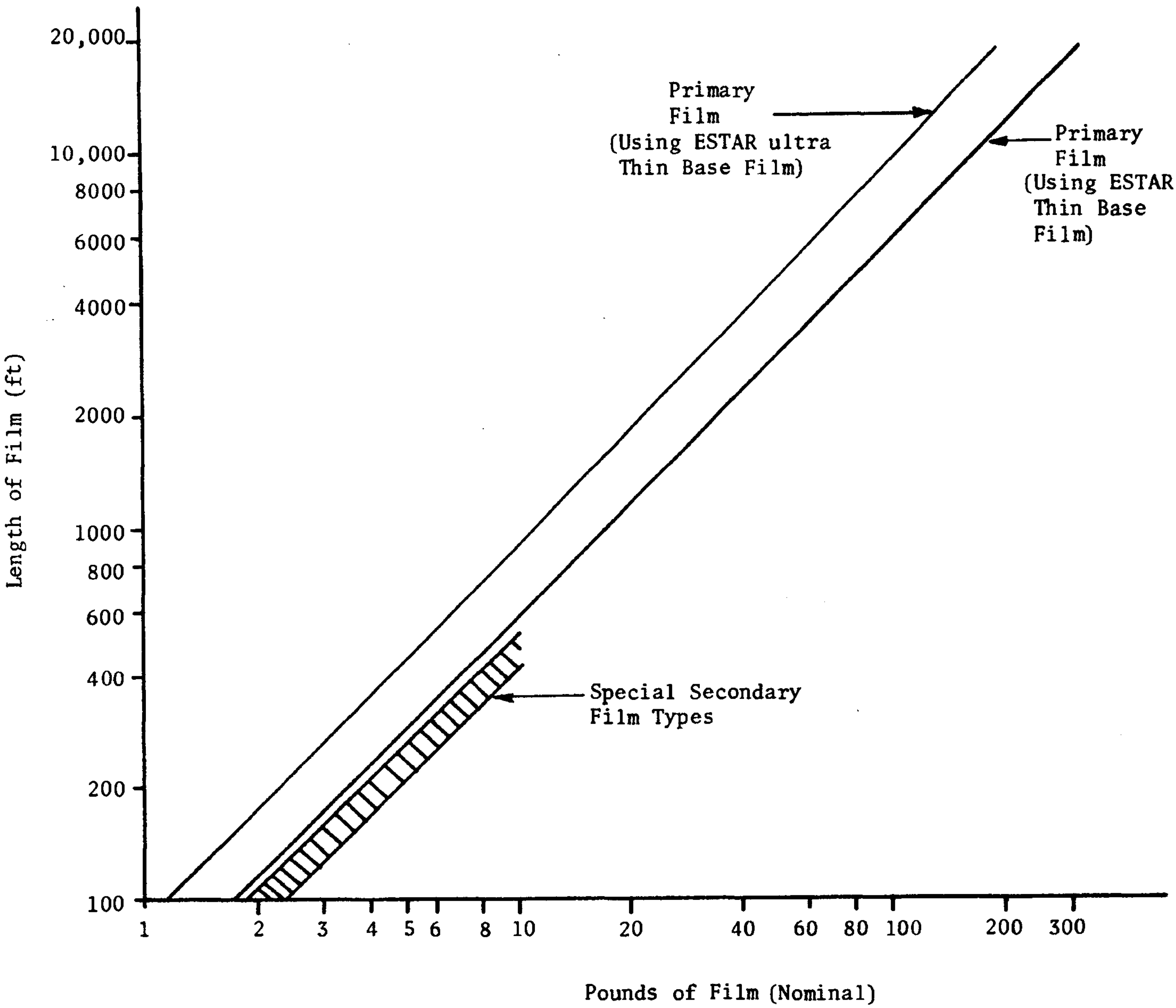


Figure 2.6-2. Film Length vs Weight

SECTION 3
EASTMAN KODAK COMPANY (EKC) INTERFACES

3.1 GENERAL

EKC flight hardware interfaces directly with equipment supplied by McDonnell Douglas Astronautics Company-Western Division (MDAC-WD), General Electric Company (GE) and McDonnell Douglas Astronautics Company-Eastern Division (MDAC-ED). The primary interfaces are associated with the mechanical, electrical, and thermal aspects of flight-hardware design. Figure 1.2-1 shows the orbiting vehicle (OV) for the manned/automatic (M/A) mode, and Table 3.1-1 is a tabulation of the major areas where the EKC equipment physically interfaces with other prime hardware. This section discusses the major photographic payload (PP) interfaces and the associated responsibilities of the various interfacing contractors.

As the mission payload integrating contractor, GE is responsible for documentation of all mission payload system segment interfaces. GE is also responsible for dynamic analysis of the OV based on inputs received from each associate contractor relative to his hardware. An output of the GE analysis is the deflections of the PP mirror elements which are provided to EKC for smear and photographic on-orbit performance predictions of the OV. An interface section will also contain the contractor requirements for this task.

TABLE 3.1-1

M/A MODE MAJOR INTERFACE AREAS

	Gemini B	LM	MM
Mechanical			
Space allocation	X	X	X
Mounting	X	X	X
Shock, vibration, and acceleration	X	X	X
Functional interaction		X	X
Alignment		X	X
Optical			X
Electrical			
Power		X	X
Commands		X	X
Instrumentation		X	X
Data signals		X	
Environmental			
Temperature, radiation	X	X	X
External finishes			X
Conductive paths	X	X	X
Cold plates		X	
Tracking-mirror (TM) view factor			X

X indicates a PP interface with the indicated module.

3.2 MISSION MODULE (MM) INTERFACES

That portion of the MM which is aft of the field break (station 345) is called the MM aft section (MMAS) and is the responsibility of EKC. This is shown in Figure 3.2-1. The section forward of the field break is called the MM forward section, (MMFS) and, for the most part, is a GE responsibility. The MM forward structure is provided to GE by MDAC-WD, who also provides the MM aft structure to EKC in accordance with the requirements defined by GE.

3.2.1 Mission Module Mechanical Interface

The optical assembly is mounted at three points to the MM structure, provided by MDAC-WD. EKC is responsible for establishing the mechanical alignment requirements of the elements within the optical assembly (OA) as well as the alignment reference for the OA to the remainder of the Dorian System.

The EKC-supplied tracking mirror (TM) is mounted to a GE trunnion via the EKC mounting ring, within the MMFS. GE is responsible for the alignment requirements of the TM to the trunnion and the electrical cable between the TM and EKC electrical boxes. EKC installs the TM ring into the trunnions and supplies GE with the necessary alignment reference points on the corrector and diagonal mirror support structures and on the primary mirror so that the alignment between the TM and the OA can be calibrated. The misalignment value is then incorporated into the TM drive software in the form of a bias. The misalignment range between the TM and the OA is specified by GE. GE is responsible for providing the electrical connector

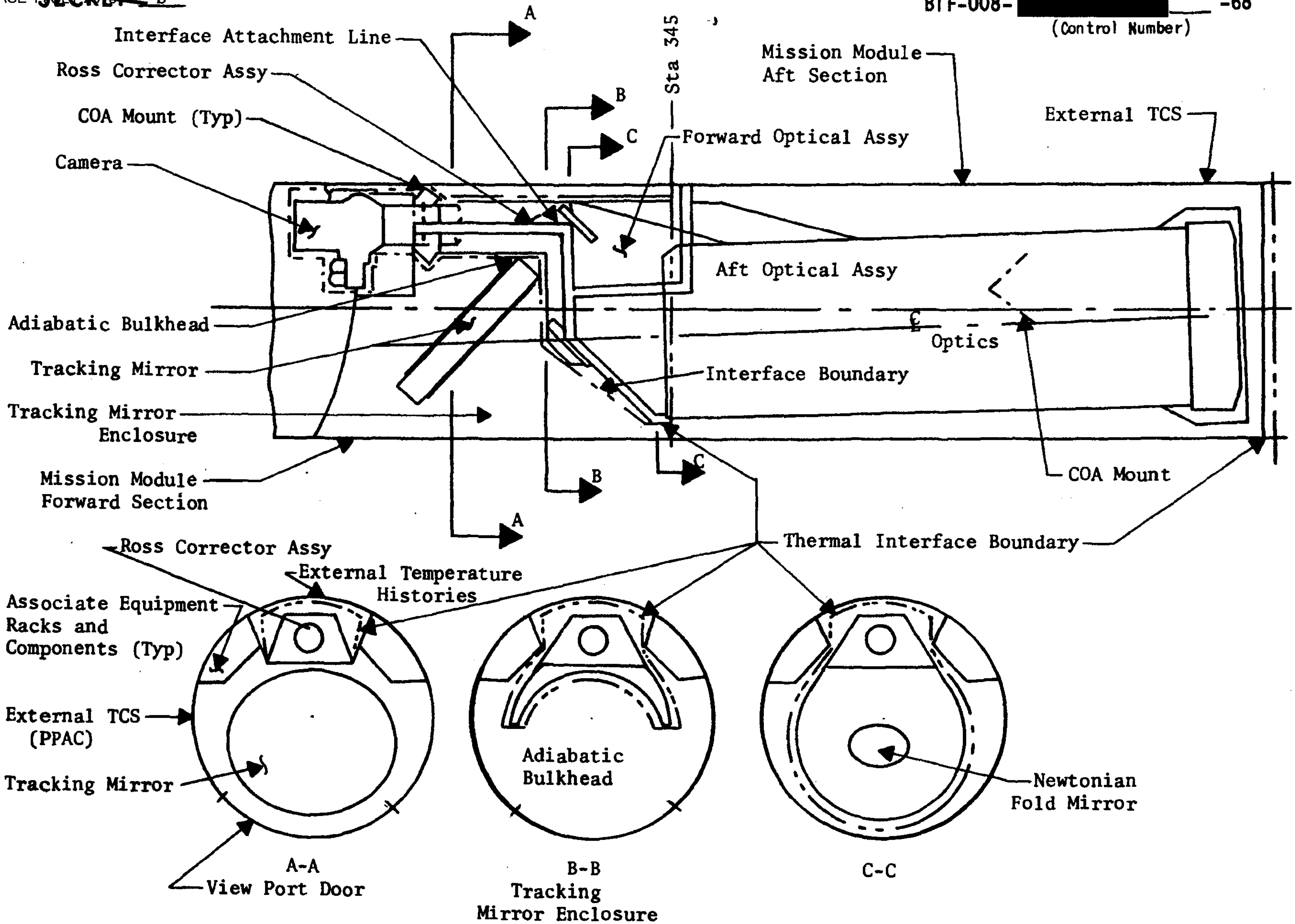


Figure 3.2-1. Mission Module Thermal Interface Boundaries

mounting brackets in the MMFS as well as the cable lengths between EKC interfaces in the laboratory module (LM) and to associate contractor interfacing equipment.

3.2.2 Mission Module Electrical Interfaces

All PP electrical interfaces are with GE. Figure 3.2-2 is a block diagram defining MM electrical interface areas. The interface areas are as follows:

a. MM Power Unit (MMPU) - The MMPU receives unregulated, 28-volt (v) power on multiple feed lines from GE. The MMPU switches and distributes this 28-v power to the utilizing MM equipment.

b. Instrumentation Processor (IP) - The IP utilizes +12-v, +5-v and -6-v power to process MM thermal instrumentation and routes these analog points to the GE/EKC interface for telemetry (TLM) paramatting and transmission by GE.

c. MM Control Unit (MMCU) - The MMCU receives control signals from the EKC controls and displays panel (1-C), located in the LM, via a GE cable and distributes the signals to EKC equipment. The MMCU also receives +12-v, -6-v and +5-v regulated power from GE, distributes this regulated power to the MM using units, and routes instrumentation signals to GE for TLM.

Those pull-away umbilical functions originating in the MM are routed to the GE/EKC interface by the MMCU.

The MMCU receives command pulses from GE and contains the relay matrices required for operational commanding of the EKC MM equipment.

The MMCU routes instrumentation points from the EKC TM equipment to GE for TLM and transmits control signals to the EKC TM equipment.

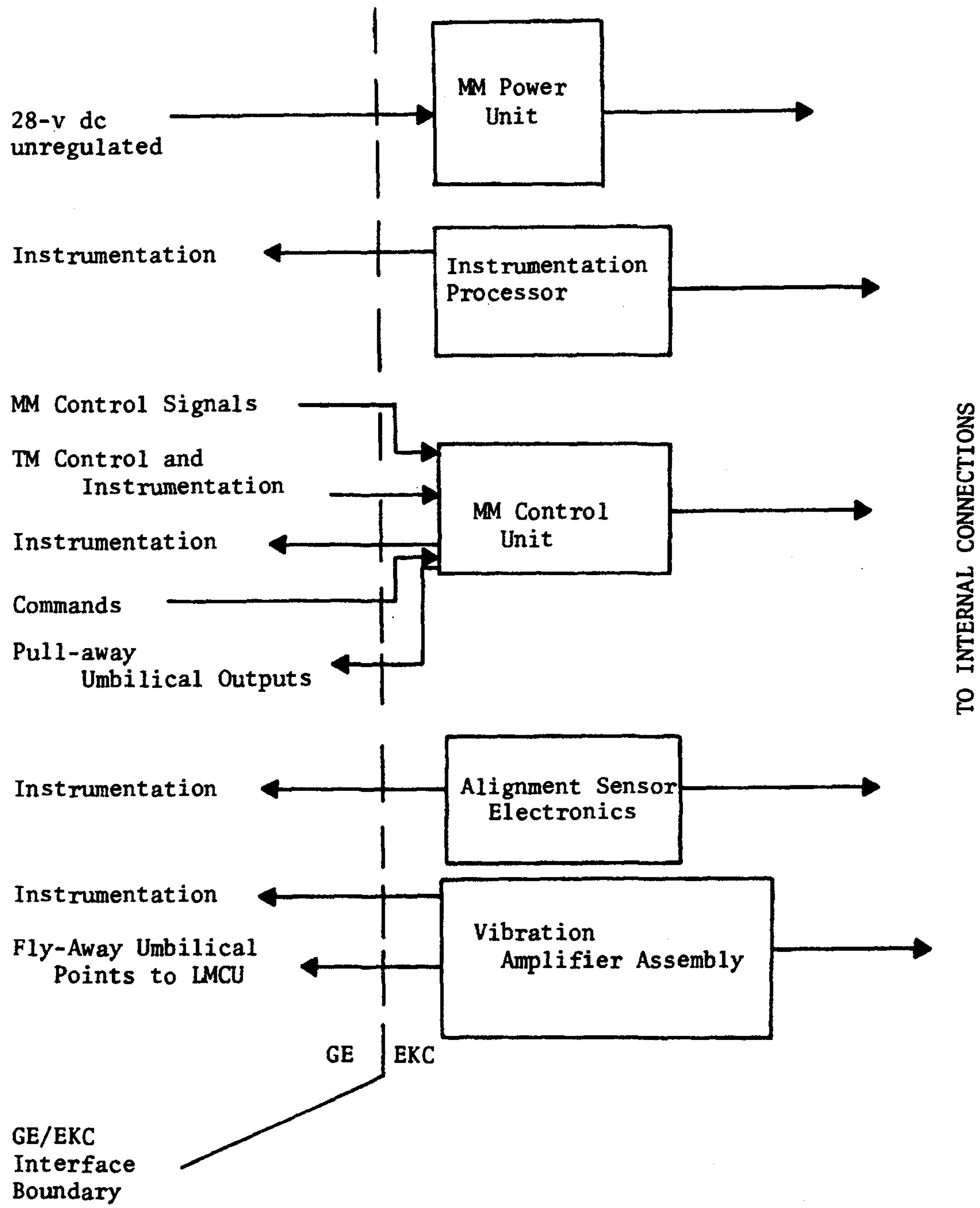


Figure 3.2-2 MM Electrical Interfaces

d. Alignment Sensor Electronics - The alignment sensor electronics provides alignment instrumentation outputs to GE for TLM.

e. Vibration Amplifier Assembly - Continuous analog instrumentation outputs from the EKC MM vibration sensors are processed in the vibration amplifier assembly and routed to GE for TLM processing. This assembly also contains the ground-conditioning instrumentation circuitry which is routed to the fly-away umbilical interface at the LM control unit via a GE cable.

3.2.3 Mission Module Thermal Interfaces

Figure 3.2-1 shows the MM thermal interface boundaries. EKC thermal interfaces for the MM are with both GE and MDAC-WD . A primary thermal interface with GE is at the MMAS/MMFS interface. EKC is responsible for thermal control of the MMAS, which includes all of the OA plus the MM aft primary structure. GE is responsible for thermal control of the MMFS which includes the TM, TM drive assembly, MM forward structure, and other GE hardware. EKC provides thermal control of MMAS hardware facing the MMFS with a GE-provided heat sink. A thermal interface exists between the TM enclosure and the MM aft annulus (that is, the space between the OA and the MM structure). An interface also exists between the TM enclosure and the lens barrel. GE is responsible for the thermal control of the TM in the closed-door configuration. EKC is responsible for establishing the thermal requirements of the TM for both the open-and closed-door configurations.

GE is responsible for supplying the air for ground conditioning the MM during the transportation and handling stages up to and including pre-launch. EKC specifies the ground conditioning requirements of the MMAS (for example, air cleanliness, flow rate, temperature, pressure, humidity). MDAC-WD is responsible for the analysis of ascent venting. EKC and GE are mutually responsible for the ascent-venting hardware requirements.

The EKC/MDAC-WD MM interface is primarily that interface which exists with the thermal control surfaces (coatings) on the MM aft primary structure. Detailed discussions of thermal interface requirements are contained in paragraph 4.6.

3.3 LABORATORY MODULE INTERFACES

3.3.1 Laboratory Module (LM) Mechanical Interfaces

The LM structure and pressurized compartment are MDAC-WD's responsibility. EKC components located in the LM interface with both MDAC-WD and GE equipment. The nomenclature of the EKC components in the LM, their location and mechanical interfaces are given in Table 3.3-1. Figure 3.3-1 shows the console and bay designations as used for the LM. The processor, located in Bay 4, interfaces directly with the other EKC equipment in Bays 1 and 2 via the GE cables. The interface connections are shown in Figure 3.3-2.

3.3.2 Laboratory Module (LM) Electrical Interfaces

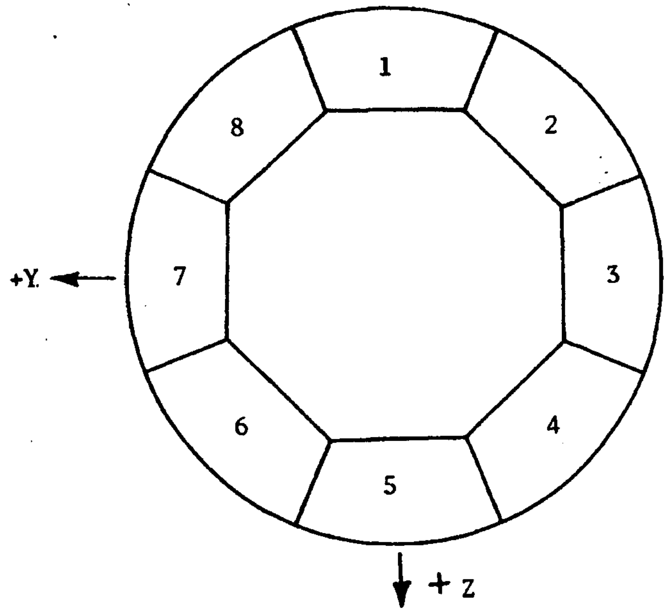
Figure 3.3-2 is a block diagram of the LM electrical interface. The following is a short description of the LM electrical interface.

a. Laboratory Module Power Unit (LMPU) - The LMPU receives unregulated +28-v primary power from GE on multiple feed lines and distributes the power to EKC equipment.

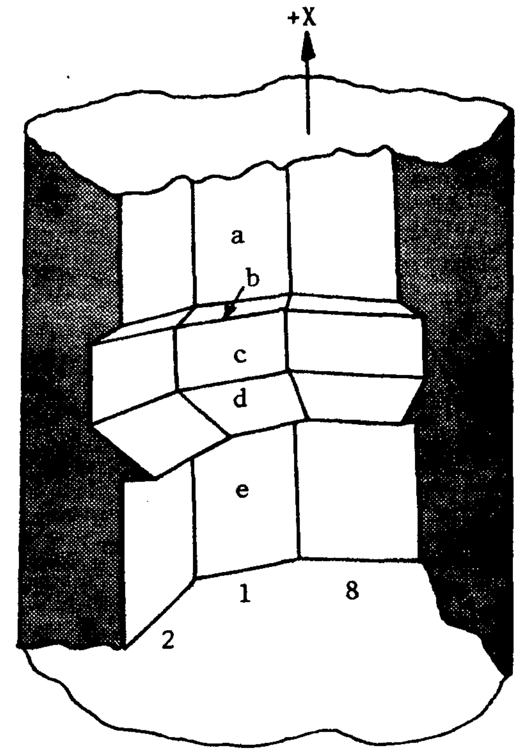
TABLE 3.3-1

EKC LABORATORY MODULE INTERFACE

Item	Bay Location	Mechanical Interfaces With
1. Electronic Packages		
a. Camera auxiliary electronics	2	GE
b. Data conversion unit	2	GE
c. Focus control electronics	2	GE
d. LM control unit	2	GE
e. Visual optics control	2	GE
f. Film handling electronics	1	GE
2. Display and control subpanels	1-C	MDAC-WD
3. Processor	4	MDAC-WD
4. Camera assembly	1	MDAC-WD
5. Visual optics assembly	2, 8	MDAC-WD
6. Primary film handling		
a. Film supply		MDAC-WD
b. Film take-up		MDAC-WD
c. LM chute assembly		MDAC-WD
7. Primary take-up reel storage	2	GE
8. Secondary film cassette storage	5	MDAC-WD
9. DRC storage (primary/secondary)	1, 2	GE, MDAC-WD
10. Bellows	1	MDAC-WD
11. Viewer	4	MDAC-WD



(a) LM Bay Numbering Scheme
(Looking toward MM, -X into paper)



(b) Panel Identification Scheme

Figure 3.3-1. LM Console Bays and Panels

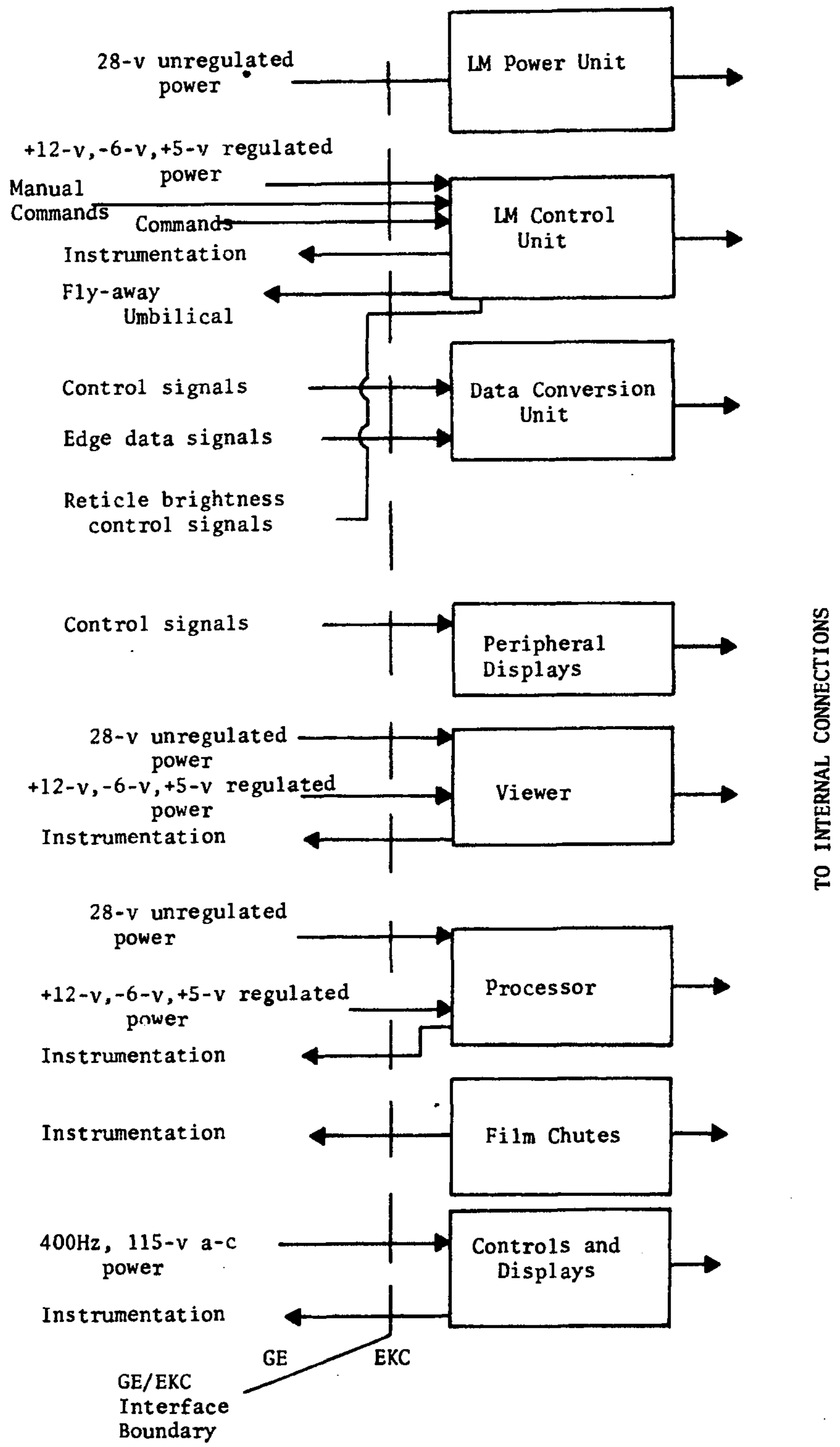


Figure 3.3.2 LM Electrical Interfaces

b. Laboratory Module Control Unit (LMCU) - The LMCU receives command pulses from GE and contains the relay matrices required for operationally commanding the EKC LM equipment. The LMCU receives +12-v, -6-v and +5-v regulated power from GE, distributes this regulated power to the LM using units and routes instrumentation points to GE for TLM.

The LMCU also outputs all EKC fly-away umbilical functions to GE for cabling to the ground equipment.

c. Data Conversion Unit (DCU) - The DCU receives binary-coded signals from GE for recording on the film by a light-emitting diode matrix. EKC supplies GE event and sequencing signals for controlling the transfer of these data across the interface.

d. Peripheral Displays - The peripheral displays unit receives digital control signals from GE for lighting target sequence information lamps in the VO eyepiece displays.

e. Processor - The film processor receives 28-v unregulated and +12-v, -6-v and +5-v regulated power from GE and provides instrumentation outputs to GE for TLM.

f. Viewer - The viewer receives 28-v unregulated and +12-v, -6-v and +5-v regulated power from GE and provides instrumentation outputs to GE for TLM.

h. Vibration Amplifier - The vibration amplifier provides continuous analog vibration instrumentation outputs to GE for TLM.

i. Controls and Displays - The controls and displays receives 400 Hz, 115-v (max) a-c power for operating the electroluminescent panels from GE. The controls and displays provide instrumentation outputs to GE for TLM.

j. Film Chutes - Film handling instrumentation is presented to GE for TLM processing at the film-chute interface connector.

3.3.3 Laboratory Module Thermal Interface

The EKC equipment in the LM consists mainly of heat-generating mounted components (as opposed to optics or structure). Therefore, each component requires a conductive mounting interface. In addition, each component interfaces with the environment of the LM. The electronic components mount on cold plates (supplied by GE), and the camera and processor require coolants for thermal control. The coolants are provided by MDAC-WD as part of the overall LM cooling system. EKC is responsible for establishing the thermal requirements of the PP components in the LM and MDAC-WD is responsible for meeting these requirements.

The thermal interface is also established at the bellows mounting flange between the LM and the OA.

3.4 GEMINI-B INTERFACE

The Gemini-B interface between EKC and MDAC-ED is indirect for security reasons. It is negotiated between GE and MDAC-ED overtly and between EKC and GE covertly.

3.4.1 Mechanical Interface

The data return container (DRC's) which are used to store primary and secondary film are returned by the Gemini B. MDAC-WD is responsible for storing the DRC's in the Gemini B. A space allocation and mounting interface exists for DRC storage in the Gemini B after loading (DRC's are stored in the LM prior to loading).

3.4.2 Electrical Interface

The DRC's do not require power or instrumentation; therefore, a need does not exist for an electrical interface.

3.4.3 Thermal Interface

MDAC-WD is responsible for supplying temperature and environmental control for the DRC's when stored in the Gemini B. The GE/EKC interface specifies these requirements for which GE must coordinate with MDAC-WD.

3.5 INTERFACE DOCUMENTATION

The method for documentation of the PP interfaces was mutually established between GE and EKC with a sectional breakdown covering each interface area. These sectional breakdowns are shown in Table 3.5-1.

TABLE 3.5-1

INTERFACE DOCUMENTATION

IF 100 - Interface Control Procedure for the Dorian Photographic Reconnaissance Satellite System Interface

IF 101 - Mission Payload System Segment to Photographic System Interface Specification

101.1	General
101.2	Mechanical
101.2.6	Thermal
101.3	Electrical
101.4	Environmental
101.5	AGE
101.6	Eastern Testing
101.7	Western Testing
101.8	Facilities
101.9	Flight Operations
101.10	Data Reduction
101.11	Simulation
101.12	Dynamic

SECTION 4
DESIGN

This section describes the current engineering design for photographic payload (PP) flight hardware. Major topics discussed are as follows:

4.1 Primary optics, mounts, locks, and alignment

4.2 Structural assemblies and mounts

4.3 Visual optics

4.4 Camera

4.5 Film handling

4.6 Environmental control

4.7 On-board processor

4.8 Electrical

4.9 Mass properties

Within each of these paragraphs, the requirements applicable to the item are presented, design trade-offs are discussed, and the selected hardware design is described.

4.1 PRIMARY OPTICS, MOUNTS, LOCKS AND ALIGNMENT

This paragraph contains a discussion of the performance parameters, the design and the hardware associated with optical assembly functions. Paragraph 4.1.1 discusses optical performance parameters; 4.1.2 the primary optics; 4.1.3 the mounts and locks and 4.1.4 discusses the alignment subsystems.

4.1.1 Optical Performance Parameters

The primary optical configuration is a [redacted] focal length, [redacted] lens consisting of the elements shown in Figure 4.1-1. In addition to the elements required to form the primary image, the lens also contains a pellicle beam splitter which provides light to the visual optics (VO) and an interchangeable mirror/pellicle which provides light to the image velocity sensor (IVS). Also included are other small optical elements associated with the alignment optics.

The optical design considerations which have an important bearing on the performance of the lens are discussed in the following paragraphs.

4.1.1.1 On-Axis Aberrations. A lens consisting of a single paraboloidal primary mirror is capable of diffraction-limited performance on-axis for all wavelengths of light, but off-axis aberrations are very large, thereby limiting the lens to near-zero field angle operation. To increase the usable field, additional lenses are incorporated into the lens formula, namely the forward and aft Ross correctors. The Ross correctors reduce off-axis aberrations to a minimal amount, but introduce some spherical and chromatic aberration on-axis. The combined effect of spherical and chromatic aberrations is defined as spherochromatism.

The spherical aberration introduced by the Ross-corrector elements is cancelled at one wavelength (λ) of light (587.6 mμ) by modifying the primary mirror from its basic paraboloidal shape. The residual spherical aberration inherent in the lens formula was determined from ray-trace data and is

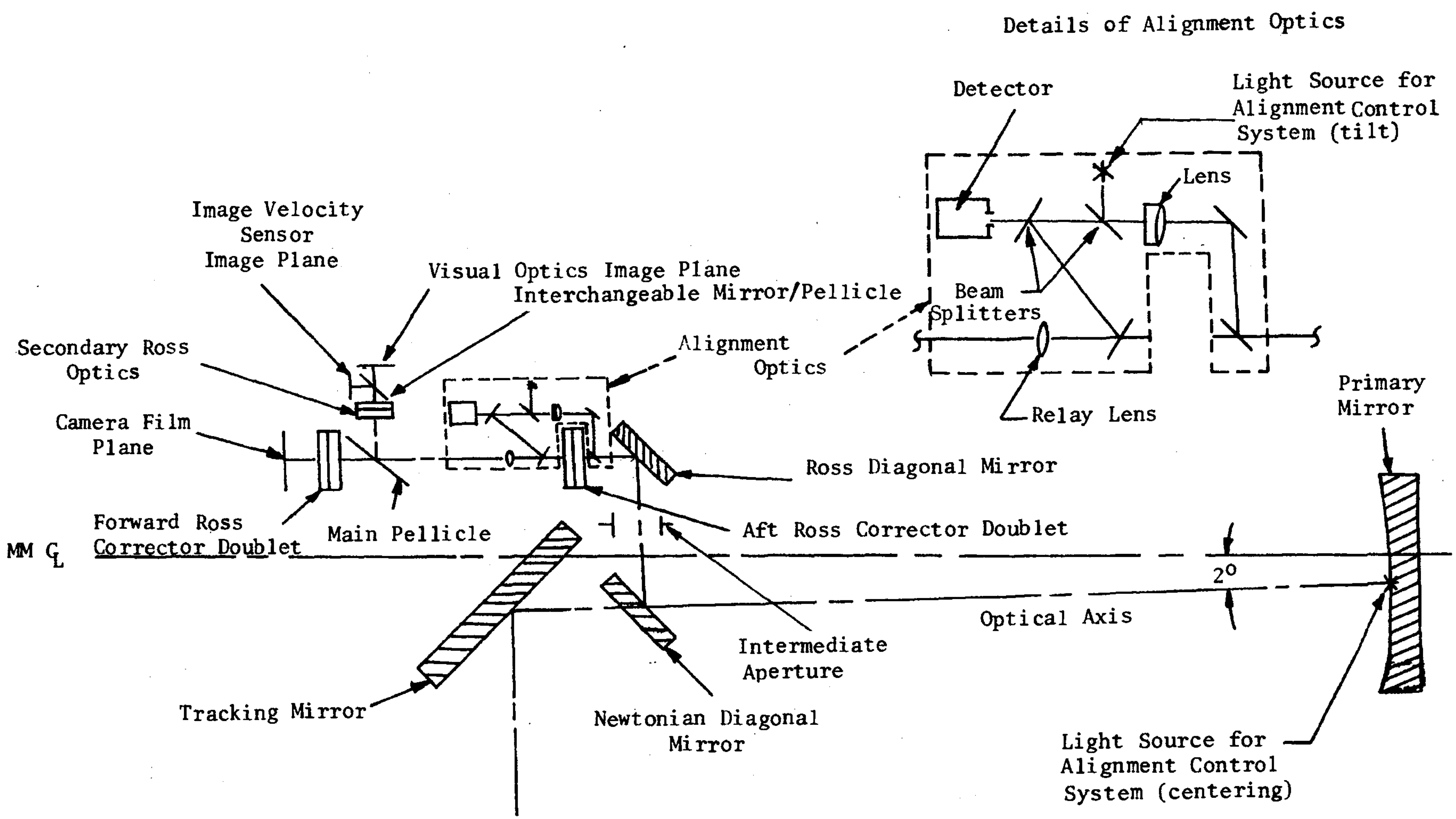


Figure 4.1-1. Optical Configuration for MOL/Dorian System Showing Detail of Alignment Sensor Optics

illustrated in Figure 4.1-2. This figure shows that the image formed by d-light (587.6 mμ) is free from spherical aberration (that is, rays from all zones in the lens aperture come to a common focus). This is true for only one wavelength of light however. Light of longer or shorter wavelength has associated with it increasing amounts of spherical aberration, as shown in the figure.

Another important property of a refracting lens is axial chromatic aberration, which is the variation of the axial image position as a function of wavelength. Because of this dependence on wavelength, the spectral components of white image-forming light do not come to a common focus, but form a spectrum (primary color) along the optical axis. Chromatic aberration in the Dorian lens is reduced by designing the forward and aft Ross correctors as a set of achromatic doublets. The result of this achromatization is that the spectrum formed by the lens is folded back on itself so that light corresponding to pairs of wavelengths come to a common focus. This folded spectrum is also shown in Figure 4.1-2. Note that e-light (546.1 mμ) and d-light (587.6 mμ) are at a common focus. The residual spectrum along the optical axis after achromatization is called secondary color. Secondary color is controlled by an optimum choice of optical properties for the glasses used in the achromatic doublets. Because the choice of optical glasses is limited, secondary color cannot be completely eliminated in practice. As a result, the principal on-axis aberration of the photographic optics is secondary color.

4.1.1.2 Lens Obstruction and Vignetting. Optical performance depends greatly on the diffraction effects of aperture shape and obstructions. The shape of the aperture in the Dorian lens, as seen on-axis, is elliptical,

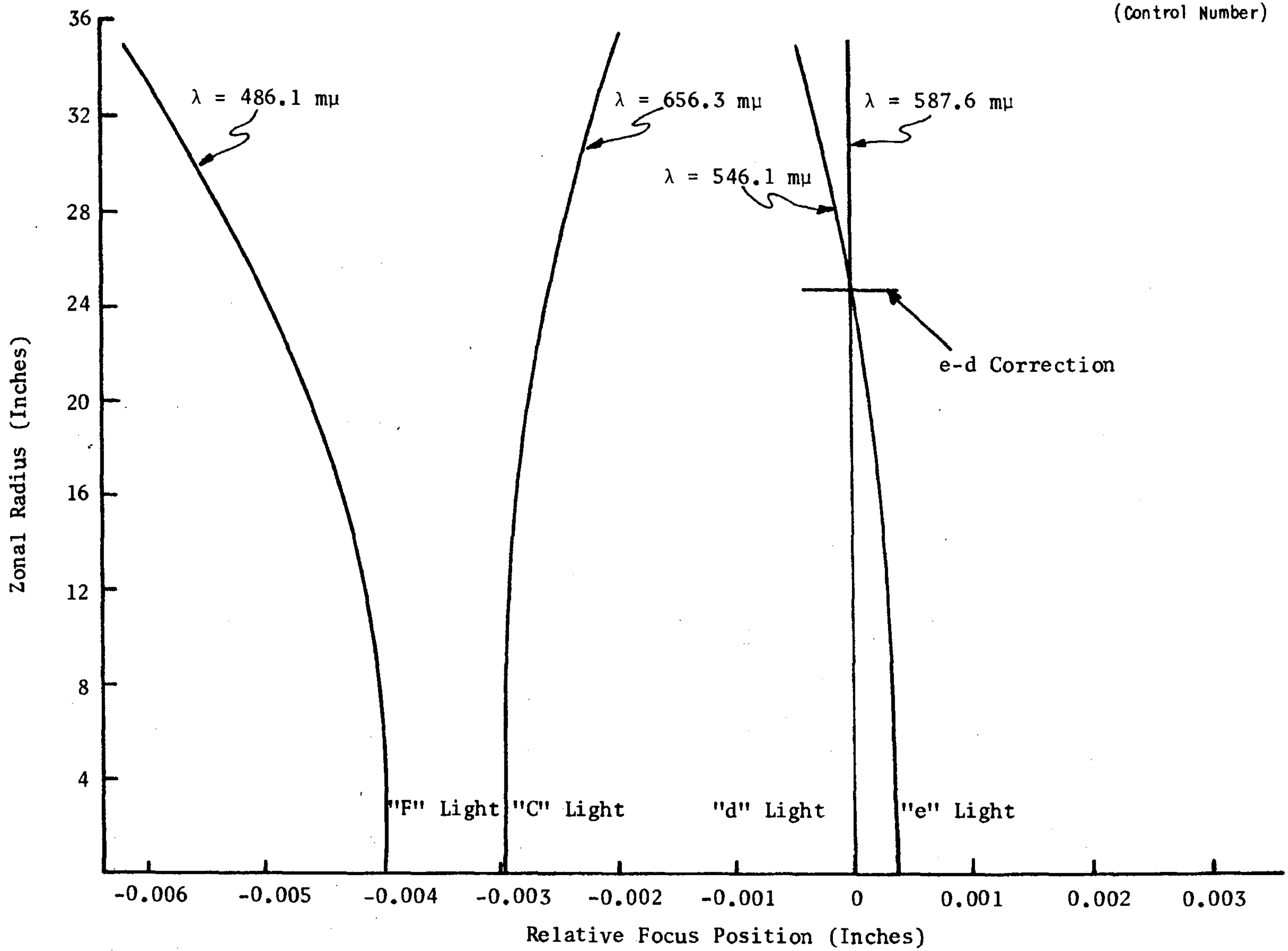


Figure 4.1-2. Spherochromatism of Dorian Lens

because of the tilted TM, and is vignetted or reduced in the image field. The central obstruction both on-and off-axis is caused by the diagonal folding mirror assembly and its mounting supports.

In the optical path the diagonal mirror is also an optical window for light rays reflected from the primary mirror toward the film plane. The design configuration for a reliable and practical mirror and mount results in a window (that is, the reflective surface of the mirror) which is smaller in area than the total obstruction. Performance requirements of the optics limit the total obstruction to approximately 17.2 percent (12.7 percent central obstruction and 4.5 percent spider obstruction). The overall obstruction is shown in Figure 4.1-3.

The vignetting by the corrector plus the small off-axis vignetting caused by the alignment-sensor (see paragraph 4.1.4) diagonal mirror produces a variation in the film-plane illumination with field angle; an 80-percent relative illumination at a 0.4-degree field angle is achievable as shown in Figure 4.1-4.

The optical configuration also provides a secondary image which is viewed by the VO and the IVS. The IVS pellicle serves as the vignetting aperture for these images. The relative illumination for these image planes is shown in Figure 4.1-5.

Two small diagonal mirrors and a relay lens are positioned at the aft-corrector doublet to provide a window and visual relay for the automatic alignment sensor. These elements are positioned within the shadow of the central obstruction, and therefore, do not affect axial performance of the lens system. The maximum diameter of these elements is 2 inches.

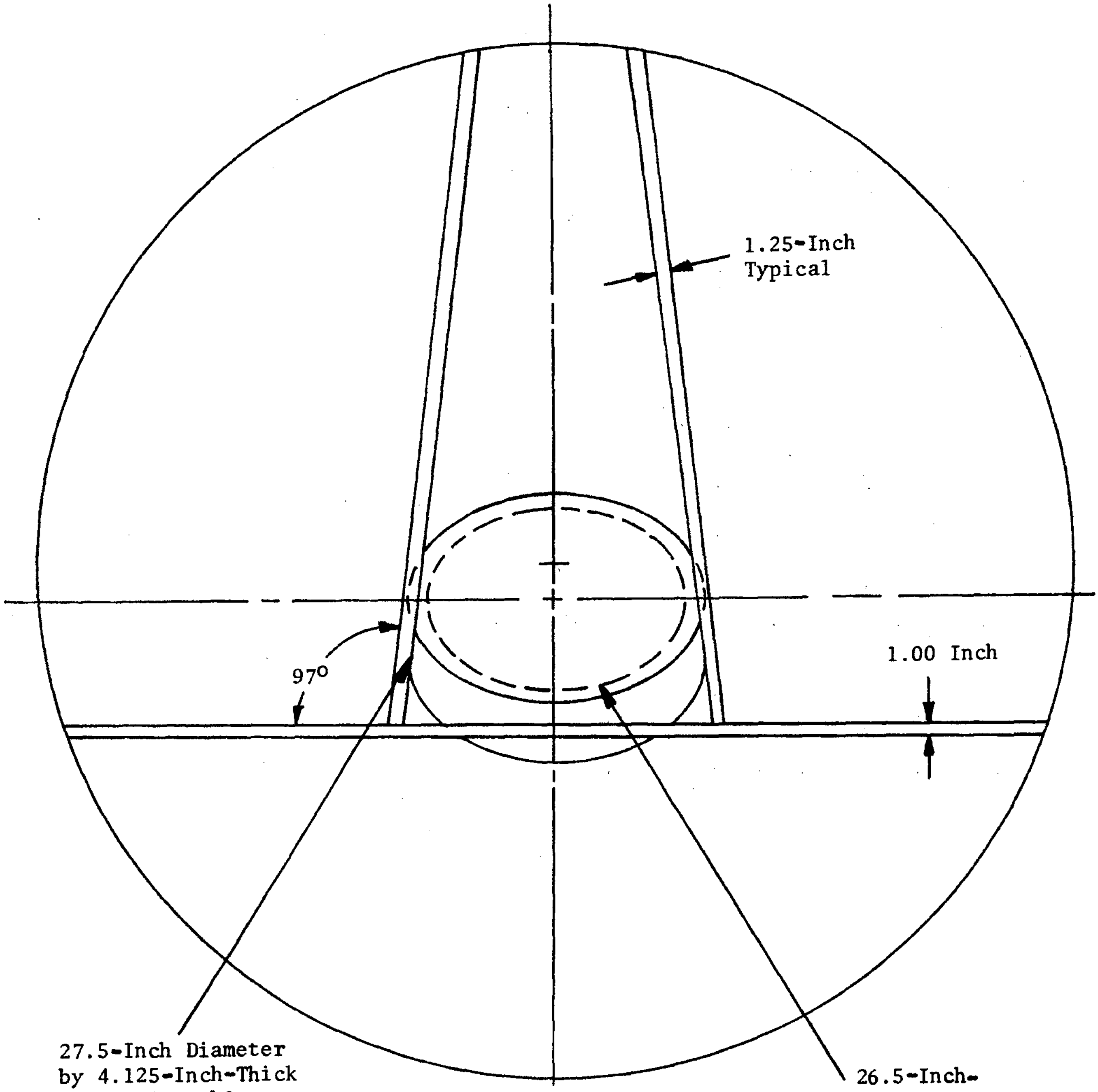


Figure 4.1-3. Central Obstruction

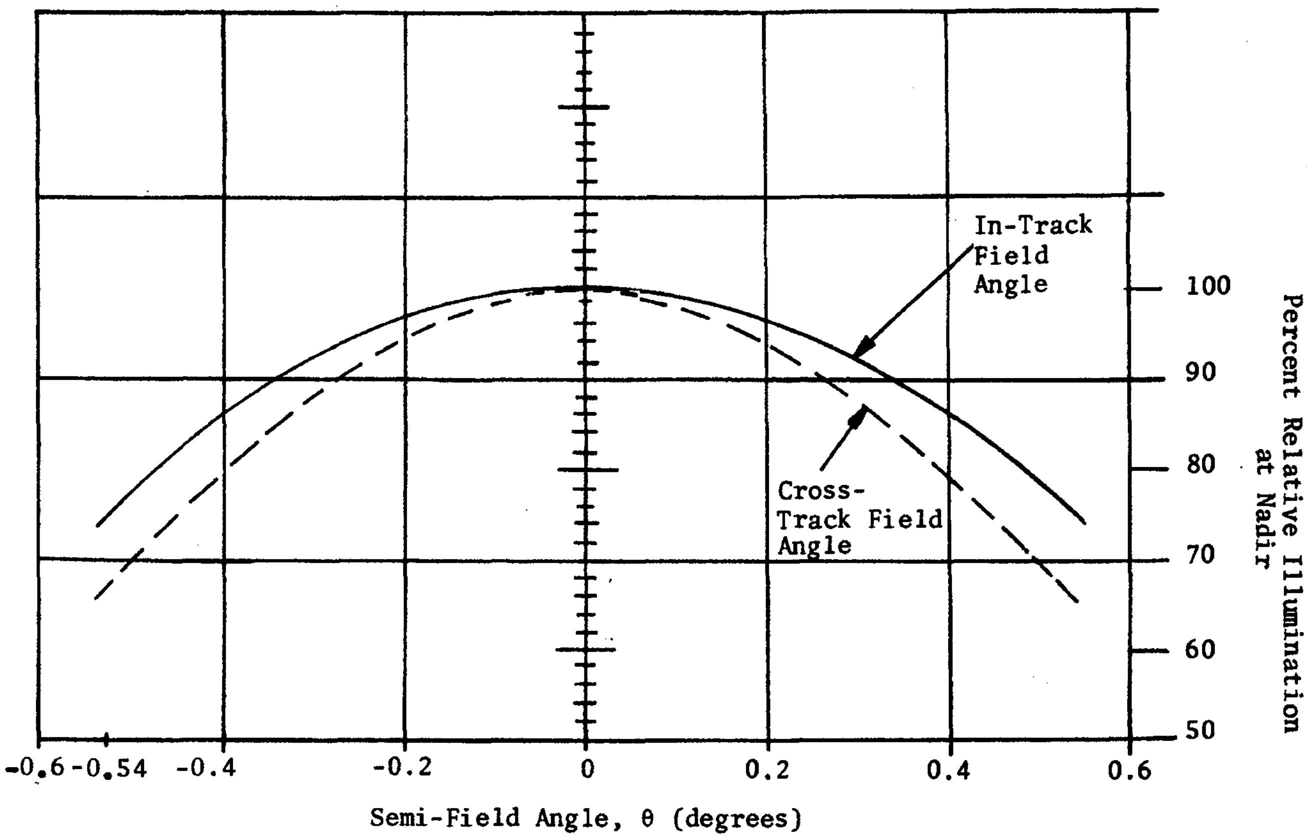


Figure 4.1-4. Relative Illumination at Nadir vs Field Angle at Film Plane

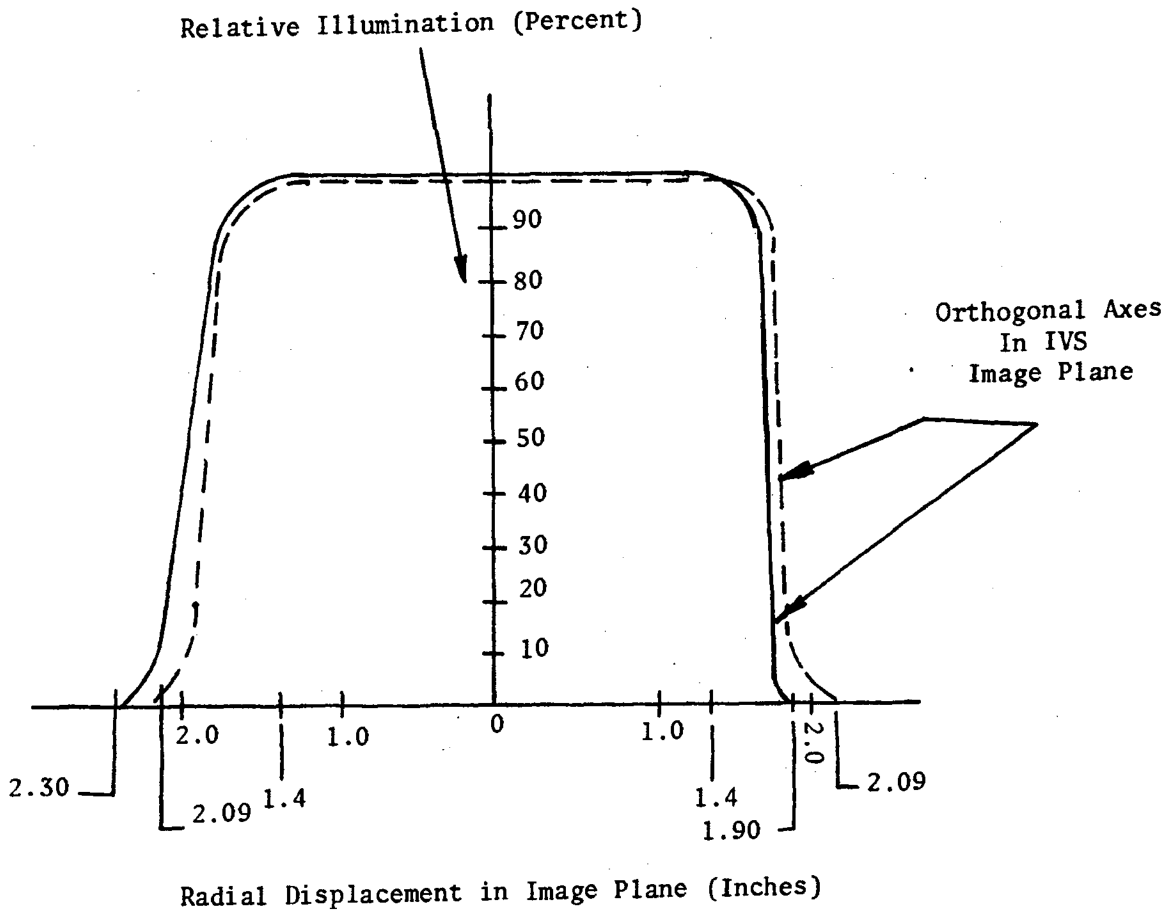


Figure 4.1-5. Relative Illumination - Visual Optics and IVS Image Planes

4.1.2 Primary Optics Design

4.1.2.1 Mirrors. The design configuration for the 71-inch-diameter primary and tracking mirrors is based on optimum rigidity for a given weight. Considered in the initial design study (as reported during the contract definition and transition phases of the program) were the factors involved in developing a successful mirror, such as fusion characteristics, polishability and material properties. Low expansion material is used in the prime optical mirrors. The design of the low expansion mirrors permits direct interchangeability with fused silica mirror mounts and support equipment.

In addition to improved coefficient of expansion properties, an integral core construction (elimination of the slots as in the fused-silica design) has been incorporated into the primary, tracking, and folding mirror designs. This construction increases the mirror stiffness over the fused silica slotted core design. A summary of design parameters for Cer-Vit and Titanium Silicate Ultra-low expansion (ULE) compared to fused silica for 71-inch-diameter mirrors is presented in Table 4.1-1.

Integral construction of Titanium-Silicate mirror designs is achieved by the fusion of struts to posts in the core. After fabrication and machining of a completed core, the face plate and back plate are fused to the core to form the blank.

Integral construction in the Cer-Vit design is attained by casting the material as a solid cylinder and then machining the core configuration in the blank through holes cut in the back plate.

TABLE 4.1-1

PROPERTIES AND DIMENSIONS OF VARIOUS 71-INCH-DIAMETER MIRROR BLANKS

	Cer-Vit	Titanium Silicate	Fused Silica
Diameter	71 inches	71 inches	71 inches
Thickness	12 inches	12 inches	12 inches
Front Plate Thickness	1.0 inch	0.9 inch	0.9 inch
Back Plate Thickness	0.625 inch	0.5 inch	0.5 inch
Core Configuration	Hexagonal	Square	Square
Cell Spacing	5.4 inches	3.0 inches	3.0 inches
Cell Wall Thickness	0.200±.03 inch	0.200±.005 inch	$0.240\pm^{.010}_{.000}$ inch
Static Deflection (simply supported)	55×10^{-6} inches	67×10^{-6} inches	95×10^{-6} inches
Weight (Nominal)	940 lbs.	890 lbs.	990 lb
Thermal Coefficient of Expansion	$0.0\pm0.1 \times 10^{-6}/°C$	$0.00\pm0.05 \times 10^{-6}/°C$	$+0.6 \times 10^{-6}/°C$

Development blanks of both the Titanium-Silicate and Cer-Vit mirror designs were fabricated. Each blank was fabricated with the prime-core geometry, plate thickness, and diameter. The blanks are 10-inches thick instead of 12 inches as in the prime designs. The development program includes grinding, polishing, and testing each blank with identical techniques.

The mirrors are compared during grinding and polishing to determine any differences in the processing of the two materials. Coefficients of expansion are measured to determine concurrence with manufacturer. A deflection test was performed on each development blank to investigate the effect of a static load. The test configuration for the Titanium-Silicate blank is shown in Figure 4.1-6. Results of the deflection test are summarized in Table 4.1-2.

Table 4.1-3 lists the type of material to be used for the primary, tracking, Ross and Newtonian mirrors.

Mirror surface quality is dependent on two factors:

a. Manufacturing errors

b. Test-measurement errors and uncertainty

The mirrors (tracking, primary, Newtonian, and Ross) were assigned a manufacturing tolerance of 0.02 λ (RMS) combined with a test measurement uncertainty of 0.02 λ (RMS).

The resultant wavefront error is obtained from the mirror surface error with the following conversion formula:

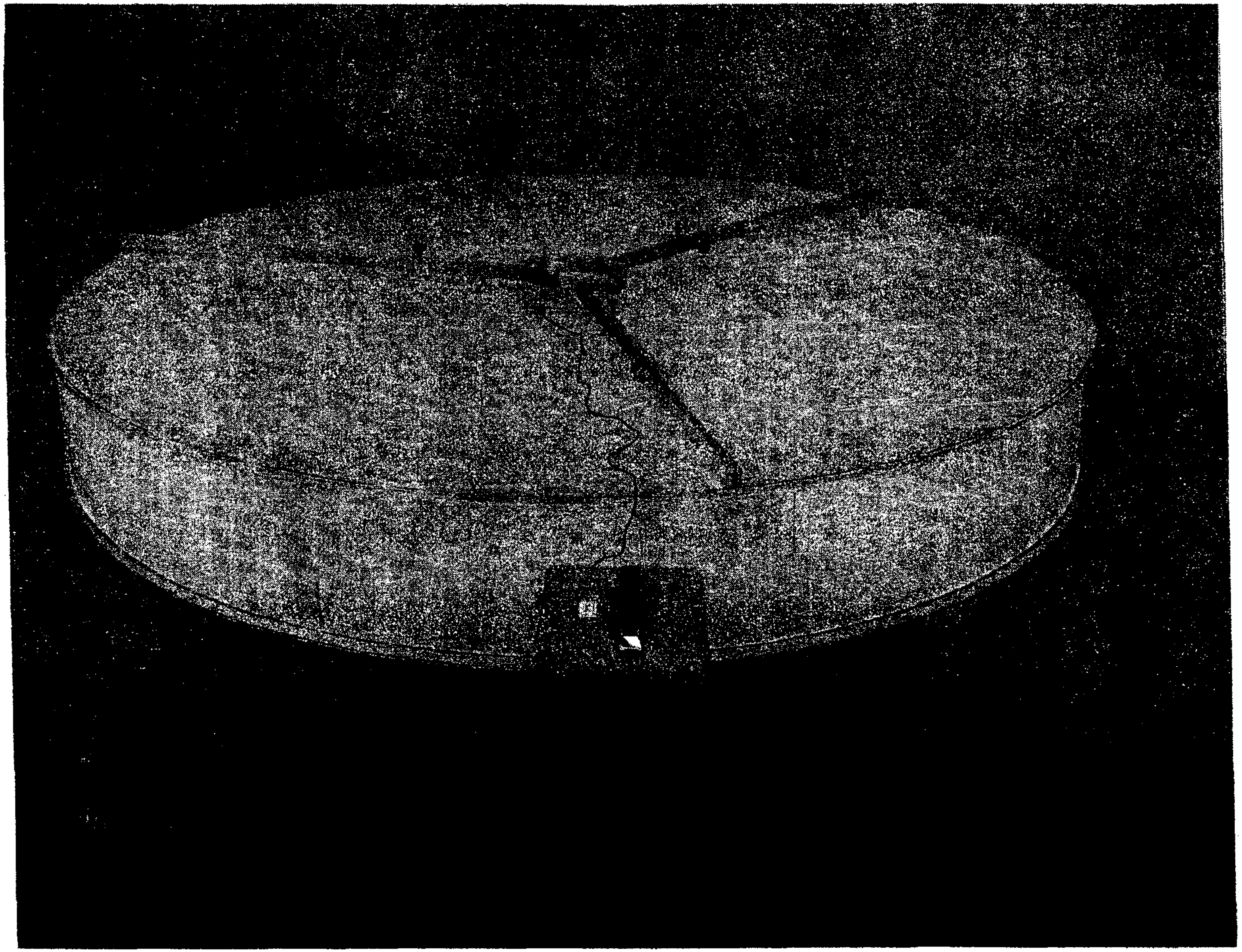


Figure 4.1-6. Titanium Silicate Blank Deflection Test Configuration

TABLE 4.1-2

COMPARISON OF CER-VIT AND TITANIUM-SLICIATE DEFLECTIONS
FOR 10-INCH THICK DEVELOPMENTAL DESIGNS

	Cer-Vit			Titanium Silicate		
Unit Load	Load Factor	Predicted Deflection	Measured Deflection	Load Factor	Predicted Deflection	Measured Deflection
(psi)	(g's)	(x 10^{-5} inches)		(g's)	(x 10^{-5} inches)	
0.5	2.09	17.8	16.4	2.29	26.5	25
1.0	4.19	35.6	34.8	4.58	51.	48

TABLE 4.1-3

TYPE OF MATERIAL USED FOR MIRRORS

Model	Primary Mirror	Tracking Mirror	Ross Mirror	Newtonian Mirror
EM	S	S	S	S
QM	S	S	U	S
OAT	S	S	S	S
FM 1	S*	U or CV	U	U
FM 2	U	U or CV	U	U
FM 3	U	U or CV	U	U
FM 4	U	U or CV	U	U
FM 5	U	U or CV	U	U
SPARE	U	U or CV	U	U

* Goal is Titanium Silicate if scheduling permits.

Legend S = fused silica
U = Titanium Silicate
CV = Cer-Vit

$$\sigma \text{ (wavefront)} = 2\sigma \text{ (surface)} \cos \theta,$$

where: σ is the RMS error, and θ is the angle of incidence on the mirror. Table 4.1-4 summarizes the calculation of the specification OQF contribution.

The total goal optical quality factor (OQF) of [redacted] is attained by reducing the test-measurement uncertainty for the plano mirrors from 0.02λ RMS to 0.01λ RMS and reducing the test-measurement uncertainty for the primary mirror from 0.02λ RMS to 0.012λ RMS. The resultant mirror OQF goal of [redacted] when multiplied by the Ross-lens OQF contributors gives the goal OQF of [redacted]

4.1.2.2 Ross-Corrector Assembly. The Ross-corrector assembly contains all the refractive elements for the [redacted] lens mounted to a rigid-support barrel. The Ross barrel (discussed in paragraph 4.2.2.2) also supports and locates the following:

a. Camera

b. Pellicle

c. IVS

d. Automatic alignment sensor

The Ross assembly serves as the optical window and pressure seal between the mission module (MM) and the laboratory module (LM). The optical elements are sealed by potting compound to the cell, which in turn is sealed by an O-ring to the end of the corrector structure. A similar design is

TABLE 4.1-4

MIRROR OPTICAL QUALITY FACTOR CONTRIBUTION (SPECIFICATION)

Mirror OQF Contributor	Surface Error (RMS)	Conversion Factor	Wavefront Error (RMS)
Tracking mirror - manufacturing	[redacted]		
- test			
Primary mirror - manufacturing			
- test			
Newtonian mirror - manufacturing			
- test			
Ross mirror - manufacturing			
- test			

Total Wavefront Error (RSS) = [redacted] (RMS)

OQF = [redacted]

used for the secondary optical elements providing an image to the IVS and VO. A bellows (supplied by McDonnell Douglas Astronautics-WD (MDAC-WD) on the LM, aft of the secondary optics) will connect to the Eastman Kodak Company (EKC) corrector structure to complete the seal between the MM and the LM. This sealing configuration results in a pressure differential across the forward Ross-corrector elements (the space between the forward and aft doublets is vented to the MM). The deflection of these optical elements resulting from the 5 psi nominal pressure differential has a negligible optical affect. The change in refractive index resulting from the vacuum (approximately 1.00029 times) causes a focus shift but does not reduce optical quality.

The aft flange and diameter of the corrector structure serve as the reference to establish the alignment axis for the forward and aft corrector lens assemblies and the alignment sensor. The reference surface of the Ross corrector assembly is also the mating surface to the corrector and diagonal mirrors support structure and thus gives an identical reference surface on the support structure.

4.1.2.2.1 Optical Quality Surface Contributions. The deviation of each Ross lens optical surface from its best fit sphere is controlled by the following tolerances:

a. Aft Corrector Elements. 0.02λ RMS manufacturing tolerance and 0.02λ RMS test-measurement uncertainty over any and all 12-inch-diameter circles.

b. Forward Corrector Elements. 0.01λ RMS combined manufacturing variation and test-measurement uncertainty over any and all 1.5-inch-diameter circles.

Pellicle quality is specified in terms of an allowable OQF contribution of 0.995. This OQF corresponds to an RMS wavefront error of 0.01λ.

Table 4.1-5 summarizes the lens surface OQF contributions and the pellicle contribution. Because it is required that the aft doublet be tested over any and all 12-inch-diameter circles, its OQF surface contribution is divided into two parts; manufacturing and testing. This procedure is not used for the forward doublet because the area to be tested is small (1.5-inch diameter). The conversion factor relating wavefront error to surface error is equal to n-1 where n is the glass refractive index.

Partial Dispersion Tolerance. The tolerance for the partial dispersion ratio difference is +0.0002 from nominal for the aft doublet and +0.0006 from nominal for the forward doublet. The related OQF for this contribution, based on possible worst-case conditions was estimated to be [redacted] Six sets of flight Ross-corrector blanks were received by EKC and measurements show that the partial dispersion values for the blanks are well within tolerance. Based on this measurement data, a more realistic value of OQF for the partial dispersion contribution is [redacted]

Inhomogeneity. The inhomogeneity for the two elements of the aft Ross corrector is $\pm 2.5 \times 10^{-6}$ over any and all 12-inch-diameter circles. It is further specified that the inhomogeneity be radially symmetric; that local inhomogeneities which are not symmetric be confined to an area not greater than $\pm 1 \times 10^{-6}$. Random inhomogeneity is limited to a total fluctuation of 2×10^{-6}. If the inhomogeneity is truly random for each of the four glass elements, the OQF contribution is [redacted] this being a worst-

TABLE 4.1-5

LENS SURFACE OPTICAL QUALITY FACTOR CONTRIBUTION

Doublet	Surface	Surface Error (RMS)	Conversion Factor	Wavefront Error (RMS)
Aft*	1 manufacturing testing	[redacted]		
	2 manufacturing testing			
	3 manufacturing testing			
	4 manufacturing testing			
Forward**	1			
	2			
	3			
	4			
Pellicle				

Total wavefront error (RSS) = [redacted] (RMS)

OQF = [redacted]

With correct orientation of the doublets to minimize the effects of irregularity, a realistic OQF would be [redacted]

* Tolerance applies over any and all 12-inch-diameter circles.

** Tolerance applies over any and all 1.5-inch-diameter circles.

case situation. In general, inhomogeneity is not truly random but has a symmetric axis, not necessarily coincident with the center of the lens. In this case, it may be possible to partially nullify the effect by a rotation of the elements. Because irregularity is also correctable in the same way, a conflict may exist, in which case compensation can be used to correct for the worst offender. In general, an OQF of [redacted] or better represents this contribution.

Table 4.1-6 summarizes the inhomogeneity OQF contribution for the worst-case situation. The peak-to-valley wavefront error is equal to the product of the lens element thickness and the inhomogeneity tolerance (one wavelength is assumed to equal 23.1 microinches). The RMS wavefront error is assumed to be 1/5 the peak-to-valley wavefront error.

Power and Dimensional Tolerances. The tolerances for power, thickness, and mounting variation for the Ross elements are sufficiently tight so that the elements contribute virtually no loss in optical quality.

These tolerances are as follows:

> Power. Two rings for the two elements of the aft-corrector set and four rings for the two elements of the forward-corrector set.
>
> Center Thickness. ±0.002 inch for all lens elements except one from the forward set, which is ±0.004 inch.
>
> Element Runout. 0.0001-inch edge thickness difference (ETD) for elements of the aft doublet and 0.0005-inch ETD for elements of the forward doublet.

TABLE 4.1-6

INHOMOGENEITY OPTICAL QUALITY FACTOR CONTRIBUTOR

Ross Element	Thickness (inches)	Inhomogeneity Tolerance	Wavefront Error (peak-to-valley)	Wavefront Error (λ) (RMS)
Aft doublet			[redacted]	
1	1.25	2×10^{-6}		
2	1.50	2×10^{-6}		
Forward doublet				
3	0.95	2×10^{-6}		
4	1.15	2×10^{-6}		

Total wavefront error (RSS) = 0.042 λ (RMS)

OQF = [redacted]

With correct orientation of doublets to minimize over-all error, a realistic OQF is [redacted]

Air Space Runout. 0.0002-inch ETD for the aft doublet, and 0.002-inch ETD for the forward doublet. The elements in each doublet, are rotated for minimum-doublet ETD.

Doublet Tilt. ±20 arc seconds for the aft doublet and ±60 arc seconds for the forward doublet.

Summary. The OQF for the Ross lens assembly is summarized as follows:

Optical surface errors	[redacted]
Inhomogeneity	
Partial dispersion	
Power, thickness, and mounting variation	
Total OQF contribution	

4.1.3 Mounts and Locks

4.1.3.1 Optical Element Mounts.

4.1.3.1.1 Primary and Tracking Mirror Mounts. The on-orbit mount for both the primary and tracking mirrors consists of three equally spaced flexure pairs, one flexure tangent and one flexure normal to the mirror in each pair. This arrangement of flexures constrains each of the six degrees of freedom without redundant constraint and thereby comprises a kinematic mount.

The flexures are required to support on-orbit loads along their axial direction. The requirement that the optical surface must not be adversely distorted limits the bending stiffness of the flexures. Thus, trade-offs of design parameters such as physical length, flexural length, spacing and cross sectional area, buckling strength, and anticipated displacements were considered in the flexure design. Spring constants for the flexures were determined for the selected flexure design.

Values for each of the various contributors to the current flexure-mount spring constants are summarized below.

Spring Constants (10^3 lb/in)

	PM Flexure Mount		TM Flexure Mount	
	Axial	Tangential	Axial	Tangential
Potting material flexures	2850	44.5	1880	44.5
3/16" dia. rod	146	117	93	110
0.050" dia. flexure	104	104	104	104
Strain gauge transducer	33	--	33	--
Total	21.2	24.6	19.7	24.3

Because the parameters listed above are all in series in the flexure design, the total or equivalent flexure stiffness is the product divided by the sum of the spring constants. Consequently the total flexure stiffness will always be less than the stiffness of the most compliant contributor.

Of the total allowable mirror-error budget, the tolerance of $\lambda/200$ was established as a design goal for the maximum allowable distortion of the mirror as a result of the transmission of a bending moment through the flexures. The flexure error budget includes all flexure displacements which result from mechanical misalignment of assembly, induced thermal bending, or other external bending forces. For the selected flexure design, the relationship between the moment transmitted by a flexure and lateral flexure displacement is shown in Figure 4.1-7. Analysis of the mirrors predict a 1 in-lb moment will distort the mirror approximately 1/200 λ.

The results of an analysis of bending stress in the flexure for various lateral displacements of the selected flexure design are plotted in Figure 4.1-8.

The flexures shown in Figure 4.1-9 are constructed from high-strength maraging steel to attain the required flexibility and strength relationship. Each flexure member consists of a 0.187-inch-diameter rod, necked down to a 0.050-inch-diameter by 0.250-inch-long section at two locations to enable the flexural action. Associated with each flexure as a protective safety feature is a load limiter which limits the axial load on the flexure. The load limiter consists of two opposing preloaded springs; each spring being preloaded to a force of 40 lb against a shoulder on the flexure rod. Essentially no displacement of the flexure rod occurs until the 40 lb spring preload is exceeded. For axial loads greater than 40 lb, displacements are proportional to the spring rate of the springs. The load limiter then permits relative displacement between the mirror and support structure without creating high stresses in the flexures, but rigidity maintains the position of the flexures if axial forces do not exceed 40 lb.

The tangential flexures of the primary mirror are attached to the end cap structure of the camera optical assembly (COA) barrel, and the three

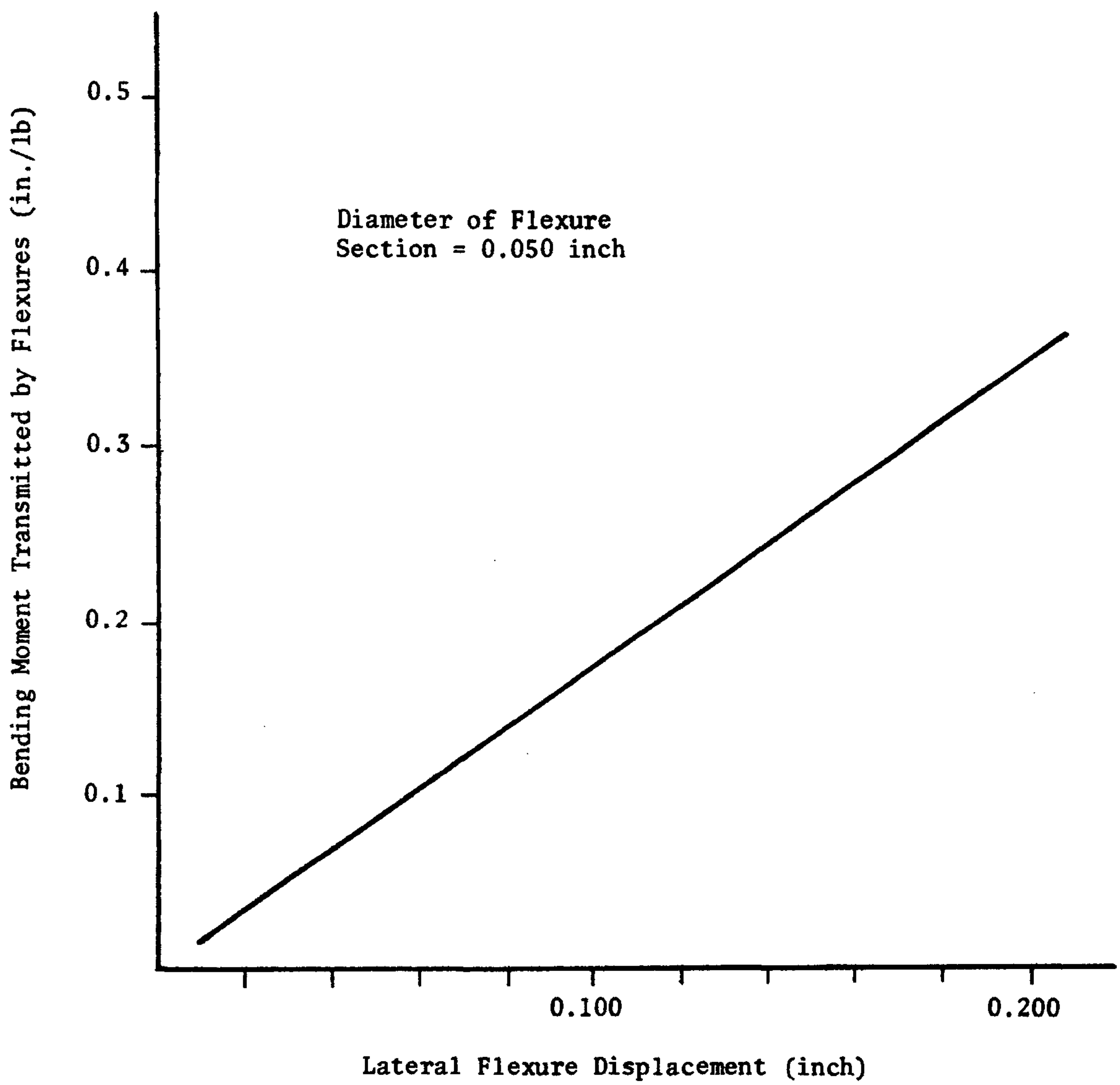


Figure 4.1-7. Flexure Moment vs Lateral Deflection

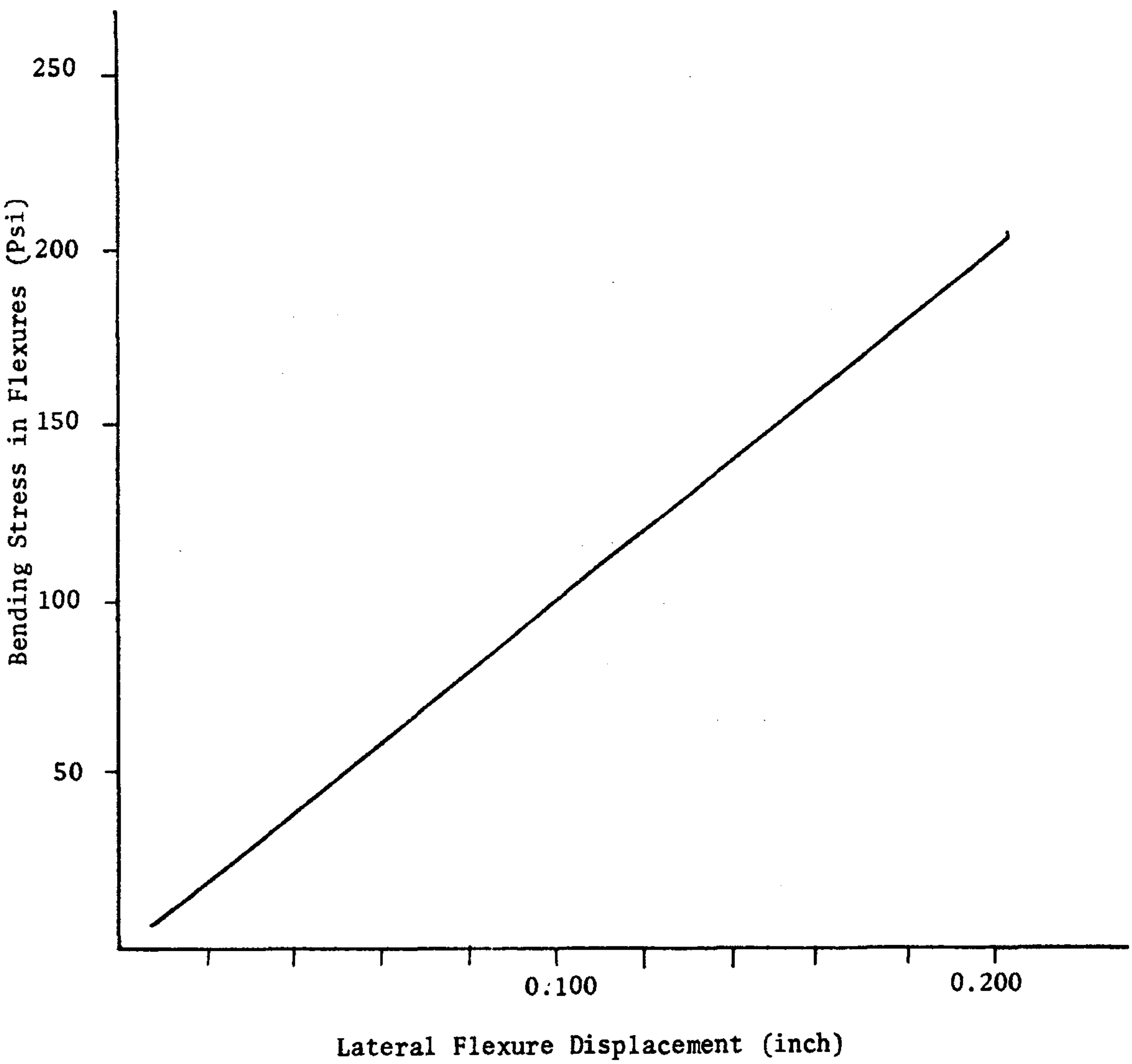


Figure 4.1-8. Bending Stress vs Lateral Displacement

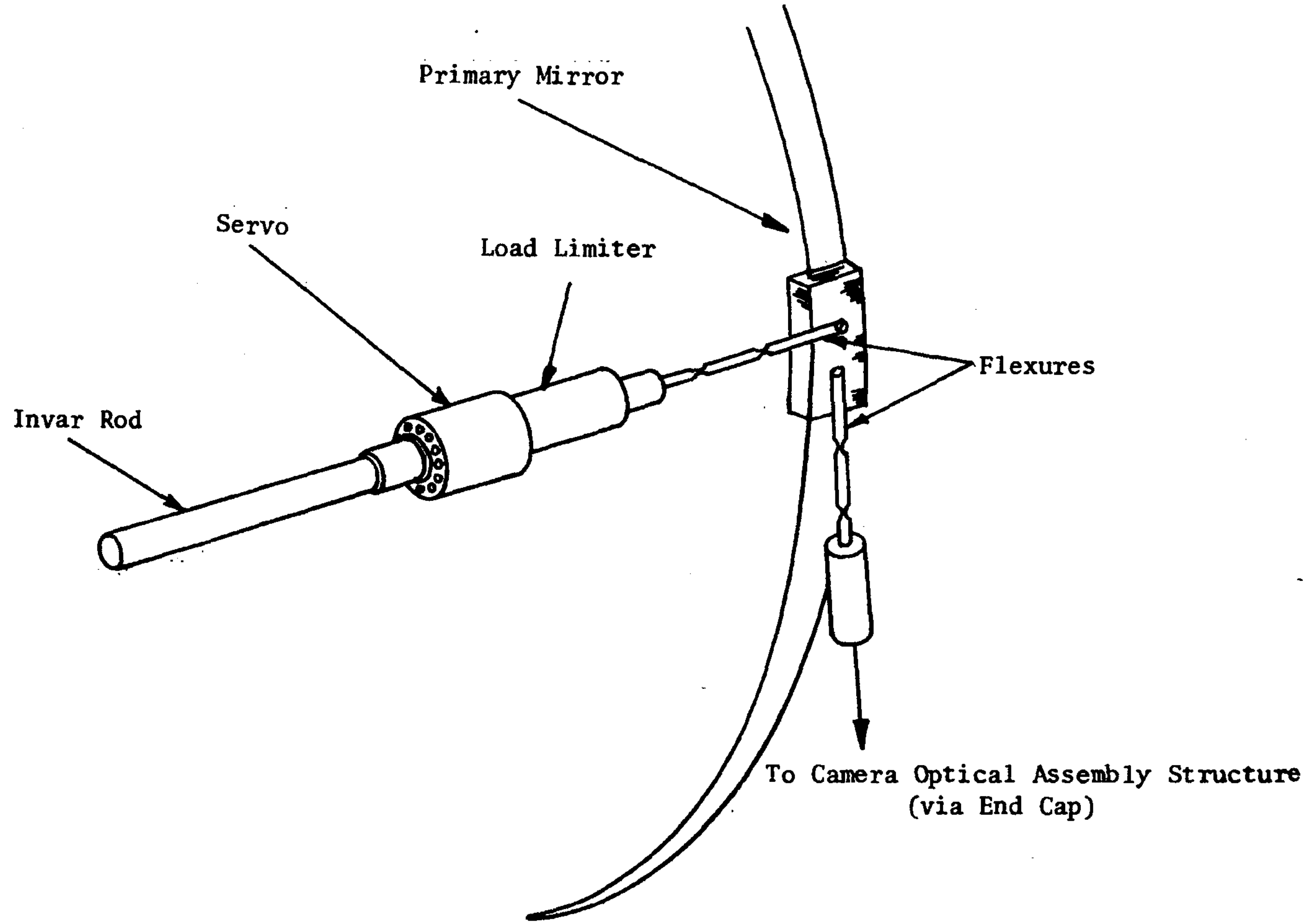


Figure 4.1-9. Primary Mirror Mounting Flexure Concept

flexures normal to the primary mirror are attached to the alignment servos on the Invar reference rods. Both the normal flexures and the tangential flexures for the TM are attached to the TM mounting ring.

During ground handling the primary mirror will be supported by an inflated air bag (see paragraph 6.2.6) and/or the launch locks (see paragraph 4.1.3.2). During launch the primary and tracking mirrors are held in place by the launch locks.

4.1.3.1.2 Diagonal Mirror Mount. The diagonal mirror is supported by a passive mount designed to fulfill the mounting requirements for both launch and orbital environments. Minimization of obstruction was considered in mount design. The mount, with auxiliary apparatus to correct gravity-induced deformations of the mirror figure, will also fulfill mounting requirements for one-g system testing. The mount is schematically shown in Figure 4.1-10. The diagonal mirror is mounted to a ring cell by using the proven technique of potting the mirror at the periphery in the 0.025-inch gap between the mirror and the ring in three equally spaced, 60-degree segments.

The diagonal mirror mount makes use of the principles of kinematic mounting to provide nonredundant support for the six-degrees-of-freedom. The supporting members of the structure are panels which effectively act as flexure members in a direction perpendicular to their plane. A delta-shaped tubular structure is fixed to the back of the mounting ring and intersects the supporting panels at each apex of the delta. The attachment of the delta structure to the supporting panels is through preloaded spherical bearings. The spherical bearing in combination with the flexural effect of the supporting panels confines two-degrees-of-freedom at each of the three mounting points.

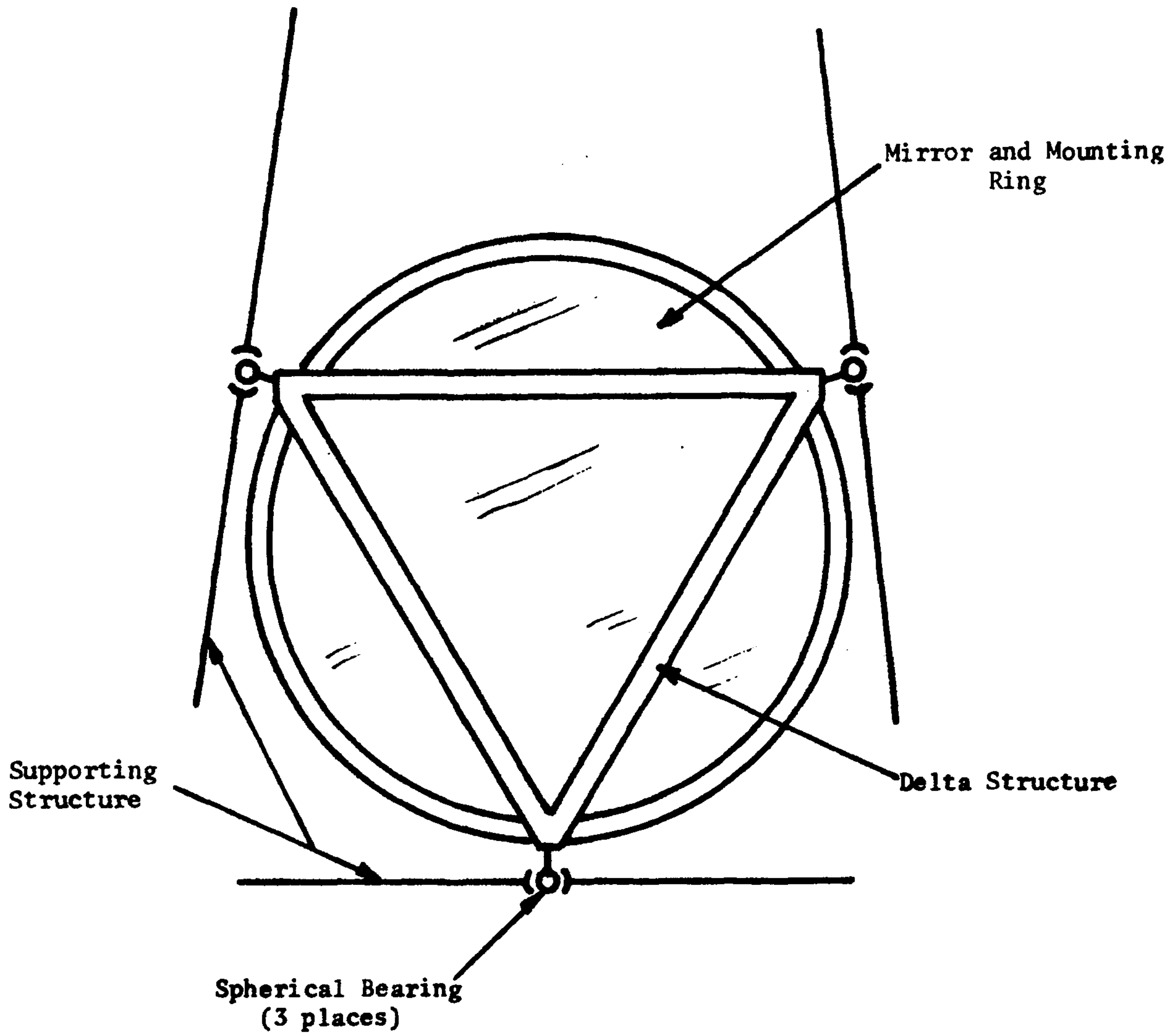


Figure 4.1-10. Schematic Diagram - Diagonal Mirror Mount

An auxiliary mirror support is used during system full-aperture optical tests to minimize the mirror surface deformation resulting from gravity. Equal and normal spring loads are applied to the mirror back at three points spaced 120 degrees apart at an optimum radius. This arrangement distributes the normal component of gravity between the mirror mounting ring and the support device, which attaches to the nodes of the delta frame.

4.1.3.1.3 Ross Mirror Mount. The corrector diagonal mirror is supported by a passive mount similar to the diagonal mirror mount.

The mirror is segment potted into an Invar ring. Six flexures are attached to the ring as bipod pairs. Each flexure is capable of supporting axial loads but does not transmit large bending moments. High-strength maraging steel is used as the flexure material to obtain the desired bending flexibility and axial strength requirements. Three flexures are tangent to the ring periphery and connected directly to the corrector diagonal mirror-support structure. The other three flexures are normal to the mirror surface and connect to linear actuating servos mounted on the structure. The servo motions allow the corrector diagonal mirror to be tilted and thereby correct decentering errors between the Ross corrector assembly and the primary mirror. The corrector diagonal mirror mount is not within the optical beam and therefore, does not have to be designed for minimum obstruction. Figure 4.1-11 shows the mount.

During tests the corrector diagonal mirror is provided with three-point spring-load support similar to that described for the diagonal mirror. In this case the device mounts on the support structure shown in Figure 4.1-11.

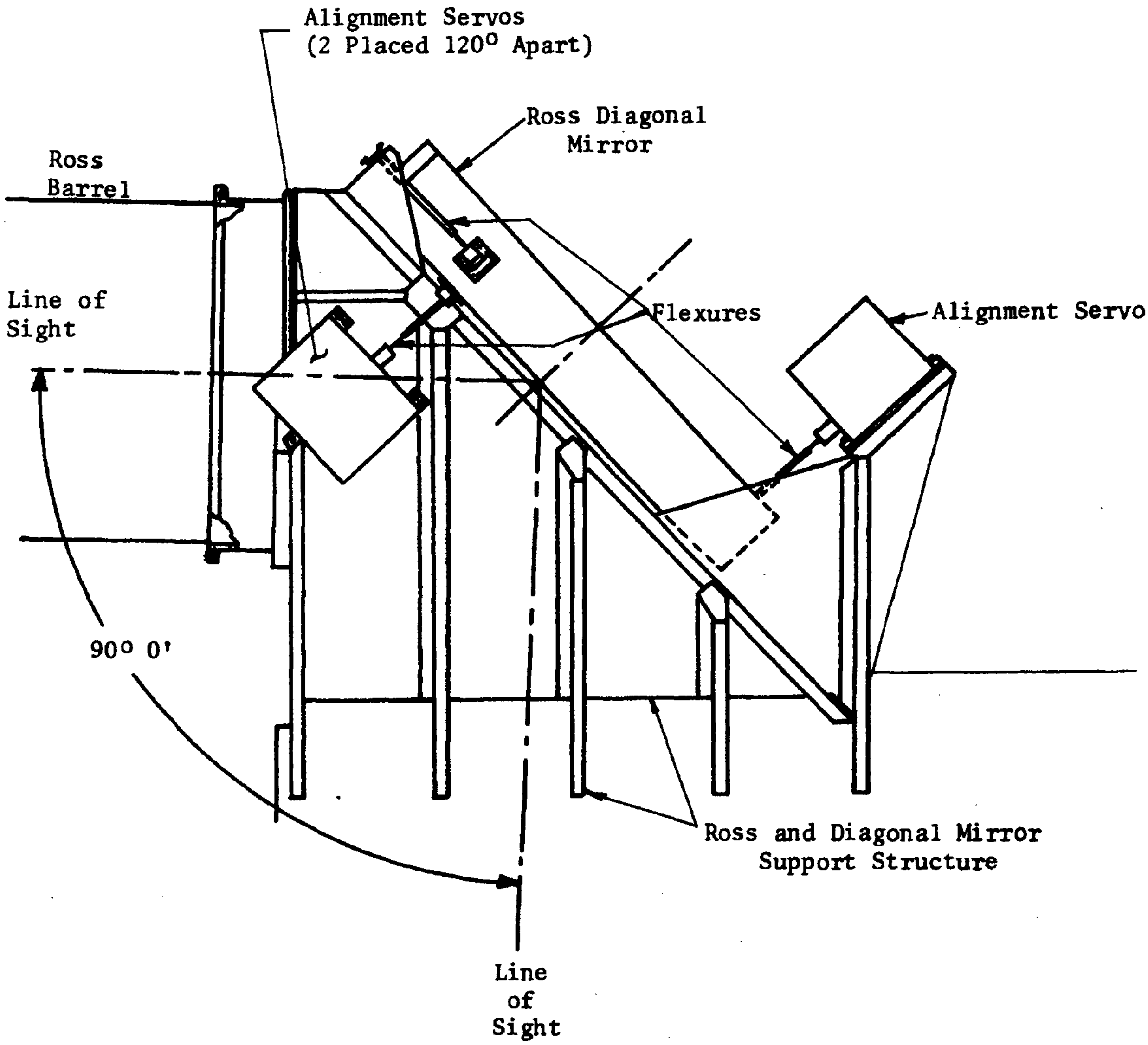


Figure 4.1-11. Ross Diagonal Mirror Mount

4.1.3.2 Mirror Launch Locks. The basic requirements for the mirror launch locks are:

a. To structurally support the 71-inch-diameter primary and tracking mirrors during ground handling and launch.

b. To release the mirrors from their structural constraints once on-orbit and to transfer support to the orbit mount.

In addition to these basic requirements, other design constraints for the mirror launch locks were considered in an effort to establish a suitable design from the standpoint of performance, reliability, and weight.

The mirror launch-lock design provides positive constraint and adequate stiffness to prevent excessive motion of the mirror during launch and ground handling, yet distributes the launch loads and prevents stresses in the mirror from exceeding design limits. Locking and unlocking operations by remote control are required during the various assembly and test phases, and for end use. Also included are features which minimize weight and power requirements and which permit adjustment of the launch locks, without loss of performance, to account for manufacturing and assembling tolerances. Redundant features are required to ensure reliable performance.

4.1.3.2.1 Hardware Description. The lock mechanism uses bar and pin members in the form of a knee linkage to support transverse loads of the mirror. By correct alignment, a preload is applied to the mirror when the linkage is in a colinear position, thereby ensuring positive constraint. The bar and pin linkage transmits only tensile or compressive loads; thus, in the absence of bending forces, the cross section, and hence the weight of each member, can be minimized.

Longitudinal preload and structural support is accomplished by a pivot and lever arm; mechanical advantage is achieved by using the lever as a fulcrum. These details are shown in Figure 4.1-12.

Friction, proportional to the magnitude of the preload, is the resisting force which must be overcome to lock or unlock the launch lock. An analysis of the torque required to accomplish these functions relates this torque to various values of coefficient of friction, thereby enabling various materials and lubricants to be evaluated. Also, by accounting for the mechanical advantage of the gear-train reduction of the launch lock, torque requirements for the drive motors were specified.

Associated with each lock mechanism is a drive module which consists of two motors, an encoder, a potentiometer, associated electronics, a differential, and gear train. Redundancy of the lock release method is accomplished by the two motors and differential. Either motor, when activated by a command, will initiate the unlocking sequence of the launch lock. One motor at each lock is reversible to accomplish locking. Separation of the drive unit from the mechanical linkage unit permits repair/replacement of the drive module in case of malfunction. A drive module (with the protective cover removed) is shown in Figure 4.1-13.

A number of developmental tests were performed on launch locks to obtain data with which to demonstrate the integrity of the lock design. The operation and performance of the locks were measured in the following test categories:

a. Vacuum

b. Misalignment

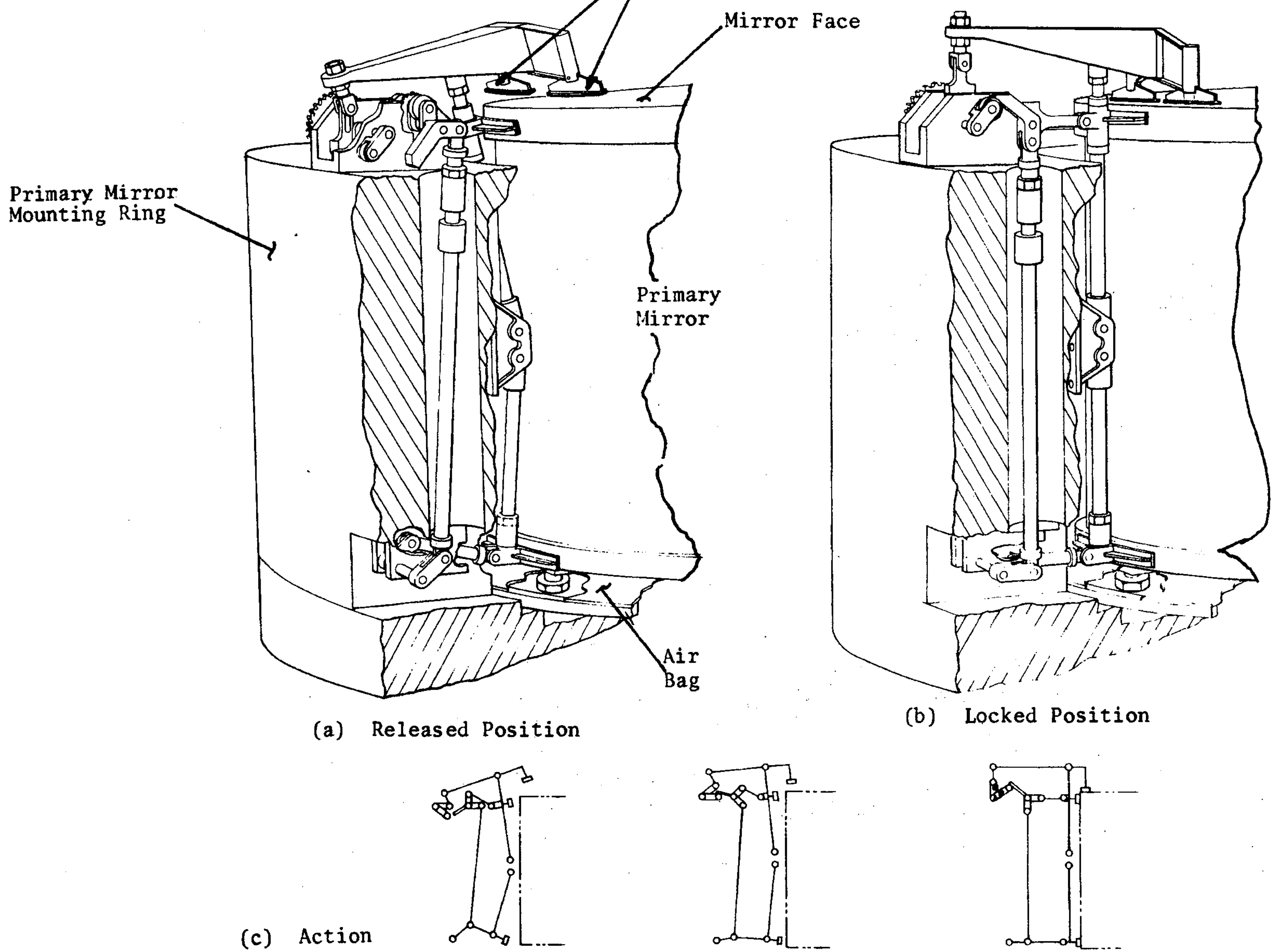


Figure 4.1-12. Primary Mirror Launch Lock

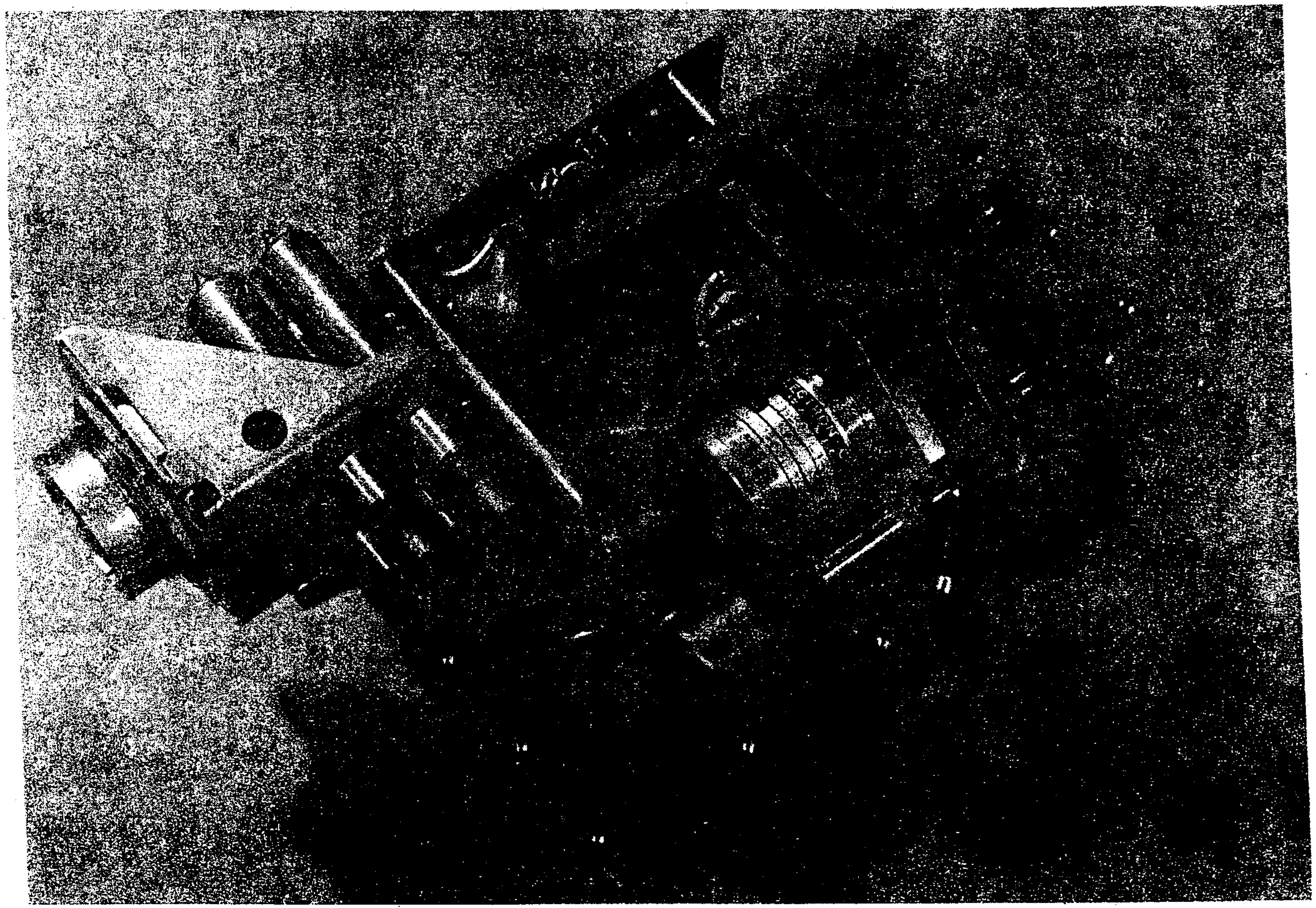


Figure 4.1-13. Launch Lock Drive Module

c. Contamination

d. Overload

e. Fatigue

Under each test condition, the locks performed satisfactorily; results are summarized below:

a. A lock was placed in a vacuum of 2×10^{-6} mm Hg and actuated through 20 complete lock and unlock cycles. No lock malfunction or appreciable change in torque values occurred during the test.

b. A lock was intentionally misaligned to produce eccentric loading on the lock. No linkage binding or other malfunction occurred during the operational test.

c. Steel machining chips were dropped in the lock gear train during an operating cycle; the lock continued to operate without binding.

d. A launch lock was adjusted to apply a locking preload force in excess of the nominal load. The lock was actuated through several complete cycles but no malfunction or degradation occurred.

e. A lock was actuated through 1550 complete cycles without a malfunction before the test was interrupted to replace 2 worn bronze gears with steel gears. Longer life characteristics are expected with the steel gears.

Reliability predictions for the launch locks are a mean-time-to-failure (MTTF) of 20,800 hours for the primary mirror launch locks and a MTTF of 11,600 hours for the tracking-mirror (TM) launch locks.

4.1.3.2.2 Lock-Set Design for Cer-Vit Mirrors. A sketch of the concept for the launch-lock design for the TM is shown in Figure 4.1-14. The lock is an electro-mechanical device with redundancy provided by a one-shot unlocking technique. The lock design was adapted to utilize, as much as possible, the baseline mounting ring designed for the fused-silica mirrors.

Both the primary and redundant lock devices are driven by a motor and gear train.

A structural H-frame, which is permanently potted to the mirror, houses a ball socket which interfaces with the lock. Other launch-lock structural members, the motors, gear trains, and associated hardware attach to the mounting ring.

Referring to Figure 4.1-14, the normal unlocking sequence is initiated when the primary drive motor and its associated gear train rotate the threaded drive shaft thereby retracting the ball nut out of the ball socket in the H-frame. In a zero-g environment the mirror and H-frame are retracted from the support arm by the forces on the flexure load-limiter springs; the load-limiter springs having been originally compressed during the locking sequence. The locking sequence is achieved by reversing the rotation of the primary motor and advancing the ball nut into the ball socket.

Redundancy in the unlocking sequence is achieved by a one-shot motor-actuated technique. The redundant drive motor and its associated gear train rotate the 1/4-turn fastener which, in turn, permits the compression spring to expand and retract the entire threaded drive-shaft and ball-nut assembly.

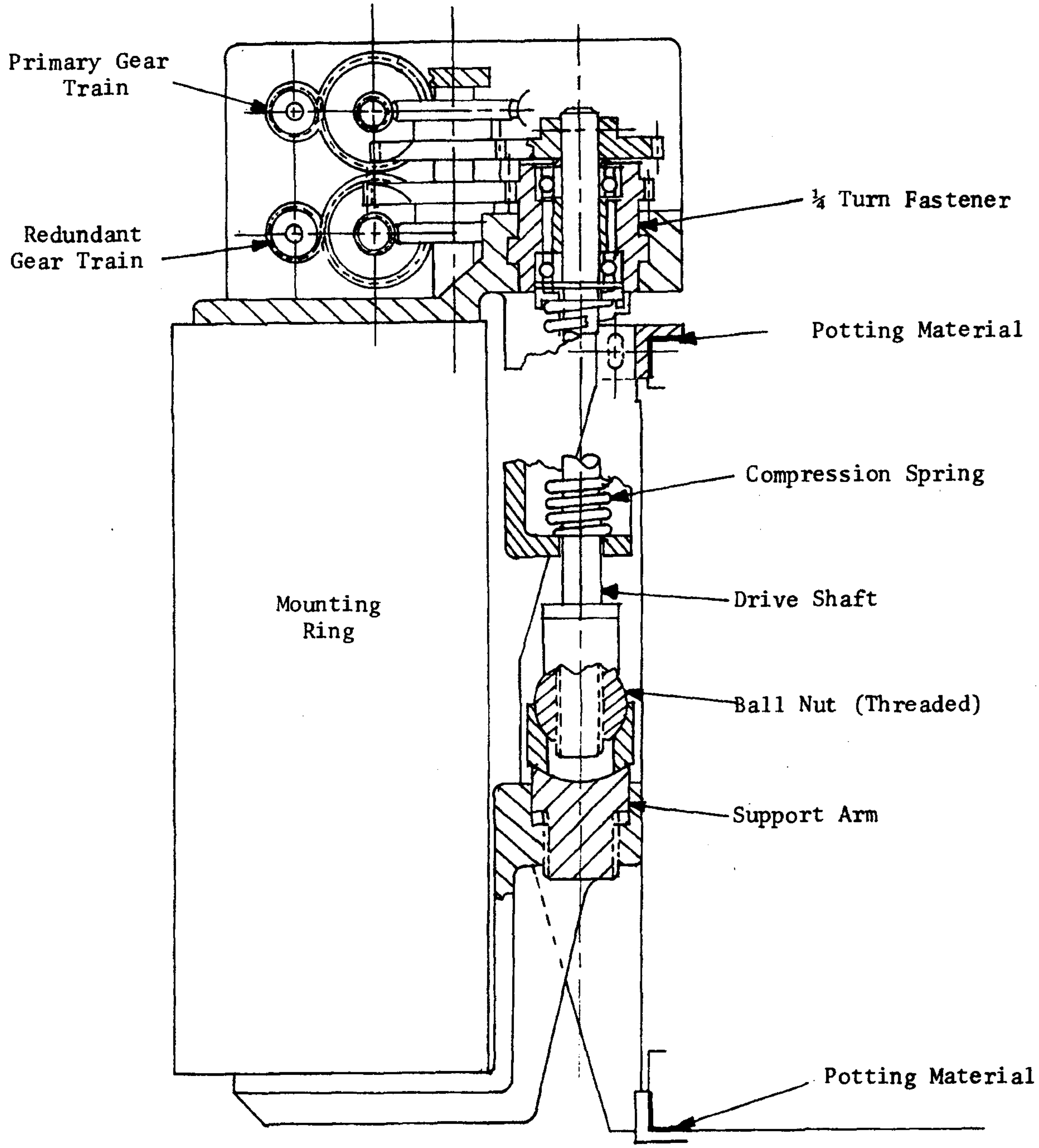


Figure 4.1-14. Lock-Set Design for Cer-Vit Mirrors

With minor modification, this design is applicable to the primary mirror assembly also.

4.1.3.2.3 Mirror Launch-Lock Control. Lock sets for both the primary and TM are controlled in the manner shown in the block diagram of Figure 4.1-15. When a voltage is present on the primary motor lock-command line and the lock is in the released position, the primary motor-drive circuit will drive the motor in a direction to cause the lock to engage. A signal from the encoder will stop the motor when the lock is engaged. (The lock command will be given on the ground only and will be used for optical and launch-lock test purposes.) When a voltage is present on the primary motor-unlock command line and the lock is in the engaged position, the primary motor drives the lock in a direction to cause it to release. A signal from the encoder will stop the motor when the lock is released. If the instrumentation signals indicate the lock is not fully released, a voltage can be placed on the redundant motor-unlock command line. This will cause the redundant motor to be driven and release the lock. The redundant motor and its associated circuitry will use a separate +28-v bus. In addition, redundant unlock commands will be applied to the redundant motor. Instrumentation information as to the state of the lock set is provided by the encoder and potentiometer. To reduce the maximum power requirement, the lock sets are to be activated in sets of three rather than all six simultaneously.

4.1.4 Lens Alignment Description

Because of the large masses of the optical elements of the PP, zero-g alignment may differ enough from one-g alignment that a means for correcting for alignment shifts is necessary. In addition, the resultant change in

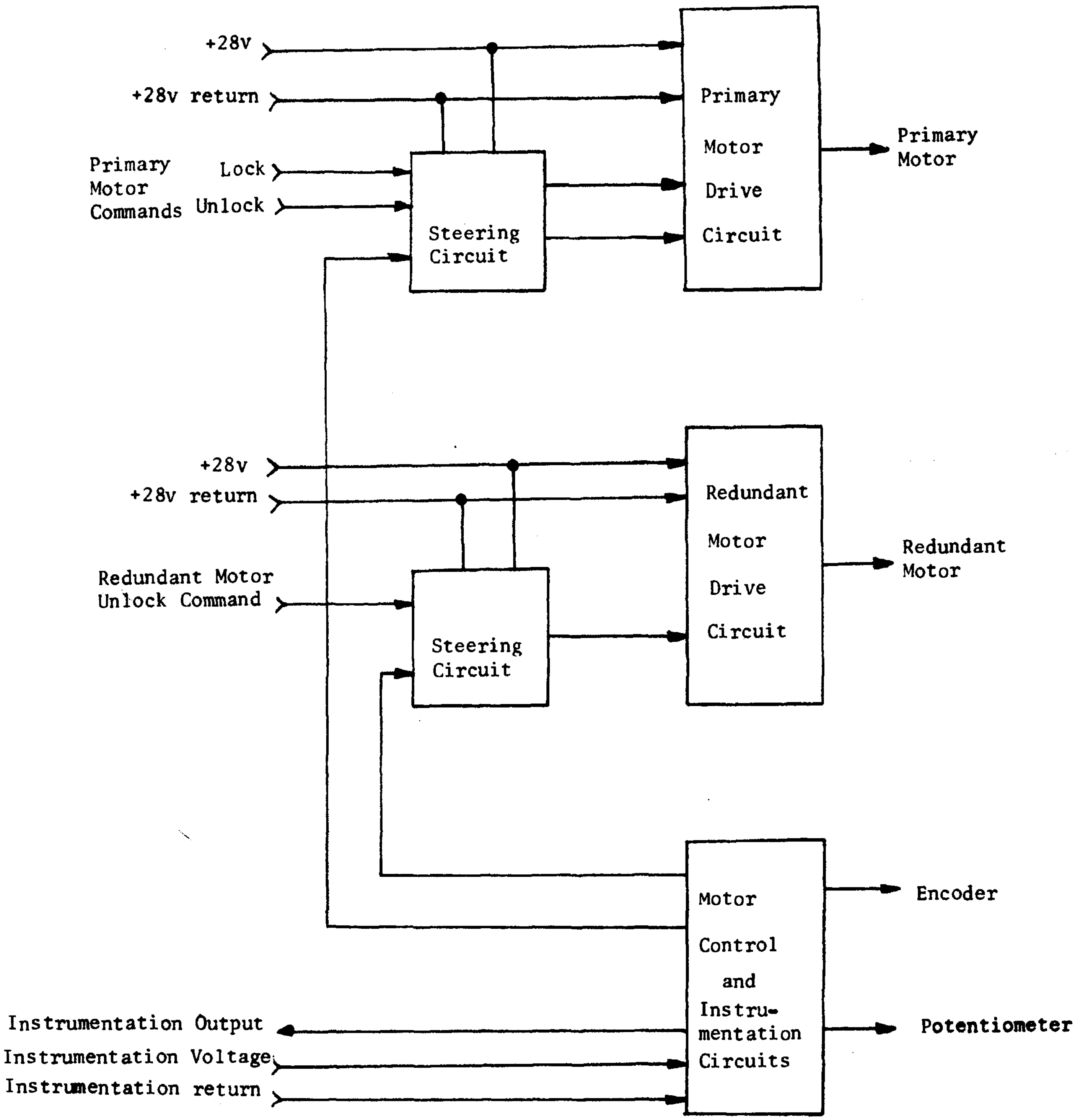


Figure 4.1-15. Mirror Launch-Lock Electronics Block Diagram

the COA line-of-sight is taken into account in the mission module assembly (MMA) alignment. The arrangement of the alignment sensor and servos with respect to the main optics is shown schematically in Figure 4.1-16.

The lens alignment requirements and procedures are based on on-orbit (zero-g) use of components assembled and tested in a one-g environment. The differences in optical alignment for the one-g to zero-g change are applied as corrections or biases to lens dimensions established during initial alignment. It is fundamental to the maintenance of lens alignment that the automatic alignment sensor is used as an assembly reference and must, therefore, have a negligible change in its own alignment between these two environments. The assembly procedure is based on this principle.

4.1.4.1 <u>One-g to Zero-g Alignment Corrections</u>. When the MM is subjected to the weightless on-orbit condition, changes in shape of some structural components can occur which affect alignment settings. The following gravity-induced factors contribute to these changes:

a. Bending of the Ross barrel

b. Deflection of the corrector and diagonal mirrors support structure

c. Unequal deflections in rod-servo-flexure assemblies

d. Bending of the COA shell

These factors produce optical misalignments (apparent tilt and decentering of the primary mirror) in excess of the allowable equivalent primary mirror tilt tolerance of 20 arc seconds (see paragraph 2.4.5.2). To ensure

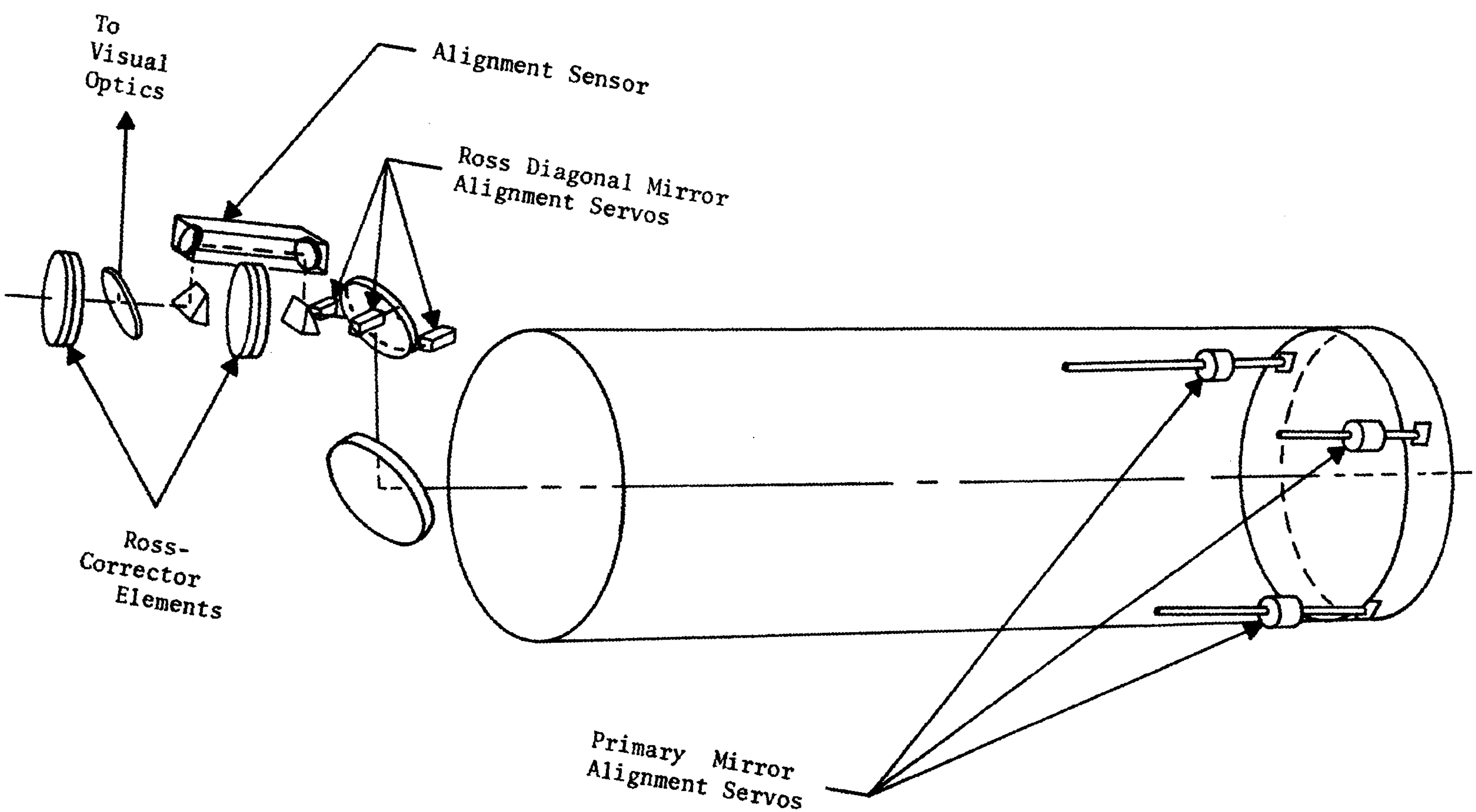


Figure 4.1-16. Alignment Sensor and Servo Drive

nominal alignment initially (before actuation of the automatic alignment system) on orbit, an equal and opposite bias is set into the Ross diagonal and primary servo assemblies after completion of optical testing.

4.1.4.1.1 Bending of the Ross Barrel. During assembly and alignment, the primary mirror optical axis is vertical and the Ross barrel at 2 degrees from vertical. This tilt and the downward weight of the Ross barrel assembly, the alignment sensor assembly and the camera or alignment instruments causes bending of approximately 3 seconds at the forward surface of the Ross barrel and results in a field tilt and decentering of the camera. This value was calculated by considering the Ross barrel to be a cantilever beam and neglecting the stiffening effect of the hood-shaped structure which partially supports the Ross barrel.

4.1.4.1.2 Deflection of the Corrector and Diagonal Mirrors Support Structure. The downward weight of the Ross barrel assembly, the alignment sensor assembly, the camera or alignment instruments, the Ross diagonal, and the Newtonian diagonal have an effect on the angular relationship of the diagonal mirrors and the two faces of the support structure. The sum of these effects produces an apparent decentering of the primary mirror of 0.22 inch in passing from a one-g to a zero-g field. This decentering (and accompanying apparent tilt) can be corrected by approximately a 1 arc-minute bias of the Ross diagonal mirror. These values were calculated by using influence coefficients for the corrector diagonal mirrors support structure from the COA dynamics math model. The stiffening effect of the hood-shaped structure which partially supports the Ross barrel was neglected.

4.1.4.1.3 Unequal Deflections in Rod-Servo-Flexure Assemblies. The primary mirror is referenced to the remaining optics by Invar rods running the length of the COA barrel, at the ends of which are the alignment servos and longitudinal flexures. During initial alignment of the COA, the primary mirror weight is supported on an air bag, not by the rods; hence, differences in stretching of these three assemblies resulting from manufacturing variations (weights and stiffnesses) are therefore insignificant.

4.1.4.1.4 Deflection at the COA Shell. Bending moments will introduce deflections into the COA shell when the MMA is tested in a one-g environment with the primary mirror optical axis oriented vertically. The deflections result in primary mirror decentering calculated to be 0.006 inch. This result was obtained by assuming the weight of the COA above the A-frames to be concentrated at the corrector and diagonal mirrors support structure and the weight of the COA below the A-frames to be concentrated at the primary mirror.

4.1.4.2 Alignment Control. The change from a one-g to a zero-g environment and the Dorian photographic resolution requirements make it mandatory to incorporate the ability to realign the primary optics when the vehicle attains orbit. The cyclic thermal stresses encountered in the MM structure during each revolution also make it desirable to sense and record the alignment condition as it exists just before each photographic pass and to realign if necessary.

The functions which provide this alignment capability allow for the following modes of operation: automatic re-alignment, ground readout of misalignment and ground command of realignment, or flight-crew readout of misalignment and manual control of the alignment servos.

4.1.4.2.1 Alignment Control System (ACS) Operation. On-orbit tilt and centering errors are to be corrected by adjusting the angular orientation of the primary and Ross diagonal mirrors. This is done by means of three servo linear actuators on each mirror, located 120 degrees apart at the mirror edge. Each servo provides independent linear motions along lines of action perpendicular to the face of the mirror.

It is to be remembered that an initial focus correction can also be made on orbit by axial translation of the primary mirror. However, the design for the alignment system is such that corrections made for tilt and decentering do not alter the focus position. Therefore realignment corrections made prior to a photographic pass do not necessarily require focus correction.

The ACS is shown in block diagram in Figure 4.1-17, and consists of three basic units:

a. The alignment sensor, which directly (optically), sequentially senses apparent decentering and tilt of the primary mirror with respect to the Ross corrector assembly and generates error signals via meter display, direct visual readout, and digital and analog signals (see Figure 4.1-18). A breadboard alignment sensor is shown in Figure 4.1-19. The engineering model (EM) system is shown in Figures 4.1-20 and 4.1-21.

b. The alignment servos, which accept alignment correction commands, tilt the Ross diagonal or primary mirror the specified amount, and generate digital and analog output verification of motions (see Figure 4.1-22).

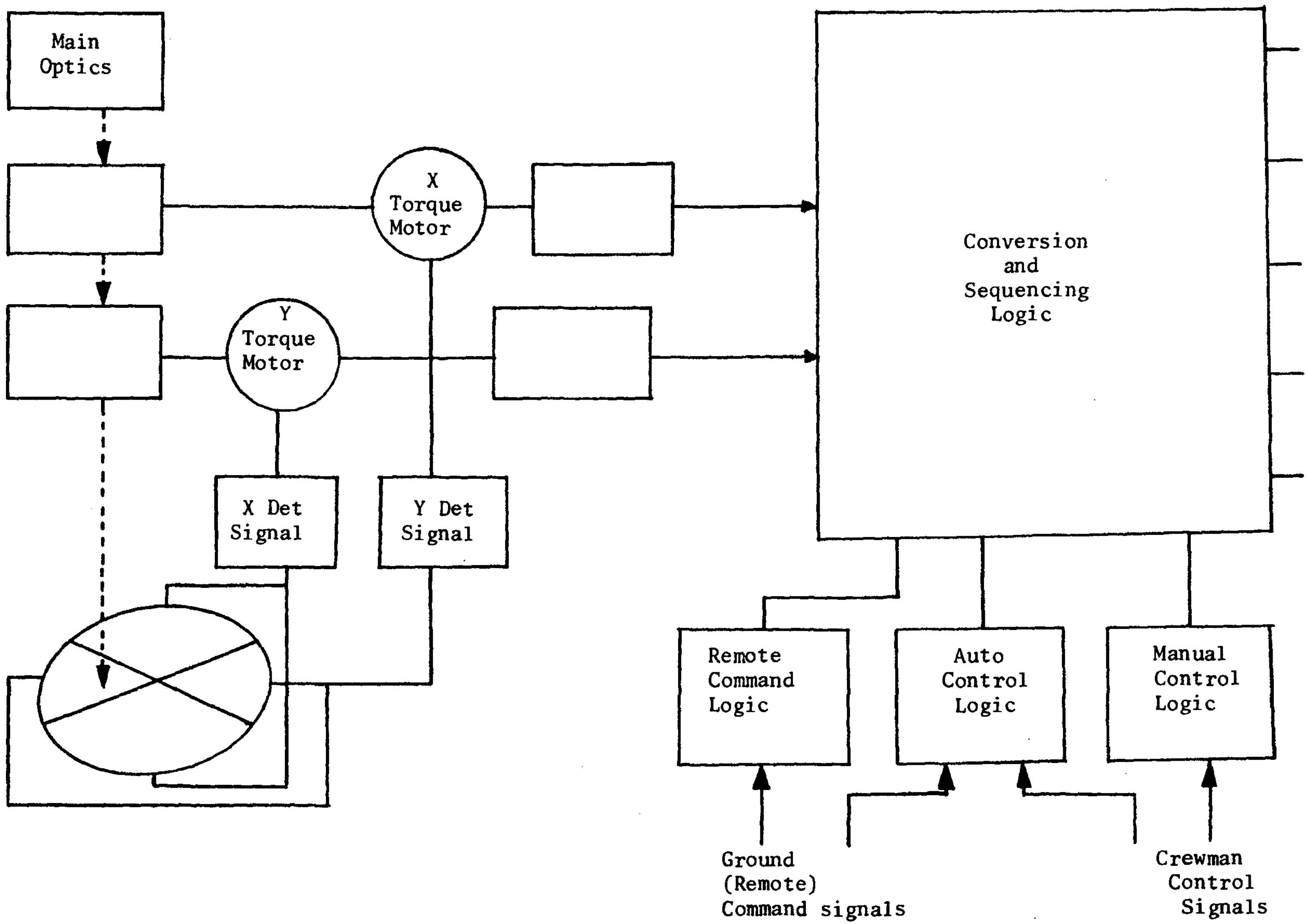


Figure 4.1-17. Alignment Control System Block Diagram

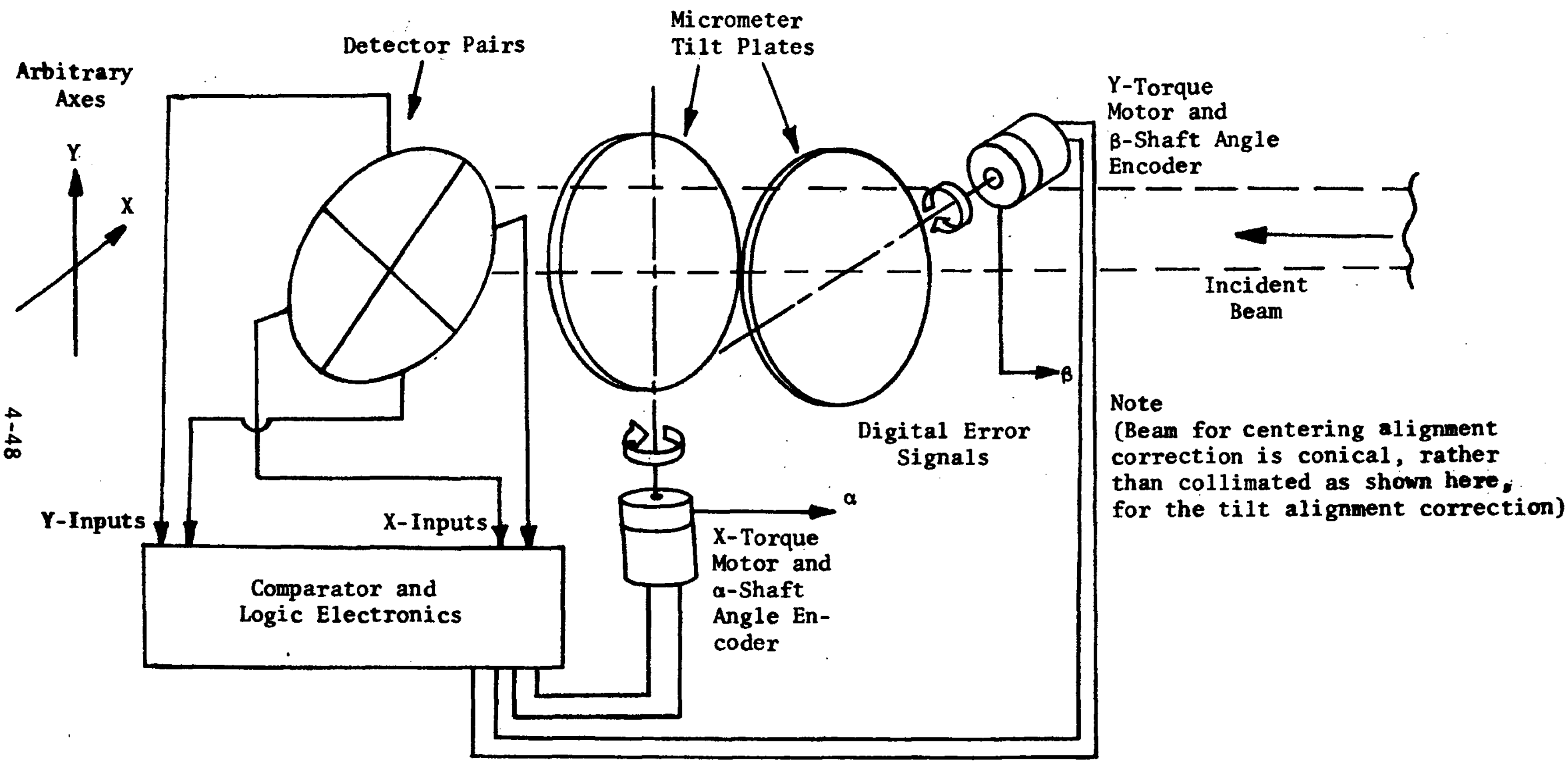


Figure 4.1-18. Schematic of Alignment Sensor Configuration

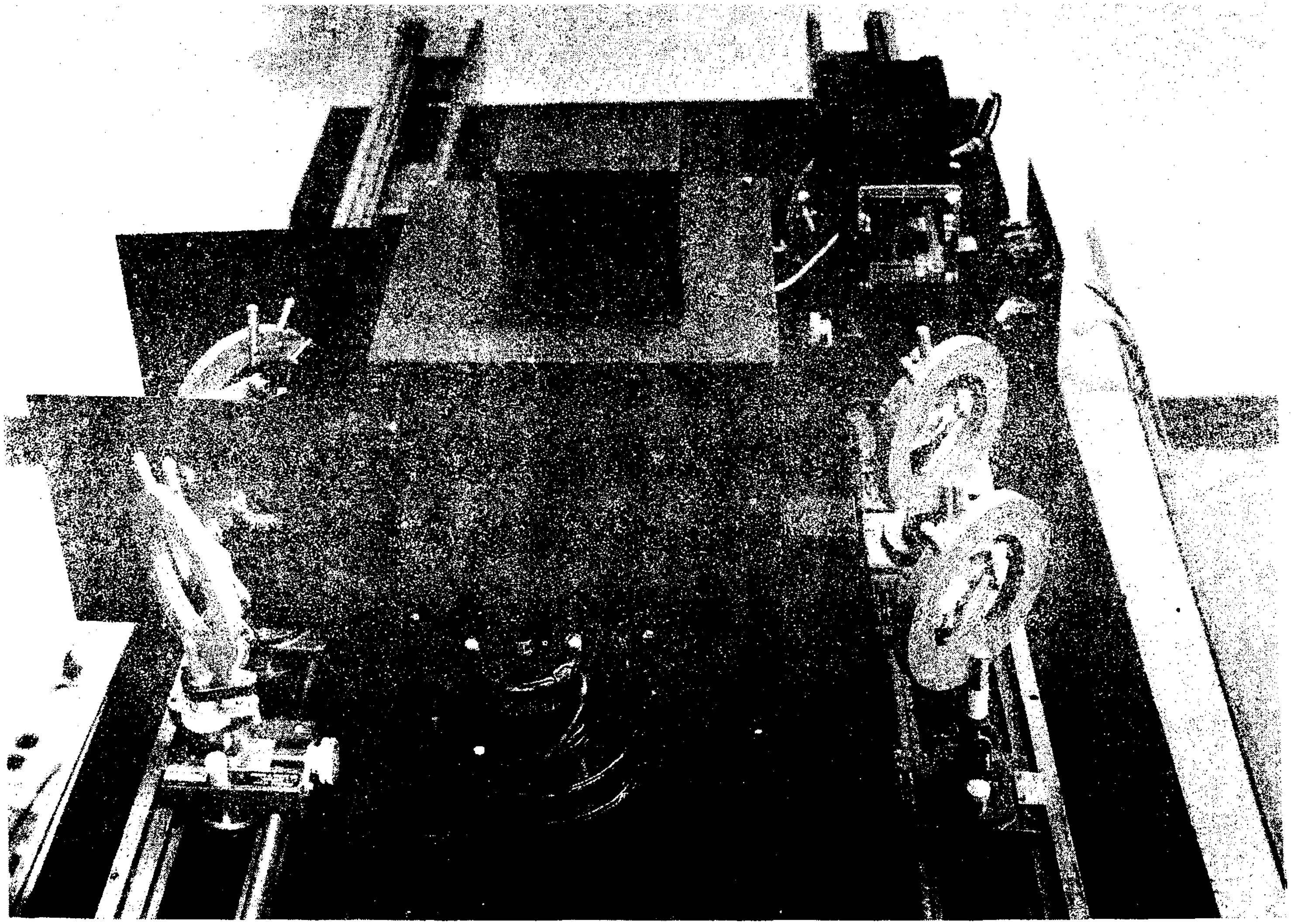


Figure 4.1-19. Alignment Sensor Breadboard

PMAS - Primary Mirror Alignment Servo
CDAS - Corrector Diagonal Alignment Servo
LSE - Leveler Sensor Electronics
AAC - Automatic Alignment Control

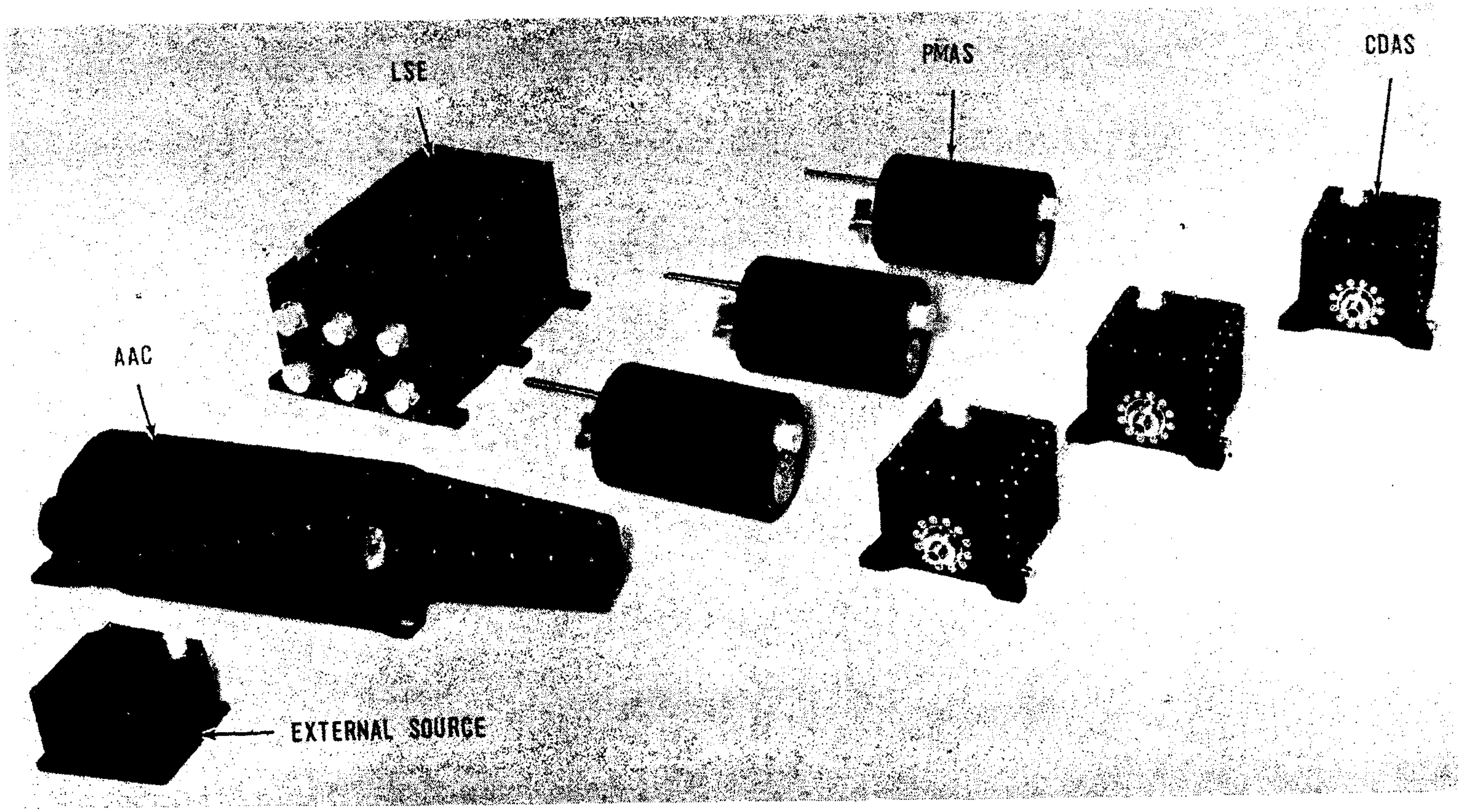


Figure 4.1-20. Alignment Control System EM Components

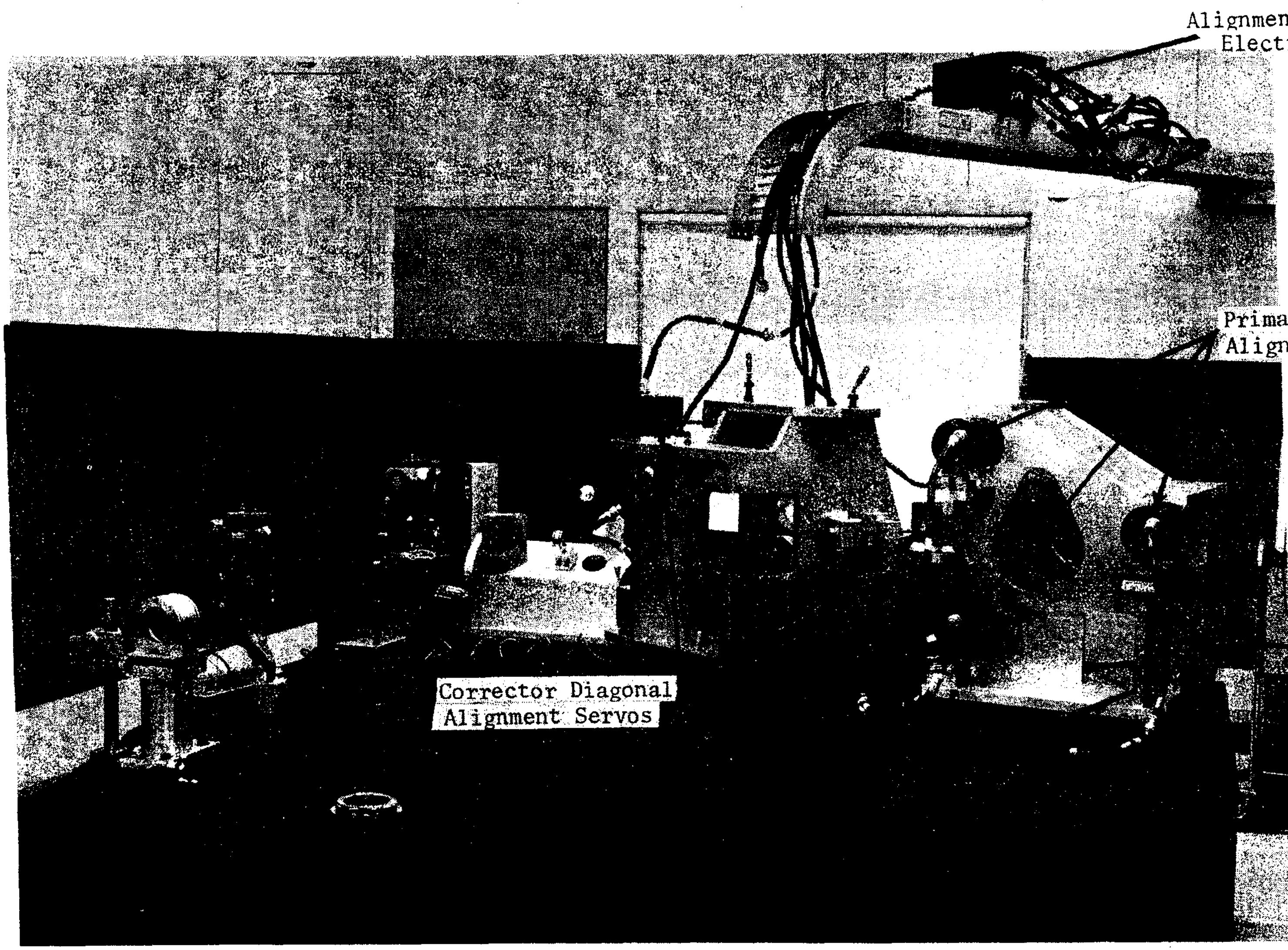


Figure 4.1-21. Alignment Control System EM Mounted on Test Stand

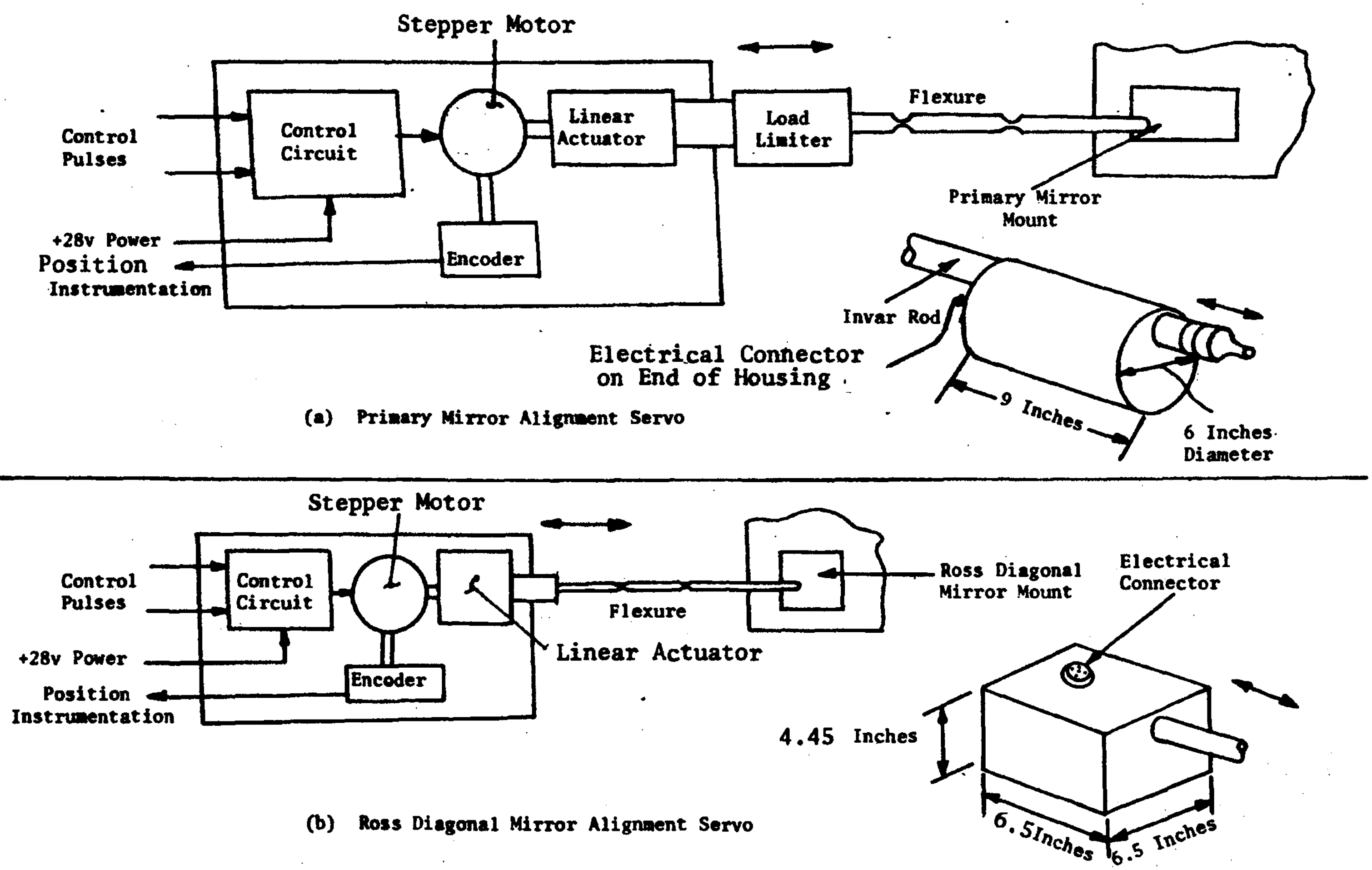


Figure 4.1-22. Alignment Servos

c. The electronics, which accept error signals and crew or ground commands to sense or correct, generate sensing commands for sensor and correction commands for servos, monitor sensor and servo responses, and generate appropriate instrumentation data.

4.1.4.2.2 Decenter Correction Operation. A light source is relayed to the center of the primary mirror. The source and a condensing lens form a light beam directed along the axis toward the Ross lenses. A small portion of this beam is deflected out of the Ross barrel by a small mirror and into the alignment sensor (see Figure 4.1-1 and 4.1-18). If a centering error is present, light rays will fall unequally on two pairs of detectors arranged in quadrants. The outputs of the detectors are compared and proportional error signals are generated. The error signals are converted to drive signals which are used to null out the optical error by recentering the image on the detector assembly. The recentering is done by driving two motors which are coupled to orthogonally mounted micrometer tilt plates in the sensor. The image shifts laterally as the plates are tilted. The amount of tilt required to null each error signal is proportional to misalignment and is measured by digital readout of shaft-angle encoders. The digital error signals provide inputs to conversion and sequencing circuits. These circuits provide outputs to the three Ross diagonal mirror-servo actuators. Through optical feedback to the tilt plates, the light beam provides closed-loop feedback control. By measuring the position of the linear actuators with digital encoders, an electrical feedback loop is established.

4.1.4.2.3 Tilt Error Operation. For detecting tilt error a light source located in the alignment sensor is used (see Figure 4.1-1). Tilt errors are corrected in a manner analogous to that described above for centering errors, except that the conversion logic and sequencing circuit provide outputs to the primary mirror (rather than the Ross diagonal mirror) servo actuators.

4.1.4.2.4 Operating Modes.

a. Automatic Mode. The sensor electronics receives error signals for tilt and centering misalignment and on command corrects alignment errors by the following procedure: sense centering error, correct centering error by tilting the Ross mirror, sense tilt error, correct tilt error by tilting the primary mirror. The cycle is repeated once. This procedure is automatically controlled by sequenced, closed-loop control.

b. Remote Mode. The ground control of alignment will allow readout of the error signals from the detectors and a programmed correction of the error. The error readout will be binary in parallel digital form. The command word consists of enable, setup, and correction bits.

c. Manual Mode. The manual mode will allow flight-crew control of alignment. The flight crew will have two choices: operate appropriate switches on panel 1-C until the error is corrected as indicated by the null readout on the panel meter or, view the error through the VO and correct by means of the same switches on panel 1-C.

4.2 STRUCTURAL ASSEMBLIES AND MOUNTS

The COA structure supports and positions the primary mirror, the Newtonian folding mirror (diagonal mirror), the Ross folding mirror, the Ross-corrector lens assembly, and the camera, as shown in Figure 4.2-1. Figure 4.2-2 is the structural development model (SDM-1) which is now being tested.

4.2.1 Concept

The configuration of the COA structure is such that the optical elements are positioned and spaced on-orbit by a continuous path of low thermal-coefficient-of-expansion Invar, and an independent load-carrying aluminum structure.

The longitudinal axis of the COA barrel is tilted 2 degrees with respect to the longitudinal axis of the MM. This orientation was made necessary because of MM space restrictions in the Z direction (see Appendix A.1).

4.2.2 Optical Support Structure, Ross Barrel, and Reference Rods

The optical support structures, Ross barrel, and reference rods within the COA form a complete Invar path, interconnecting all mission module aft section (MMAS) optical elements. Thus, the geometric relationships between optical elements can be held nearly constant over the operating temperature range (see paragraph 4.6).

4.2.2.1 Corrector and Diagonal Mirrors Support Structure. The corrector and diagonal mirrors support structure is rigidly bolted to the forward end of the aluminum COA barrel (described in paragraph 4.2.3) forming a common reference plane from which all other optical elements are supported and located. The structure is illustrated in Figure 4.2-3.

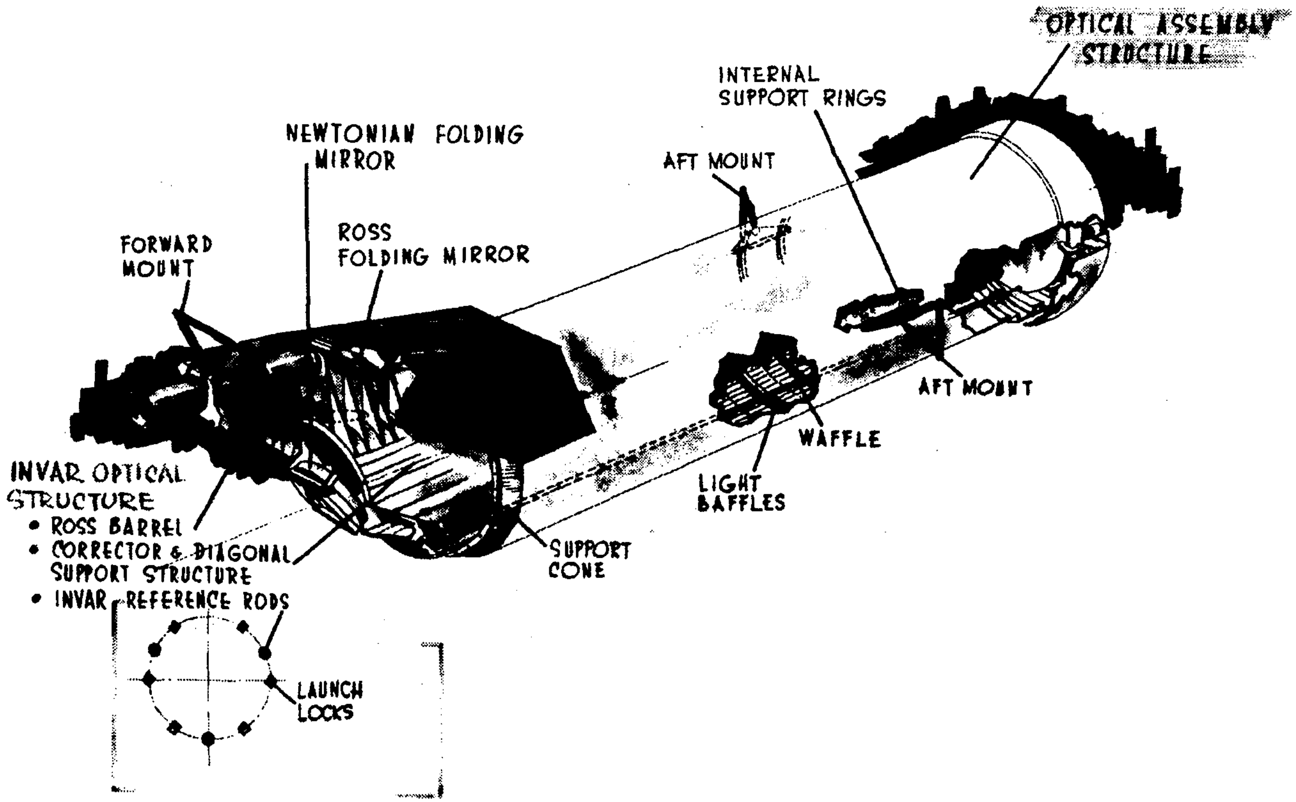


Figure 4.2-1. Optical Assembly Structure and Mounts

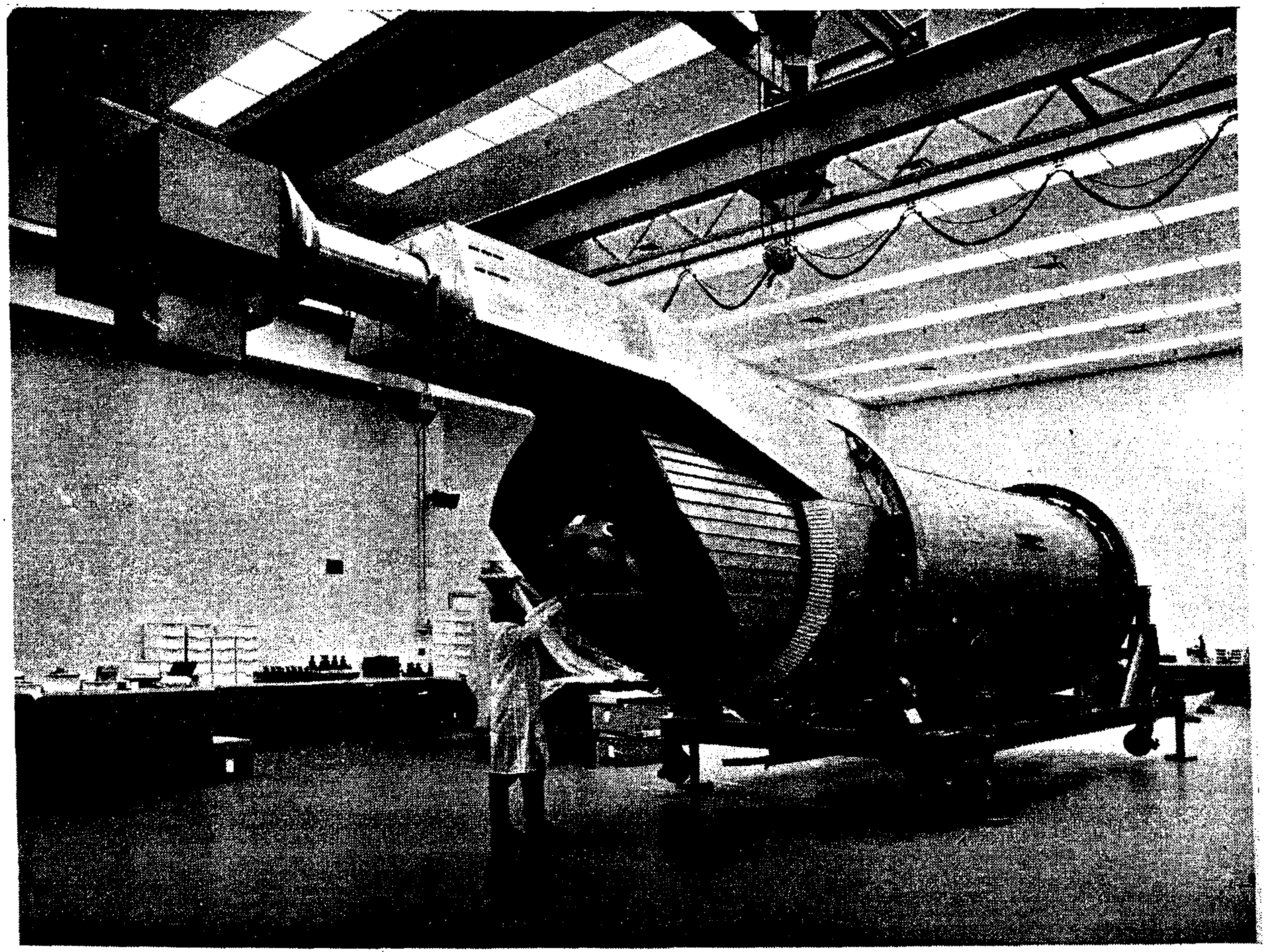


Figure 4.2-2. Structural Development Model COA

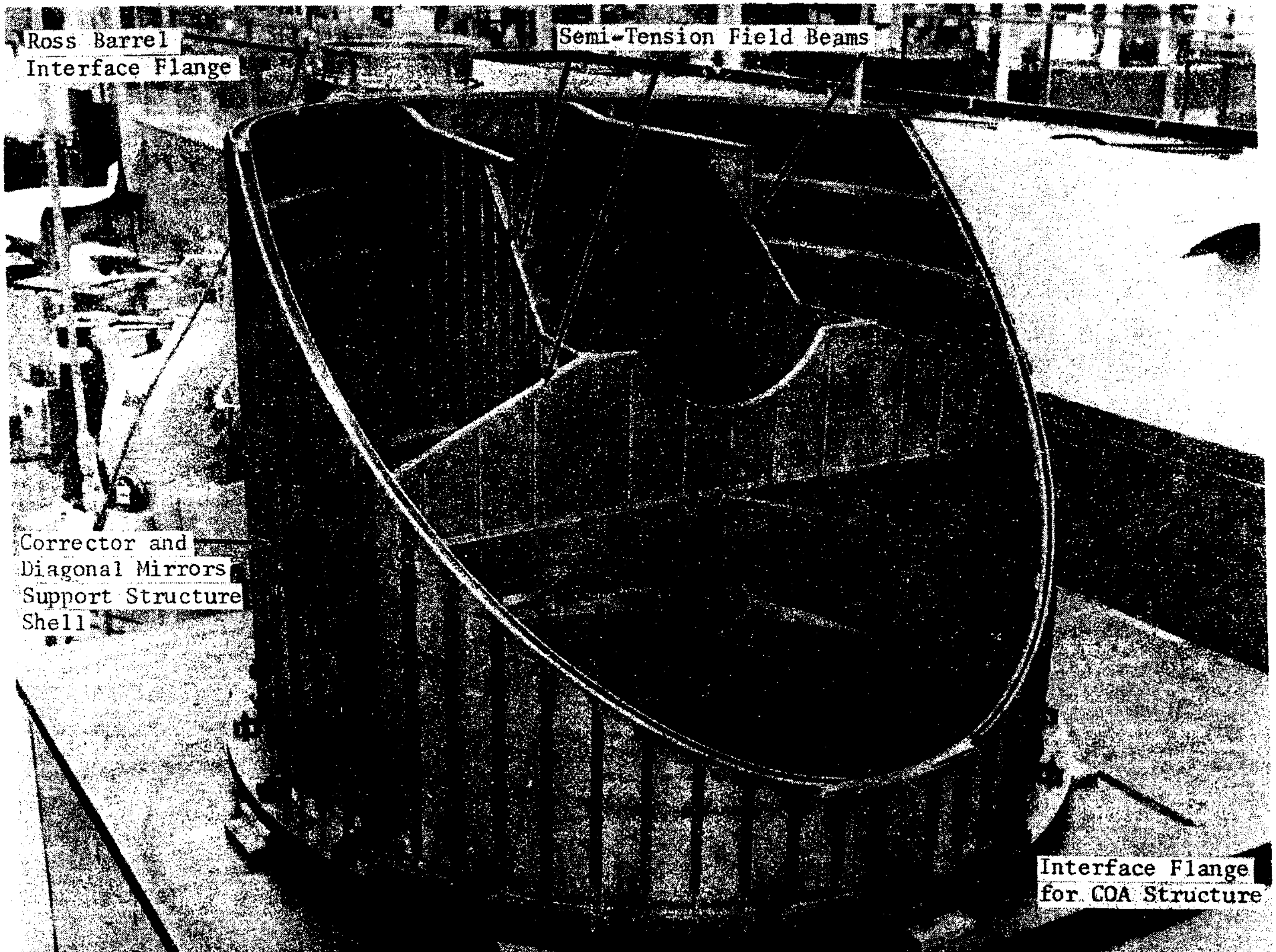


Figure 4.2-3. Corrector and Diagonal Mirrors Support Structure

It is a semimonocoque-type structure composed of Invar rings covered with thin (0.015-inch thick) Invar sheet. External longitudinal zee-stiffeners are used to increase the bending stiffness of the shell and to preclude buckling of the structure during the ascent phase of the mission. The internal rings of this structure also provide optical baffles to prevent stray reflections from entering the optical path.

The entire corrector and diagonal mirrors support structure is spot welded. This structure directly supports the Newtonian folding mirror (diagonal mirror) and the Ross diagonal mirror. These two mirrors are interconnected by two, deep, Invar beams to minimize the relative displacements between them. As a result, these two mirrors behave dynamically as one and can be likened to an optical rhombohedron. A cross beam is also incorporated to provide additional stability to the pair of beams. The three beams just described form a spider which partially obstructs the optical path. Minimization of the obstruction was considered in the design. Also, as much of the spider as possible is hidden in the shadow of the Newtonian mirror.

The beams which support the mirrors are of the semi-tension field type; that is, the webs are thin and will elastically buckle at maximum load. Because the buckling is elastic, the webs will not contribute to any permanent deformation of the structure. This type of construction gives the maximum on-orbit stiffness for minimum weight.

4.2.2.2 Ross Corrector Barrel. The corrector and diagonal mirrors support structure also supports the Ross-corrector barrel by providing a flange to which the barrel is bolted. The Ross corrector supports the Ross optical elements, and part of the alignment and VO. At its forward end, it provides a supporting flange for the camera. The Ross-corrector barrel is shown in Figure 4.2-4. The Ross barrel is a semimonocoque shell. Stiffening rings are incorporated at all concentrated load points. These rings and the end flanges are fusion welded to the shell.

Additional support is provided to the Ross barrel corrector and diagonal mirrors support structure by three flexures which are located near the forward end of the barrel and connected to the aluminum forward support structure in such a way as to limit the relative motion between these structures in the transverse plane only (see Figure 4.2-5). The addition of these flexures, however, makes the Invar and aluminum structures internally redundant. Therefore, a redundant static load analysis was performed to correctly size and design the Invar optical support structures thus far described.

4.2.2.3 Reference Rods. The corrector and diagonal mirrors support structure also supports the forward ends of three, equally spaced, Invar reference rods. The aft end of each rod is attached to a servo, a load limiter, and a flexure. The flexure is attached to the primary mirror. A detail drawing is shown in Figure 4.2-1. The three rods provide a thermally stable mechanical spacer between the corrector and diagonal mirrors support structure and the alignment servos at the primary mirror. The rods are supported transversely at several locations along their length by the aluminum COA barrel. The rods themselves have little transverse stiffness

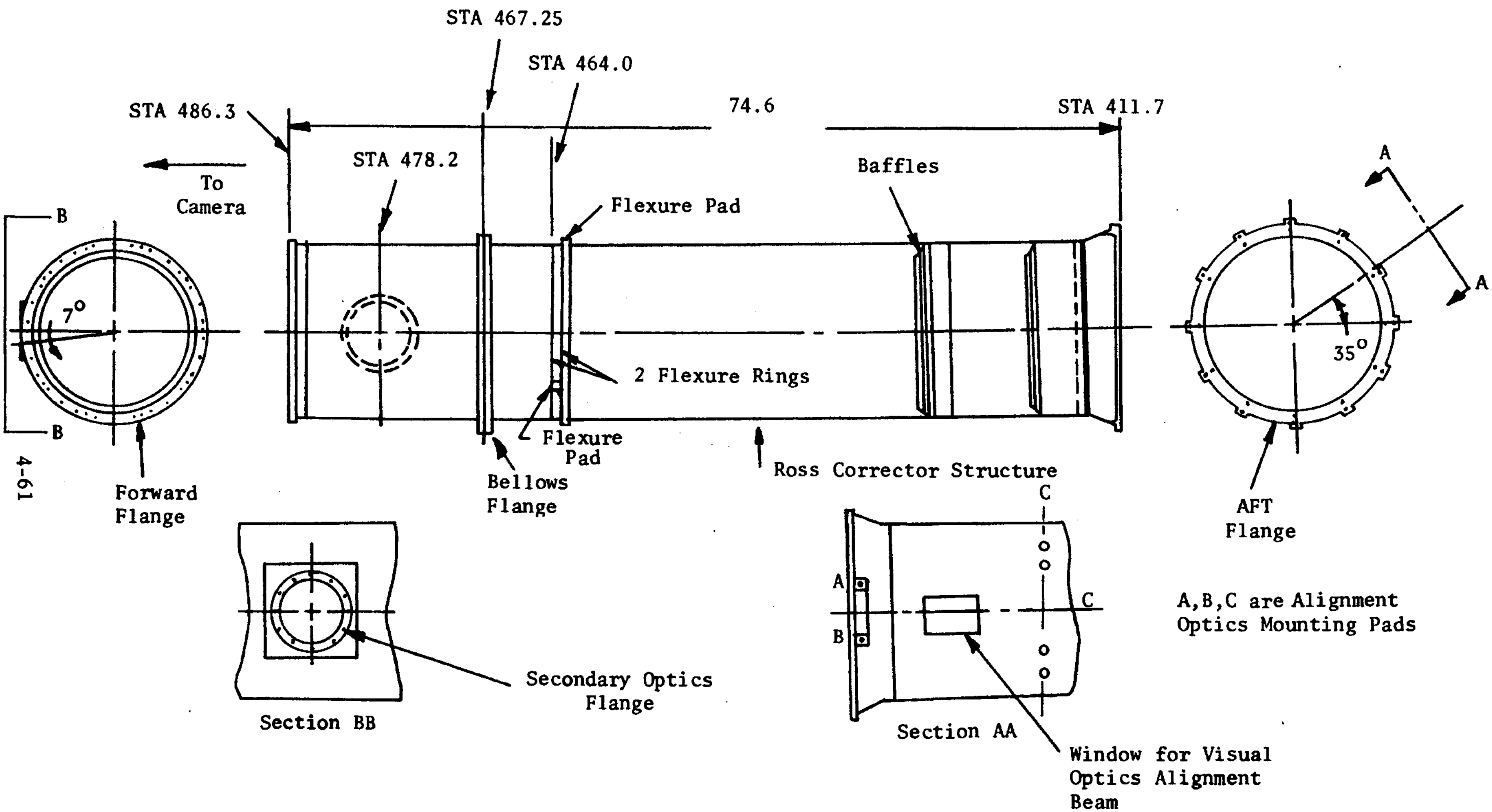


Figure 4.2-4. Ross Barrel Structure

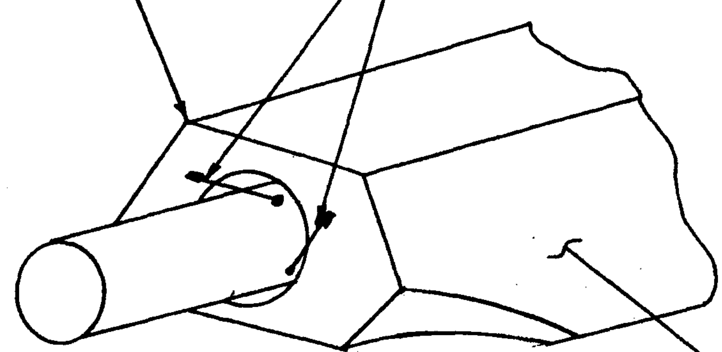


Figure 4.2-5. Forward Support Structure

and do not position the primary mirror in the transverse direction. The aluminum COA barrel provides transverse support to the primary mirror via three flexures from the end cap to the primary mirror as shown in Figure 4.1-17.

The reference rods are tubular with the necessary fittings at each end for mounting to the corrector and diagonal mirrors support structure and to the servos.

4.2.3 Camera Optical Assembly Structure

4.2.3.1 Camera Optical Assembly Barrel. The COA barrel is the main aluminum structure. The barrel serves as a load bearing structure on the ground and during launch and also supports thermal control heater tapes and blankets. The COA barrel is shown in Figure 4.2-1. It is a semi-monocoque design, made from three-separate waffled skins seam-welded into a cylinder. The skin's inner surfaces are machine waffled in 2.5- by 6-inch rectangles to a final skin thickness between 0.018 and 0.035 inch, leaving upstanding rib patterns about 0.218-inch thick. This design closely follows proven missile-booster structure designs. The cylinder is suitably reinforced with internal rings as needed. The forward end of the barrel terminates in a short truncated cone section of corrugated aluminum skin with a machined ring. The corrector and diagonal mirrors support structure (Invar) bolts to this ring at jig-drilled holes.

The aft end of the barrel terminates in a flange drilled to take the end cap (described below). Internal longitudinals exist between major internal reinforcing rings, on each side, to take the loads from the main mounts. Light baffles made from magnesium are appropriately spaced along the inside of the barrel.

4.2.3.2 Forward Support Structure. The forward support structure, shown in Figure 4.2-5, is an aluminum, cantilevered box-like structure. The forward end is linked by three flexures to the Ross-corrector barrel. Under the action of lateral loads, resistance to bending is shared between the Invar Ross barrel and the aluminum structures.

The floor of the box is removable for installation of the assembled Ross barrel and diagonal mirror support structure. The forward support structure also supports MM electronic packages.

The forward support structure is permanently attached to the COA barrel described above.

4.2.3.3 End Cap. The end cap mounts the primary mirror as seen in Figure 4.2-1. On orbit, the primary mirror is supported by flexures from the end cap (which hold it centered in the end cap) and by the three longitudinal flexures extending from the Invar reference rods.

For launch and handling, a circular box section inside the end cap mounts the launch locks, supporting and restraining the mirror. For ground testing, an air bag is included which acts as a support for the primary mirror during vertical testing (see paragraph 4.2.7). Launch acceleration force on the mirror is resisted by six pads on which the launch-locked mirror rests. These pads, by means of built-in static load measuring cells, can be adjusted to give uniformly distributed support to the back of the mirror.

The end cap terminates in a shaped bulkhead of spun, chem-milled aluminum. The bulkhead acts as a taut diaphragm to distribute launch loads out to the cylindrical skin of the end cap.

Large holes in the end cap skin permit egress of vent and conditioning air during ascent.

4.2.4 Camera Optical Assembly (COA) Mounts

The COA mounts are designed to minimize the bending transmitted to the COA by thermal hotdogging of the MM. The COA is mounted within the MM shell on three ball-joint fittings. Two main-support ball joints are positioned near the aft end and on the sides of the COA barrel, with the stabilizing third joint at the forward end on top of the aluminum structure (see Figure 4.2-1). This third point is linked to the MM external shell by a small A-frame link hinged parallel to the lateral Y-Y axis. By this means, the ball-jointed support point is restrained laterally (Z-Z and Y-Y), but is free to move in the longitudinal (X-X) direction.

The main-mount ball fittings are attached to each side of the cylinder by machined aluminum channels on the outside. These match and are attached to internal longitudinals between the main structural rings.

An A-frame connection to the MM shell is achieved by pairs of large ball-ended turnbuckles. Turnbuckle barrels are made from titanium for the purpose of minimizing heat conduction along these link paths. The design was optimized thermally within strength requirements. The outboard connections of each pair of turnbuckles at the MM are hinge-linked parallel to the Z-Z axis.

4.2.5 Access

The structure provides load-carrying access panels to provide access to the Ross diagonal mirror servos (forward), and to the primary mirror servos and launch locks (aft).

4.2.6 Spacer Ring

A 2-inch gap filled with a segmented magnesium-lithium spacer ring is located between the aft end of the COA barrel structure and the end cap containing the primary mirror. This allows for adjustment of structure length to the focal length of a particular mirror to be installed. When the assigned mirror's focal length is known, the spacer can be cut to the appropriate length.

4.2.7 Air Bag

For test purposes, the end cap incorporates a sealed compartment closed by a rubber diaphragm (air bag) on which the primary mirror rests (see paragraph 6.2.6). The air bag is capable of inflation to 0.25 psi above ambient. In the vehicle vertical position for ground testing, and after the release of the launch locks, the primary mirror can be floated up 0.125 inch on the uniformly distributed inflation air pressure within the compartment. The air bag will remain intact during tests and assembly of the MM. Current plans call for spring retraction of the air bag when deflated and venting the air bag during launch.

4.3 VISUAL OPTICS

VO requirements, design considerations, hardware description, operation, and electrical control are discussed in paragraphs 4.3.1, 4.3.2, 4.3.3, 4.3.4, and 4.3.5 respectively.

4.3.1 Requirements

The visual optics assembly (VOA) consists of all the elements necessary to provide the flight crew and the IVS with a view of the image from the main lens. Output is presented at either of two output stations in the LM to enable the flight crew to perform visual tracking and target surveillance. Variable magnification in the range 125 to 1000X is required. Derotation prisms establish image orientation so that the vehicle's ground track appears vertical in the image at the initiation of tracking of each target. However, the derotation prisms do not move during tracking.

The capability for varying the division of light rays between the VO relay and the IVS is required. The options are: to supply all the light rays to the IVS to the VO relay and the other half to the IVS. The general configuration and space-envelope required is shown schematically in Figure 4.3-1.

4.3.2 Design Considerations

4.3.2.1 Magnification Techniques. VO designs examined include both the zoom and step methods for providing variable magnification. Although the zoom method is capable of unbroken observation of a point of interest during magnification change, size-and magnification-range requirements force a compromise in image quality. The particularly difficult problem are the simultaneous correction of chromatic and nonchromatic aberration throughout the zoom range, field aberration at low magnification, and uncompensated vibrational impulses.

A step method of magnification can more easily correct field curvature and provides improved resolution over the zoom method. Simulations have shown that, provided that the change in magnification is modest and the effective blackout period is less than 0.2 second, observation of a point of interest is not impaired by step magnification change. In fact, rapid step magnification change is a further advantage over the zoom system.

4.3.2.2 Viewing Capability. The selected design for the prime VO hardware is a four-step system providing magnification of 125, [redacted]

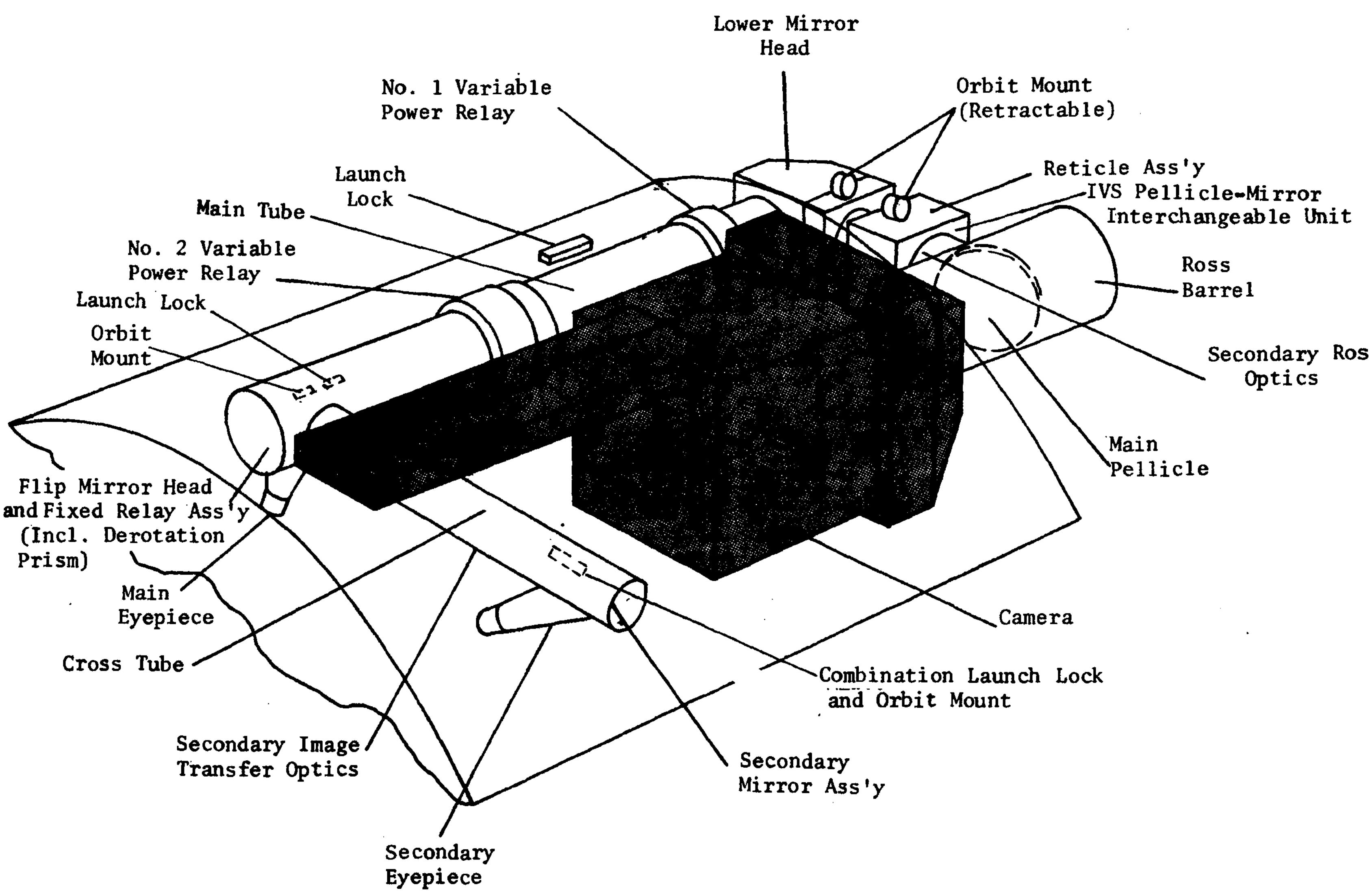


Figure 4.3-1. Schematic of Visual Optics Assembly

[redacted] A design concept was developed to reduce effective blackout time to a minimum (less than 0.2 second). Counter-rotating components are used where possible to eliminate inertial reactions.

A reticle to indicate field coverage is used to assist the crewman in planning magnification changes. The reticle shows by concentric circles the field coverage at higher magnifications than the one in use. This concept is illustrated in Figure 4.3-2 through 4.3-5 where views of a target at magnifications of 125, [redacted] are simulated. When viewed from a distance of 10 inches, the apparent field of view is 40 degrees, and the scale is correct for an 80-nautical-mile (n mi) viewing altitude. Resolution and format are not simulated. Proceeding from each figure to the next, the ground scene area included in the outermost circle inscribed in the reticle expands to fill the field.

The entrance pupil of the VO is established by the primary mirror and modified by the TM. The Newtonian mirror and spider mount form an obstruction of about 17.2-percent relative area. The exit pupil is an image of the entrance pupil and the obstruction and is thus an annular ring with a black center. It is located about 2.5 inches from the last lens of the eyepiece. The crewman must place his eye at this position for correct viewing with the VO.

Observation at low magnification requires that the eye pupil be placed in the annular ring of the exit pupil. The width of the annulus is as big as or greater than the eye-pupil diameter and no problem is anticipated in

[redacted]

Figure 4.3-2. Target Viewed From 80 n mi
at Magnification of 125

[redacted]

Figure 4.3-3. Target Viewed From 80n mi at Magnification of [redacted]

[redacted]

Figure 4.3-4. Target Viewed From 80 n mi
at Magnification of [redacted]

[redacted]

Figure 4.3-5. Target Viewed From 80 n mi
at Magnification of [redacted]

maintaining the pupil in the correct position. The natural reflex of an observer is to move the eye to the position of greatest brightness. Regardless of the shape of the exit pupil, the eye must seek a position in space within or encompassing the illuminated portion of the pupil. This condition is not unique to the Dorian system; it is common in the use of conventional Newtonian telescopes and creates little difficulty in viewing. The exit pupil is a function only of the entrance-pupil dimensions and magnification. Figure 4.3-6 shows the change in pupil size and position as a function of magnification. Note that the maximum lateral eye shift is only about 0.2 inch.

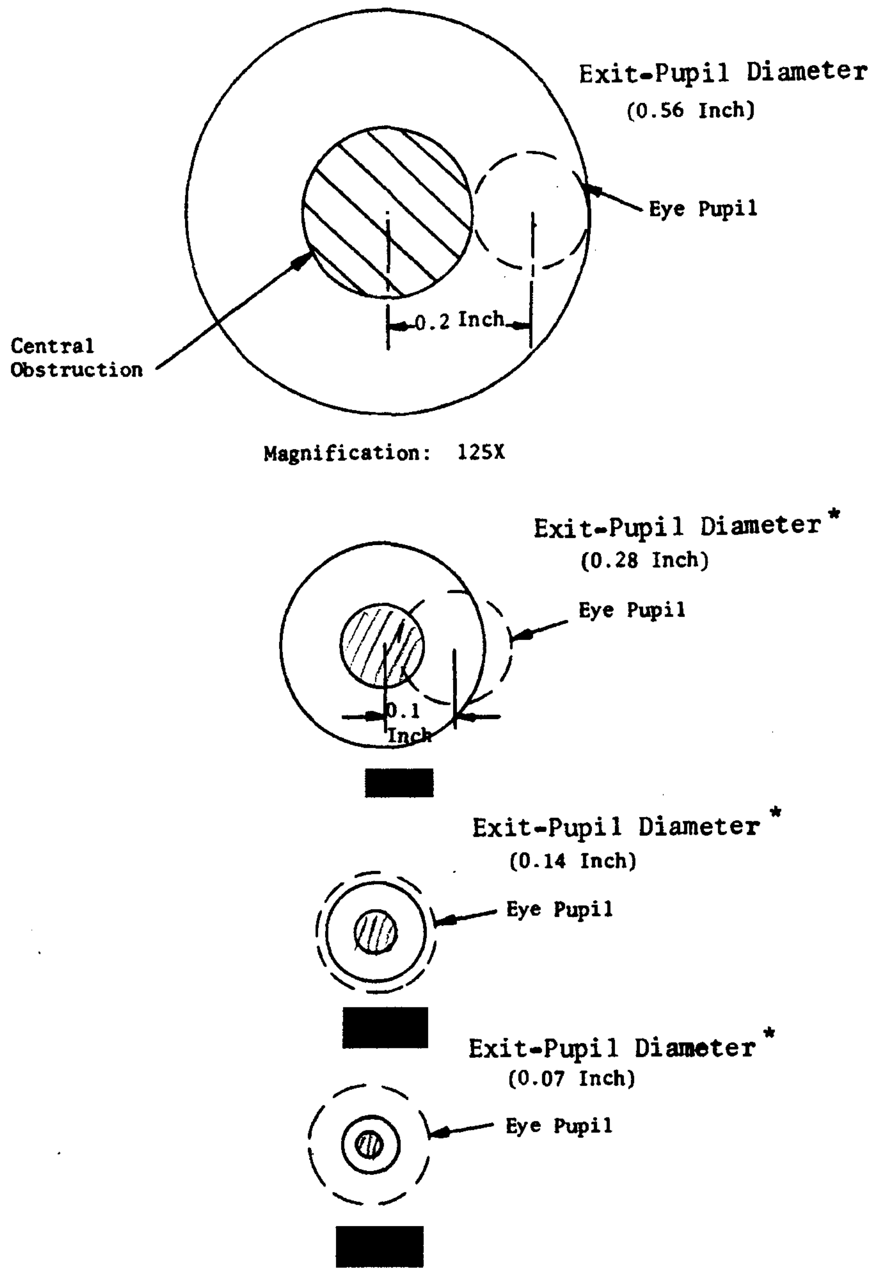
4.3.3 Hardware Description

The VO and functional components are discussed in this paragraph starting at the secondary Ross optics (see Figure 4.3-7). This paragraph also includes mount and interface discussion.

Optical design and development was aided by the use of breadboards and models. Figure 4.3-8 is the VO formula sample which consists of essentially prime optics. This model is used to study the optical characteristics of the VO only, and is therefore manually operated.

4.3.3.1 Visual Optics Functional Units.

4.3.3.1.1 Interchangeable Mirror/Pellicle Assembly. This assembly is mounted between the secondary Ross optics and the reticle and is part of the secondary Ross barrel. The purpose of the assembly is to reflect



* Primary mirror only; tracking mirror dimensions not included

Figure 4.3-6. Exit Pupil/Eye Pupil Relationships

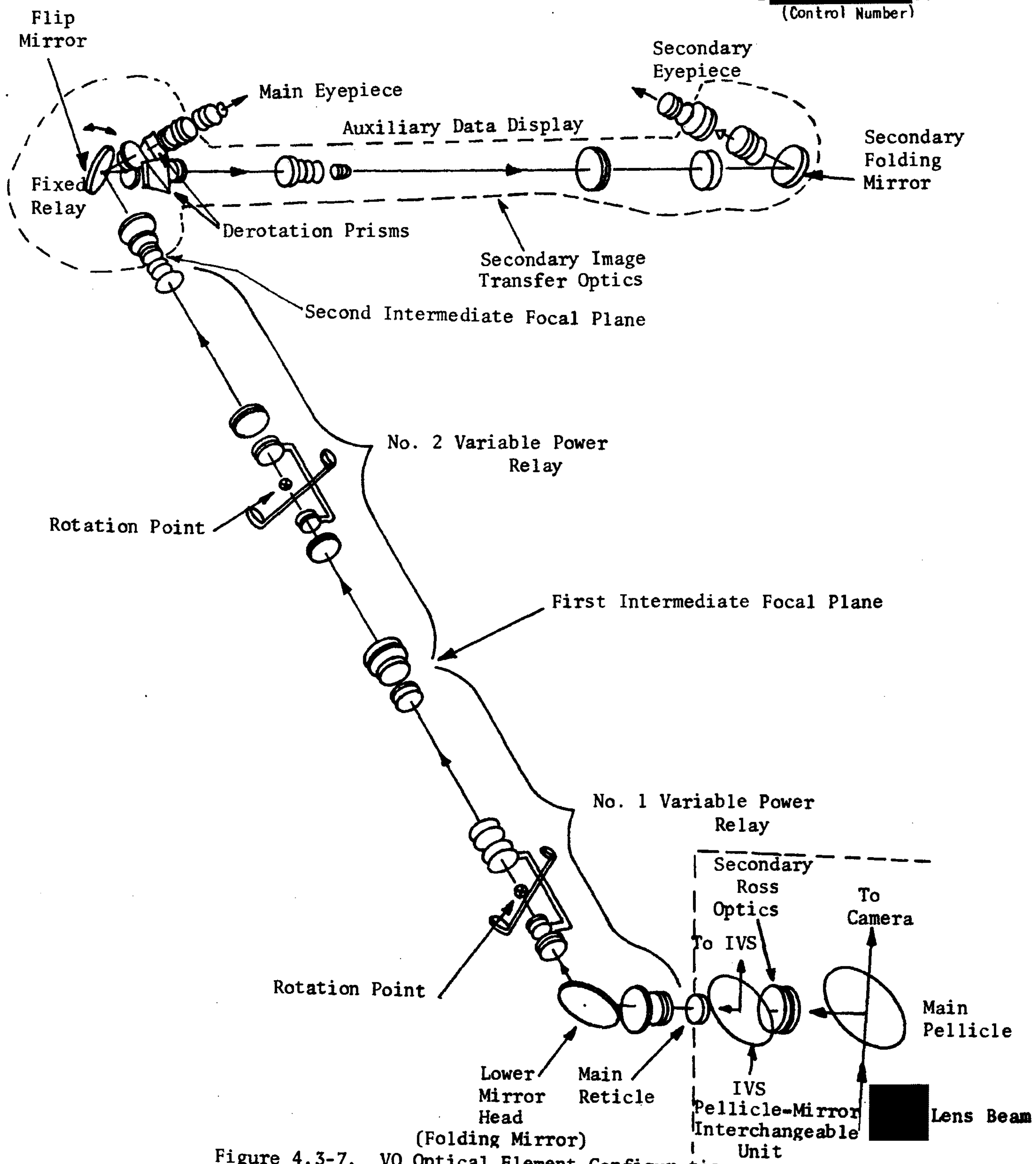


Figure 4.3-7. VO Optical Element Configuration

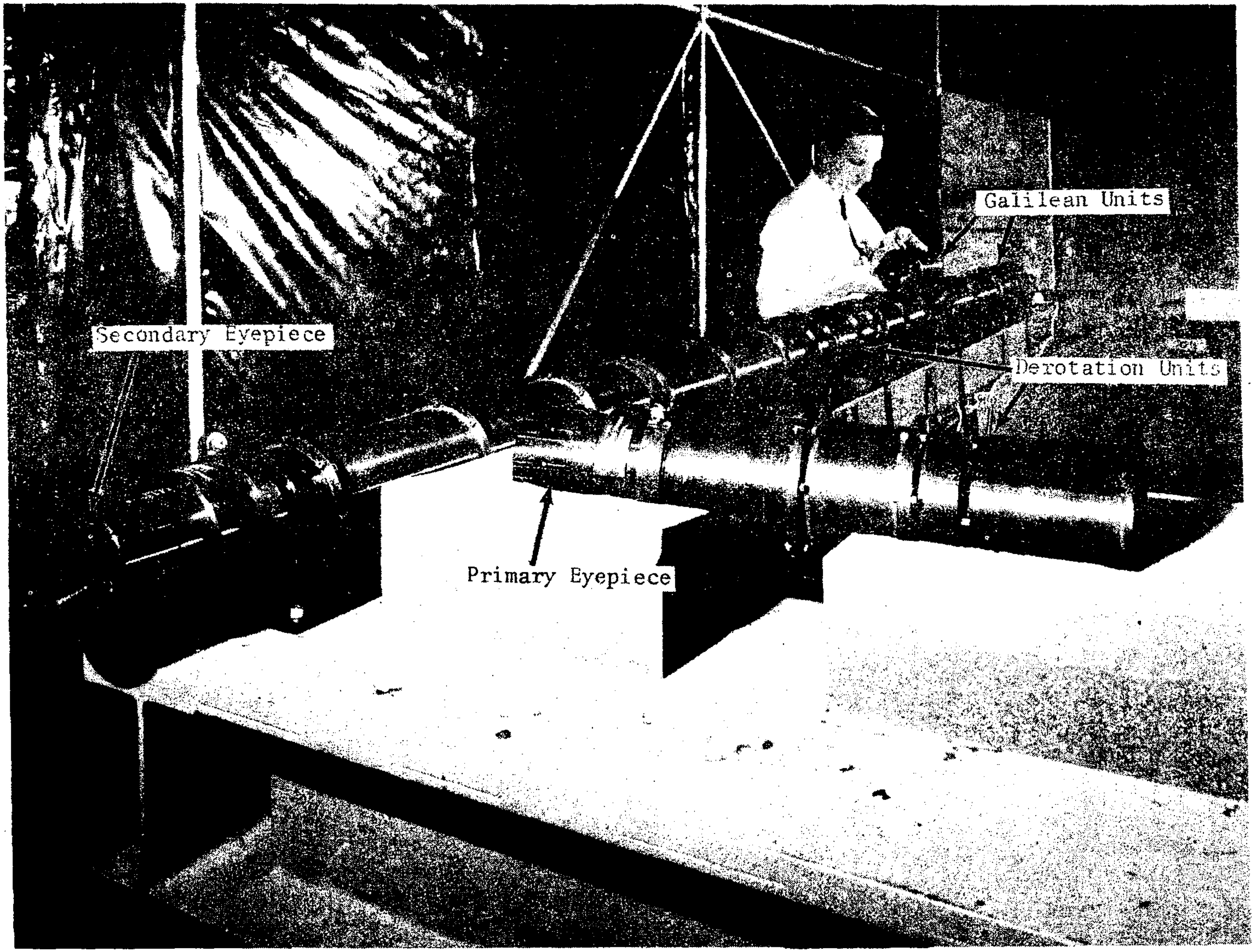


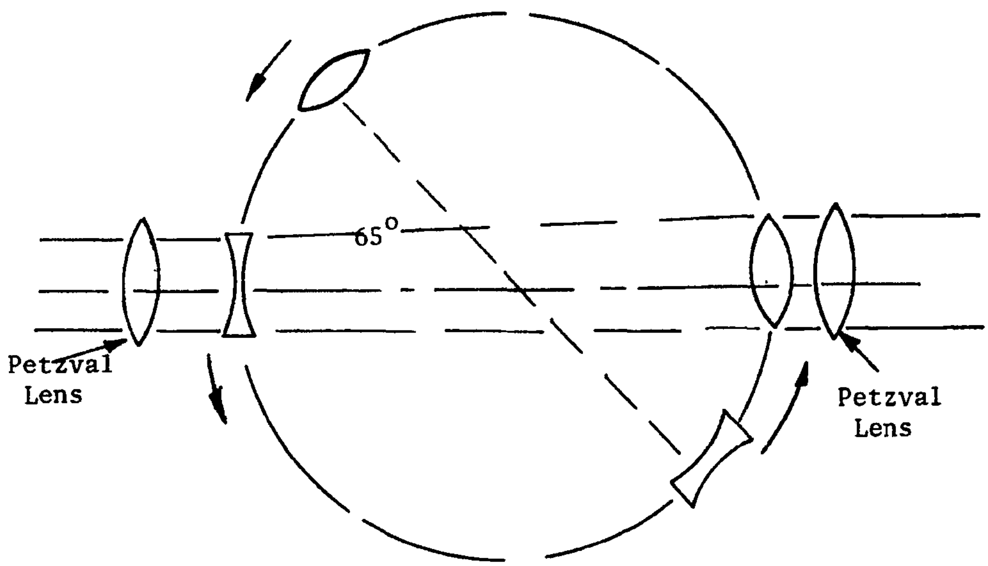
Figure 4.3-8. Formula Sample - Visual Optics Relay and Eyepieces

inputs to the IVS. The assembly consists of a dual path slide, a full reflecting mirror and a partial reflecting pellicle driven in and out of position by a push-pull hand-operated cable. Positional mode indication will be mechanical/visual (no electrical drive or instrumentation will be used).

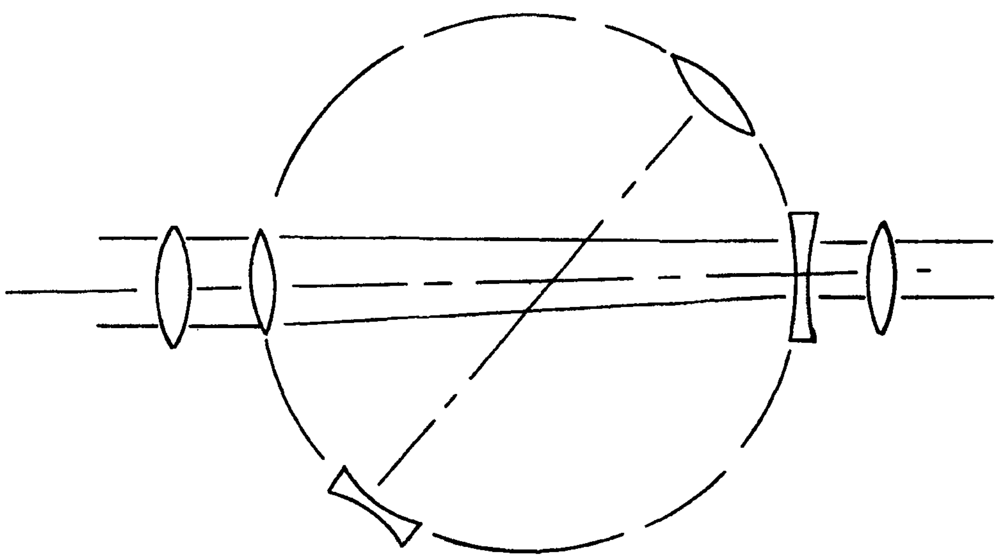
4.3.3.1.2 Reticle Drive. The reticle is mounted in a ball screw. A servo drive with inputs proportional to slant-range changes maintains coincident focus of the recticle and scene. A manual/electrical override permits prefocus setting. The VO is mounted to the ball screw and follows the servo-driven motion for focus on the reticle. A manual/mechanical adjustment permits prefocus of the VO on the reticle.

4.3.3.1.3 Variable Power Relays No. 1 and No. 2. Each relay consists of two Petzval-type lenses with collimated light between them. A Galilean telescope is mounted in the collimated light space. Each relay can produce two magnifications in the ratio of 2 to 1 (with no focus shift) by mechanical inversion of the Galilean elements. Figure 4.3-9 shows the movable elements which are motor driven.

4.3.3.1.4 Galilean Telescope Drives. To minimize the time required to accomplish inversion of a set of Galilean-telescope optics, a duplicate set of optical components is used (see Figure 4.3-9). The design permits minimum rotational displacement to bring one or the other set into alignment on the optical axis. The minimum angular rotation in which this can be accomplished is approximately 65 degrees. The rotary motion of the



First Position



Second Position

Figure 4.3-9. Magnification Change Unit (Rotatable Galilean Telescope Pair) Mounted in Collimated Light Space of Variable Power Relays elements is counteracted by a flywheel geared to the rotating assembly. The only remaining inertial impulse into the VOA from these units will be the motor drives themselves. These impulses will be damped by the isolation mounts and no counter-rotating masses are planned.

A precision positioning Geneva-drive mechanism is mounted to each of the two lens-mount units. The driving arm of the Geneva will be motor driven. Spring loading maintains the lens unit against the end positions to ensure no lens motion during viewing.

4.3.3.1.5 Fixed Relay. A fixed-magnification relay transfers the image to the main eyepiece focal plane. The flip mirror and the derotation prism, each with a motor drive, are contained within the fixed relay.

4.3.3.1.6 Flip Mirror Drive. The flip mirror reflects the image to either the fixed relay or to the secondary image-transfer optics. The design for the mechanism includes a cage mounted on ball bearings to rotate a mirror around the axis of the main VO system for horizontal angle adjustment. During this rotational adjustment a spring-loaded, follower-arm mechanism pivots the mirror for vertical angular position. Adjustable stops at the end of both motions permit simple, accurate adjustment for compensation of manufacturing and alignment tolerances.

4.3.3.1.7 Derotation Prisms. Two derotation prisms are required because of the lack of usable space within the main tube: one for the main eyepiece and one for the secondary eyepiece. A Schmidt (Pechan) prism was chosen because it has a minimum size for the aperture covered and has an odd number of reflections, as required for correct image orientation. These prisms are located in the two optically equivalent sections of the fixed relay. Each prism is mounted in a cage which rotates on ball bearings. A spur gear and pinion, driven by a motor reducer unit, accomplish the rotation.

4.3.3.1.8 Secondary Image Transfer Optics. That part of the fixed-magnification relay after the flip mirror (including the derotation prism) is repeated as part of the image-transfer optics for the secondary eyepiece. A secondary folding mirror reflects the image to the secondary eyepiece.

4.3.3.1.9 Eyepieces. The primary and secondary eyepieces are identically constructed and are monoculars of 3.5-inch focal length. The eyepieces have independent focus adjustment through a range of minus 4 diopters to plus 2 diopters.

4.3.3.1.10 Auxiliary Data Display. An auxiliary display indicating photographic sequencing parameters is presented in each of the VO eyepieces and is visible at all magnifications. The display is located on the periphery of the field of view as shown in Figure 4.3-10, and the brightness of this display is fully adjustable. The background for the auxiliary display lamps will appear to be flat black. The lamps numbered 1 through 32 turn on for one second durations sequentially and sweep from number 1 (that is, the forward most tracking mirror position) to 32 (that is, the

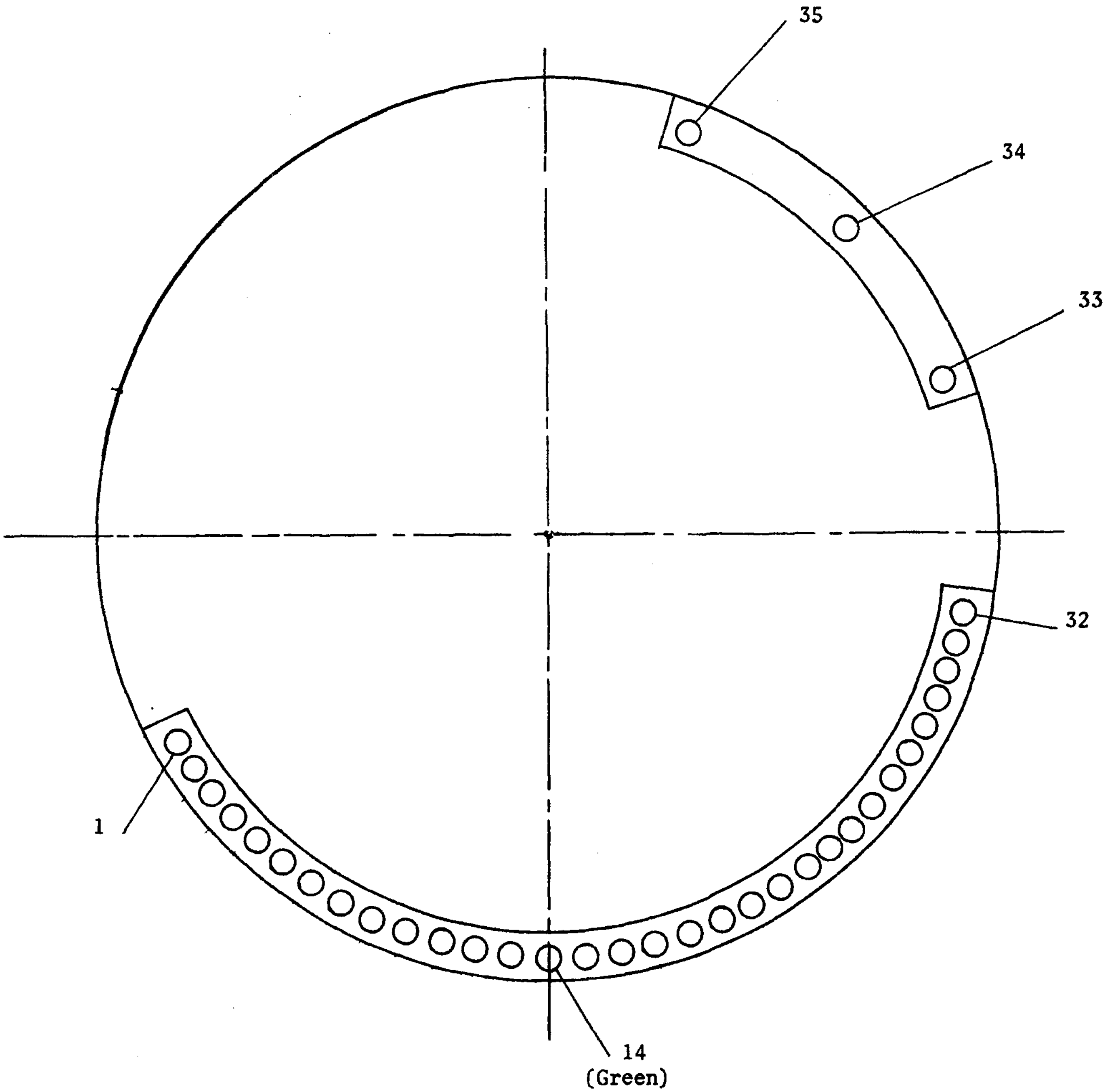


Figure 4.3-10. Auxiliary Data Display

aft most tracking position) in approximate synchronization with TM motion. Lamp number 14 denotes nadir and is green in color. Lamps which are on at the beginning of the TM sweep denote positions where a photograph has been programmed. The primary camera is assumed to be programmed unless otherwise noted by lamp number 33. This lamp will turn on one second prior to a secondary camera programmed photograph. A maximum of 10 programmed positions can be indicated for any one TM sweep. The functions of lamps 34 and 35 are not defined.

4.3.3.2 Mounts

4.3.3.2.1 Launch Mounting

Aft End Support. A bracket is mounted to the LM structure just forward of the bulkhead at station 518.80. Prior to launch, the VOA is to be separated from the secondary Ross barrel at the interface mount and retracted (approximately 3 inches) to be secured to the launch bracket. This mount takes only Y-Z shear loads. Flexible steel cables fastened to the end of the hollow sleeve through the center of the isolation mount and passing through the hollow sleeve of the positioning funnels are spring loaded on a take-up negator wheel. The flexible cables guide the assembly into operating position after release from the launch bracket on-orbit. The spring tension holds positioning balls in place.

Forward End Supports. The forward launch support for the main tube is located on the side of the flip mirror casting opposite the secondary Ross tube. This mount will take all of the ±X axis loads of the main VOA. It will take Y-Z shear loads and share Y-Z moments with the pivot arm bearing. This mount will be manually retracted after orbit has been achieved. The operational orbit mount is adjacent to this launch mount.

The combined launch-orbit mount for the secondary tube assembly is located on the inboard side of the cross tube next to the secondary eyepiece tube, and does not require a locking or release operation. The mount will take the X-Z plane shear loads but no moments.

4.3.3.2.2 <u>On-Orbit Mounting</u>. The VO relay is suspended between the secondary Ross barrel and the LM structure by vibration-isolation mounts.

<u>Interface to Secondary Ross Barrel</u>. The position of the VOA with respect to the secondary Ross optics and main reticle must be maintained within a tolerance which permits comfortable viewing and sharp focus. Precision target tracking is not dependent on precise alignment of the VO to the secondary Ross optics. Rather, the VO acts as a magnifier to enable the crewman to track the target relative to the reticle, which is a fixed part of the Ross barrel. The interface of the VOA and the secondary Ross barrel is made through three circular, multiplane, low damping, elastic isomer mounts as shown in Figure 4.3-11. The outer flanges of these mounts are rigidly mounted to the secondary Ross barrel. A hollow conical positioning cup will be fixed in the center of the flexible mount. A hollow cylindrical shaft with a positioning ball on one end will be mounted to the ball-screw sleeve carrying the reticle. The spherical ball will nest in the hollow cone for accurate positioning. A spring-loaded negator motor will hold

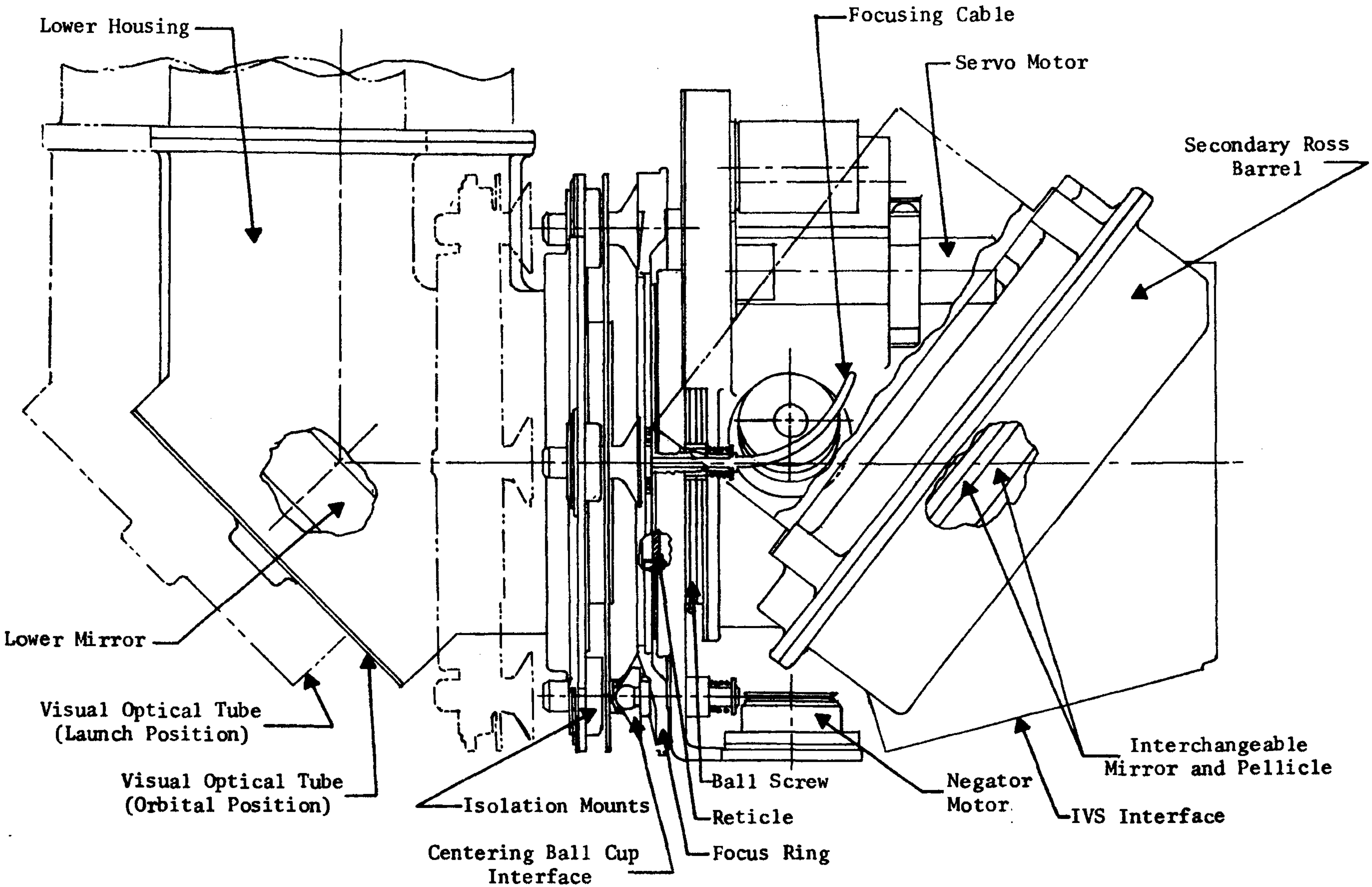


Figure 4.3-11. Retractable Interface Mount, VOA to Secondary Ross Barrel

them together. A rotatable ring with wedged ramps will provide the relative motion between the VOA and the reticle required for focusing. This ring is located between the positioning ball and the reticle mount.

The only connection between the VOA and the secondary Ross barrel is through the three isolation mounts. Impulse and vibrational transmissibility will be determined by the characteristics of these mounts. This focusing motion will be mechanical-manual.

Interface Mounting to the Laboratory Module Structure. Two points require interface mounting to the LM structure, one at the forward end of the flip-mirror head and the other at the outboard end of the secondary mirror mount for the secondary eyepiece. Both of these mounts are circular, low damping, isolation mounts with the outer flange mounted to the LM structure and the inner sleeve to a ball bushing which rides on a rod mounted to the VO. This permits complete longitudinal and pivotal freedom and allows the VOA to follow and maintain its relative position to the secondary Ross barrel and main reticle, regardless of LM structure displacement relative to the Ross barrel. The space envelope around the VO barrel must be sufficient to permit freedom of movement within the expected thermal displacements of the Ross barrel assembly to the interface mounting points on the LM structure.

4.3.4 Operation

4.3.4.1 Interchangeable Mirror/Pellicle Assembly. Operation of this assembly is manual-mechanical by means of a push-pull cable. The available positions can be locked.

4.3.4.2 Reticle Focus Servo. Combined VOA and reticle focus on the ground scene is automatically maintained by servo drive once the initial, manual prefocus has been set by the crewman. The range of focus adjustment is sufficient for any slant range within the photographic orbit envelope.

4.3.4.2.1 Manual, Mechanical Adjustment. It is important that the VOA initially be adjusted for sharp focus on the reference pattern of the main reticle. This procedure follows completion of focusing operations on the primary optics. The crewman at the main eyepiece of the VOA will adjust the eyepiece for his accommodation by correctly setting the diopter scale to his predetermined value. After the correct eyepiece accommodation setting has been made, the crewman will operate the VO manual-mechanical adjustment until the reticle image is sharply focused. The image will be focused by depth of focus averaging at the high [redacted] magnification. The operation should be performed with environmental door closed, using the illuminated reticle pattern.

4.3.4.2.2 Manual - Electrical Focus Override. With the environmental door open the crewman will operate the reticle servo override to obtain sharp focus of the ground scene on the reticle target image. Focus on the ground target is a dynamic operation and requires that the focus setting be finalized when the TM stereo angle is within 15 degrees of nadir. This corresponds to a tracking time of approximately 12 seconds at 80 n mi altitude. The focus servo drive rate is such that a switch-on time of approximately one to two seconds will produce an observable focus change. A single target may not be sufficient to finalize and check focus in which case a second or third target may be required. This is not a simple operation and a detailed operational procedure and crew training will be required for efficient performance. The crewman will next check that the reticle pattern and target image are both sharply focused together. The depth of focus at 125X is [redacted] therefore, no further focus adjustment for the automatic control to maintain focus. The crewman at the secondary eyepiece then adjusts his eyepiece for the correct focus for his eye by adjusting for sharp focus on the main reticle pattern at high magnification; the crewman is not to change the VOA override focus.

4.3.4.3 Magnification Change. Magnification will be automatically preset to 125X for each target. Additional magnification changes occur on command by the flight crew.

4.3.4.4 Flip Mirror. Flip-mirror operation is automatic, although the flight crew has the capability to override the programmed sequence.

4.3.4.5 Derotation. Normal operation of the derotation prisms is completely automatic. However, de-activation of either derotation prism by the flight crew is possible.

4.3.4.6 Visual Alignment Option. An image of alignment target lamp and reticle from the alignment sensor is projected into the VO system to permit the crewman to perform visual alignment of the optics, if it is desired. The procedure is to set the VO magnification at the power designated for this operation (125X [redacted], and position the eye pupil in the normally obstructed center area of the exit pupil. The crewman can then observe the alignment-target lamps and initiate necessary corrective action.

4.3.5 Electrical Control

4.3.5.1 General. VO operation uses the C and D panel, LMPU, LMCU, and the main tracking and acquisition panels. The functional relationships between these units are summarized in Figures 4.3-12 and 4.3-13. VO functions are listed in Table 4.3-1 to designate manual and/or automatic control sources.

Unregulated power for VO operation is switched within the LMCU by actuating a manual switch on the C and D panel (panel 1-C). All electrical packaging is located on the VO. Instrumentation power is provided by the LMCU.

All commands to the VO are digital, in the form of switch closures provided by the LMCU and the C and D unit. Reticle positioning and VO focusing are performed automatically by use of the slant range compensation (SRC) commands. Both functions are performed simultaneously by using the same servos. Image derotation for each viewing station is also performed automatically by the derotation commands.

All VO motor-drive signals are instrumented in the form of digital (CW, ON-OFF; CCW, ON-OFF) instrumentation output signals.

4.3.5.2 Reticle-Focus Control. Figure 4.3-14 is a block diagram of the VO reticle-focus control. The reticle-focus control is basically a null-type servo device with automatic positioning and an electrically controlled manual override. A +4.7 v d-c command-excitation signal is generated and

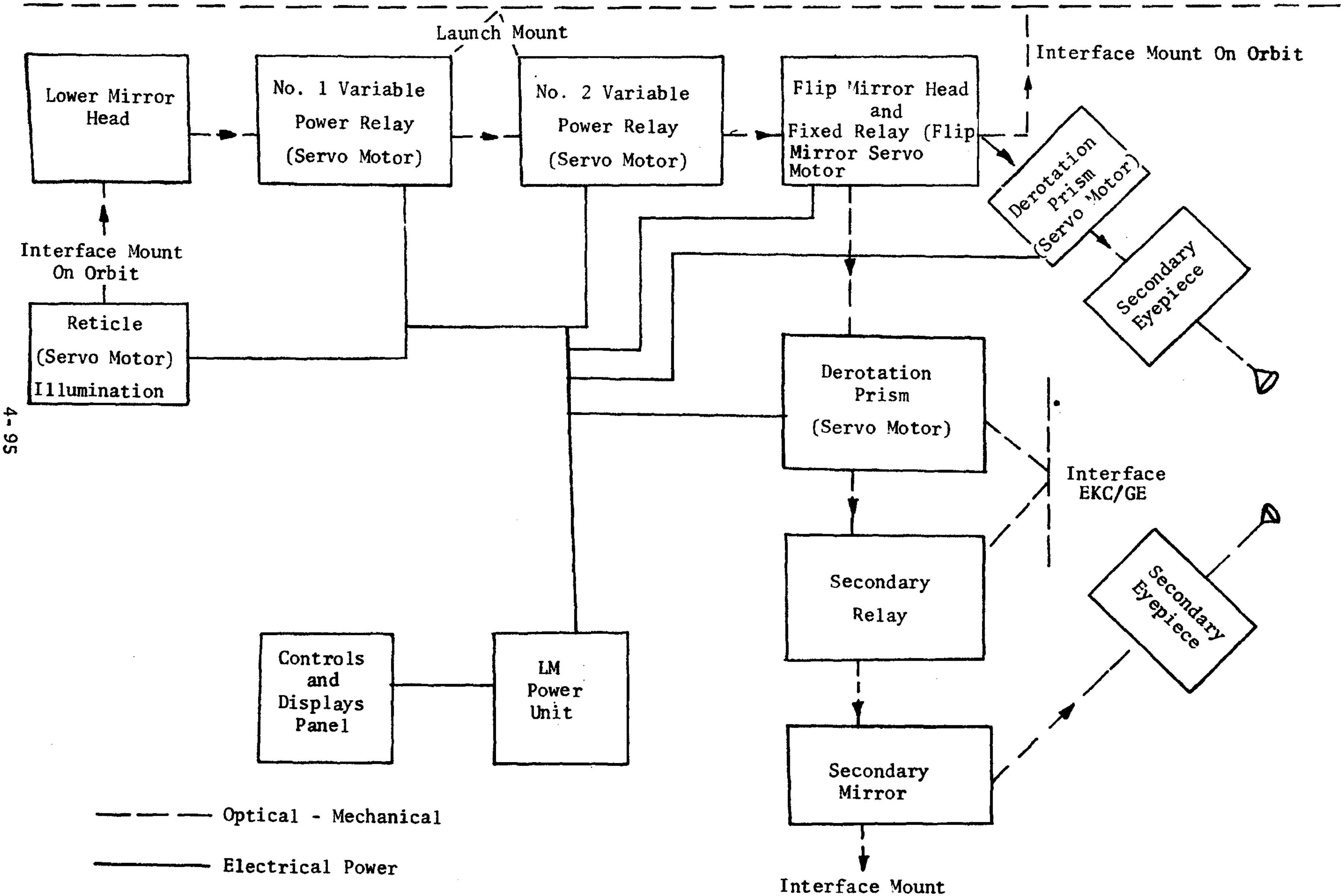


Figure 4.3-12. Visual Optics Power Distribution Block Diagram

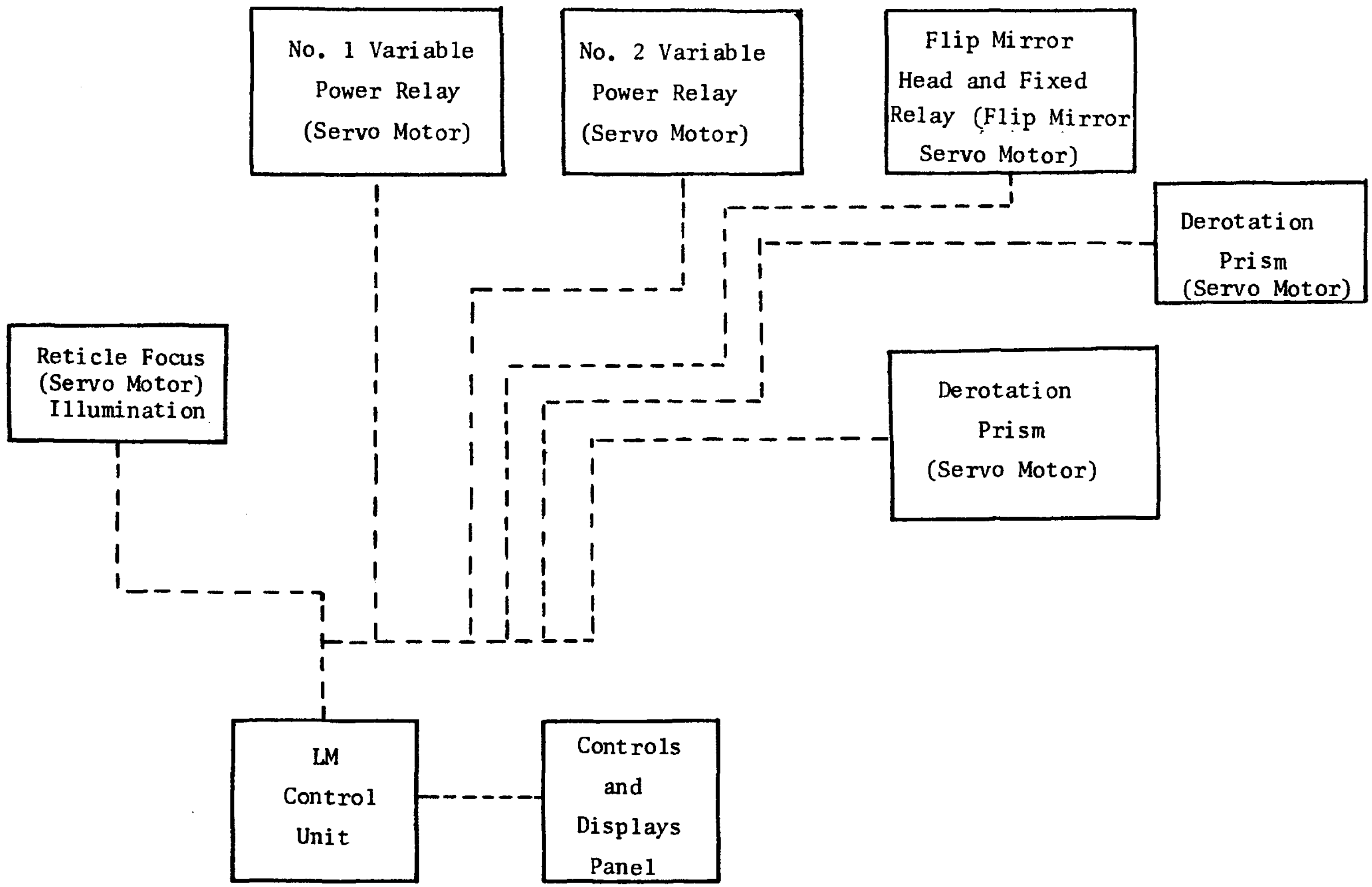


Figure 4.3-13. Visual Optics Control Signals Block Diagram

TABLE 4.3-1

VISUAL OPTICS FUNCTIONS

Function	Automatic Control Source	Manual Control Source
Unregulated power	No automatic control	C and D Panel
Reticle focus (4.3.5.2)	LMCU	C and D Panel (override only)
Magnification (4.3.5.3)	LMCU	Tracking and Acquisition Panel
Flip mirror (4.3.5.4)	LMCU	Tracking and Acquisition Panel
Image derotation (4.3.5.5)	LMCU	C and D Panel (inhibit only)
Reticle illumination (4.3.5.6)	No automatic control	Tracking and Acquisition Panel

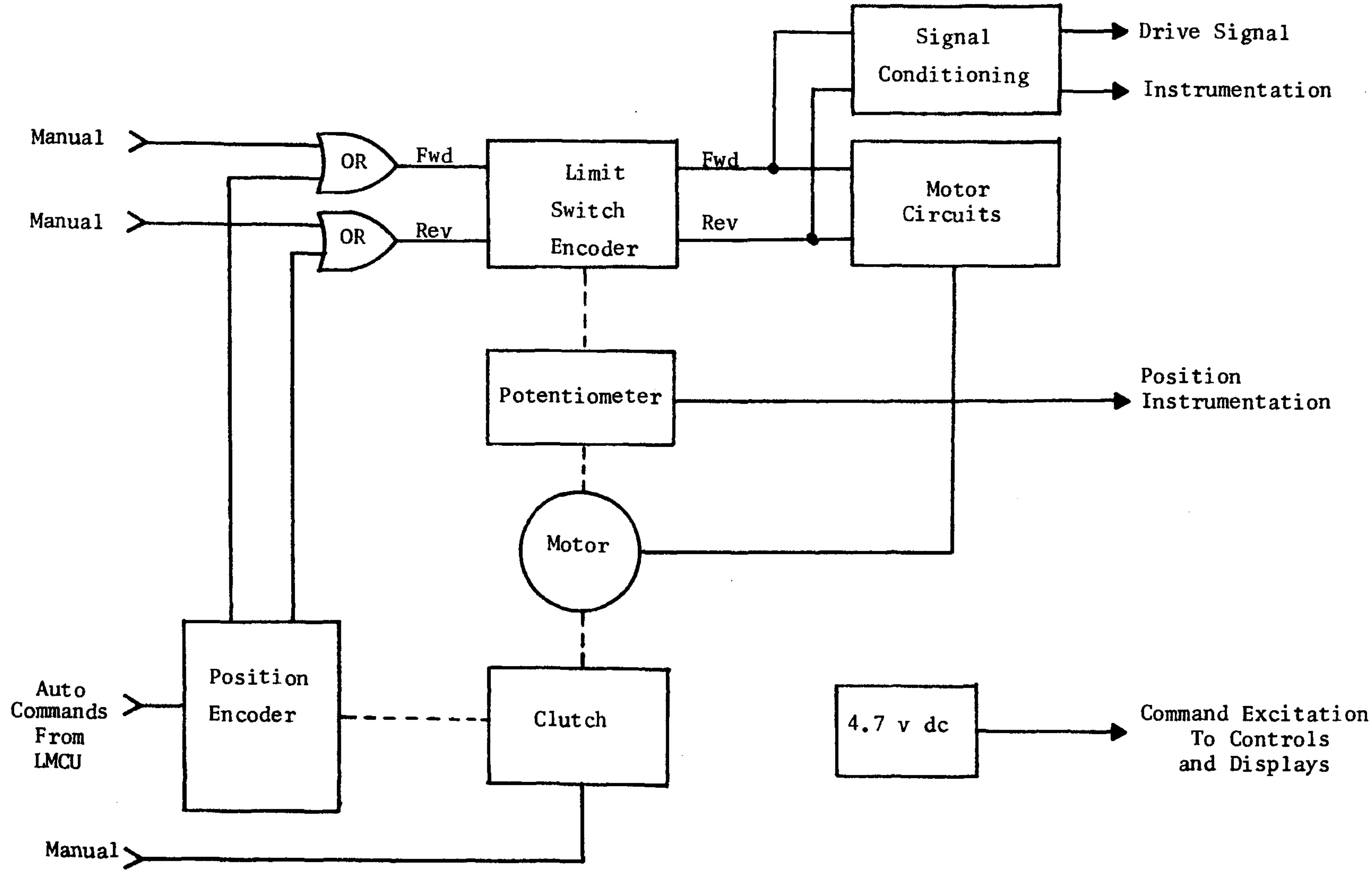


Figure 4.3-14. Reticle-Focus Control Block Diagram

sent to the C and D panel. In automatic operation, if the encoder-position code does not match the LMCU command code, the position encoder then sends a drive signal to the motor circuits. As the position encoder turns, the position code changes until it matches the command code. When the two codes match, a null is reached and the position encoder removes the drive signal to the motor circuits.

In manual operation, the drive signal bypasses the position encoder and a clutch disconnects the position encoder from the drive motor, permitting changes in reticle-focus without disturbing the automatic position code. This effectively gives the reticle position and VO focus a new reference with respect to the automatic SRC positioning commands.

The limit switch encoder serves as an extreme travel limit switch in either operating mode. The OR gates provide drive-signal isolation between the two modes. All control signals are less than +5.0-v dc. Position instrumentation is analog, using a potentiometer and the +5.0-v d-c regulated supply.

4.3.5.3 Magnification Controls. Magnification is controlled from each tracking-acquisition panel by flight crew-initiated commands to the LMCU. An automatic reset to the minimum magnification position occurs when the TM changes to a new target. The two magnification controls are identical but completely separate. Each control makes use of a motor, limit switch encoder, and switch closures as a servo device.

A block diagram for one magnification control is shown in Figure 4.3-15. The operation of the control is as follows: A +4.7-v d-c command-excitation signal is generated and sent to the LMCU. The command relays in the LMCU send the signal to an encoder. Motor operation requires alternating clockwise and counterclockwise drives, so a limit-switch encoder is used. As the limit-switch encoder moves from one extreme to the other, the drive-signal path opens and removes the drive signal to the motor circuits.

Manual and automatic operation make use of the same set of relay contacts in the LMCU and no additional circuits are required in the VO. Position instrumentation is analog, using a potentiometer and the 12.0-v d-c regulated supply.

4.3.5.4 Flip Mirror Control. Flip mirror operation will be controlled automatically by a selection command. A manual override capability is provided on each tracking-acquisition panel. However, manual and automatic operation make use of the same set of relay contacts in the LMCU, and no additional circuits are required by the VO. The electrical block diagram is identical to that of Figure 4.3-14. Position instrumentation is analog, using a potentiometer and the +12.0-v d-c regulated supply.

4.3.5.5 Derotational Controls. Each derotational control is similar to the reticle-focus control except that there is no manual override capability, therefore eliminating the need for a clutch, limit switch encoder, and OR gates.

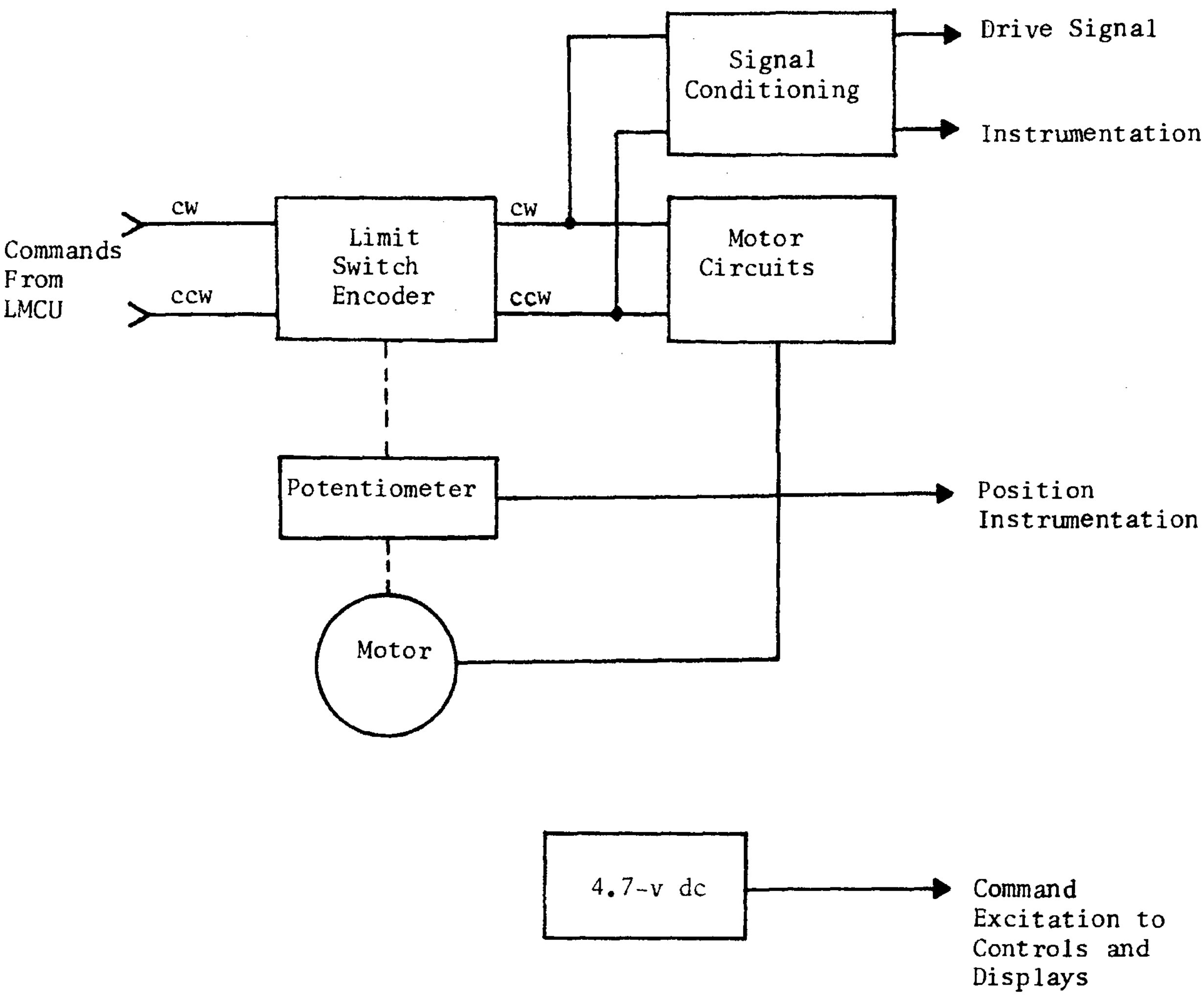


Figure 4.3-15. Magnification and Flip Mirror Control Block Diagram

Each derotation control has a crew-initiated inhibit switch located on the C and D panel. If derotation operation is not desired, the inhibit switch interrupts the 4.7-v d-c command excitation signal.

Position instrumentation is analog, making use of coarse and fine potentiometers and the plus 12.0-v d-c and +5.0-v d-c regulated supplies.

4.3.5.6 Reticle Illumination. The tracking and acquisition panels provide a potentiometer at each viewing station for controlling reticle illumination. The station in control is determined by the selection command of paragraph 4.3.5.4.

4.4 CAMERA ASSEMBLY

This paragraph contains a description of the requirements and design approach for the camera assembly. Major camera functions and hardware are also discussed.

4.4.1 General Requirements

The mission of the camera assembly is to photograph with maximum fidelity the high-resolution image formed by the optical assembly. In the manned/automatic (M/A) mode of operation, the optical image is recorded on either primary or secondary film. Figure 4.4-1 describes the M/A mode camera assembly. In the automatic mode of operation, the secondary film-handling assembly is removed from the camera assembly and the image is recorded on primary film only. A photograph of the M/A mode camera simulation model is shown in Figure 4.4-2. The camera mock-up is shown in Figure 4.4-3.

To perform its mission, the camera assembly is provided with the following functional capabilities:

a. Across-the-format image motion compensation (X-format IMC) during exposure of primary film.

b. Variable exposure range of 4 stops.

c. Adjustable platen position for maintenance of focus, including programmed compensation for slant range variations.

d. Advancement and positioning of the primary film to meet the maximum exposure rate of one frame per second; separate secondary film handling to advance and position the film to expose one frame per three seconds.

e. Rapid interchangeability of the primary and secondary film in the image plane.

f. Recording of coded selected-mission data on the film.

g. Filtration of the secondary infrared-color photography.

4.4.2 Constraints

Four constraints have had major impact on the camera-assembly hardware design. These constraints are allowable volume, vibration, frame rate, and film-type priority.

4.4.2.1 Volume. The camera assembly must have exterior dimensions such that it can be passed through the 37-inch-diameter access port in the LM or be easily disassembled to accomplish the passing. This constraint arises from the possible need to remove the camera from the LM after LM-MM mating. (During assembly of the launch vehicle (LV), the camera assembly will be attached to the OA prior to mating of the LM aft bulkhead to the LM structure.)

4.4.2.2 Vibration. To satisfy the vibrational smear requirement of paragraph 2.4.3, the camera must not cause a smear rate of more than [redacted] per second [redacted] in 0.005 second) when X-IMC is not used and shall not cause a smear rate of more than [redacted] per second [redacted] in 0.005 second) when X-IMC is used.

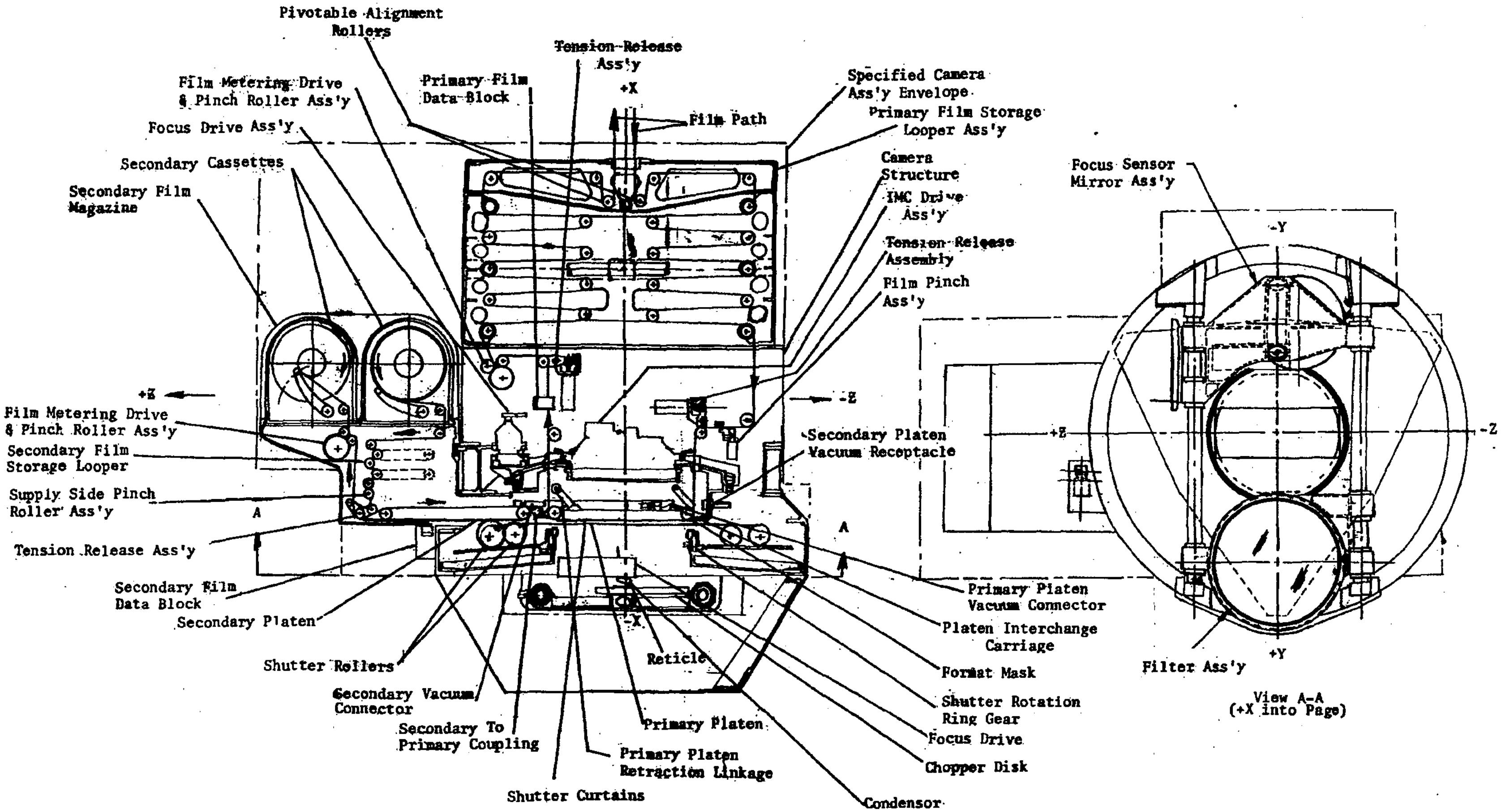


Figure 4.4-1. Camera Assembly

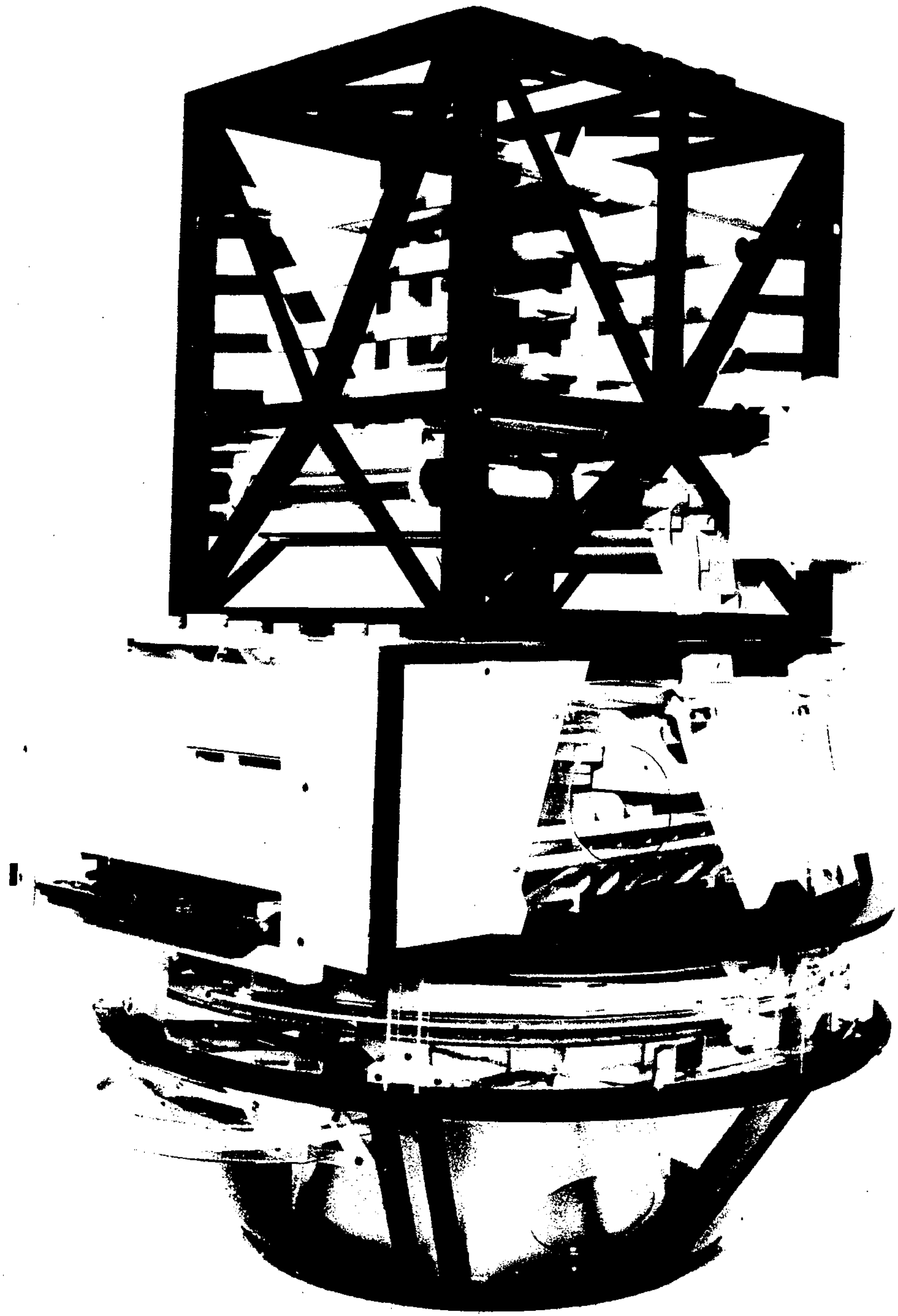


Figure 4.4-2. Camera Simulation Model

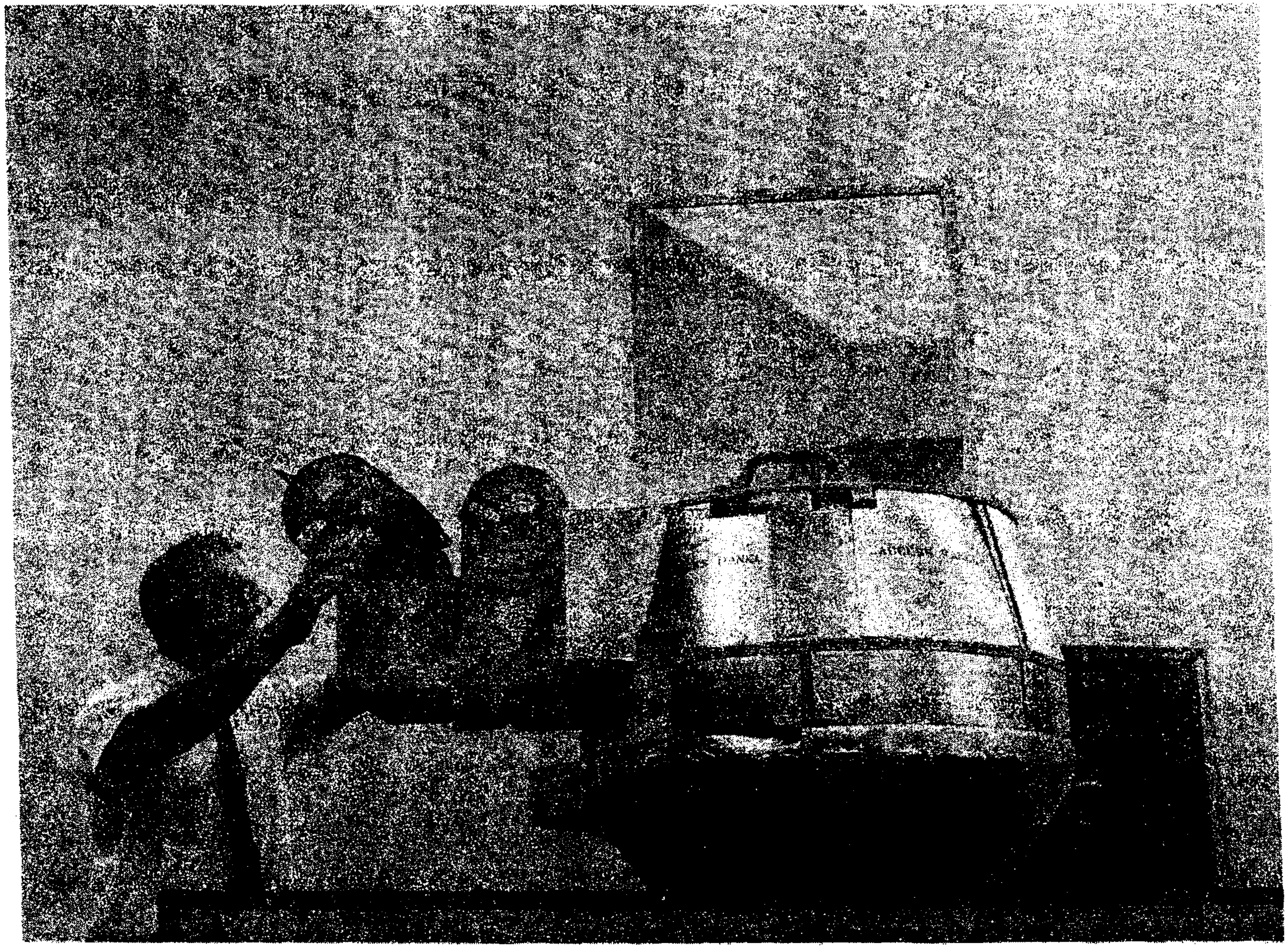


Figure 4.4-3. Camera Mock-up

4.4.2.3 Frame Rate. The maximum frame rate of one frame per second requires an electrical power source capable of high peak-power delivery. Little time is available to perform setup functions between frames. Consequently, large momenta are generated, creating a need for momentum compensating devices, which in turn consume additional electrical energy.

4.4.2.4 Film-Type Priority. The camera design is based on achieving optimum primary platen performance with high-definition black-and-white film, and will not be compromised to improve secondary platen operation or accommodate other film types.

4.4.3 General Design Selection

A sectional view of the camera assembly conceptual design is shown in Figure 4.4-1. The figure is referred to throughout this portion of the report when various camera components are described.

The baseline camera design shows the influence of the dual mode operational capability and multi-film-type requirements in the M/A mode. Early design analysis indicated that introduction of a relay mirror lens into the optical ray path to provide more than one exposure station was too costly for the amount of data return. Consequently, a single exposure station was chosen, enabling a relatively simple optical configuration to be maintained. Weight, space, and reliability factors led to the decision to provide not more than two film strands, only one of which can be introduced at the exposure station at a given time. In the M/A mode either of two strands is available: the primary black-and-white strand or the secondary, special film strand (the type of special film is selected and loaded by the flight crew prior to a pass and is not changeable during the pass).

Major camera components and functions are discussed in detail in the following paragraphs.

4.4.4 Shutter

4.4.4.1 Requirements. The shutter design must meet several unique requirements. At least 85-percent shutter efficiency and high reliability are essential. To provide for X-IMC, a focal plane shutter is a basic requirement. To satisfy the rotation requirement of the selected X-IMC method (see paragraph 2.4.4.3) the entire shutter assembly must be rotatable about the X-axis through a ±111-degree sector in 3-degree steps. In addition, the drive must be capable of rotating the shutter as much as 55 degrees between frame exposures at one-second intervals. Eight exposure times (0.0025, 0.0036, 0.005, 0.007, 0.010, 0.014, 0.020, and 0.040 second) are required.

4.4.4.2 Design Approach. The shutter is mounted on a turntable which rotates about the optical axis so as not to obstruct the optical field of the lens. A bidirectional slit is incorporated rather than an unidirectional slit, as explained below. These concepts are discussed below and illustrated by Figures 4.4-4, 4.4-5, 4.4-6, and 4.4-7.

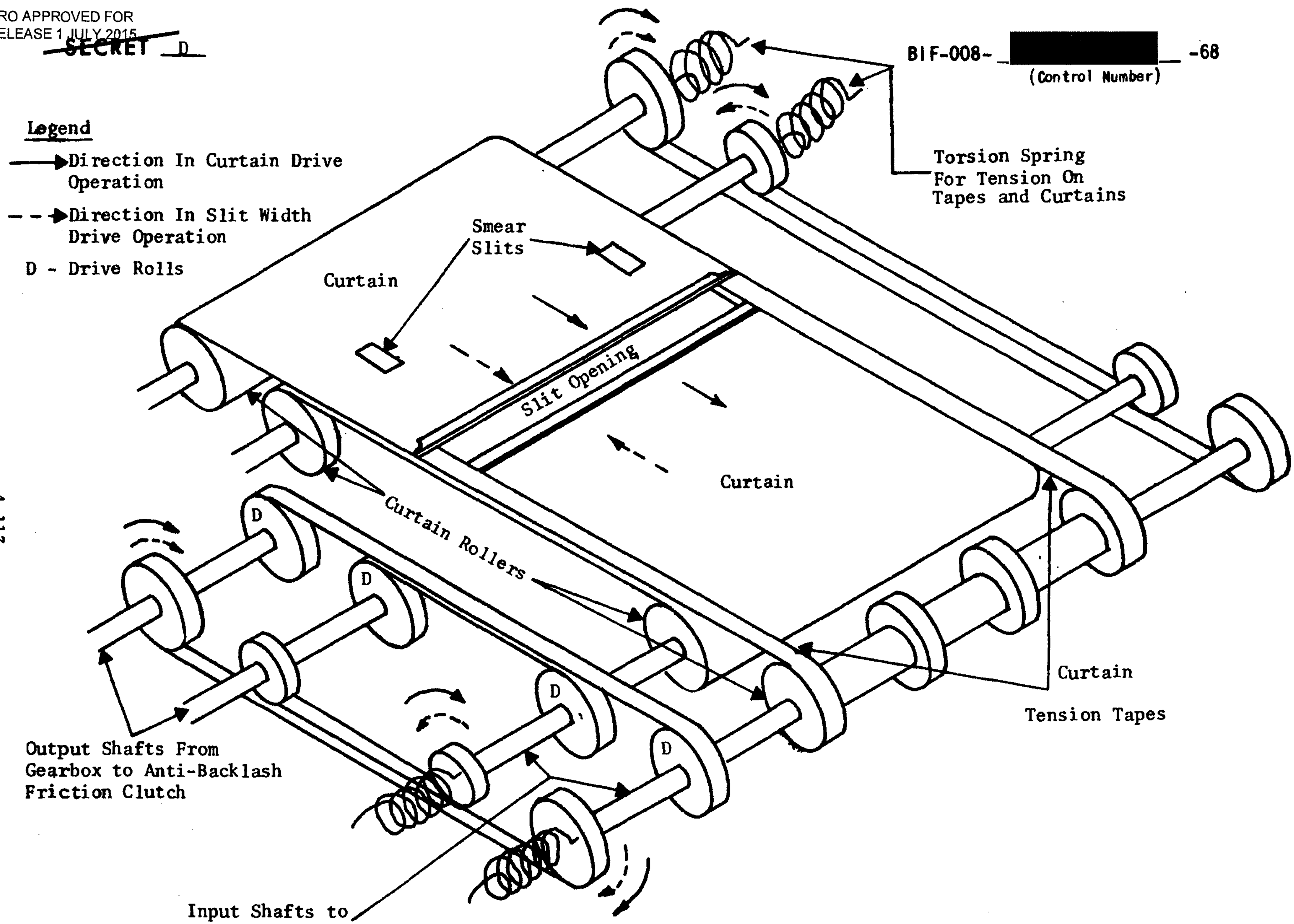


Figure 4.4-4. Shutter-Curtain Drive Tape System

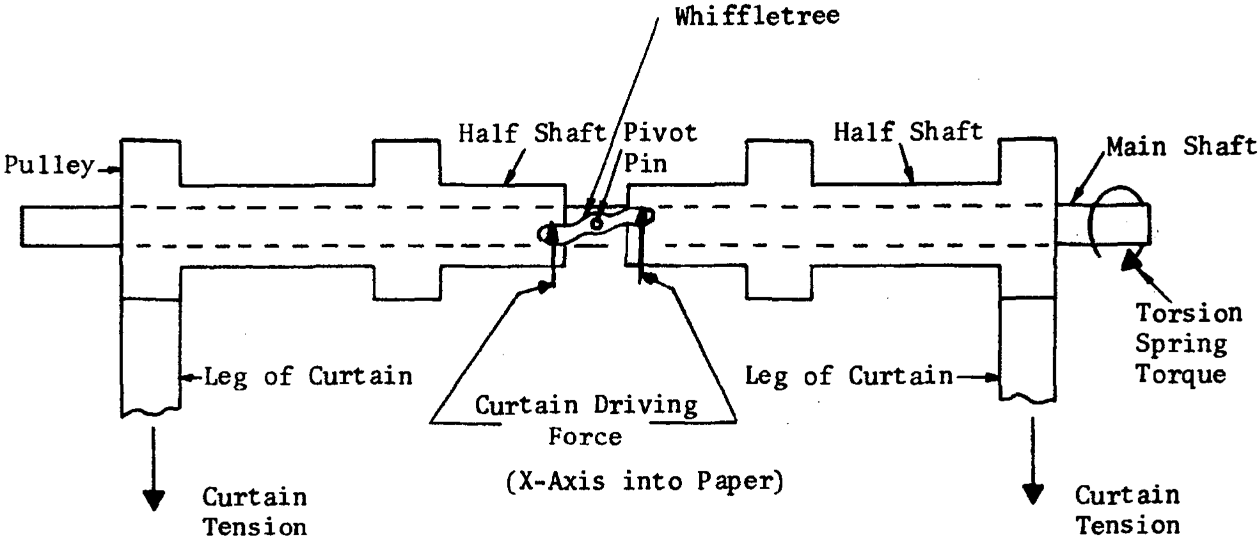


Figure 4.4-5. Whiffletree Assembly

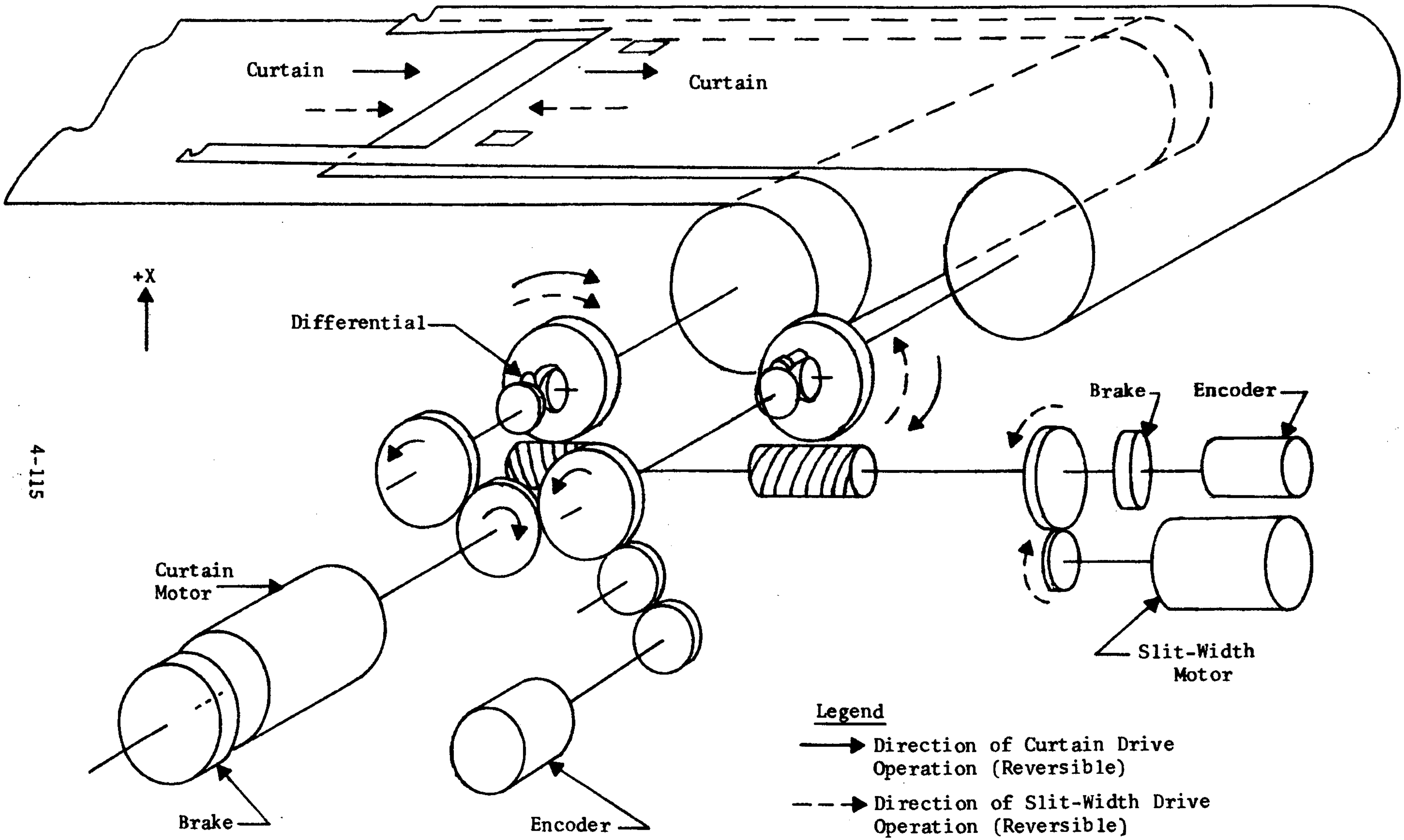


Figure 4.4-6. Curtain and Slit-Width Drive

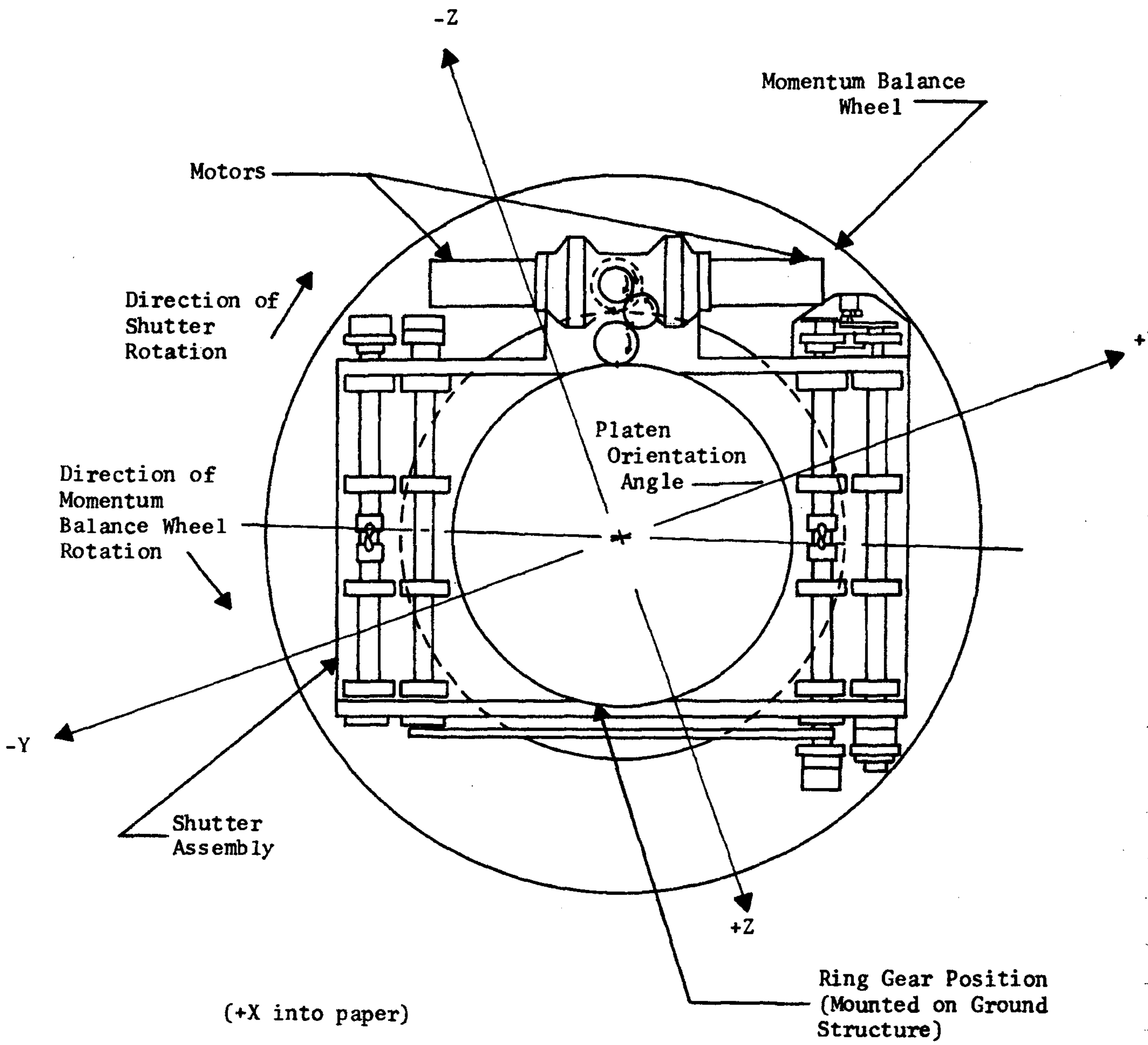


Figure 4.4-7. Shutter Rotation Drive

A constant-velocity double-curtain design which permits adjustment of the slit width was conceived as the most appropriate design approach for providing the range of exposure times. The constant velocity allows fixed cycle times for other camera functions, so that control of power consumption and auxiliary devices is simplified. The normal mode of operation is to reverse the direction of travel of the two curtains on consecutive frames, rather than driving the slit across the format in the same direction. The bidirectional slit capability has several additional advantages over a unidirectional slit. The need for rewinding the curtains to the drive side, requiring capping (or closing) of the exposure slit (inherent with a unidirectional drive), is eliminated by the bidirectional slit. Capping and rewinding reduces reliability by requiring twice as many traverses and increases the risk of double exposure or nonexposure resulting from capping failure. The bidirectional slit requires less electrical power and reduced peak power loads.

4.4.4.3 Hardware Description. The shutter design incorporates the following major functional items:

a. Curtain assembly
b. Curtain and slit-width drive
c. Shutter rotation drive
d. Smear slits

The curtain assembly is shown schematically in Figure 4.4-4. Each curtain is wrapped around two rollers. The tension tape, wrapped around one roller opposite the curtain, is connected to a torsion spring which maintains tension (set at 5 lb). The torques at the pair of rollers associated with each curtain are equal and opposite, resulting in no net torque at the curtain drive motor when the slit is within 2.5 inches of the format center. The stainless-steel slit edges act as stiffeners for the curtain cutout. The curtain surface between rollers is further stabilized through the use of whiffletrees (see Figure 4.4-5) which provide smoother, more wrinkle-free tracking of the curtains.

The slit width will vary between 1.75 and 0.11 inches, corresponding to exposure times of 0.040 and 0.0025 second, respectively. The curtain and slit-width drive assembly gear-train schematic is shown in Figure 4.4-6. The spindle of each differential is connected to a drive pulley, and the differential and gears are mounted on the spindle shafts. When the spindles are counter-rotated the curtains are moved in opposite directions. The slit width is thereby changed without affecting the position of the slit centerline. The curtain drive motor causes both differential spindles to rotate equally in the same direction, thereby maintaining constant slit width as both curtains travel across the format. Curtain travel and slit width adjustment always occur at different times. Both the curtain and slit width drives have mechanical stops to prevent curtain and tape destruction resulting from electrical malfunction during shutter operation. Rotational momentum balance of the curtain drive system is provided by a balance wheel mounted on the motor shaft.

The shutter mechanism (Figure 4.4-7) is rotated on a four-point contact ball bearing and has an adjustment range of ±111 degrees about the X-axis to accommodate IMC requirements. Two counter-rotating gear motors are mounted on the shutter-curtain carriage assembly and drive against the momentum balance wheel. The rotation drive motors are also geared to a stationary ring gear mounted onto the structure to ensure equal speed and angular displacement of the momentum balance wheel and the curtain carriage assembly.

Electrical power is provided to the rotating shutter curtain carriage assembly by a flexible cable which wraps or unwraps around a drum mounted on the shutter assembly.

Smear slits are provided in the curtains to permit recording of image smear (see paragraph 2.5.4).

4.4.5 Platen Assembly

The platen assembly contains the mechanisms which provide the operating functions related to IMC, focus, platen interchange, and film flatness. These functions are provided respectively by the jog velocity and vector-rotation drive mechanisms, the focus drive and support frame, the primary to secondary interchange assembly, and the platen vacuum film holding device.

Referring to Figure 4.4-1, the subassemblies interface by means of mechanical supports and drives which impart the desired relative motions. Jog velocity and vector rotation drive are functions imparted by the IMC drive (see Figure 4.4-8). The focus drive location is shown in Figure 4.4-1, with its relationships with the support frame and additional detail given in Figure 4.4-10. The two platens, primary platen retraction linkage, and platen interchange carriage are shown in Figure 4.4-1, and the interchange operation is shown in Figure 4.4-9. The platen vacuum film holding device is shown in Figure 4.4-11.

The first subassembly is the primary platen which is supported by a retraction linkage to the registration support frame (Figure 4.4-9). The secondary platen interchange mechanism, located at the same level, passes through the registration frame (Figure 4.4-8) and carries the secondary platen into place.

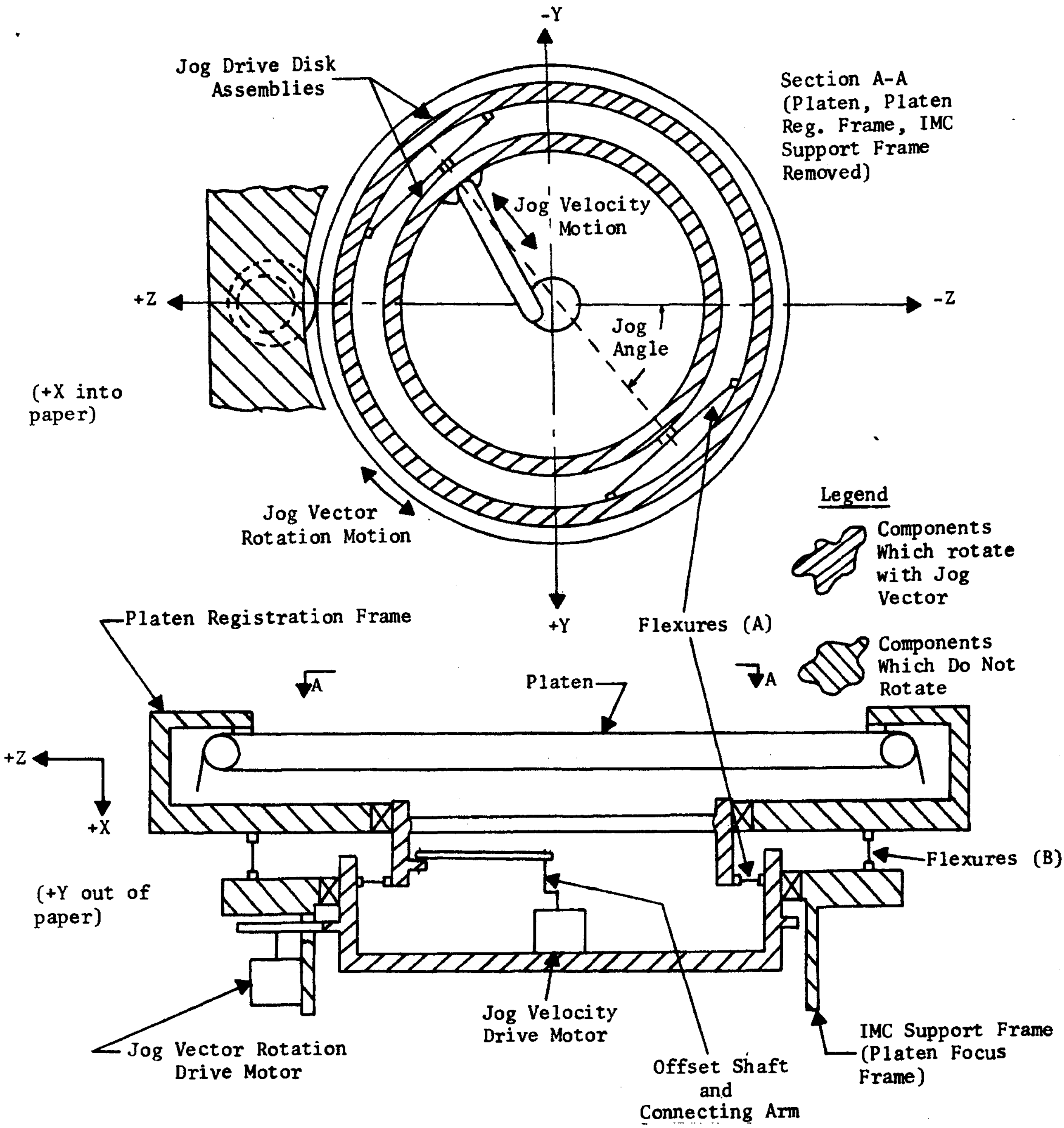


Figure 4.4-8. Image Motion Compensation Schematic

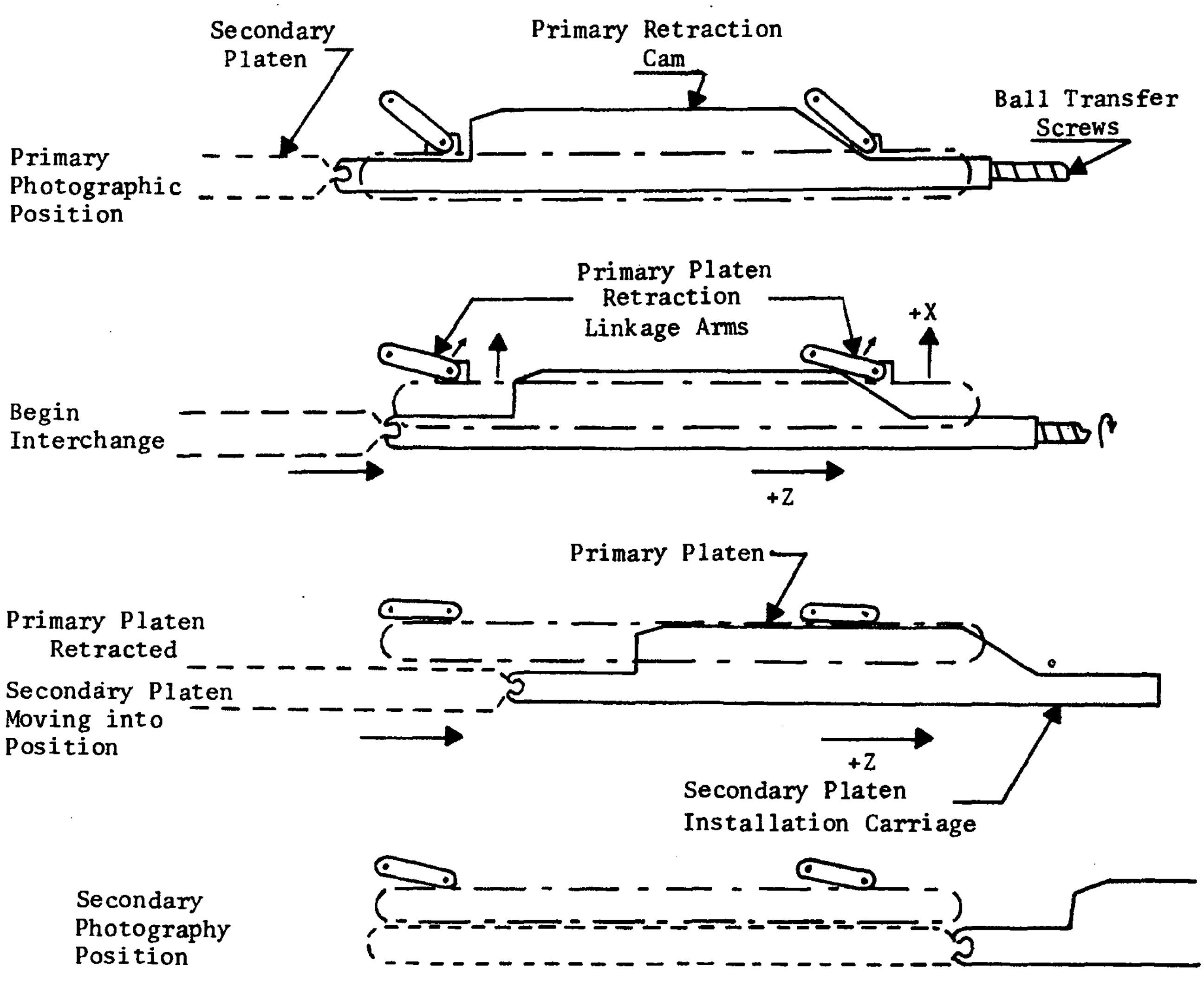


Figure 4.4-9. Schematic Diagram of Platen Interchange Mechanism Sequence

The next assembly level comprises the main platen-support structure or focus frame. The platen and registration frame are supported from this frame by flexure assemblies which permit relative jog motion in the desired directions. The jog drive couples the two frame assemblies together. The focus frame supports the focus drives, making the final interface connection to the camera structure.

4.4.5.1 Primary Platen. The primary platen supports the primary film at the focal plane during exposure and imparts the required jog velocity for IMC. It consists of a rectangular, waffled-out beryllium plate with a film roller on each end and contains a perforated film clamp surface. The primary platen is maintained in the focal plane by resting on three precision registration surfaces machined in a registration support frame. This frame also provides the anchor points for the linkage assembly which supports and guides the platen during the interchange operation.

4.4.5.2 Across-The-Format Image Motion Compensation.

Requirements. The X-IMC method requires movement of the primary film (platen) at a linear velocity in a specific direction during exposure (see paragraph 2.4.4.2). Maximum IMC velocities are of the order of 0.24 inch per second and are shaped in such a manner as to be linear over the frame time, passing through zero velocity at exposure midpoint. The direction of film vector (platen) motion must be rotatable through ±60 degrees about the camera X-axis. Changes in orientation of 30 degrees between frame exposures are a required capability. It is necessary to synchronize the film motion to the shutter travel such that the velocity of film motion is not greater than ±0.002 inch per second when the shutter-slit centerline crosses the optical axis.

Hardware Description. X-IMC implementation incorporates platen (jog) drive and platen-rotation (jog angle) drive functions (see Figure 4.4-7). The jog-vector rotation (direction of platen jog) is set prior to exposure by rotating the jog-drive disk assembly into the desired position. During photography, movement of the platen registration frame is restricted to a back-and-forth motion by flexures (A). During photography platen velocity (jog) begins its motion with the platen at the center of its range of travel, and moves through the commanded velocity profile. Control is imposed through the jog-velocity drive motor, and offset shaft and connecting arm.

4.4.5.3 Interchange of Platens.

Requirements. To meet the desired system versatility in the M/A mode, capability is provided to interchange platens such that the minimum time between exposure start of a primary frame and exposure start of a succeeding secondary frame (or vice versa) is 2 seconds. The camera is capable of exposing up to two frames of secondary film during any one target sequence. The two frames can be commanded in series or separated by primary film exposures.

Design Approach. Several methods for interchanging the film strands to the exposure station were evaluated, including (1) pivoting separate platens; (2) temporarily bonding secondary film to primary film, carrying it to the exposure station in piggy-back fashion, and peeling it off just after exposure; and (3) shuttling separate platens. These methods were compared with respect to the time necessary to effect the change, tolerances on positional repeatability, compatibility with X-IMC, space restrictions, and reliability. Shuttling of a separate secondary platen and its film strand into the exposure station was selected as the most appropriate method for interchange (see Figure 4.4-9). In the selected method, the separate primary platen is retracted in the +X direction out of the way of the secondary platen during secondary strand exposure. The secondary platen is retracted in the +Z direction out of the way of the primary platen during primary strand exposure. Location of the secondary film handling in the +Z direction gains flexibliity in that a change to an extended mission can be accommodated with a minimum impact on the overall camera design.

Hardware Description. The platen interchange mechanism provides the means by which the primary film can be replaced by the secondary film when so desired. It consists of the primary platen with its support and retraction linkage, the registration support frame in which the primary platen is contained, the secondary platen installation carriage, which includes the primary retraction cams, the secondary platen itself, the electrical drive assembly, ball-transfer screw, and the interchange momentum balance.

After a secondary magazine has been mounted on the camera and the secondary platen is manually inserted into the standby position in the camera, the platen assembly is ready for an interchange operation. At this time, the secondary platen is uncoupled from the magazine and is coupled to the platen interchange mechanism.

A primary to secondary interchange command initiates the operation of the interchange drive, controlled by a position servo. The platen motion during interchange is shown in Figure 4.4-8. During a primary to secondary interchange, the interchange cams first engage with the cam followers on the primary retraction linkage. The cams cause the primary platen to retract and drive the secondary platen through most of its range of travel into the operating position. The cams then pass out from under the primary linkage, allowing the primary platen to move back toward the registration seat pads. At this time, the primary platen contacts three transfer pins which press against the secondary platen, moving it to seat on the regisgtation pads.

The platen interchange mechanism is counterbalanced to minimize dynamic disturbances to the camera. This action is performed by driving a pair of balance weights in the direction opposite to the platen motion.

4.4.5.4 Focus Drive.

Requirements. The platen is positionable in 0.0006-inch increments over a 0.1-inch range along the X-axis for focus control. The tolerance on positioning of the platen center to the commanded focus position is ±0.0003 inch. The platen must not be tilted more than 0.005 degree with respect to the Y-Z plane and its surface must be flat to within ±0.0004 inch.

Hardware Description. The focus drive (see Figure 4.4-10) provides the means for driving the primary or secondary platen along the optical axis to the focus position required for the next exposure frame. It also forms the interface between the platen assembly and the camera structure. Operation of the drive responding to a focus command causes simultaneous rotation of the three ball-screw assemblies. This results in the translation along the X-axis of the focus-frame mechanism including the jog and rotation drives, flexures, platen-support frame, primary platen, and secondary platen if installed.

4.4.5.5 Platen Vacuum System.

Requirement. The film must be kept flat to within ±0.0003 inch of either platen.

Design. The vacuum system (Figure 4.4-11) operates on both the primary and secondary platens to hold the film flat in the focal plane. It consists of a double-piston, single-stroke vacuum pump and flexible tubing for connection to the platen-registration frame. The platen-registration frame contains internal flow paths which terminate in the precision registration pads. When either platen is seated against the precision registration pads, the vacuum connection is completed through the pads.

When the vacuum command arrives, a solenoid trips the single-stroke pump. On completion of the photographic cycle, a motor-driven cam restores the pump pistons to the preset position.

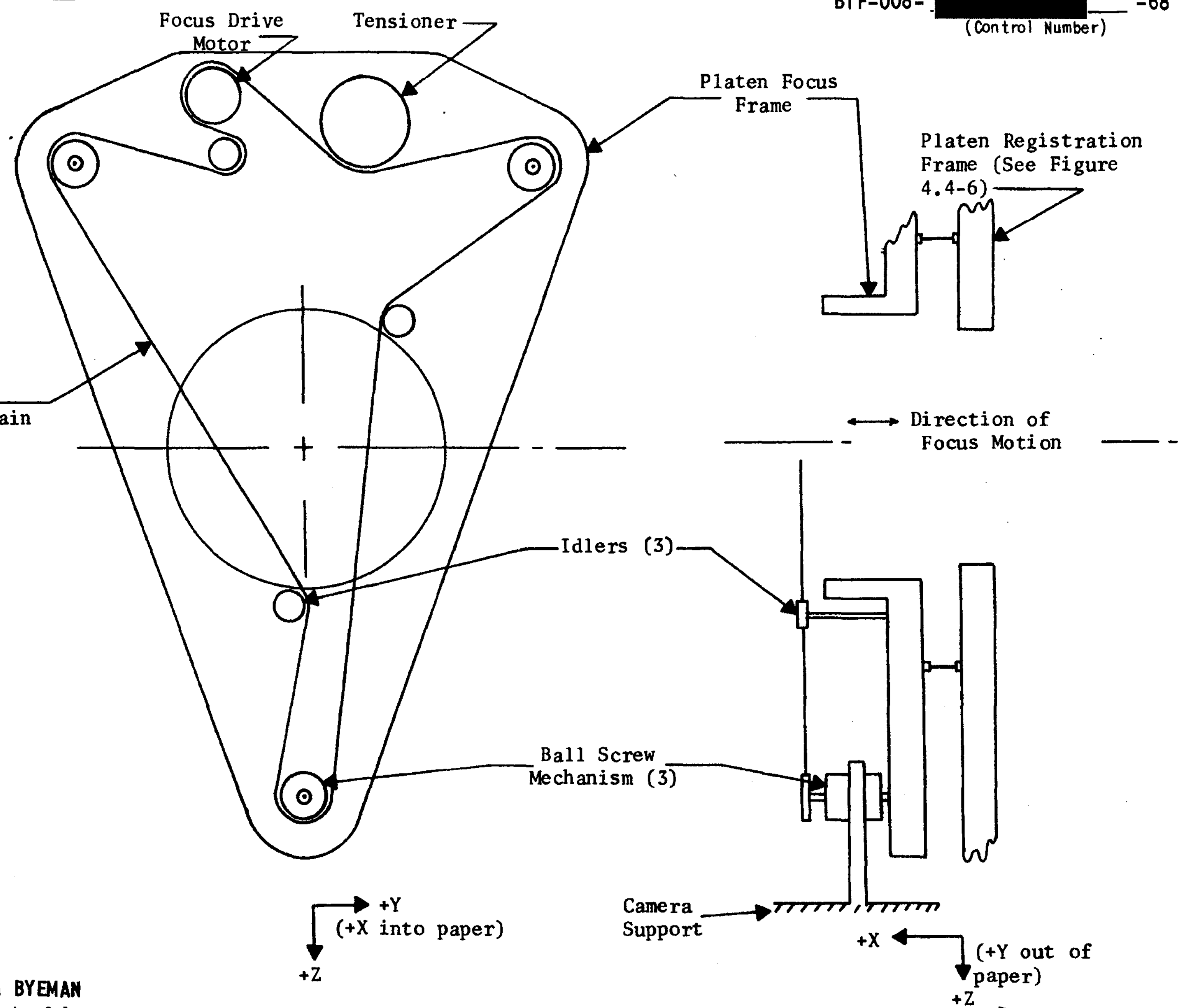


Figure 4.4-10. Focus Drive Schematic

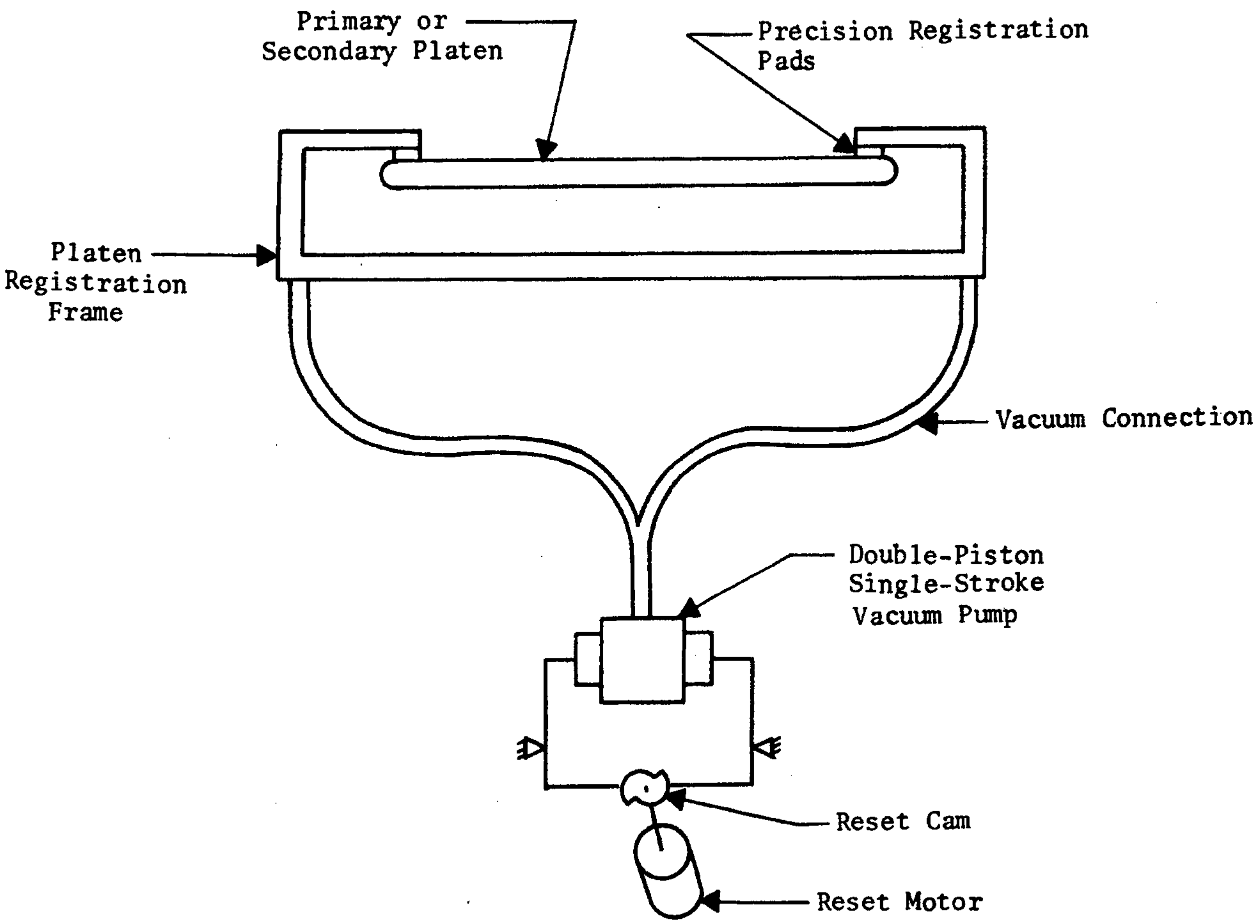


Figure 4.4-11. Vacuum System Schematic

4.4.5.6 Secondary Platen.

Requirements. The secondary platen must meet the same basic requirements as the primary platen, except those peculiar to X-IMC, which is not required on secondary exposures. However, the design will allow the incorporation of X-IMC for the secondary platen, if directed at a later date.

Hardware Description. The secondary platen is almost identical in size and construction to the primary platen. It is also made from beryllium with the same perforated film clamp surface and waffle back surface, but has the following differences: (1) the vacuum connection for the secondary platen is made by means of passages which join directly through the registration pad seats, providing instantaneous coupling and uncoupling from the vacuum supply, and (2) the secondary platen is supported by a series of rollers located on two sides which allow it to travel freely from the guide channels in the secondary magazine to similar channels in the interchange frame of the camera.

4.4.6 Camera Film Handling

4.4.6.1 Camera Primary Film Handling. The function of the primary film handling assembly in the camera is to provide an intermediate storage capability of 10 frames of primary film, to automatically realign the film to specified tolerances, and to rapidly index the film through the platen assembly with a minimum of mechanical disturbances.

The requirements which govern the design of the film transport system include storage capacity of the looper, photographic frame rate, film tension, accuracy of film tracking, and minimization of self induced vibration.

The primary film handling assembly consists of a number of subassemblies inter-connected through the film and controlled by the logic (see Figures 4.4-1, 4.4-11, and 4.4-12). The following tabulation lists the detailed requirements of the camera primary film handling:

a. Accept film from an external supply at a tension level of 3.5 ± 0.5 lb and have the capability to correct for a lateral misalignment tolerance of the incoming film of ±0.06 inch.

b. Store approximately 104 inches of film in the storage looper (shuttle) which is sufficient for one 10-exposure sequence with normal supply feed into the looper.

c. Guide the film and control its lateral alignment at the platen within ±0.065 inch.

d. Clamp the film on the supply and take-up sides of the primary platen and provide slack film to the platen during jog.

e. Store that portion of the primary film which is displaced from the exposure position during primary-to-secondary platen interchange and return it to the exposure position during secondary-to-primary interchange.

f. Advance 10.4 ± 0.125 inches of film within 0.372 seconds after exposure.

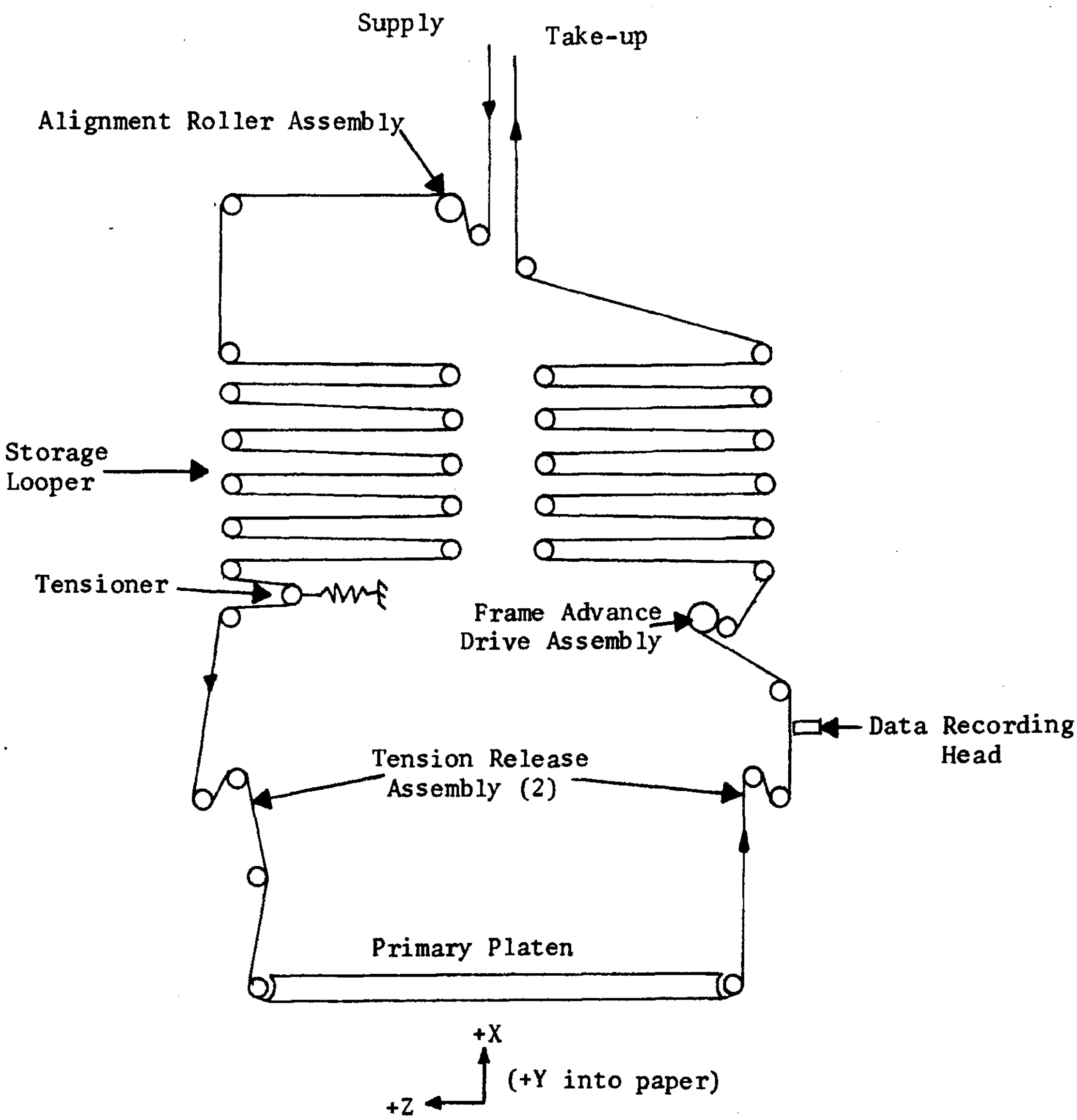


Figure 4.4-12. Primary Film Handling Assembly Schematic

g. Locate the film adjacent to the data recording head with a spacing of 0.002 ± 0.0005 inch.

h. Allow the exposed film to be returned to an external take-up mechanism.

i. Provide associated control sensors and instrumentation sensors to measure looper position.

The primary film handling assembly is functionally illustrated in Figure 4.4-11. The primary film handling structure is a lightweight-aluminum truss design used to support the film handling mechanisms.

4.4.6.2 Secondary Film Handling Assembly. The secondary film handling assembly (see Figure 4.4-13) is designed to supply, store, index, guide, and record data automatically. The design characteristics of the secondary film handling are as follows:

a. Each daylight-loading type cassette has a film capability of 10 ± 1/4 lb of 9-1/2-inch-wide thin-base film.

b. Each cassette has a built-in film-type indicator and a film-footage indicator which operates from a radius sensor arm.

c. Each cassette is equipped with a manually operated friction lock which prevents the accidental unwinding of the film from the spool after removal of the cassette from the secondary magazine.

d. The secondary magazine has a built-in film-clamp and film-cutting mechanism.

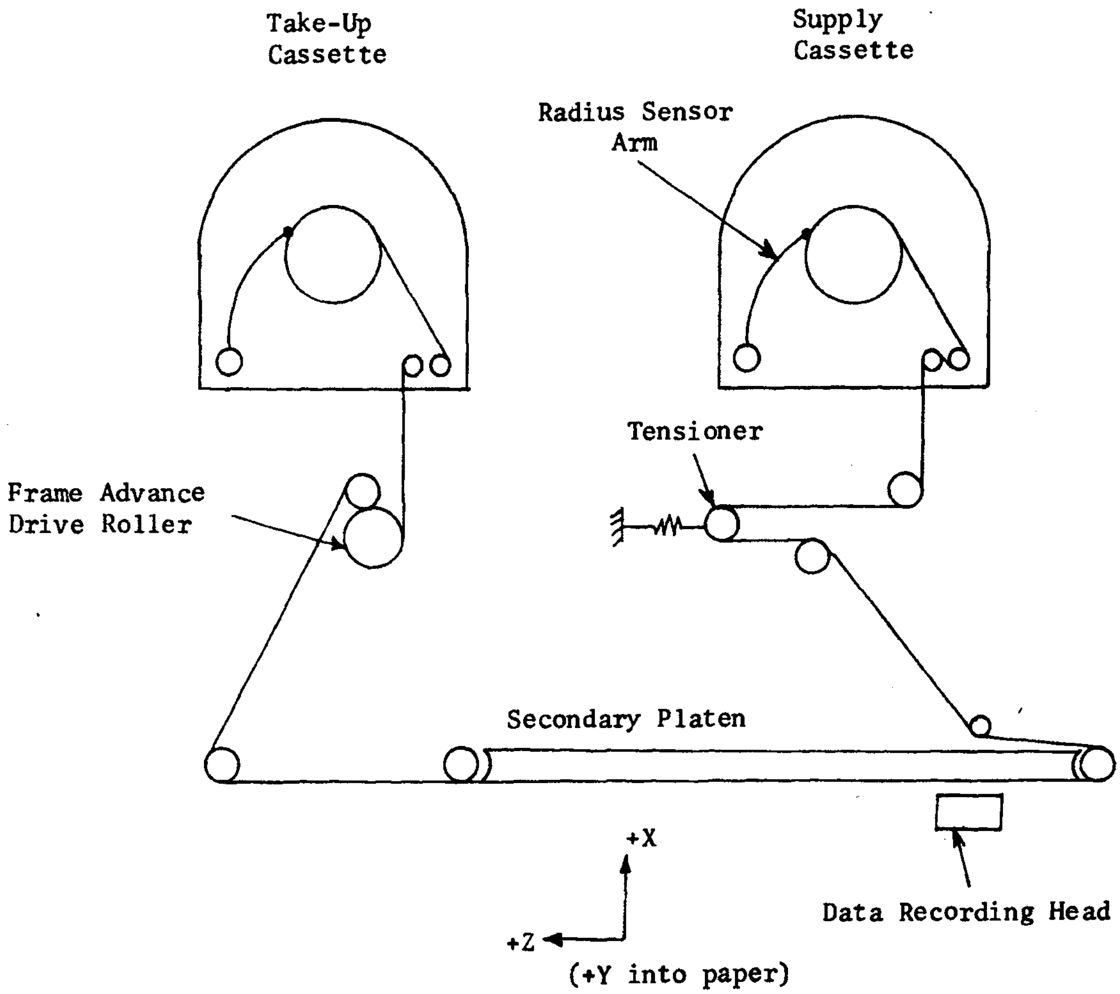


Figure 4.4-13. Secondary Film Handling Assembly Schematic

e. A partially filled take-up cassette is removable from the magazine.

f. Both the supply and the take-up cassettes can be removed from the magazine and reloaded into the magazine without cutting the interconnecting film.

g. The film path design is such that the change of film does not cause light flashing of more than 4.5 feet of film, and the removal and replacement of a take-up cassette does not cause light flashing of more than 6 feet of film.

h. The secondary platen can be manually inserted to the STANDBY position from the STOW position within the magazine by actuation of a crank located externally on the magazine.

i. The secondary film handling assembly is designed to transport film automatically from the supply spool to the take-up spool through a closed-loop servo system.

j. The major moving elements are momentum balanced.

k. Secondary frame advance completion pulses are provided.

The mounting interface between the primary and secondary structures is based on a tapered dovetail slide design. The interface attachment between the two assemblies is accomplished by lowering the secondary magazine into the primary structure in the -X direction, then rotating a single-lever mechanism which, by a wedge action, locks the two assemblies together rigidly, and simultaneously advances two registration pins into the primary structure to provide accurate alignment of the secondary magazine assembly to the main camera structure.

Data are recorded by a luminescent diode-array recording head after the frame has been indexed to the next position. As a result of the functional characteristics of the secondary film transport system, data are recorded: (1) when the secondary platen is at OPERATE, or (2) when the secondary platen is at STANDBY. For the OPERATE condition an auxiliary back-up plate is moved into position, while in STANDBY condition, the secondary platen serves as the back-up plate.

4.4.7 Filter

The filter assembly is manually inserted into the optical beam for infrared color photography with secondary film. The filter housing travels on slides and is located by stops at the beginning and end of travel. The filter will be photographically equivalent to a Kodak Wratten Gelatin Filter No. 12.

4.4.8 Focus Sensor

4.4.8.1 Requirements. The focus sensor is required to detect and compensate for focus offsets as discussed in paragraph 2.4.5.1. These errors arise from the following sources:

a. Initial errors following launch and alignment
b. Small errors which result from environment or structural instability.

In addition, there is a focus shift caused by variation in image plane location as a result of changes in slant range. This shift is predictable and is compensated for by translating the film between frames in small increments based on the computed location of the image plane.

The required two-sigma (2σ) focus accuracy is ±0.002 inch. To meet this requirement a 2σ accuracy of ±0.001 inch is required of the focus sensor.

A focus drive mechanism is required to position the platen in response to commanded adjustments. The focus sensor breadboard is shown in Figure 4.4-13(a).

4.4.8.2 Principles of Focus Sensor Operation. The Dorian focus sensor (Figure 4.4-14) uses the fixed-reticle scene-scan approach. A pair of folding mirrors is moved into the primary light path to direct part of the light through a rotating focus-shifter disk onto a reticle and photodetector. The optical path to the reticle is changed in length by the shifter disk. As the shifter disk rotates, the image plane alternates along the optical path from one side of the reticle to the other side, corresponding to the two thicknesses of the disk. When the lens is at best focus, the reticle is midway between the shifting planes (See Figure 4.4-15). The mechanical alignment of the focus sensor assembly to the platen ensures that when the reticle is in this position, the emulsion plane of the film is at best focus. The focus sensor requires that the TM be stopped so that the image is moving; this image motion across the reticle generates an amplitude-modulated light signal which is a function of the radiance distribution in the image, the MTF of the lens, and the transfer function of the reticle.

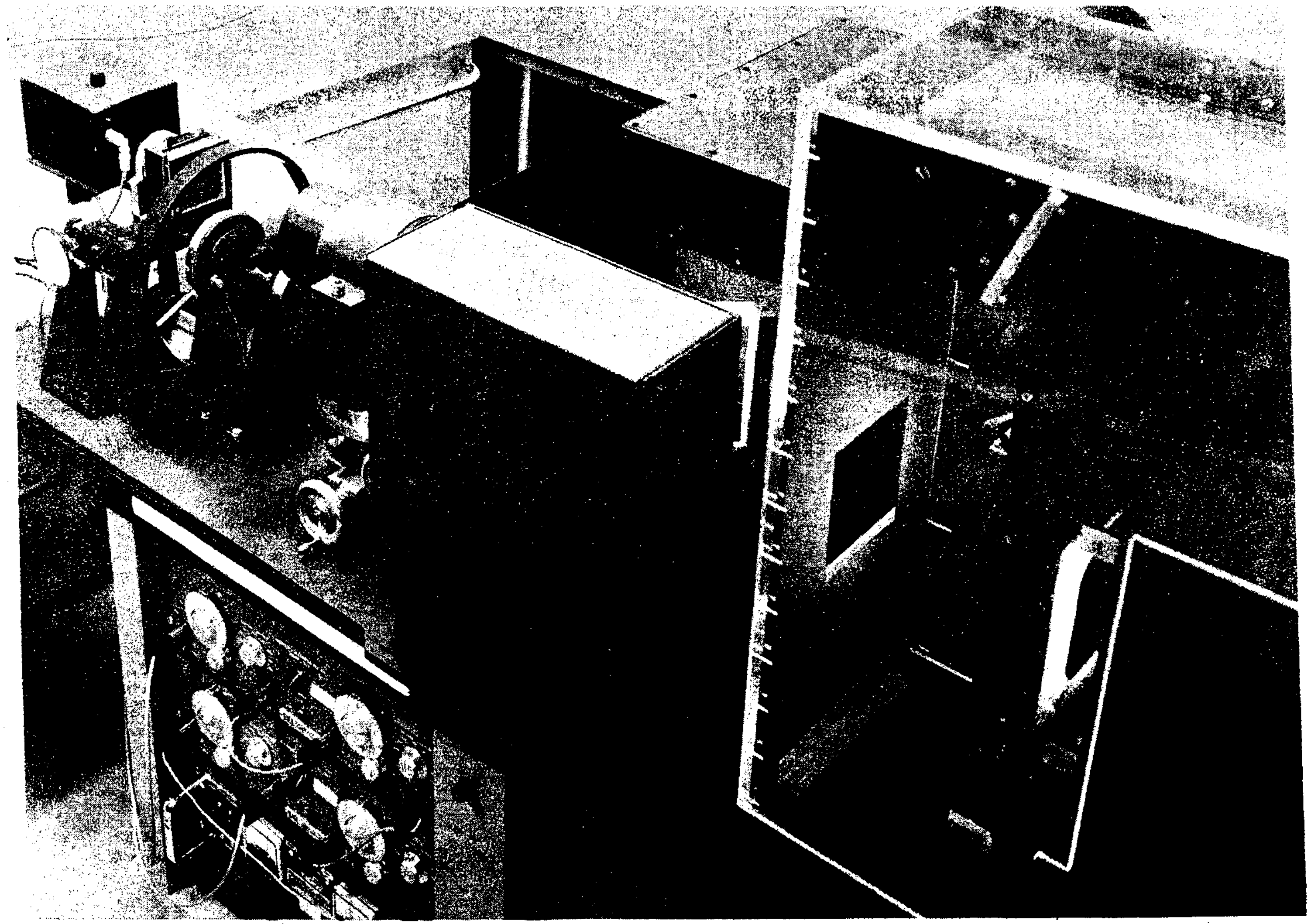


Figure 4.4-13(a). Focus Sensor Breadboard

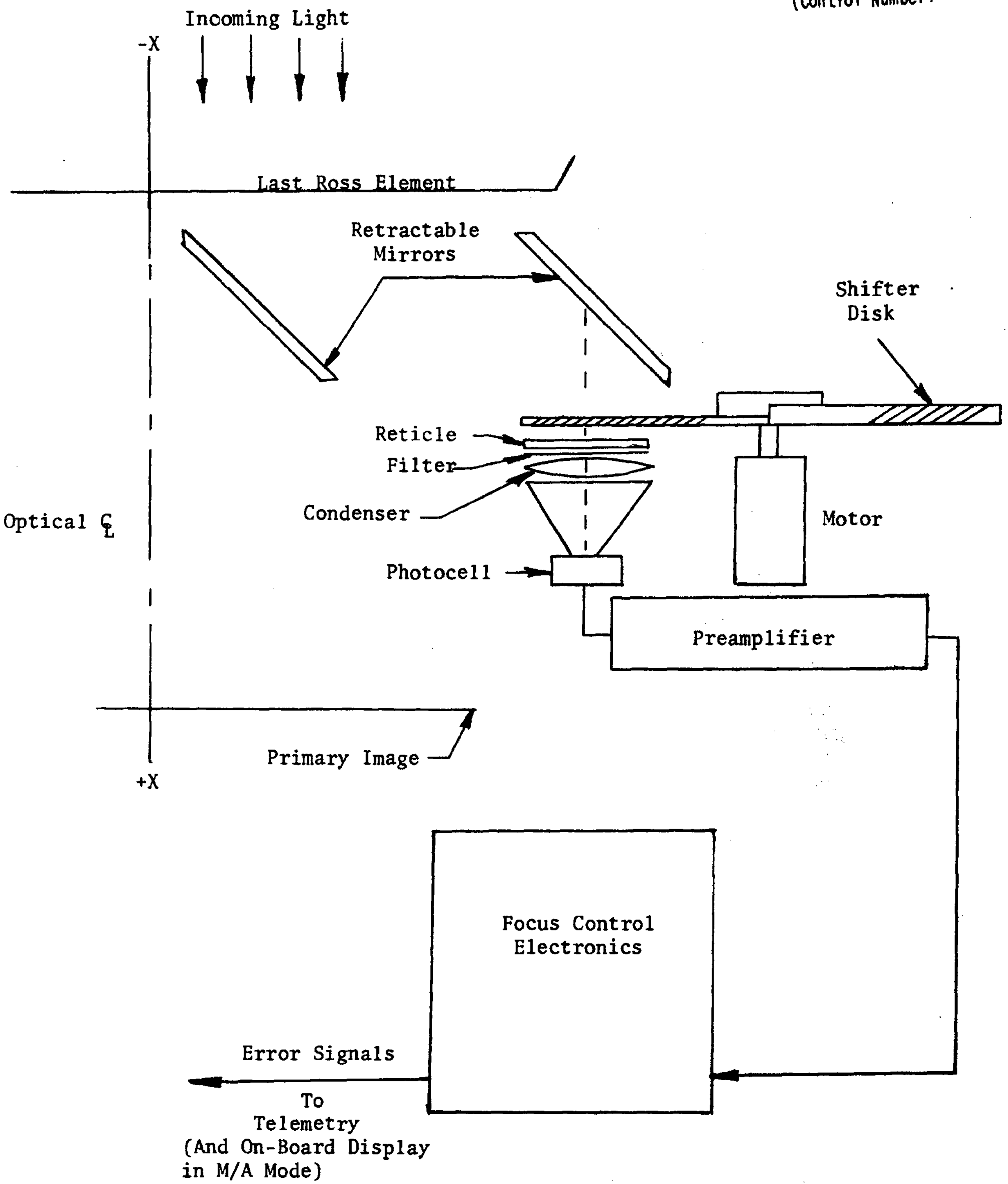


Figure 4.4-14. Focus Sensor Schematic Block Diagram

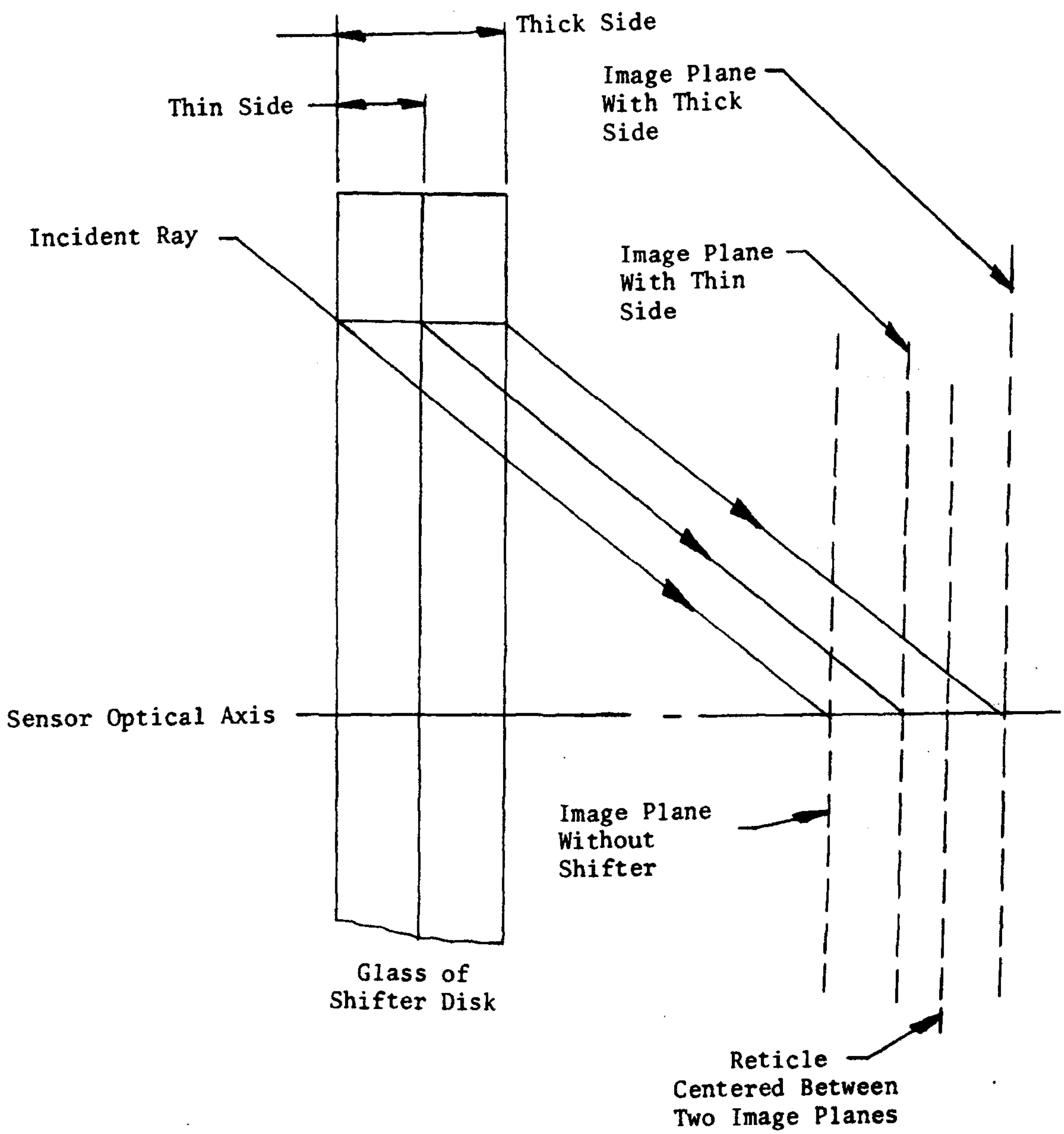


Figure 4.4-15. Focus Sensor Image Planes

The radiance detected is a function of scene content, haze level, cloud cover, and sun angle. The reticle partially filters the scene, transmitting those frequencies which vary as odd harmonics of the reticle spacing and a d-c level of scene radiance. Filtering is accomplished in such a way that all objects whose spatial period is not an even harmonic of the reticle generate a signal at a temperal frequency which is a product of the object velocity and reticle spacing. The maximum a-c response of the reticle is produced by those scene objects whose spatial geometry matches the reticle geometry in the image plane. The maximum d-c response occurs from those filtered objects whose radiance level is the largest.

The light signal is directed to a photodetector which produces an electrical signal. The photodetector is capacitor-coupled to the focus electronics to block and d-c output of the photodetector. The electrical output signal is amplified, electronically filtered, and demultiplexed in synchronism with changes in the shifter-disk thickness. The demultiplexed signals are then integrated and compared. Should the sensitive surface of the film not coincide with the plane of best focus (that is, when the reticle is not midway between the shifting image planes), the output signal will be higher or lower than the nominal value. The magnitude of the error signal indicates the amount and direction that the platen must be moved to be at the plane of best focus.

4.5 FILM HANDLING

The film handling assembly consists of the film supply, take-up assembly, the equipment required to transport film to and from the camera assembly, the data return containers (DRC), and film viewer. This paragraph concerns the handling of film external to the camera, including primary and secondary films, in the M/A mode. The film viewer is discussed in paragraph 4.8.

4.5.1 Requirements

The film handling assembly is required to perform the following functions:

a. Provide a single primary film supply of 190 lb of 9.46-inch-wide ESTAR Thin Base Film similar to Type 3404 High Definition Aerial Film but have a capacity for up to 240 lb of this same film type.

b. Provide five supplies of approximately 10 lb each of special (secondary) ESTAR Thin Base Films so as to give a total frame capability (primary plus secondary) of 15,000 frames; provide three take-ups of approximately 10-lb capacity each, for three special films; and provide two take-ups of approximately 1-lb capacity each for film to be processed and viewed on-board.

c. Transport the primary film from the supply to the camera and from the camera to the take-up without degradation of image quality and at a rate commensurate with operation of the camera sequences of up to 10 primary frames. Frame rate can be as high as one frame per second within the sequence, and a minimum of 5 seconds. Time lapse must occur between 10-frame sequences.

d. Provide a means for manual transfer of exposed film to the Gemini B and storage of film in the Gemini B.

The film handling assembly must also be capable of handling ESTAR Ultra Thin Base primary film. Film handling flow requirements are summarized in Figure 4.5-1.

4.5.2 Design

4.5.2.1 Configuration. The film handling equipment is located in the LM as illustrated in Figure 4.5-2. The equipment consists of five major assemblies; the primary supply assembly, the LM film-chute assembly, the primary take-up assembly, the DRC's, and the film viewer (the film viewer is described in paragraph 4.8). The film path shown by the arrows in Figure 4.5-2, is as follows: prior to launch a single supply reel carrying all of the primary film is placed into the primary supply assembly. As film is used in the camera assembly, the primary supply assembly feeds film to the camera via the LM chute at controlled rates and tension.

From the camera assembly, the film returns via the LM chute to the primary take-up assembly. When the first take-up reel is full, the film on the take-up reel is wrapped with opaque material, the reel is manually removed from the primary take-up, and placed into a DRC for return in the Gemini B. As soon as possible after each DRC is loaded, a crewman takes it to the Gemini B for storage, so that if an emergency requires flight-crew recovery, the accumulated data can be returned. Small amounts of primary film can be removed from the take-up for processing and viewing to check overall photographic operations. This removal can be done only prior to the beginning of each fill of the primary film take-up reel.

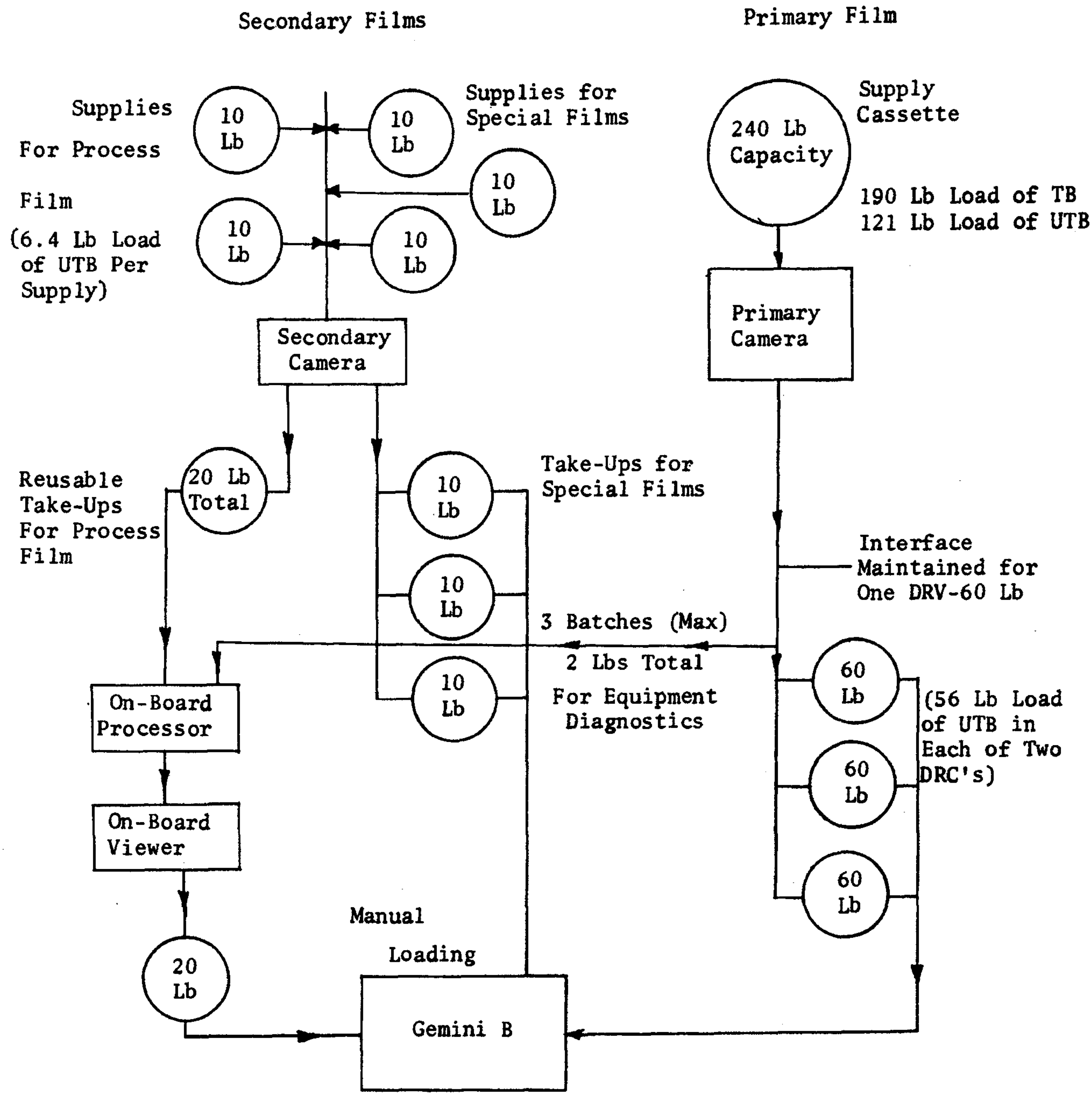


Figure 4.5-1. Film Handling Flow Chart

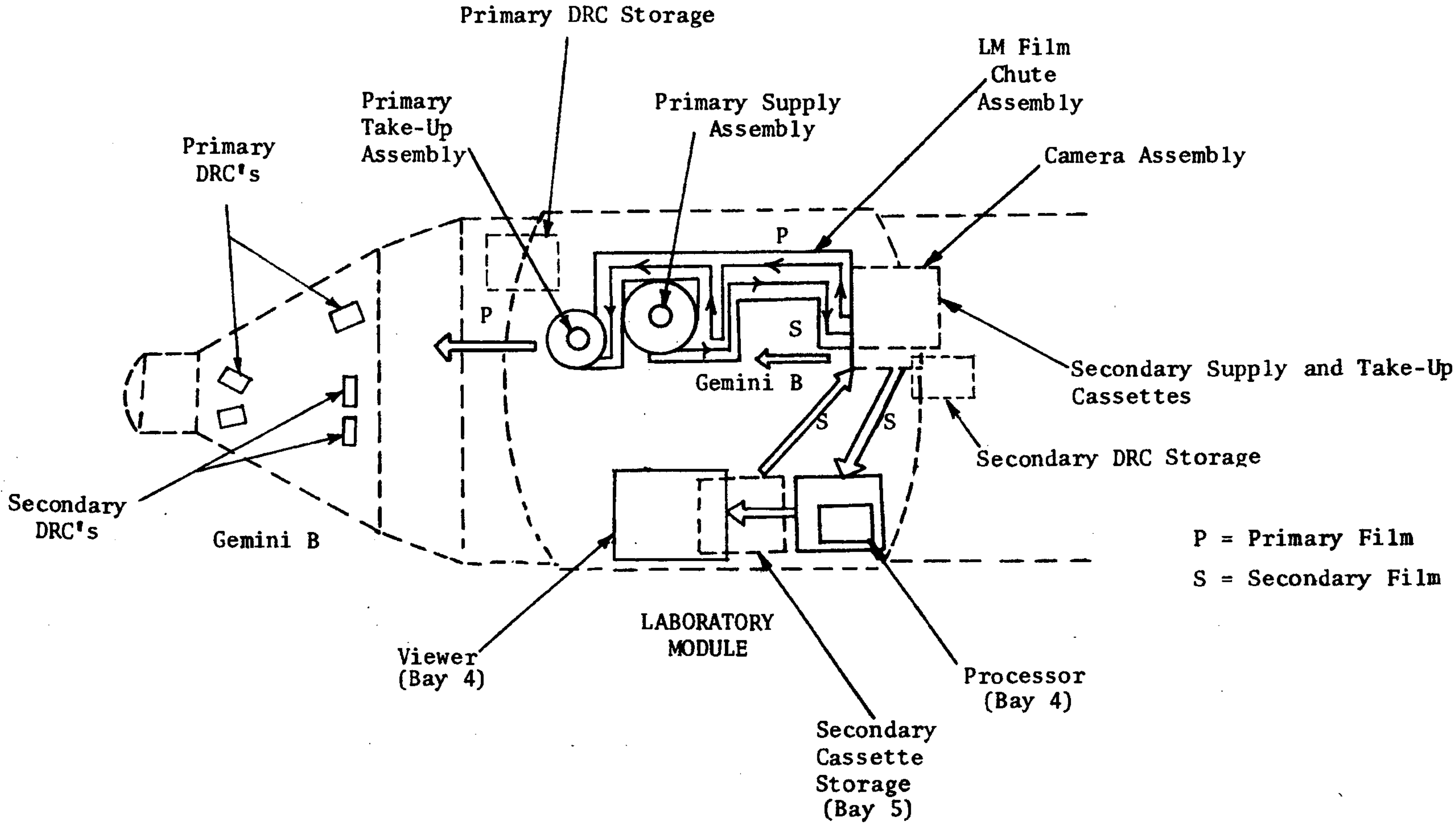


Figure 4.5-2. LM Film Handling Concept - M/A Mode

4.5.2.2 Primary Film Advance. Three different modes of feeding primary film to the camera assembly were evaluated. The first is the intermittent mode of film handling, in which the film supply looper located in the camera is filled only during the time interval between targets. The second is the intermittent/creep mode, in which the film motion is stopped during two exposures of a target sequence but can feed film to the camera assembly looper during other exposures of the photographic sequence as well as during the time interval between target sequences. The third is a creep mode of operation in which film enters the camera assembly looper (supply side) at low velocities whenever the looper contains less than its capacity of film. In comparing the three modes, worst-case film-handling situations were considered with regard to effects on photographic quality, mission versatility, and hardware factors.

The creep feed has the advantages of requiring much less power than intermittent feed, and in analog computer simulations it has been shown that supply and take-up tension transients can be minimized. Because of its overall advantages, the creep mode of operation was selected for PP film handling.

4.5.2.2.1 Method of Operation.

Supply to Take-up. A schematic film path, including the camera film looper and associated electronic controls is shown in Figure 4.5-3. To supply unexposed film to the camera assembly and take up the exposed film from the camera, the following takes place: the camera advances unexposed film by removing it from the supply side of the camera looper, running it past the platen, and transporting it, after exposure, into the take-up side of the looper.

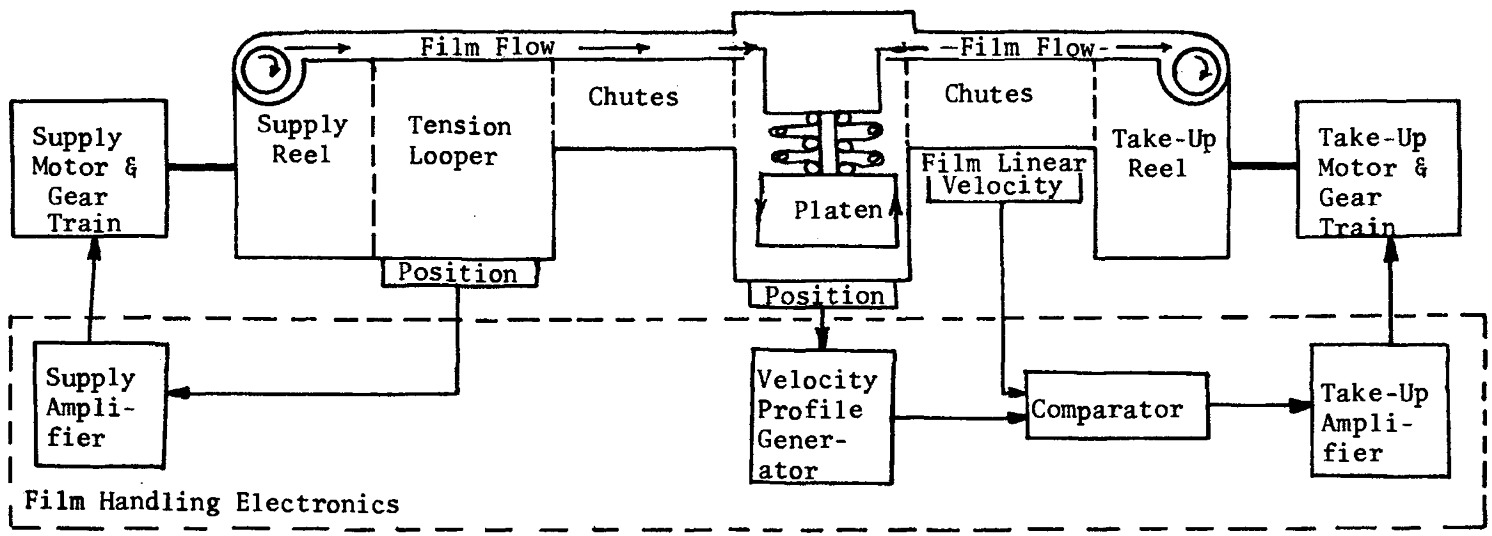


Figure 4.5-3. Block Diagram Primary Film Handling Control - Manned/Automatic Mode

These operations cause the camera supply looper carriage to move away from the take-up side of the camera toward the supply side. This change in looper position causes a sensor to send a signal to a velocity profile generator. This unit produces a controlled acceleration signal which is fed through the comparator to the take-up amplifier. The amplifier produces a signal which starts to accelerate the take-up motor. The linear velocity of the film in the take-up chute is monitored and an analog signal of this function is subtracted from the output of the velocity profile generator in the comparator. Thus, the difference between these two signals is used to control the take-up motor. If the camera continues to expose film at the maximum rate (one exposure/second), the profile-generator signal will saturate after 8 frames, and film velocity will become constant at about 10 inches/second.

When the camera stops exposing film, the storage looper carriage is driven back towards the reference position. This action decreases the output of the velocity-profile generator and the take-up motor is decelerated. Continuation of this operation returns the system to the initial conditions as the looper carriage returns to the reference position, and the take-up motor moves smoothly to a stop.

This film handling method is desirable because of its ability to supply the needed amounts of film with a minimum of tension transients and to maintain a nominal tension level. Tension transients must be minimized to prevent smear during photography. Analog simulations show that tension transients can be held to less than a few ounces in magnitude and will have long, rather than short, cyclic variations. Normal film tension is 3.25 + 0.75, -0.25 lb.

Take-Up to Data Return Container. Three portions of exposed primary film, each being up to 60 lb, will be placed in DRC's for return in the Gemini B. The procedure for the flight crew to transfer the film from the primary take-up assembly to the DRC is expected to be as follows: (1) open the film chute and clamp the film; (2) splice opaque leader to the film and run two or three wraps of the opaque leader onto the take-up assembly reel by actuating the take-up reel motor; (3) cut the film, open the take-up assembly cover, remove the loaded film reel, and place it in the DRC; and (4) store the DRC in the LM or carry it into the Gemini B.

4.5.2.2.2 Film-Advance Hardware Descriptions.

Primary Supply Assembly. The function of the primary supply assembly is to store and protect the film supply during launch and on orbit, and to deliver film to the camera on demand at controlled rates and tensions. The primary supply assembly, illustrated in Figure 4.5-4 consists of four major subassemblies which are described below. The primary supply assembly engineering model (EM) is shown in Figures 4.5-5 and 4.5-6.

Drive Spindle Assembly. The drive spindle assembly provides the torque to drive the supply reel. The assembly includes a pair of concentric cylinders separated by bearings. The inner cylinder contains a motor, gears for driving the outer cylinder and two brakes. An electrically actuated brake locks the supply during periods of (power off) photographic inactivity, during launch, or in case of power failure to maintain film tension. A manually operated friction drag brake can be engaged and manually adjusted to prevent film spillage in case of certain failures of the film handling servo system. The entire film handling servo system contains redundant

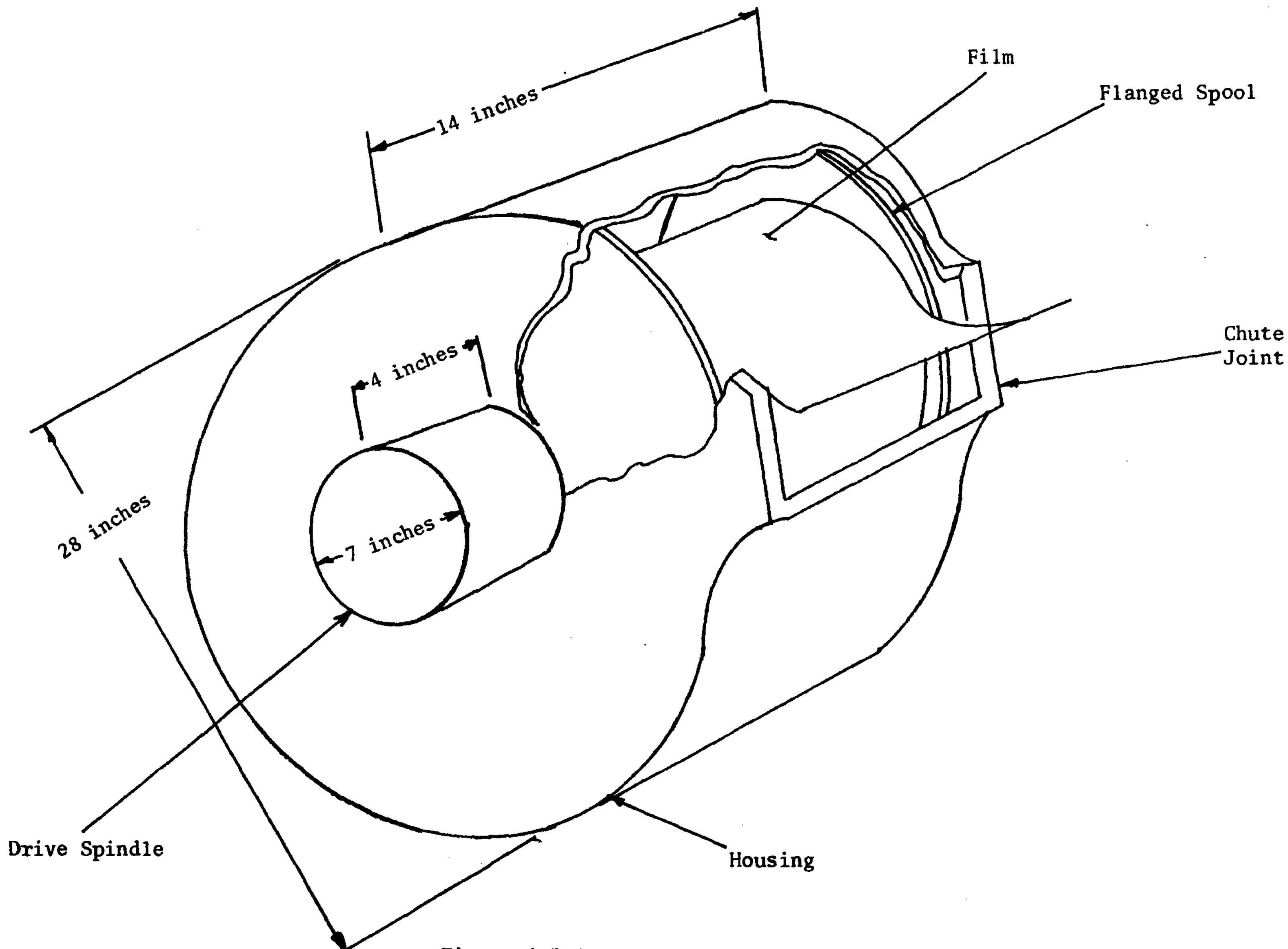


Figure 4.5-4. Primary Supply Assembly

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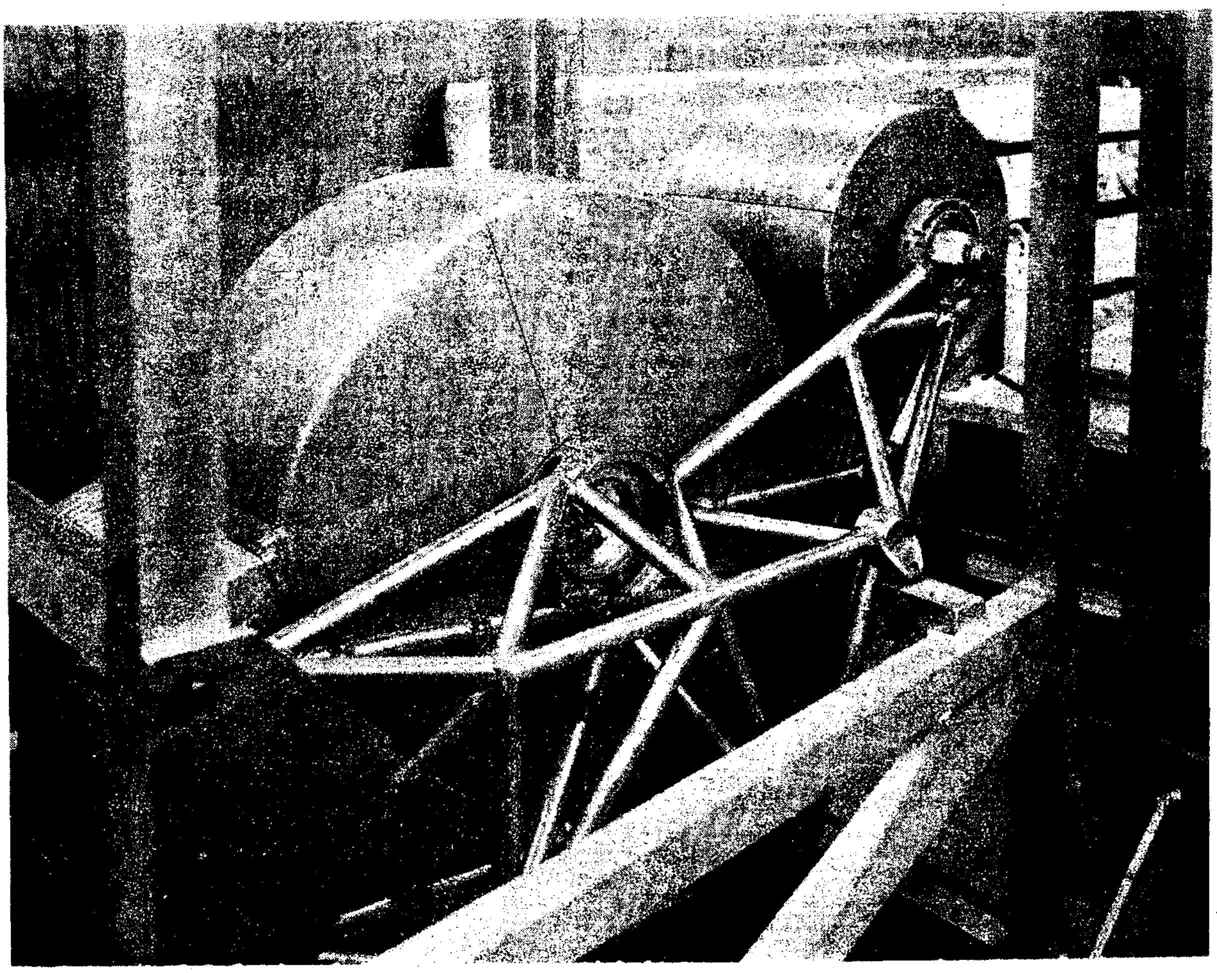


Figure 4.5-5. Primary Supply Assembly Engineering Model

Handle via BYEMAN
Control System Only

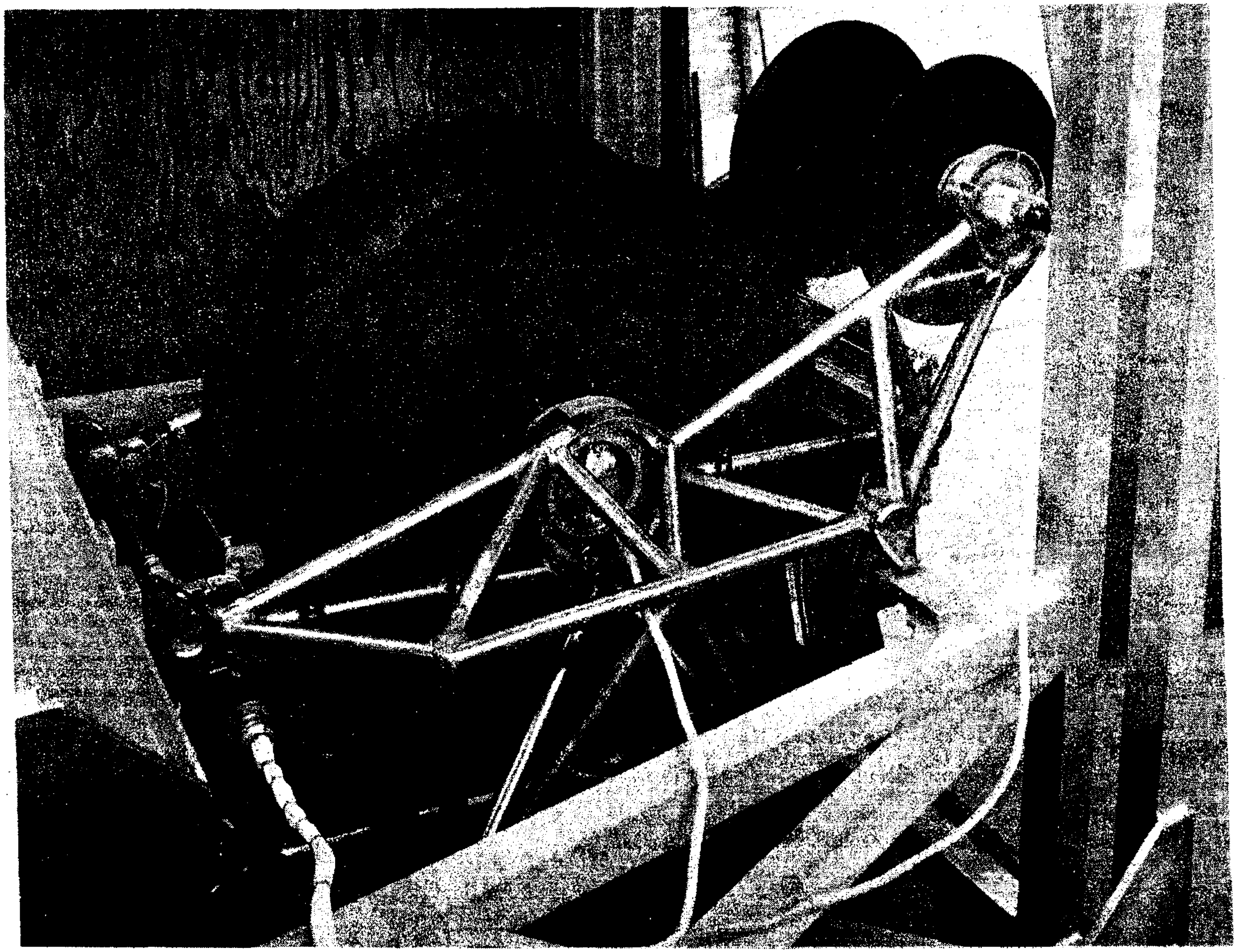


Figure 4.5-6. Film Transport System Supply Spool and Take-Up Reel

circuitry and the electrical brake is a dual coil type, either coil of which is sufficient to control the supply reel during power interrupt conditions. The inner cylinder and its contents are fixed with respect to the support structure.

Supply Reel. The supply reel consists of a hollow cylindrical aluminum core to which two aluminum honeycomb flanges are affixed. The supply reel fastens to the outer cylinder of the drive spindle assembly.

Housing Assembly. The housing assembly is a cylindrical, lighttight enclosure for the film supply contained on the supply reel. Mechanical support of the housing assembly is provided at its attachment interface with the drive spindle assembly.

Chute Joint Assembly. The chute joint assembly provides a lighttight, flexible coupling between the housing assembly of the primary supply assembly and the LM chute set. Lighttight slip joints are provided by appropriate fittings to the housing assembly and LM chute set, respectively.

Primary Take-Up Assembly. The function of the primary take-up assembly is to receive exposed film from the camera assembly at controlled rates and tensions, wind the film on a primary take-up reel and to support and protect this film while it is in the primary take-up assembly.

The primary take-up assembly consists of three major subassemblies as shown in Figure 4.5-7 and as described below. The film take-up assembly EM is shown in Figures 4.5-8 and 4.5-9.

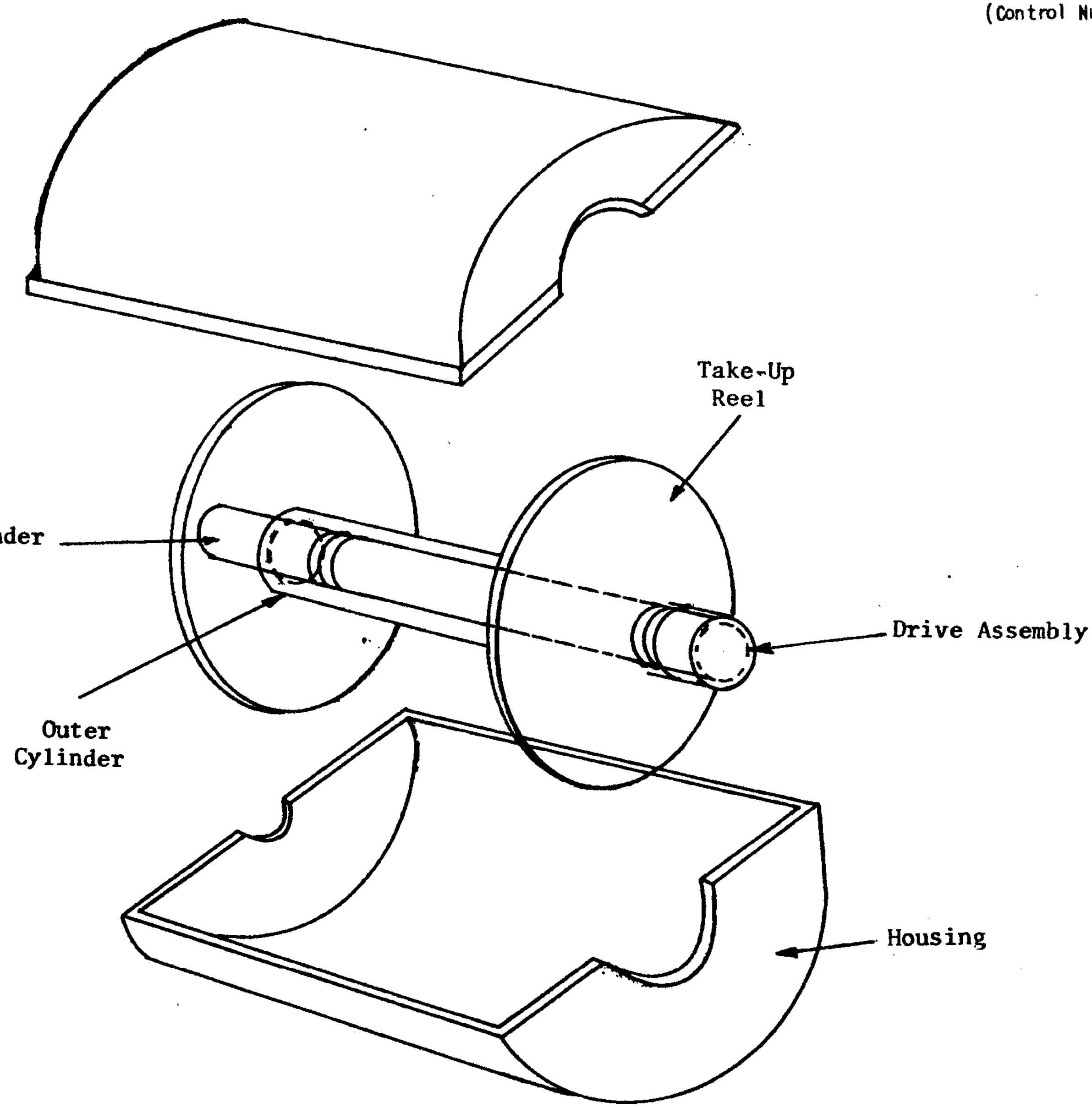


Figure 4.5-7. Primary Take-Up Assembly Concept

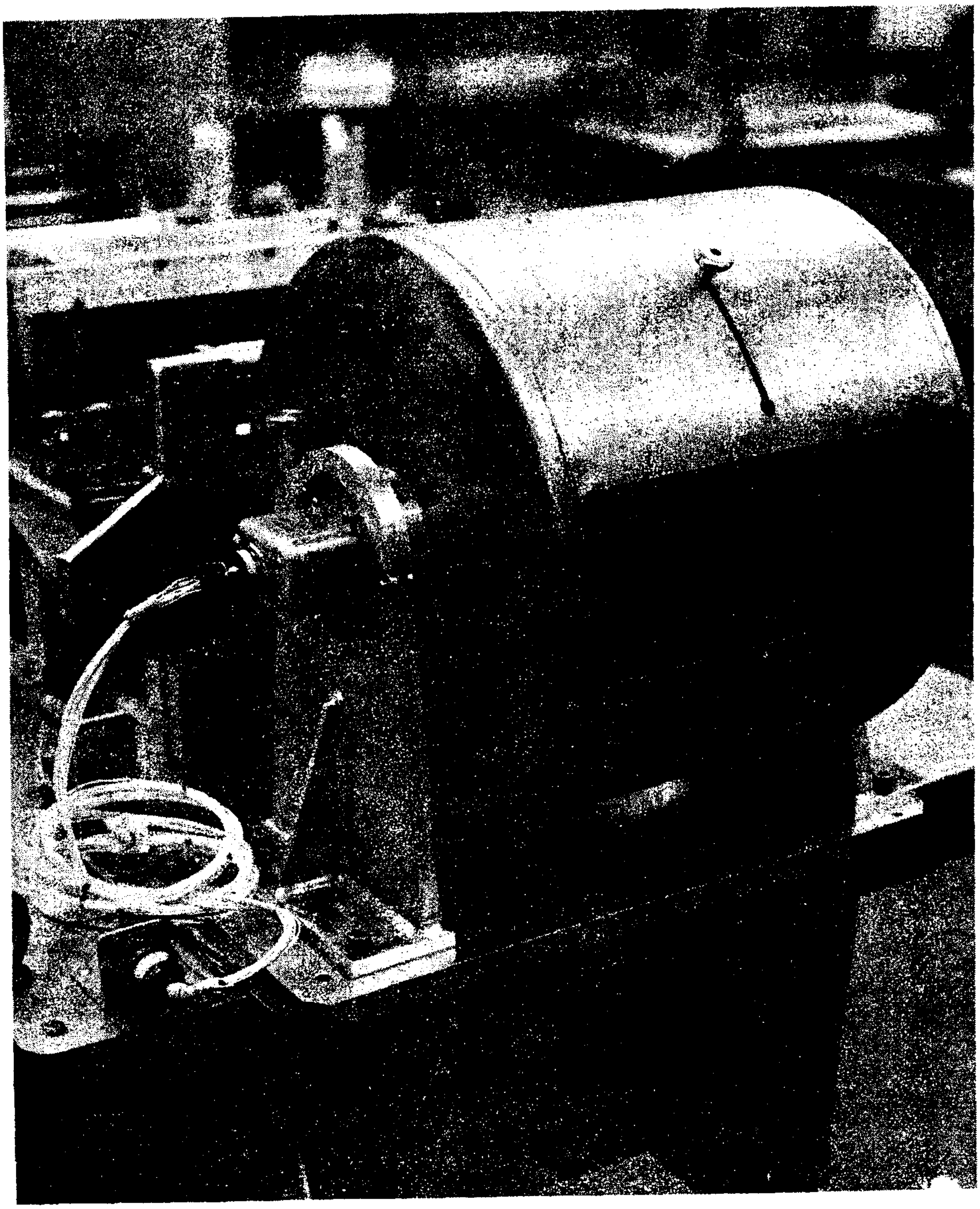


Figure 4.5-8. Film Take-Up Assembly

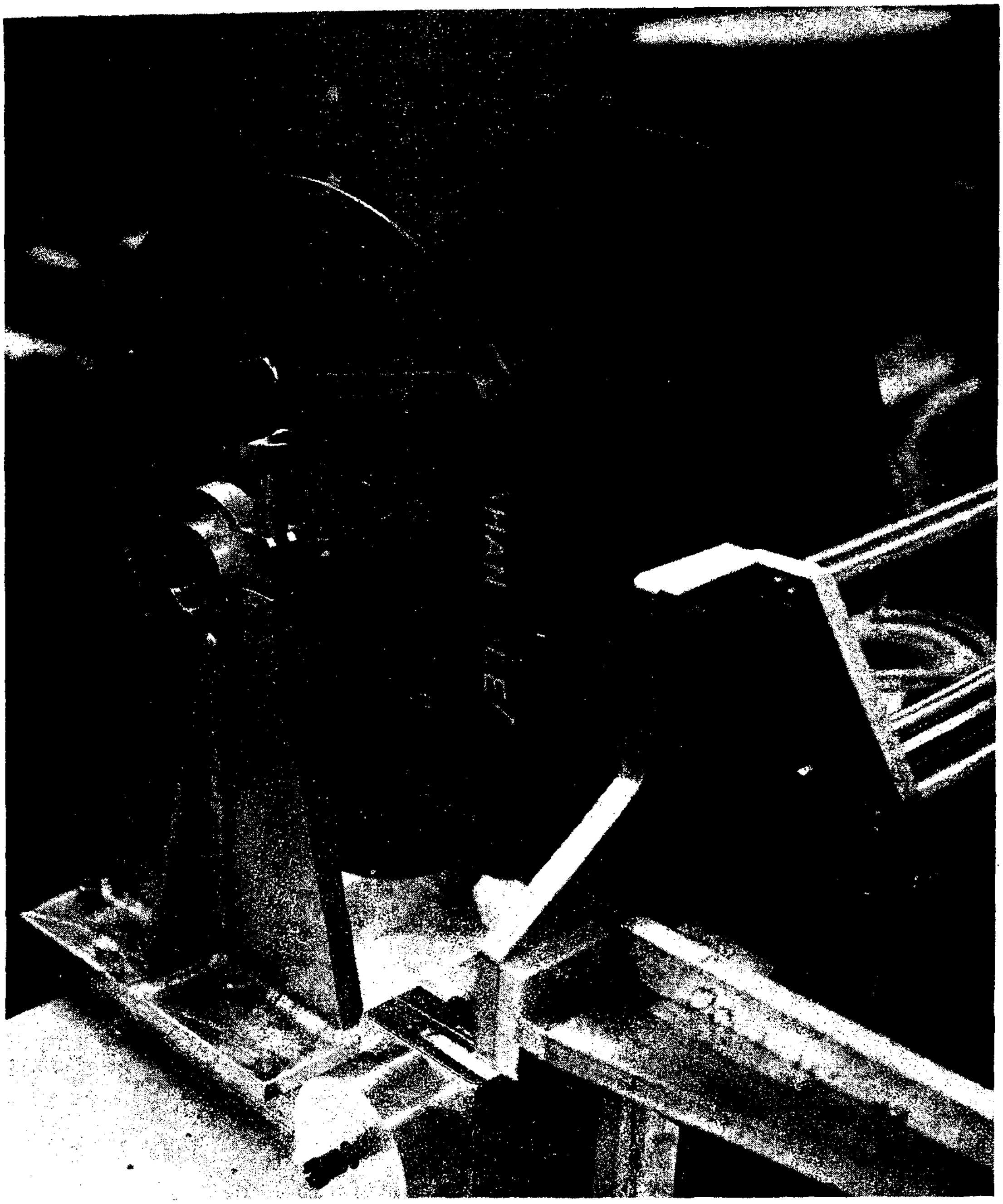


Figure 4.5-9. Film Take-Up Assembly - Spool and DRC Mounting Flange

Drive Assembly. The drive assembly consists of two cylindrical aluminum shells, a drive motor, ratchet assembly, a reel lock, and gears. The two cylindrical sections are concentric, the outer section is mounted to the inner by two bearings permitting rotation of the outer cylinder relative to the fixed inner cylinder. Rotation of the outer cylinder is accomplished by a torque motor mounted to the fixed inner shell.

The ratchet assembly contains a manually operated release device. Three positions of a control knob (1) launch lock, (spindle and reel locked to the structure), (2) operate (spindle permitted to rotate forward but not backward), and (3) reverse (spindle allowed to rotate in reverse for threading and film removal). A safety mechanism is included to prevent damage in case operation is attempted with the controls in the lock or reverse positions.

The lighttight housing encloses the take-up reel and the drive assembly. The housing separates into two parts to facilitate changing the take-up reels. When the housing is removed from the chute assembly, lighttightness is maintained by a sliding door at the interface. The two halves are held together by four draw catches.

Take-Up Reels. The take-up reels are passive devices which serve two purposes. They wind up film when operated with the drive assembly and serve as storage reels within the DRC's. Film on take-up reels is protected from light flashing by an opaque wrapping applied during on-orbit reel interchange. Each of the three take-up reels consists of one cast aluminum flange, a core, and one honeycomb flange.

4.5.2.3 Film Alignment and Transport. Because the camera is mounted on the end of the Ross barrel, an integral part of the MM, and the film supply is mounted to the LM, a significant lateral (±Y) displacement of as much as ±1.5 inches can occur between these units while on-orbit. The chute assembly must transport film from the supply to the camera across the moving interface. The design approach used provides for appropriate degrees-of-freedom in the chute assembly so as to force all chute deflections to result in twisting of the film only about its neutral axis as described below.

4.5.2.3.1 Neutral Axis Twisting. The neutral axis of the film is defined as the axis along the center of the film length. Neutral axis twisting can be permitted between two rollers if the roller axes are maintained perpendicular to the neutral axis of the strand between them. In Figure 4.5-10a, a strand of film is shown undergoing neutral axis twisting with no change in film-path direction. Note that in Figure 4.5-10b, rollers were added to achieve a change in film-path direction. Note that in Figure 4.5-10b, the axes of rollers A and B are both perpendicular to the neutral axis of the strand between the rollers, as required.

Where it is necessary to make a change in direction of the film path without a net vertical separation between input and output strands, (see dimension d, in Figure 4.5-10b) two neutral axis twisting sections are placed back-to-back as shown in Figure 4.5-11. Use of this technique can be seen in the film-return path (camera to take-up) in Figure 4.5-2. Also, a variation of the same technique is used in getting the film from the supply to the camera. In this case neutral axis twisting also takes place in the horizontal section of the chute (between rollers B and C in Figure 4.5-11) because of the lateral displacement of the camera with respect to the supply as mentioned above.

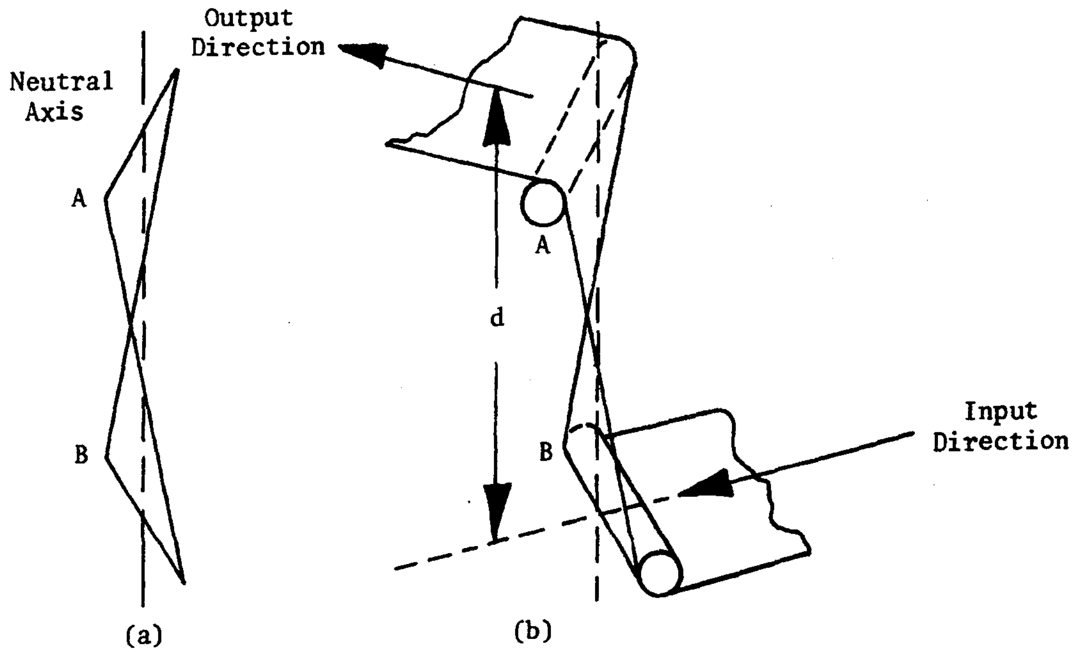
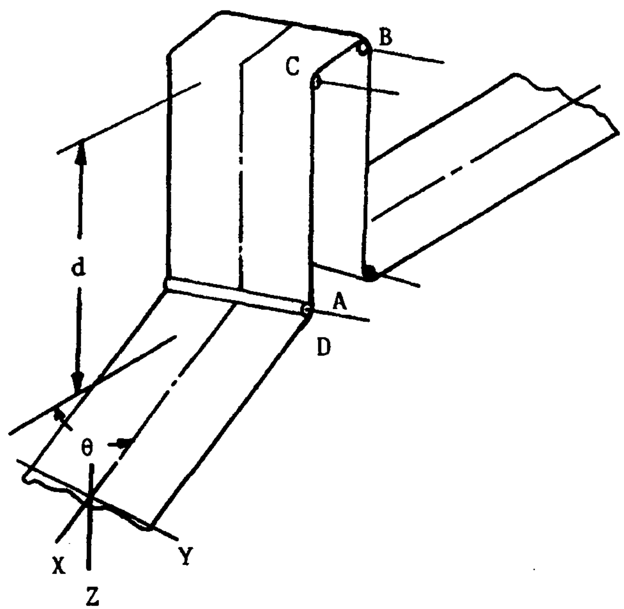


Figure 4.5-10. Film Neutral Axis

Limitation:

$$\theta = \frac{2 \text{ degrees} \times 2d}{\text{Foot}}$$



Ground Rules:

All rollers must lie in planes parallel to the XY plane.

Rollers B and C must be parallel to each other.

Figure 4.5-11. Neutral Axis Rotation Concept

Because the displacements and angles to be accommodated are variable on-orbit, the structural supports for the film rollers must be configured as shown in Figure 4.5-12 to give the chutes the necessary freedom of motion. The guide slot in the vertical chute section permits rollers C and D to rotate with respect to each other although maintaining their perpendicularity with the neutral axis of the film path between them. Film-chute articulation in other degrees-of-freedom is similarly accommodated by appropriate location of guide slots to permit neutral axis rotation of other sections of the film strand. The film transport system EM showing roller pivots and guide slots is shown in Figure 4.5-13.

4.5.2.3.2 Film Transport Hardware Description. The LM film chute (Figure 4.5-14) consists of the five functional subassemblies which are described below.

Pivoting Chute Assembly. The pivoting chute assembly consists of a framework onto which a series of rollers is fastened. The framework is connected by pivots (see Figure 4.5-12) so oriented that the pivot axis of the framework is coincident with the neutral axis of the film as it passes over the rollers in each section. Hence, when one end of the chute (the supply/take-up section) is displaced relative to the other end (the camera), the film necessarily twists about its own neutral axis as described in paragraph 4.5.2.3.1. The pivoting chute permits film to track successfully when one end of the chute is subjected to any combination of the following displacements (relative to the other end of the chute):

a. 0.5 inch in the ±X direction
b. 1.5 inches in the ±Y direction
c. 1.5 inches in the ±Z direction

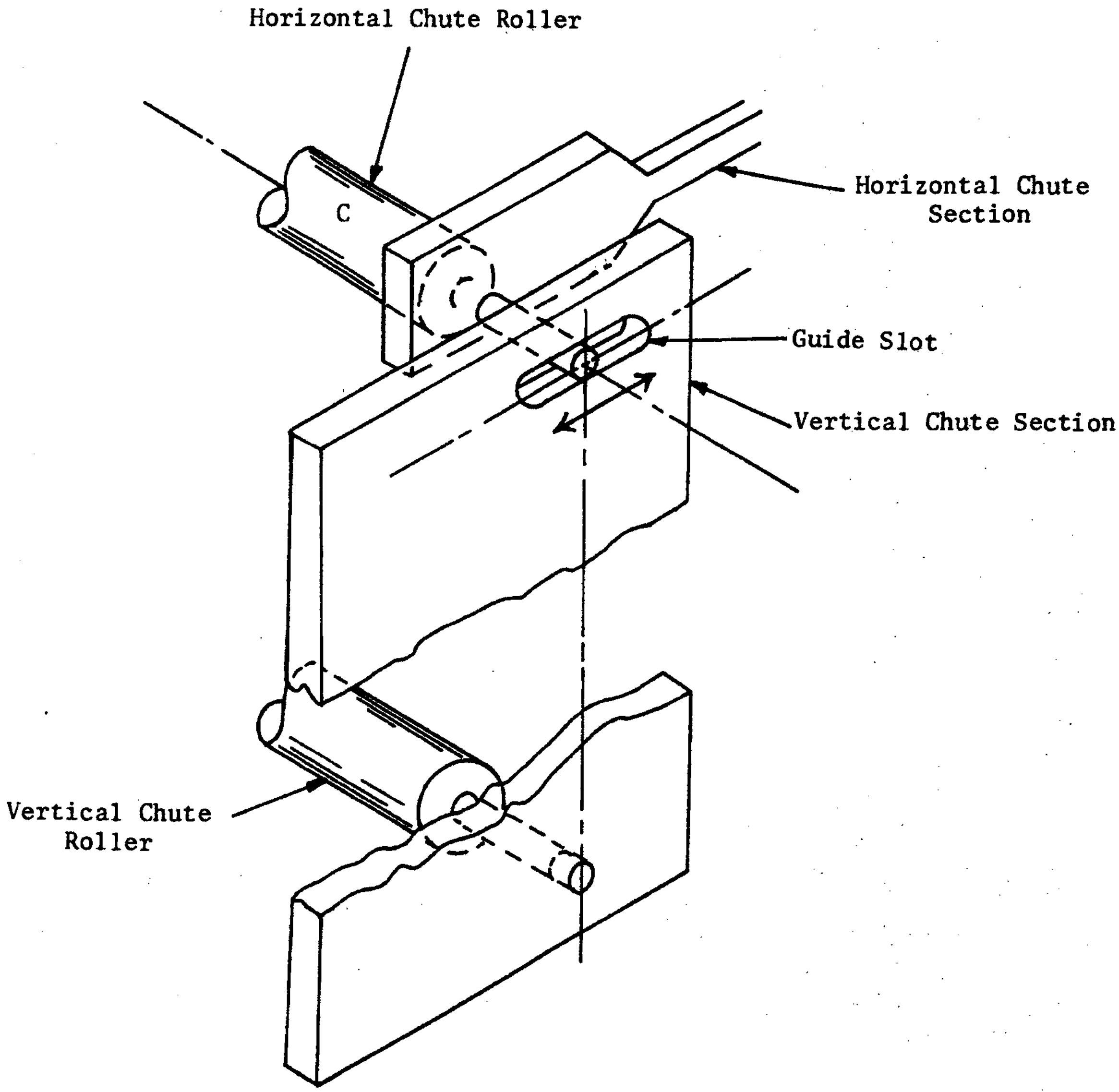


Figure 4.5-12. Horizontal Chute Support

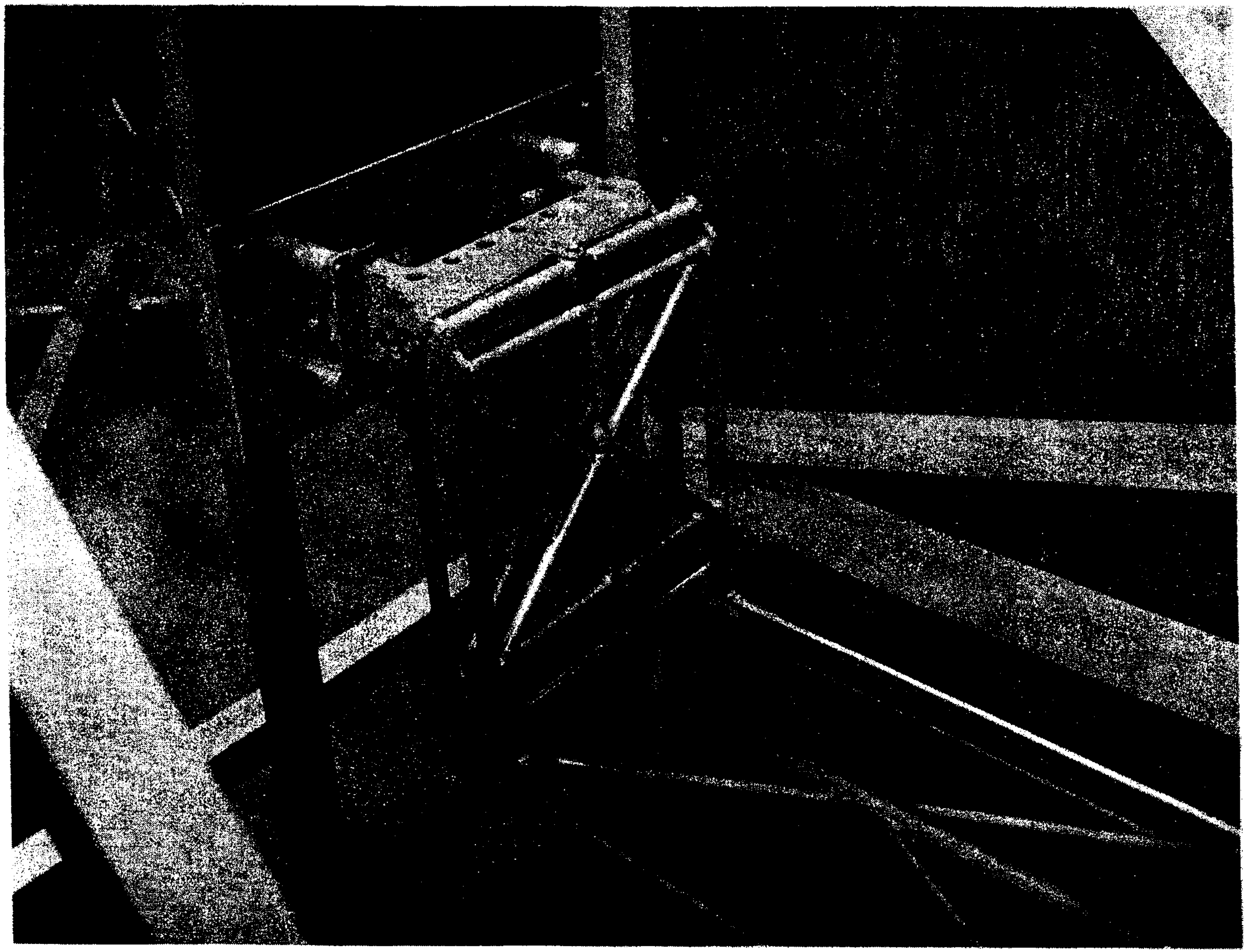


Figure 4.5-13. Roller Pivots and Guide Slots

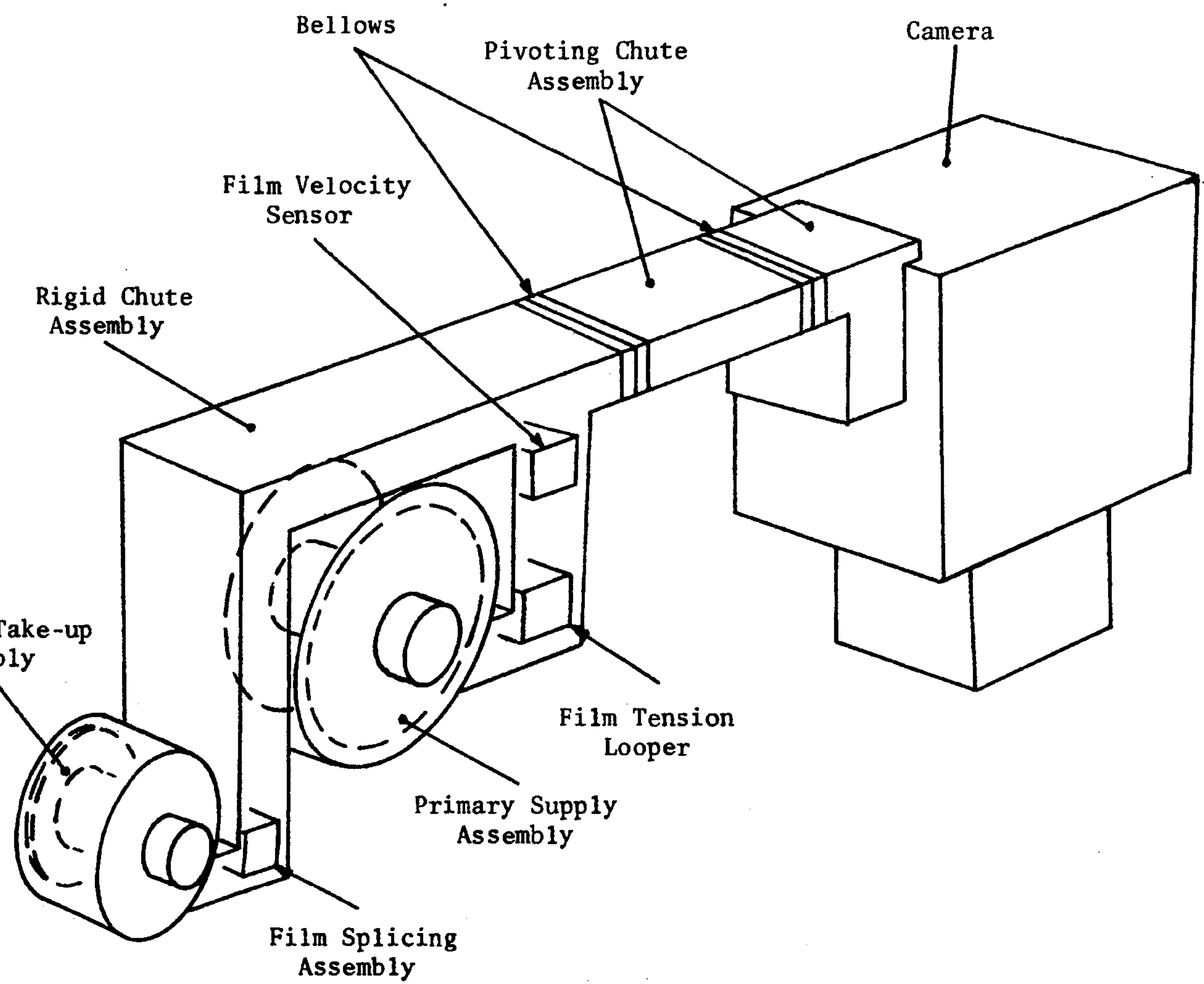


Figure 4.5-14. LM Chute Assembly Concept

The entire pivoting chute subassembly is enclosed in lighttight casings connected by flexible accordion-type bellows. See Figure 4.5-15 for the EM film transport system.

Rigid Chute Assembly. The function of the rigid chute assembly is threefold:

a. It maintains a preferred film path which is prealigned before installing the chute in the LM.

b. It houses the film splicing assembly and provides an access door through which manual access is available to the splicing assembly.

c. It houses the film tension looper subassembly, film-velocity sensor, film metering device, and environmental pressure and temperature-instrumentation points.

The rigid chute assembly consists of a series of rollers fastened to a rigid-truss framework. The framework supports the supply and take-up reels and maintains alignment of the rollers and reels. A lighttight casing, internal to the truss framework, encloses the film path and protects the film from light fogging.

Film Splicing Assembly. The film splicing assembly (located in the film path just ahead of the take-up reel) consists of a clamping device, a cutting area, and a supply of opaque-film trailer. The function of the film splicing assembly is to provide for the clamping and splicing of the opaque trailer to the primary film. This film splicing assembly is used when it is necessary to remove a filled take-up reel for insertion into a DRC. The crew will splice the trailer to the film, wind the opaque wrapper onto the take-up reel, and then cut the film strand. The reel and contents is then light protected and is ready for removal from the take-up cassette assembly.

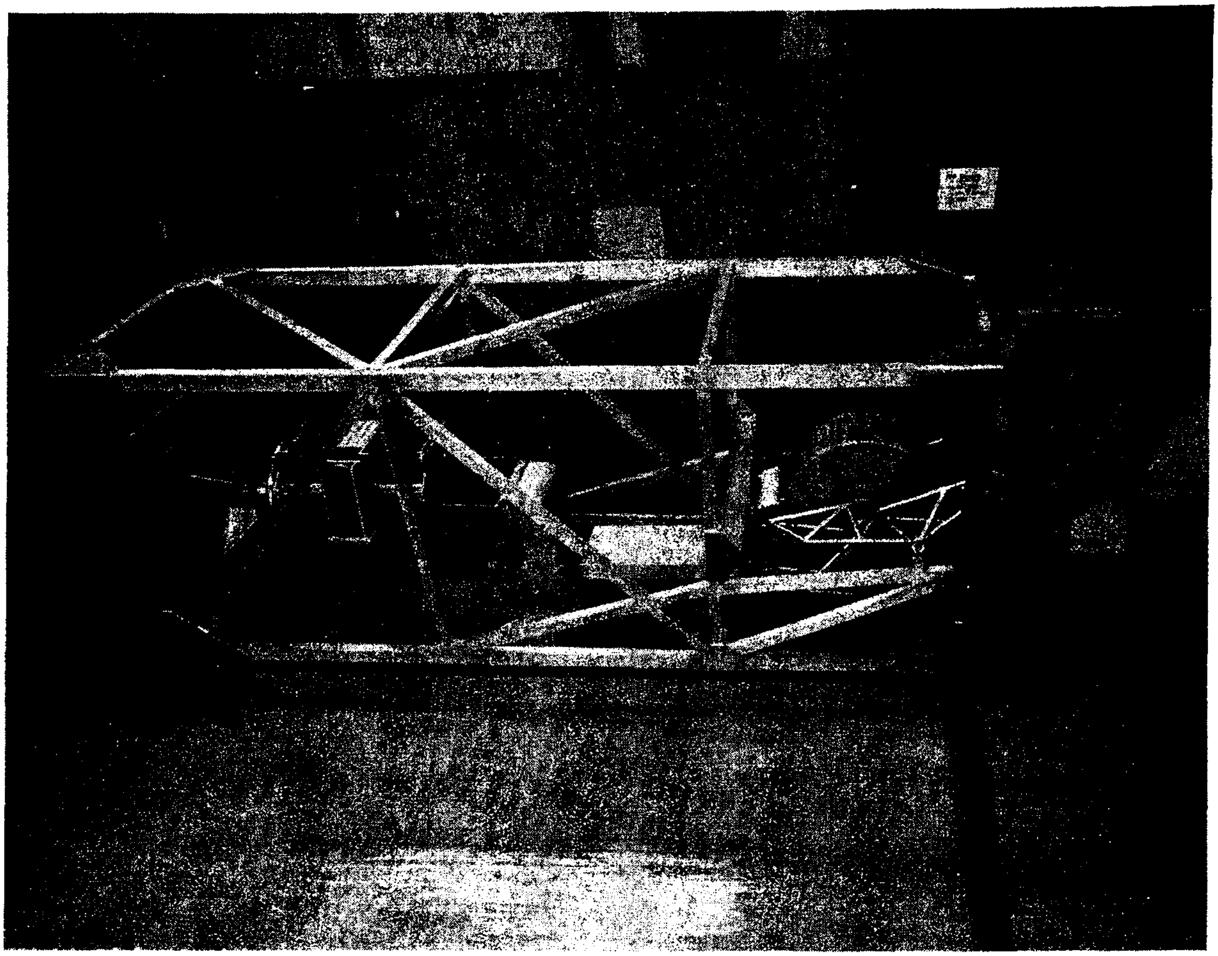


Figure 4.5-15. Film Transport System Engineering Model

Film Tension Looper Assembly. The film-tension looper assembly consists of a tension looper and an instrumentation circuit to monitor film tension. The function of the device is to supply an analog signal which is related to film tension and the time rate of change of film tension. The signal is used as an input to the film handling electronics which control the motor contained within the primary supply assembly.

Film Velocity Sensor. The film-velocity sensor outputs an analog voltage proportional to the film velocity. The voltage is then compared with the voltage which would exist if the film were traveling at its ideal velocity.

The difference in the two voltage values is used as an input voltage to the drive mechanism to adjust actual velocity to more nearly match the ideal velocity.

4.5.2.3.3 Film Transport Test Results. The film transport system test set is shown in Figure 4.5-16. EM test data analysis of the film transport assembly has verified that all operational conditions can be maintained within specified limits. There are no degrading effects produced as a result of the positions of the film transport system. Therefore the presence of gravity is not considered essential to operation and conversely it can be assumed that gravity will also not produce any degrading effects.

Film tracking was measured at the entrance to the camera. Lateral displacement did not exceed 0.015 inch throughout a full mission length of film.

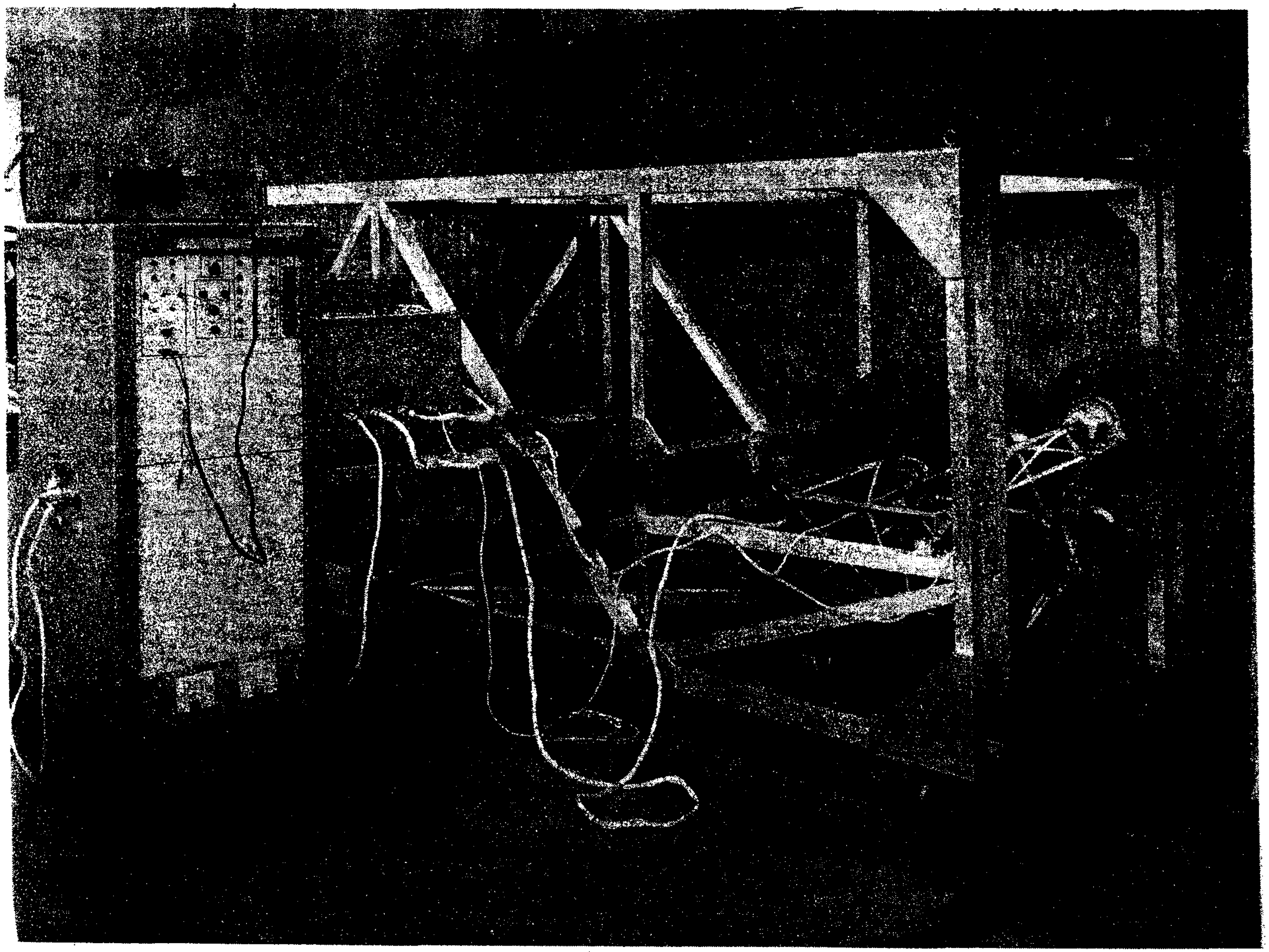


Figure 4.5-16. Film Transport System Test Setup

Also, misalignment of the camera, with respect to the LM mounts of the film transport specified limits in all three axes (to simulate vehicle thermal bending), did not alter the film tracking.

Preliminary tests of power interruption indicate a controlled stoppage of all film and reel motions. Film tension did not exceed the specified limit of 4.0 lb during this test. The nominal tension is 3.25 lb. Normal operating tension was measured consistently as 3.25 ± 0.05 lb.

All film transport system tests were performed using a simulated camera (Figure 4.5-17) which produces film advance and looper position signals similar to the prime camera. However, inertias of moving parts are somewhat different and a full acceptance test of the film transport system must use a prime camera rather than a substitute.

Tests were also performed in a helium/oxygen atmosphere with no change in performance and no materials degradation.

Light-leak tests showed a few minor instances of light fogging caused by an insecure or inadequate light lock labyrinth between housings sections but corrective design changes were made.

4.5.2.4 Secondary Film Handling External to the Camera. The secondary film is supplied in five supply cassettes each of which holds a nominal 10-lb film load. There are expected to be four film types: 10 lb of

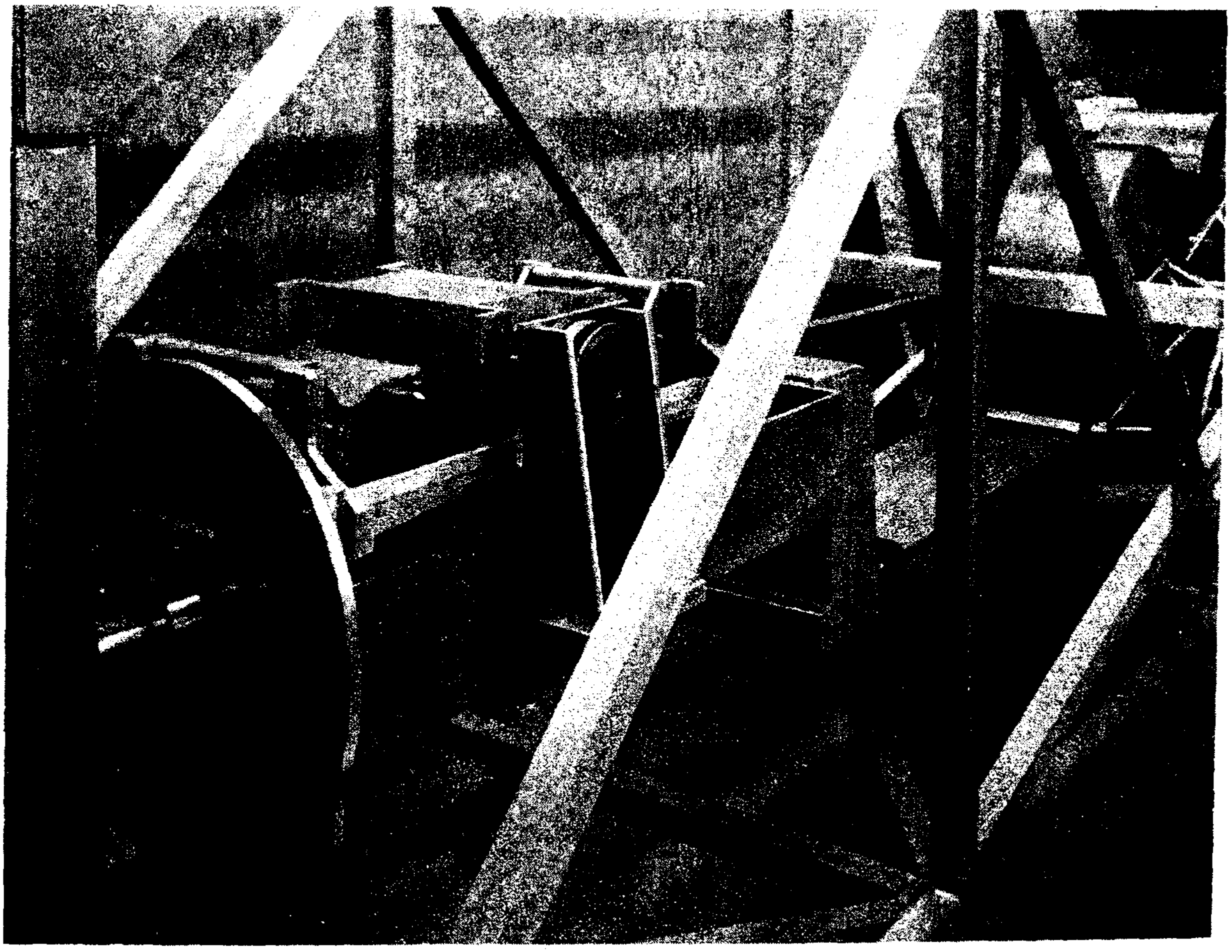


Figure 4.5-17. Simulated Camera

infrared-color film, 10 lb of high-speed black-and-white film, 10 lb of color film, and two 10-lb loads of black-and-white film for on-board processing. These films are stored, both before and after exposure, in the LM until the end of the mission when they are transferred manually to the Gemini B. The handling which these films receive while in the LM varies according to film type.

The film flow for the on-board processed film is shown in Figure 2.6-1. The film supply cassette and take-up cassette are mounted to the camera and the film is manually threaded to the take-up. Secondary film exposures are made until this take-up cassette contains up to 50 feet of film. Next, this cassette is replaced by another one and hand-carried to the processor. After processing is completed, the film is hand-carried to the viewer. Capability will exist at the viewer to spool the film onto one of three DRC reels which nominally hold 6 2/3 lb of film. As a batch of processed film comes off the spooling device at the viewer, it is wound over the previous batch until the reel is full. The full reels are stored in the LM until transfer in a secondary DRC to the Gemini B.

The other secondary film types are each handled as a supply cassette/take-up cassette pair; that is, until completion, the supply cassette remains connected to the take-up cassette by a short length of film. When one of these film types is to be used in the camera, the appropriate supply cassette and take-up cassette are removed from storage in the LM, and mounted to the camera. The film attaching the two is threaded into the secondary camera magazine. About four and one-half feet of film will be exposed to the LM interior lighting during each change of film types and will not be used for photography. Including the on-board processed film, it is estimated (for design purposes) that there may be 25 changes of the four secondary film types during a thirty-day mission.

The other three reels of special secondary film types will be manually removed from the full secondary take-up cassette and placed into a secondary DRC.

4.5.2.5 Data Return Containers (DRC). DRC's are required to provide a means for returning exposed and processed film in the Gemini B. Their size and shape is dictated by space availability and their mountings must be strong enough to withstand recovery impact forces.

There will be a total of five DRC's of three configurations and three mounting plates. Each set consists of three identical primary DRC's with mounting plates and two dissimilar secondary DRC's. Space will be provided in the LM for storage of the DRC's during launch and during the mission. DRC's will not be in the Gemini B during launch. The primary DRC's are configured to accept the spool of the primary take-up assembly. One flange of the spool is constructed with a set of protruding tongue and groove type ways which slide into and mate with the primary DRC mounting plate. The mounting plate is permanently fastened to the Gemini B. The flange of the take-up assembly spool also mates with a lighttight cover which is fastened to the spool by a barrel-clamp/handle assembly. The handle will be used for manual transport and also serves as a device to securely lock the DRC to the mounting plate in the Gemini B. Three primary DRC's will be recovered, one in each of the two Gemini B foot wells, and the third mounted to the center beam between and aft of the position of the crew's helmets.

Two secondary DRC's will be provided and will be stored between and aft of the crew's seats. Each of these DRC's will contain three spools of film. The upper secondary DRC will hold three secondary take-up spools which will be removed from the secondary take-up cassettes. The lower secondary DRC will receive three smaller (5-inch diameter) spools on which processed film will be wound.

The total return capability of the DRC's is 230 lb of film.

4.6 ENVIRONMENTAL CONTROL

Environmental control equipment protects the PP optical assembly and LM components from experiencing temperature, pressure, and humidity changes which could degrade performance. The environmental requirements and design approaches for prelaunch, ascent, and on-orbit conditions are presented in the following paragraphs.

4.6.1 Prelaunch

4.6.1.1 Requirements. There are two periods during which the MM must be thermally controlled: (1) the two-to three-month period from OV assembly and erection on the Titan III M, until roll-back of the mobile environmental shelter (MES), which occurs approximately 1-1/2 hours before launch; (2) the 2-1/2 hour (maximum) period when the vehicle is exposed to the ambient launch-pad environment. This period extends from MES roll-back until a lift-off or a launch scrub.

The responsibility for the design of the MM ground-conditioning system is divided between EKC and GE as described in Section 3. EKC defines the air-weight flow rates, temperatures, pressures, and humidity requirements for the MM aft section. The venting areas and locations needed to ensure an adequate design are worked out with the associate contractor. The associate contractor is responsible for the conditioning requirements for the TM enclosure and equipment racks, and for providing the conditioned air for the entire MM. LM ground conditioning is the responsibility of another associate contractor. EKC provides the LM equipment requirements. The environmental control equipment of the MM must control the temperature of the OA such that within five hours after lift-off the OA, with the view-port closed, remains within the following thermal control range specification:

> Large fused-silica mirror-temperature differentials must be less than 0.1 F, front-to-back and less than 0.25 F, radially. Smaller fused silica folding mirrors' temperature differentials must be less than 0.2 F, front-to-back. The OA must be maintained isothermal within about 2 F in the range of 70 ± 5 F.

The purpose of prelaunch conditioning is to permit on-orbit thermal stabilization in time for the first photographic operation.

The environmental control equipment must be the sole source of air flow into the OA to prevent any influx of contaminants. Clean-room conditions must be maintained for solid-particle control. Condensible oils and volatiles present in the inflowing air must be controlled such that they do not degrade the optics or thermal control surfaces.

The environmental control equipment must prevent condensation of water vapor inside the MM. Conditioned air must have a moisture content no higher than 23 grains per lb of dry air. The PP components in the LM are protected by the operation of associate contractors' coolant, cold plate, and atmospheric conditioning systems.

4.6.1.2 Design Approach. Ground conditioning is accomplished in the MM through the use of ground-powered flight heaters which are located in the MM, MM-internally directed conditioned air, and an environmentally controlled MM shelter, the MES. During the period from erection of the OV on the Titan-III M until MES roll-back, the MM ground conditioning is accomplished by controlling the MES environment to 65 ± 5 F and trimming the MM interior to 70 F through the use of the flight heaters. During this period, there is no air flow inside the MM. During launch-pad exposure of the MM, from MES roll-back until a lift-off or a launch scrub, ground conditioning to 70 F is accomplished through the use of MM internally-directed conditioned air and the flight heaters. This temperature is selected because all lens grinding, polishing, and assembly operations are performed at a temperature very near the final use temperature.

Contamination control is accomplished during manufacturing and assembly by maintaining areas such that they do not degrade optics or MM components. Where it is impractical to maintain large areas at the correct cleanliness level, special tents, covers or smaller clean areas will be used. During storage, shipping, and handling of optics or MM components, special handling equipment and containers were designed to ensure the appropriate cleanliness. When the MM is on the pad, with air circulating within, contamination will be controlled by filtering solid-particle contaminants from MM internal air. Intake locations for internal air will be remote from contaminant sources so that oil and volatile contamination is reduced to a level which will not degrade optics or MM components.

4.6.1.3 Hardware Description. Figure 4.6-1 depicts the ground conditioning concepts. The OA is equipped with 84 flight heaters which are used during ground conditioning. The heaters are capable of supplying 5 watts per heater. Approximately 250 square inches of vent area is provided near the field break, Station 345, for ground venting.

All the MM air enters near Station 500 and is distributed in the TM enclosure by an internal duct. Distribution of the air in the MM is accomplished by correctly matching the flow resistances of the air flow paths from the TM enclosure down the lens tube through the OA end cap to the OA-MM annulus, and forward to the overboard vents. The remaining air flows from the TM enclosure through the radiation barrier-annulus flow restriction to the overhead vents. These flow paths are shown schematically in Figure 4.6-1. Part of the PP-allocated air is ducted into the OA hood section for conditioning the Ross elements and electrical equipment located on the Ross hood.

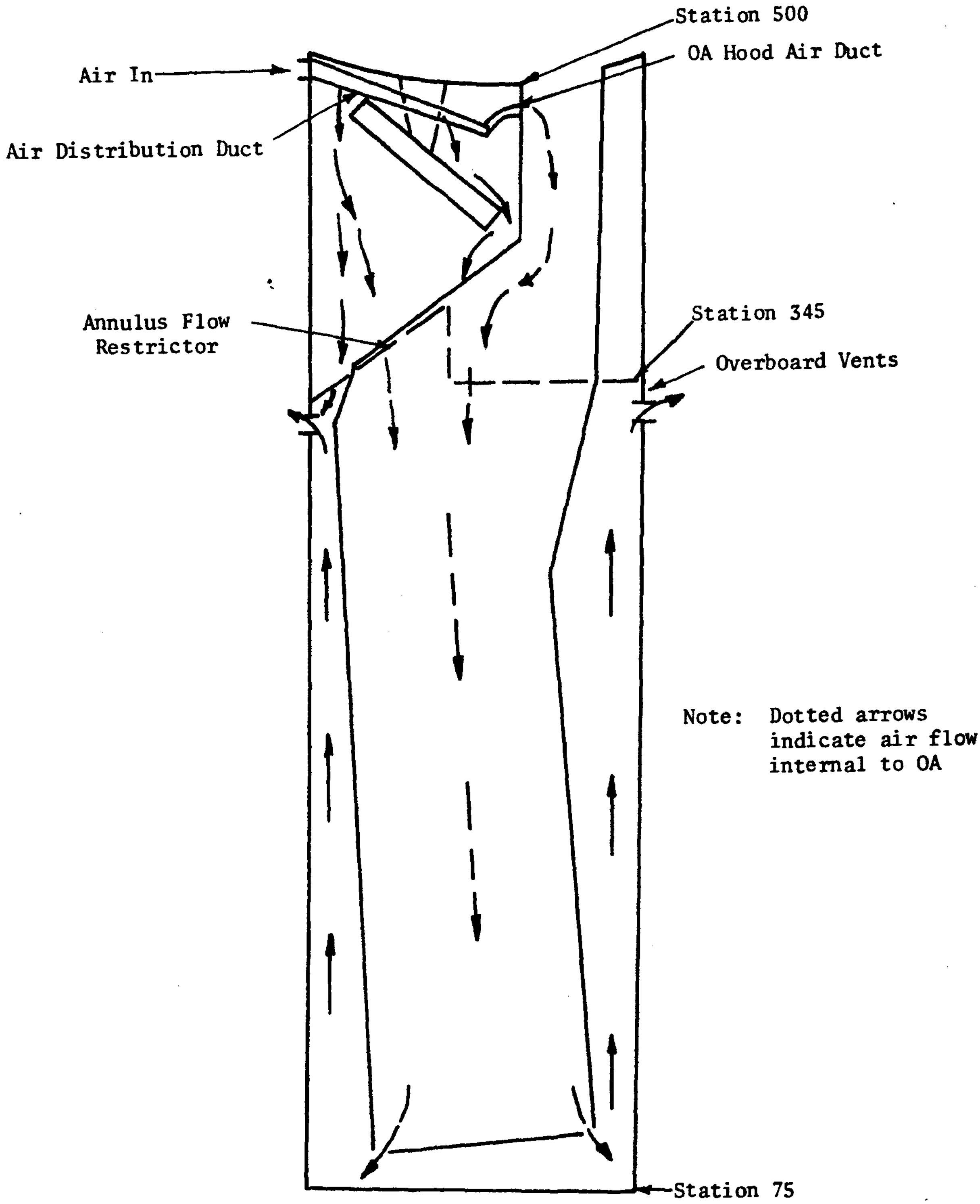


Figure 4.6-1. Ground Conditioning System

To achieve a temperature level of 70 ± 1 F within five hours after lift-off, a procedure for ground conditioning was established which requires that prior to launch minus 14 days, the MES is controlled to 65 ± 5 F, and flight heaters are used to trim the system to 70 F. From MES roll-back until the inlet air duct is disconnected from the MM, air at 70 ± 1 F is blown through the MM at 370 lb/minute.

Calculations indicate that this design will adequately meet the requirements. To prevent the migration of external air into the OA, the pressure within the OA must be greater than the static wind loading on the side of the OV.

4.6.2 Ascent

4.6.2.1 Requirements. Over-all ascent venting of the MM and the LM are the responsibility of an associate contractor. The PP contractor's responsibilities include venting for his own closed assemblies such as the Ross barrel, camera, film handling assemblies, and processor. Detailed interfacing is needed to ensure the safe venting of PP equipment and compatibility with the ground-conditioning concepts, because the resultant design controls the air flow in both cases.

The size and location of vents must permit air flow fast enough to prevent explosion, but slow enough to prevent damage to delicate parts such as thermal blankets. The design also must permit repressurization so that parts will not be damaged during ground tests in vacuum chambers. The vents must also be correctly designed to ensure required cleanliness levels within the MM and its parts. During launch and ascent, the environmental control design must provide sufficient venting of the OA to prevent physical damage from the pressure differential which builds up between the air within the OA and the atmosphere outside. The maximum rate of drop of external pressure which must be accommodated is 800 mm of Hg per minute. In addition, the OA must be adequately protected from the ascent temperature extremes on the outer MM skin.

The OA thermal control must afford protection from the ascent heating pulses expected on the MM skin. In the vicinity where the bow shock waves from the T-III M state 0 solid rocket motors impinge on the MM skin, ascent temperatures are currently predicted to reach about 500 F.

4.6.2.2 Design Approach. The OA thermal insulation blankets, made from thin, low heat-capacitance Mylar, with a maximum service temperature of only 250 F, must be protected in the bow shock area from the high radiant-energy pulse. This is done with outer-blanket layers made from thin aluminum foil, separated by a glass cloth material.

The OA thermal insulation blankets are perforated to permit venting during ascent. The camera, film-handling equipment, electronic packages, Ross barrel, and primary mirror are vented by correctly located and sized ports. Except for the electronic packages, vent ports are filtered to protect against contamination during storage and handling of the components.

4.6.3 On-Orbit

4.6.3.1 Optical Assembly.

4.6.3.1.1 Requirements. Once orbit is achieved, the environmental control equipment must provide a stable and uniform temperature field for the OA.

EKC provides thermal control for the MM aft of Station 345, including the complete OA, and specifies temperature requirements to an associate (see Figure 4.6-2). OA temperature-control requirements include isothermal temperature-level change from an initial point of best focus; and temperature differentials which may exist between any two points in the OA. The isothermal temperature giving best focus is set at 70 F. The allowable isothermal temperature level variation from this point is ±5 F for the OA.

The currently identified allowable temperature differentials across or through the various mirrors are as follows:

		Fused Silica	Titanium Silicate (ULE)
a.	through Newtonian mirror	0.2 F	0.5 F
b.	through Ross folding mirror	0.2 F	0.5 F
c.	through primary mirror (front to back)	0.1 F	0.25 F
d.	across primary mirror (radially)	0.25F	0.6 F

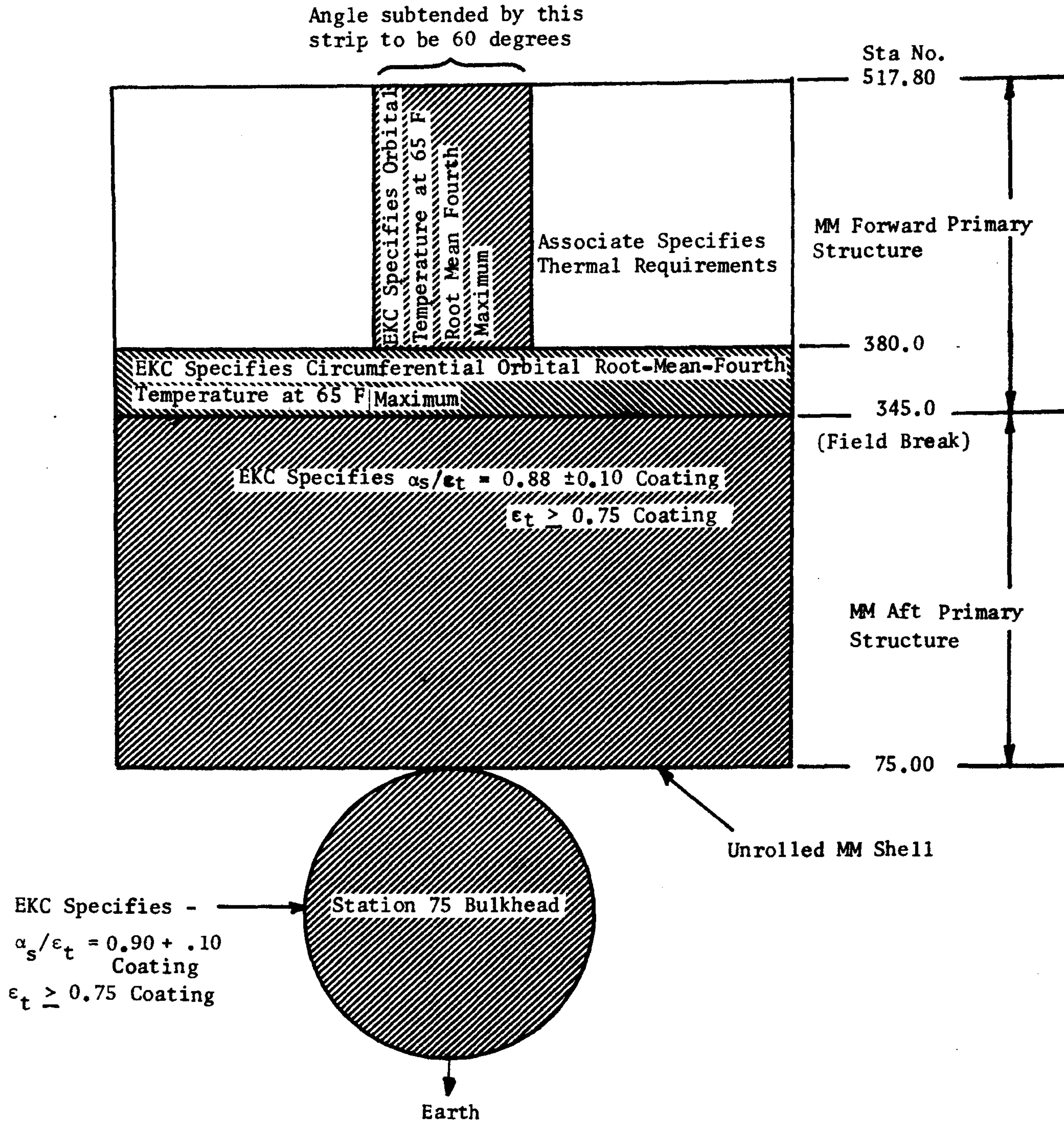


Figure 4.6-2. MM Shell Thermal Requirements

The values for fused silica are based on 1/10λ criteria, and are within the state-of-the-art of temperature control; but if the maximum differentials occurred simultaneously, OA performance would be out of specification. The values for titanium silicate are based on a 1/40λ criteria, which will result in satisfactory OA performance even if they occur at the same time.

Requirements for MM shell temperature control are based on allowable thermal bending of the shell (hotdogging), OA temperature-level requirements and side-to-side OA temperature-differential requirements.

The minimum allowable hotdogging radii of curvature for the MM shell are:

a. In XZ plane (pitch) 17,000 inches
b. In XY plane (yaw) 15,000 inches

All reference to titanium silicate or Cer-Vit presupposes that the coefficient of expansion of the selected material is less than or equal to 0.05×10^{-6} in/in C.

4.6.3.1.2 Design Approach. The temperature of the MM shell will be controlled by applying external and internal thermal control coatings. Two coating configurations for the outside were studied: one having an emittance of 0.25, the other having an emittance of 0.75. Both configurations have a solar absorptance/infrared emittance (σ/ε) ratio of 0.88 ± 0.10 for the cylindrical portion of the MM aft shell (aft of Station 345). The results of this study show that the thermal hotdogging in either case is well within allowable limits. Table 4.6-1 shows hotdogging radii for ε=0.75, the worst case, compared to allowable limits. The coating with the emittance

$\geq$ 0.75 was selected because of the higher probability of achieving the narrow tolerances on σ/ε. Minimizing the tolerances on σ/ε reduces the environmental power requirement. The orbit root-mean-fourth temperatures versus beta angle and coating tolerances are shown in Figure 4.6-3. Skin temperatures for $B = 60^{o}$, $\sigma/\varepsilon = 0.88$ versus orbital time for the various nodes are shown in Figure 4.6-4.

TABLE 4.6-1

THERMAL HOTDOGGING

	Minimum Radii of Curvature, Inches	
	In XZ Plane (Pitch)	In XY Plane (yaw)
Requirement	17,000	15,000
Worst-case predicted	64,000	30,000

The Station 75 bulkhead external thermal control coating has an σ/ε of 0.90 ± 0.10 with $\varepsilon \geq 0.75$. The emittance of the internal surface of the bulkhead is 0.10 which minimizes temperature oscillations transmitted to the blankets on the COA end cap.

A thermal annulus, averaging 18 inches in width, is formed by the internal surface of the vehicle skin and the outer surface of the thermal blankets on the optical assembly. This annular cavity provides the desirable effect

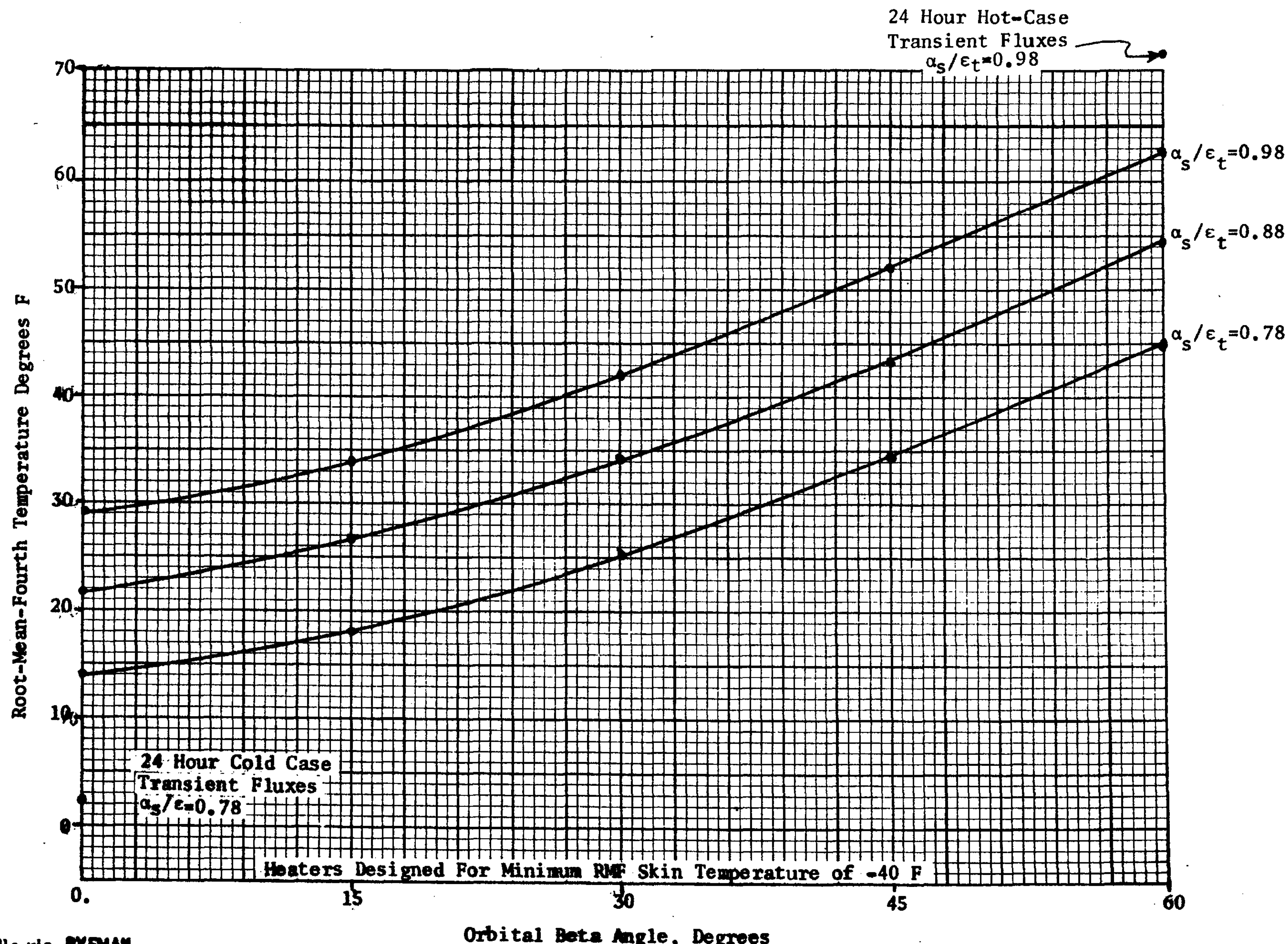


Figure 4.6-3. Operating Temperature as a Function of Beta Angle and Coating Properties ϵ=0.84

of permitting radiant energy emitted by warmer portions of the skin to pass to cooler portions of the skin by direct radiation and multiple reflection from the highly reflective specular surfaces of the thermal blankets. This reduces the variation in temperature around the vehicle skin. The effectiveness of the annulus is a function of its inner and outer surface characteristics. If both surfaces are of low emittance (and preferably specular) the circumferential temperature variation around the outer surface of the OA insulation blankets is minimized. If the inner surface of the aft MM shell has high emittance and the outer surface of the OA insulation blankets has low emittance, the circumferential temperature variation (and thus the thermal distortion) around the aft MM shell is minimized.

A study of relative movement between the OA and the MM shows that hot-dogging of the external shell (Figure 4.6-5), with a low emittance coating on its internal surface, does not present any interference problems. However, the average temperature variation circumferentially around the outer blanket layers, as seen in Figure 4.6-6 is greatly reduced with the low emittance coating on the interior of the MM shell. This reduced temperature variation on the outer blanket layers reduces the variation around the lens tube (limited to 2°F side-to-side to prevent thermal bending of the lens tube).

The thermal blankets present a high radiative resistance between the heated OA structure and the external MM shell. The thermal blankets also have a high damping coefficient which reduces thermal variations transmitted to the OA structure. Thermostatically controlled heaters on the OA structure supply the power required to maintain the OA within design temperature limits.

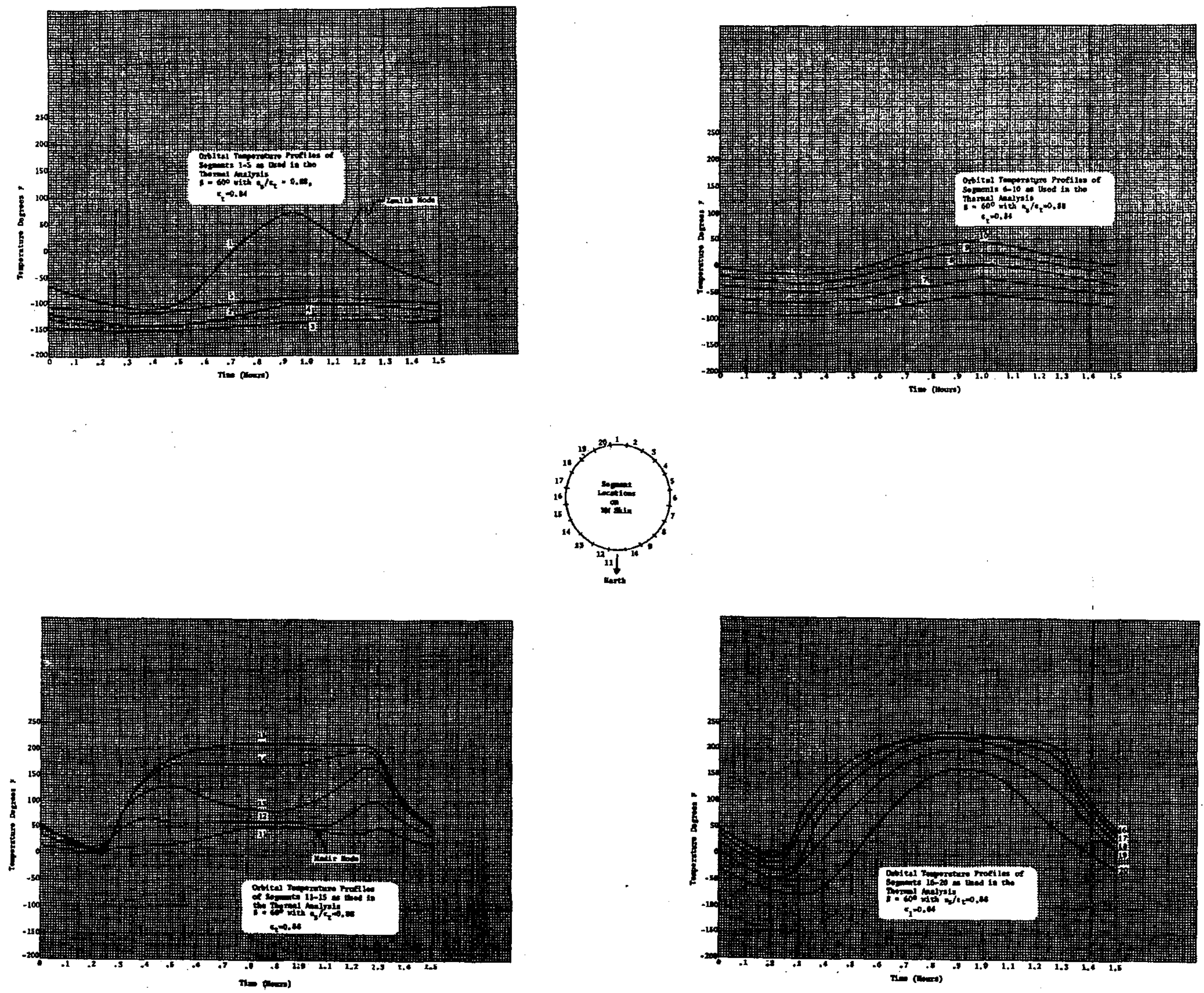


Figure 4.6-4
Orbital Temperature Profile

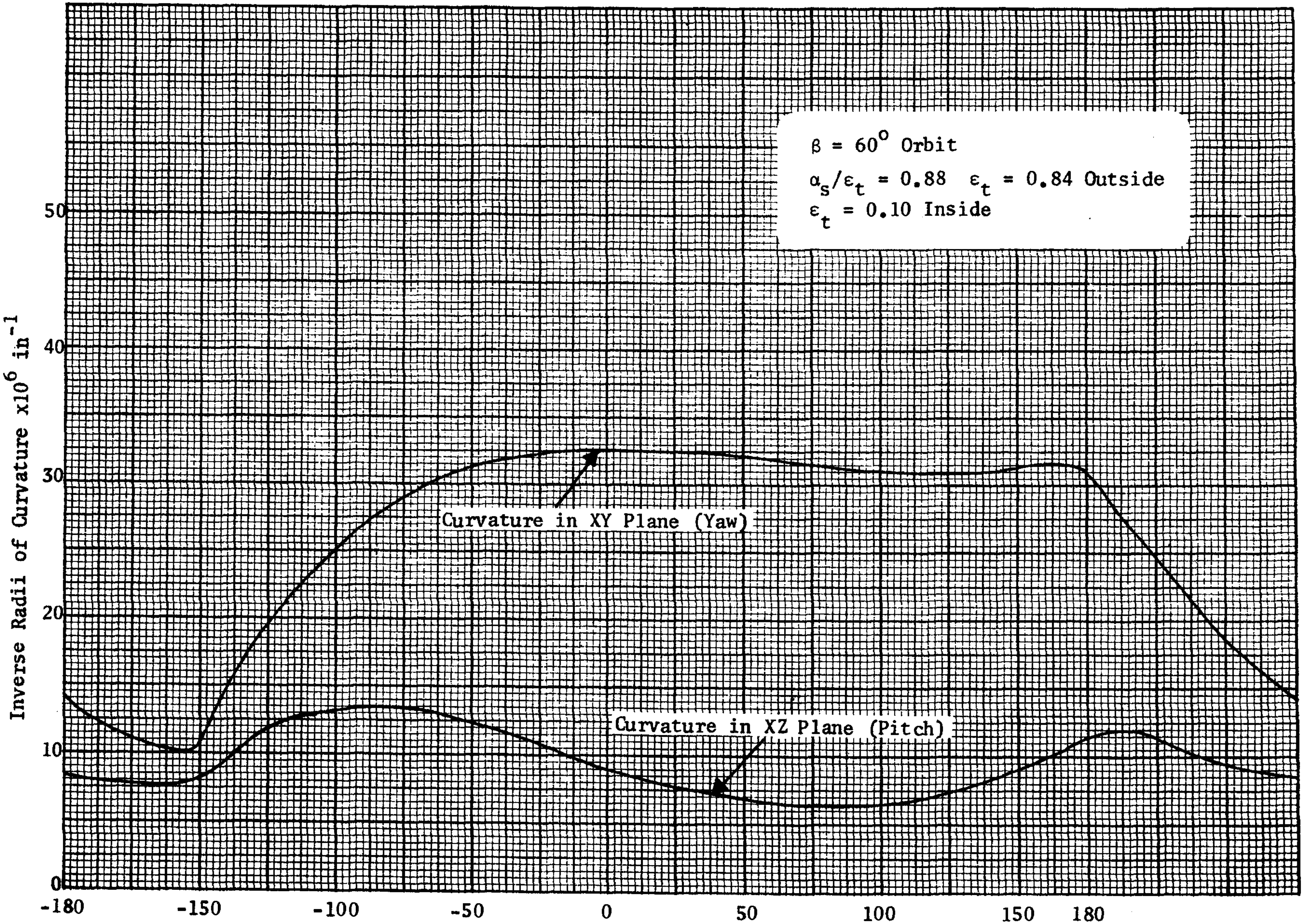


Figure 4.6-5. Hotdogging Curvatures

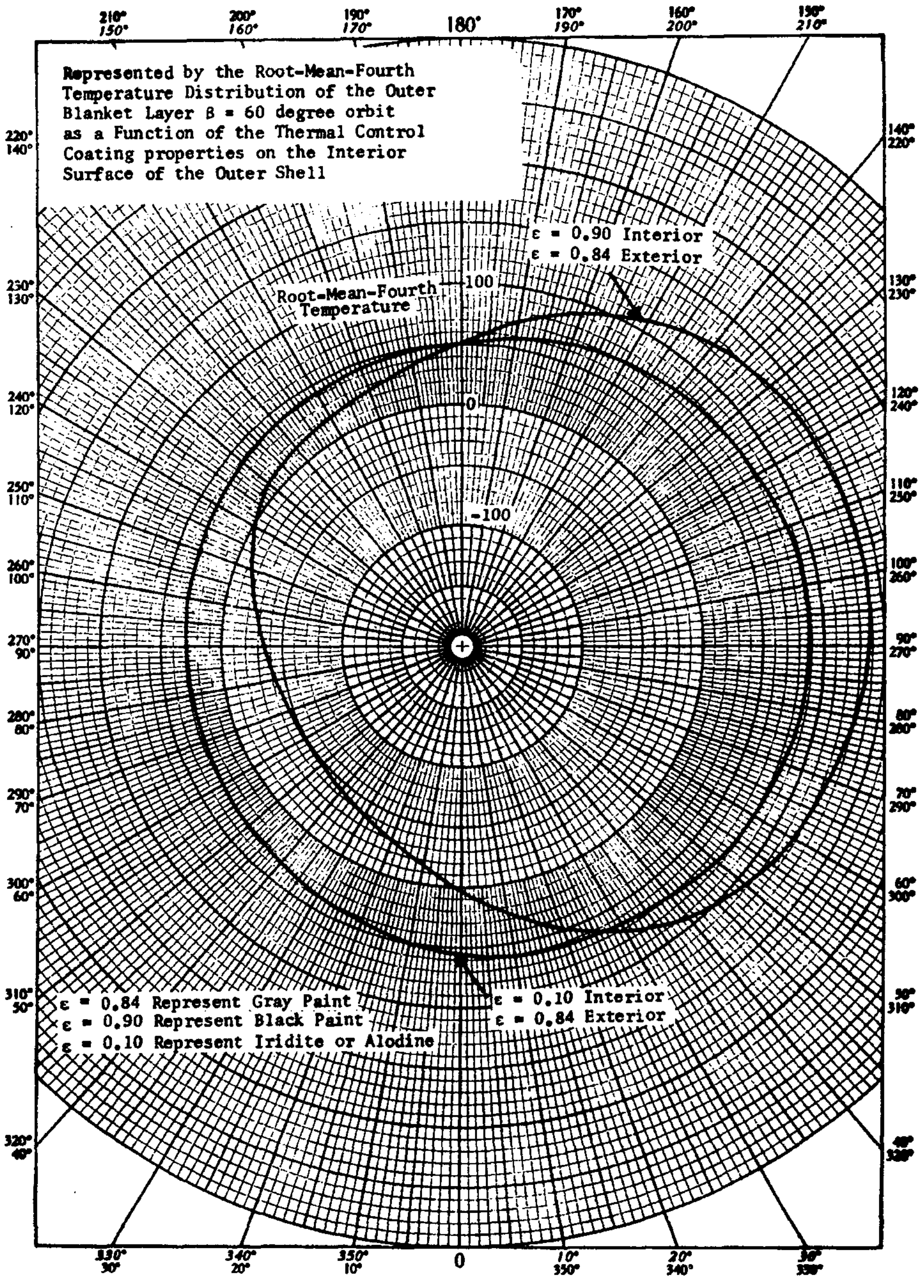
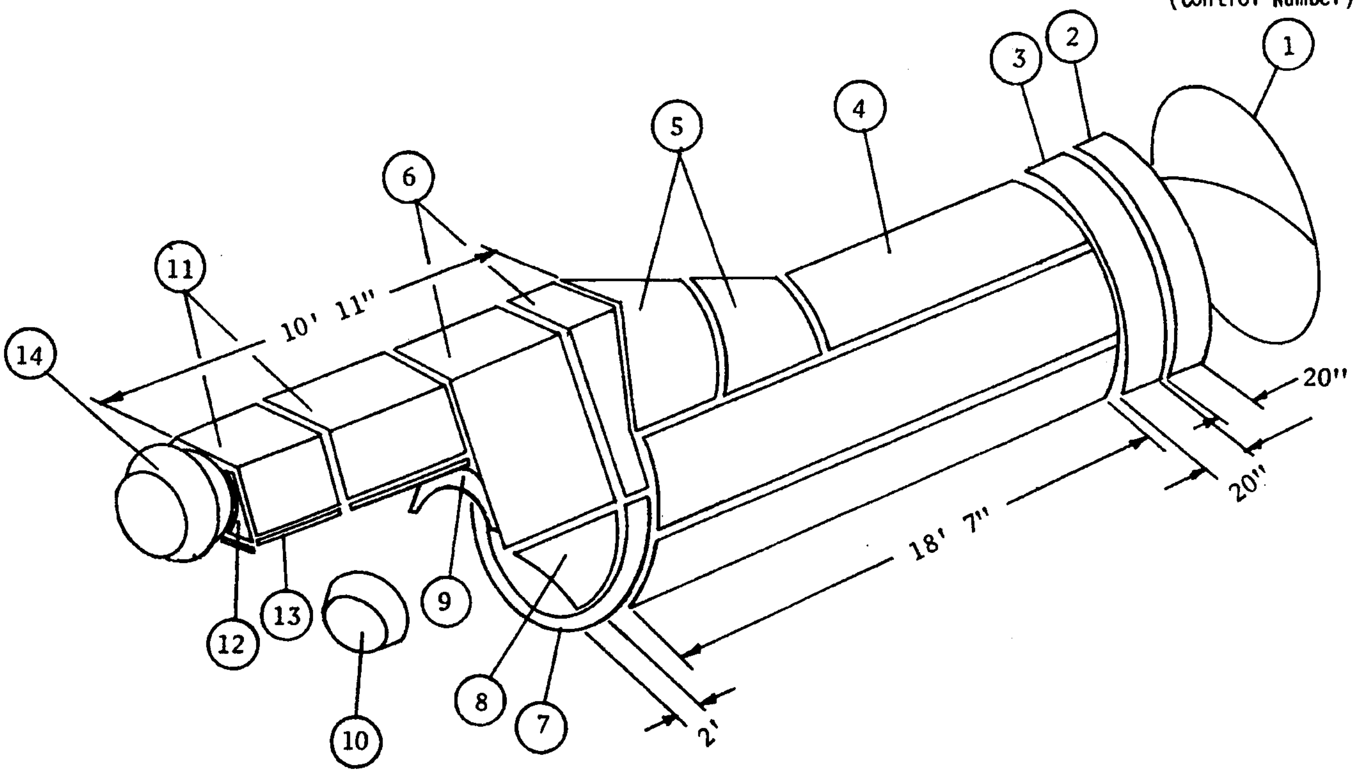


Figure 4.6-6. Damping Characteristics of the Thermal Annulus

4.6.3.1.3 Equipment Description. Coating parameters as defined by EKC are shown in Figure 4.6-2. Temperature requirements for areas coated by associates, with temperatures specified by EKC are also shown on this figure. McDonnell Douglas Astronautics Corporation (MDAC) has picked a potassium-silicate base coating for the external thermal control coating, with patches of a silicone-base material applied in sheet form to conform to the skin corrugations in the areas affected by the secondary rocket motor (SRM) bow shocks. MDAC has provided EKC data demonstrating the long-term stability, of the reflective properties, of this potassium-silicate coating under orbital conditions.

The radiative thermal resistance between the external MM skin and the optical assembly is provided by the thermal blankets shown schematically in their relative positions in Figure 4.6-7. These blankets are made up of about 50 layers of 1/4-mil-thick aluminized Mylar, dimpled to increase thermal contact resistance between layers. Outer and inner layers are thicker for durability. All layers are perforated, permitting venting of entrapped air. The blankets are built up to a thickness of about 0.6 inch. Because sheet widths are manufacturing limited by the vendors and could present handling problems, the blankets are assembled in sections, with seam lengths being minimized. Blankets are fastened to the OA structure with Velcro tape. A high thermal resistance path, via conduction, between the OA and the skin is provided by the three COA mounts.

Because the maximum average skin temperature is 63 F, and the nominal temperature of the OA is 70 F, there will be a net heat flow out of the vehicle, which must be made up by electrical strip heating elements. These heater strips are bonded to the OA in the pattern shown in Figure 4.6-8.



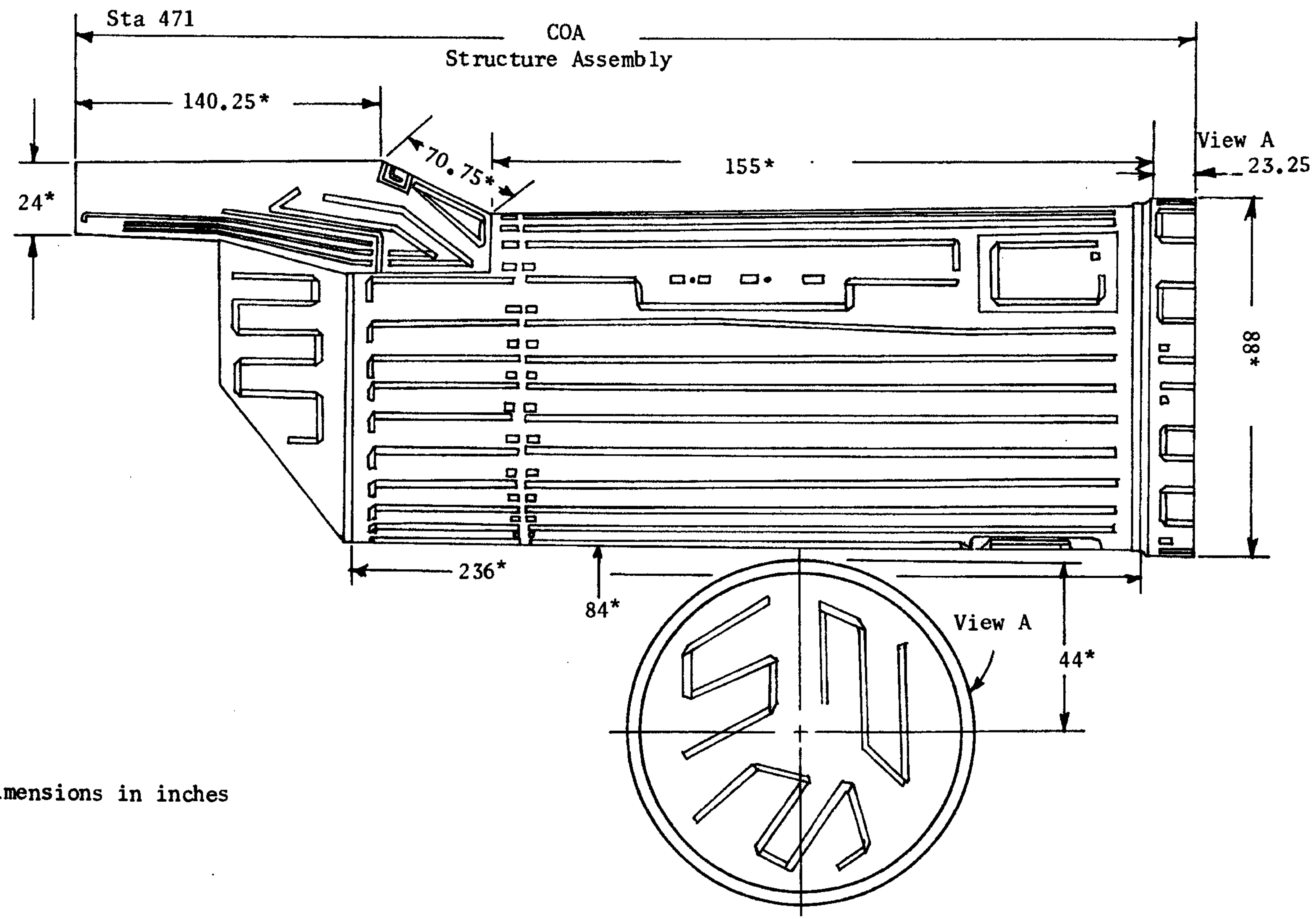
Major Blanket Assemblies

COA Bay Bkts 1 2 3 4 5
Ross Corrector Bkts 6 11 12 13 14
Mirror Support Bkts 7 8 9 10

1. End Cap Bkt*
2. Primary Mirror Barrel Bkts
3. Primary Mirror Transition Bkt
4. Barrel Bkts
5. Hood Bkts
6. Ross Corrector Transition Bkts
7. COA Transition Bkt to Mirror Support
8. Mirror Support Barrel Bkts
9. Mirror Support Cap Bkt
10. Newtonian Mirror Bkts
11. Corrector Bkts
12. Corrector End-Cap Bkts
13. Corrector Underpanel Bkt
14. Corrector Bellows Bkt

* Bkt = Blanket

Figure 4.6-7. Blanket Assembly Configuration



* Dimensions in inches

Figure 4.6-8. Heater Strips in Close Contact with the OA

The strips are covered by the thermal blankets. The nominal heater-control set point is 70 F. Reliability is achieved through the use of many small (6 watts or less) redundant heaters. The maximum orbit average heater power has been estimated at 195 watts in a β = 0-degree orbit.

4.6.3.2 Tracking Mirror.

4.6.3.2.1 Requirements. The principal figure requirement specified by EKC is that the TM must start a photographic pass with minimum deformation. To accomplish this the temperature of the fused-silica TM must be held to practical design limits, which have been set at 70 ± 0.5 F for the temperature level, 0.1 F for the front-to-back maximum steady-state temperature differential, and 0.25 F for the radial maximum temperature differential. Implementation of these requirements is an associate contractor's responsibility. Control to these levels will still be acceptable for substitute materials of titanium silicate or Cer-Vit.

4.6.3.2.2 Materials and Finishes. To provide the best possible thermal stability consistent with mirror manufacturing capabilities, several mirror materials and optical surface coatings were evaluated. Results of these studies showed that the then current state-of-the-art for low coexpansion mirror materials dictated the use of fused silica for all EKC mirrors. This material has a thermal coefficient of expansion of about $+0.3 \times 10^{-6}$ F. The use of either titanium silicate (ULE) or Cer-Vit for the tracking mirror is now anticipated, with a coefficient of thermal expansion for either material equal to or less than 0.05×10^{-6} C.

The objective of the TM coating is twofold: (1) to raise the reflectance in the photo-sensitive bandwidth (about 0.40 to 0.72 microns) to get as much illumination as possible to the film, and (2) to raise the reflectance of the solar and reflected solar (albedo) bandwidths (solar is about 0.2 to 4.0 microns, albedo is about 0.35 to 4.0 microns) to reduce the flux absorbed by the mirror. Current coatings are made from evaporated high-purity chromium-silver alloy, overcoated with a protective layer of magnesium fluoride and lanthanum oxide. Solar reflectance is 0.92 (+0.01, -0.02). Infrared reflectance is 0.97 (+0.01, -0.02) for earth emission and mirror emission.

4.6.3.3 Effects of a Two Position Door. EKC conducted a study for the Air Force (AF) to determine the thermal effects of a two-position sliding mask, assuming a mirror material with a coefficient of thermal expansion equal to 0.05×10^{-6} C. The following two recommended configurations resulted. Because of the potential reduction in resolution loss, the reduced heater power, and because no external coating change is needed, EKC prefers Configuration B (a three-position sliding mask). However, other MOL system constraints may dictate that Configuration A (the two-position sliding mask) be chosen.

4.6.3.3.1 Configuration A.

a. Description.
   1. Utilize a view-port with minimum area (88 ft^2).
   2. Use a two-position sliding mask.
   3. Reduce the solar absorptance-infrared emittance ratio of the external skin of the MMAS to 0.80 ± 0.08 from 0.88 ± 0.10.

b. Performance Estimate.

1. Predicted resolution loss will be 5 lines/mm maximum on 21 March and 15 lines/mm maximum on 21 June, with the view-port open not more than a total of 36 minutes in any 24-hour period and not more than 10.5 minutes in any single revolution.

2. Environmental heater-power requirements are increased to 206 watts from 195 watts for β = 0-degree orbits.

3. Subsolar heating may be required near 21 December.

4.6.3.3.2 Configuration B.

a. Description.

1. Utilize a view-port with minimum area (88 ft^2).

2. Use a three-position sliding mask to reduce the door area in the nadir view and view angles forward of nadir. (Three positions of sliding mask assumed to be for nadir look.)

3. Maintain the external solar absorptance-infrared emittance ratio at 0.88 ± 0.10.

b. Performance Estimate.

1. Predicted resolution loss is 3 lines/mm maximum on 21 March and 8 lines/mm on 21 June with the viewport open not more than a total of 36 minutes in any 24 hour period and not more than 10.5 minutes in any single revolution.

2. Heater power will remain at 195 watts for β = 0 degree orbit.

3. Subsolar heating may be required at 21 December.

4.6.3.4 Laboratory Module Components. Thermal control of LM PP components is provided by an associate contractor. For EKC components, temperature will be controlled by the use of associate-provided coolants, cold plates, and atmosphere. EKC is providing internal component heat exchangers, specifying requirement for coolant flow, temperature, convection coefficients, power dissipation, and pressure drops for EKC components. All PP electrical boxes will be cooled by associate-provided cold plates, and EKC is providing cold-plate temperature requirements, finish descriptions, and heat loads.

4.7 ON-BOARD PROCESSOR

4.7.1 General

The capability for processing primary film and one type of black-and-white secondary film is provided within the LM in the M/A mode by a processor-dryer unit. This equipment in conjunction with an on-board viewer permits the flight crew to make timely inspection of test photographs to help assess photographic performance.

The processor uses the BIMAT processing method. BIMAT processing consists of laminating BIMAT film with exposed photographic film, and then separating the two films after a mono-bath processing solution has developed and fixed the latent image. The mono-bath solution is contained in the gelatin coating of the BIMAT film and is called the imbibant.

To process film, the flight crew manually transports a cassette of film to the processor, attaches the cassette to the processor, performs preliminary operations including thread-up and initiates an automatic processing cycle. Inside the processor, the BIMAT film is laminated to the exposed photographic film for a length of time which will produce the desired sensitometric properties in the developed negative. After the processing period, the negative is stripped from the BIMAT film. The used BIMAT film is fed to a waste take-up receptacle within the processing unit. The processed negative passes through a drying section so that its relative humidity is reduced to approximately 50 percent. It is then wound on a reel to await use by the flight crew.

4.7.2 Requirements

The on-board processor is required to batch process small samples of the primary film and a larger quantity of secondary black-and-white film. During a 30-day mission, the required processing capability is 43 batches of film; the total quantity of film including leaders and trailers is not to exceed 1,160 feet of secondary film plus 110 feet of primary film. A batch is a continuous splice-free strand of film with a maximum length of 50 feet, including the leader and trailer section of the strand. The total length of the leader and trailer section required for the processor is nominally 6 feet.

Time requirements imposed on the on-board processor include a requirement that the film processing rate shall not be less than 5 inches/minute. It is expected that a batch of film 50 feet in length could be processed in 3 hours including required thread-up and drying operations.

The resolution degradation of film processed in the on-board processor shall not exceed 15 percent of the quality level of the same film and image BIMAT processed on the ground under controlled laboratory conditions.

Space is allocated for the processor in the aft section of Bay 4. The dimensions are 54 by 18 inches.

4.7.3 Configuration

4.7.3.1 Basic Elements. The following subassemblies together perform the required processing functions. Figure 4.7-1 shows the physical arrangement of components and shows the BIMAT film and photographic film paths.

a. Pressure Shell. Encloses the entire processor to provide: (1) a lighttight environment, (2) protection of the BIMAT film from a vacuum, (3) control of contaminants and, (4) thermal and moisture control.

b. BIMAT Film Supply. Serves as a container for the BIMAT film supply spool and provides the correct environment for BIMAT film storage.

c. BIMAT Film Take-Up. Receives and stores used BIMAT film.

d. Processor Drum. Maintains the required time and temperature relationship for the film to BIMAT-film laminate.

e. Film Dryer. Gas impingement dryer, removes excess moisture from the processed film.

f. Film Supply. Provides a lighttight container for the incoming exposed film.

g. Film Take-Up. A removable spool which receives film which has been processed and dried.

h. BIMAT Drive Roller. A driven element which regulates the processing velocity.

i. Electronics Package. A sealed container within the processor which houses all of the electronics required for processor operation.

4.7.3.2 Operation. Primary film is transferred to the processor supply magazine from the primary take-up. This transfer is facilitated by placing the processor supply into a transfer adapter which is attached to the primary take-up station. Secondary film is directly wound into the processor supply at the camera. The filled processor supply is transported to the processor, the processor door is opened and the supply is placed in the correct position.

Film threading is facilitated by three rollers which have alternate positions for threading and processing. With the rollers in the thread position as shown in Figure 4.7-1, the film can be threaded by the flight crew in a straight path between the supply and take-up. Actuation of the three rollers, controlled by switches on the internal control panel, places the film into the correct path for processing.

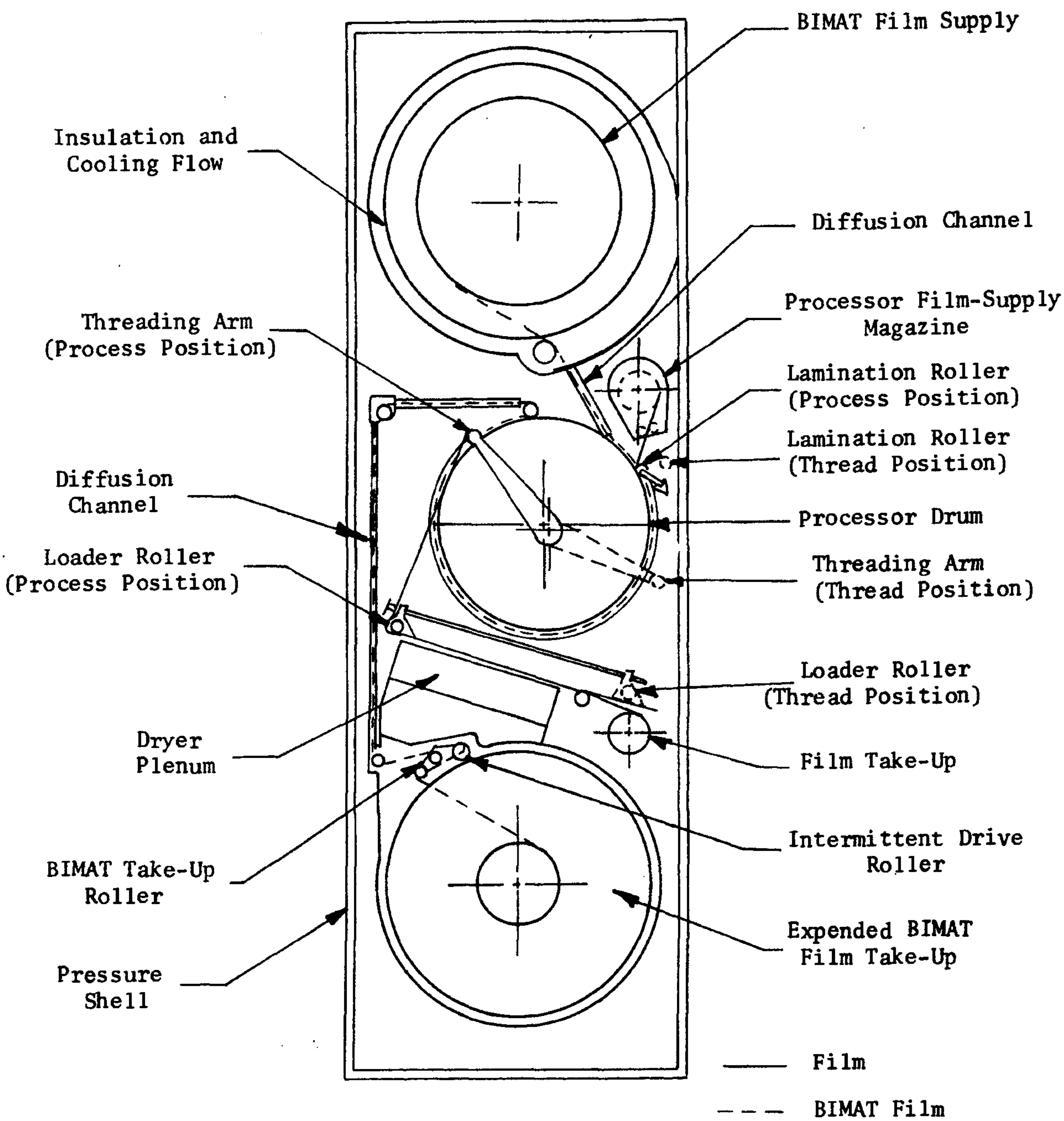


Figure 4.7-1. Side View Schematic of On-Board Processor

The door of the processor is then closed and processing is initiated by depressing a switch on an external display. This display is located in the upper left-hand section of the processor and contains a meter and signal lamps for monitoring the processing cycle. At the end of the cycle, when all of the film is processed, dried and wound onto the take-up spool a signal light is illuminated. A crewman can then open the door and remove the spool for viewing.

4.7.4 Processor Mechanical and Thermal Design

4.7.4.1 Pressure Shell. A pressure shell equipped with inflow and outflow pressure relief valves encloses the processor. The valves open at a 0.5 psi pressure differential. The shell and valves restrict interchange of gases between the LM and processor and maintain a 0.5 psia minimum pressure in the processor in the event the LM is depressurized. The minimum pressure prevents catastrophic boil-off from the BIMAT film and protects the potassium thiocyanate drying pads.

The shell structure is an aluminum-polyvinyl chloride laminate. An access door is provided on the front of the processor. The side surfaces are cooled by on-board coolant circulation.

4.7.4.2 BIMAT Film Storage. To ensure its quality, BIMAT film must be maintained in a high-humidity low-temperature environment from time of manufacture through completion of processing. A single roll of BIMAT film is provided for the mission and is stored within the processor. The storage compartment is maintained within the temperature range of 45 to 60 F by on-board coolant.

4.7.4.3 Diffusion Channels. Diffusion channels are used to partially isolate the BIMAT film supply and take-up compartments from the remainder of the processor interior. They restrict water-vapor diffusion out of the BIMAT film storage compartments which could condense and degrade processing quality. Gaseous contaminants are also restricted in this manner. In addition, dry-out of the BIMAT film supply, with its possible degradations, is averted. Diffusion channels, approximately 0.125-inch high and 10-inches wide, enclose the entire BIMAT film path from the storage compartment to the processor drum.

4.7.4.4 Film Dryer. During the image-development time interval, in which the film and BIMAT film are in contact, moisture is transferred to the film. This absorbed water must be removed from the film to permit subsequent handling. In the film dryer a fan and ductwork circulate processor atmosphere over the phtogoraphic film surface and then through potassium thiocyanate pads. Moisture absorbed by the atmospheric gases passing over the film surface is transferred to the potassium thiocyanate pads. Upon completion of a batch a valve in the ducting redirects the circulating atmosphere over the wet BIMAT film on the processor drum. After 20 minutes the BIMAT is dry and the fan stops. Drying the BIMAT on the drum reduces the humidity in the processor during idle periods and prevents the resultant formation of condensate.

4.7.5 Processor Electrical Design

4.7.5.1 Processor Electronic Equipment. The processor electronic equipment consists of the circuits which control the heaters, motors, instrumentation, and overall functioning of the processor. The processor functions in three modes. In the BIMAT storage mode, only the circuits operate which control the electric heaters for the BIMAT coolant. These heaters maintain the BIMAT film at the correct temperature. In the standby mode the circuits operate which control power flow to the processor-drum heaters in addition to the coolant heater controls. The processing drum heaters maintain the drum at the correct processing temperature. Also, in the standby mode, all other circuits are ready to function whenever a crew member actuates a control switch. In the operate mode both temperature control circuits and the circuits that control the flow of film and BIMAT function.

Electronic circuits provide power to the dryer blower motor, the thermostatically controlled processor drum heater, and the film and BIMAT film take-up torque motors. Regulated voltage maintains a constant speed for processing and constant tension throughout the processor.

4.7.5.2 Processor Controls. The switches and displays used by the flight crew to control and monitor the processor are located on both an internal and an external control panel. The internal panel contains the switches which control the thread-up operation. The external panel contains a toggle switch for selecting the BIMAT storage or standby mode, a momentary contact toggle switch for initiating or halting the operate mode, and the instrumentation displays.

A crewman initiates the processing operation by momentarily moving the OPERATE switch to the ON position. The control circuits energize the equipment necessary for operation, provided that there is adequate photographic film supply tension, the process heater is at operating temperature, and the access door is closed. A crewman can halt the processing operation at any time by momentarily moving the OPERATE switch to the OFF position. In this event the circuits revert to the standby mode. At the completion of the processing operation, the circuits automatically revert to the standby mode.

4.7.5.3 Processor Displays. The processor external control panel is considered an independent entity within the LM and provides signals for diagnostic checks for monitoring operational status, and as alarms for hazardous conditions. Malfunctions or operations beyond design levels are signified by illumination of an appropriate indicator located on the external processor control panel. In addition, where feasible, a meter with switching provides for selecting and displaying actual values of out-of-limit instrumented points. Diagnostic appraisal of the situation can be made and subsequent corrective action taken.

4.8 ON-BOARD VIEWER

A viewer will be provided above the processor in LM Bay 4. The purpose of the viewer is to aid the flight crew in visual analysis of the on-board processed film. A conceptual schematic of the viewer appears in Figure 4.8-1.

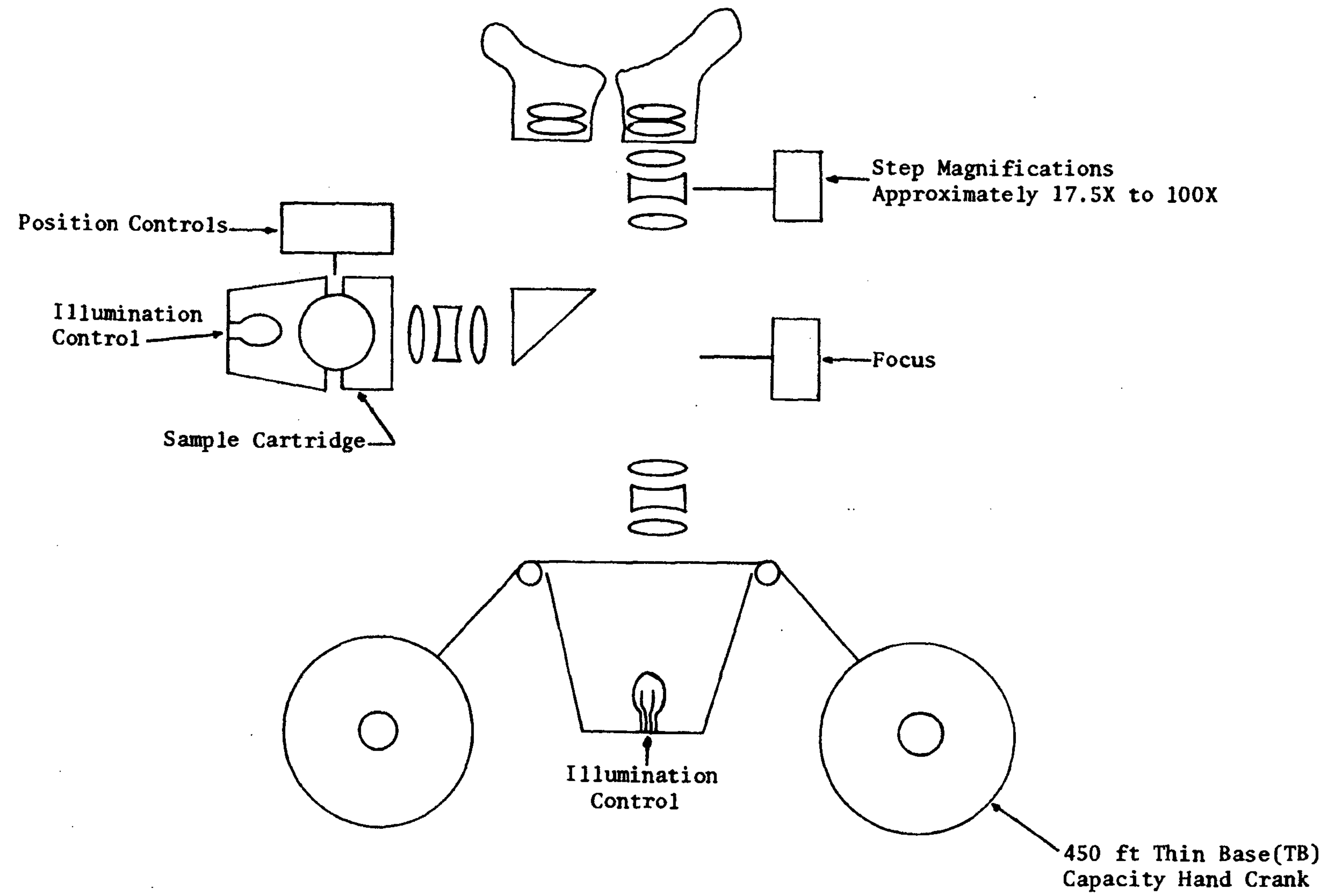


Figure 4.8-1. Concept - Viewer Schematic

The viewer will consist of a diffusely illuminated screen, a comparison, microscope and storage as well as associated handling equipment for processed film.

a. Illuminated-Screen-Light Table. An illuminated table will be used for viewing complete frames of processed primary or secondary film. The light table will have a variable brightness control, and means for low magnification viewing with a fixed-base magnifier. Associated with the light table will be film handling mechanisms capable of splicing film batches together, and winding or rewinding processed film across the viewing screen. The supply side and the take-up side of the film-handling mechanism will interface with the processor take-up reel, and the lower secondary DRC reels respectively.

b. Comparison Microscope. The comparison microscope will consist of a split-field optical system with step magnifications from approximately 17.5X to 100X. The comparison microscope will be for simultaneous viewing while comparing a portion of the processed film to a reference image. The reference film will be supplied in a cassette attached to the microscope. The microscope can also be used to view, at high magnifications, only the processed film.

4.9 ELECTRICAL DESIGN

The function of the electrical equipment is to operate and monitor the status of the PP. The interconnection of the various components is shown in Figure 4.9-1.

The PP receives power, commands, and control signals from an associate contractor's equipment. Associate contractors are responsible for receipt, formatting, and transmittal of EKC instrumentation. Electrical interfaces with associate contractors are summarized in Section 3.

Electrical design details of the EKC-provided flight hardware concerned with power, commands, instrumentation, and EMC control are discussed in the following paragraphs. Details of the EKC-provided electrical flight equipment associated with lens alignment, mirror launch locks, visual optics, camera, film handling, environmental control, and on-board processor are discussed in the sections covering the design approaches to these hardware items.

4.9.1 Power

The OV uses fuel-cell power plants for power generation. These fuel cells are supplied by McDonnell Douglas (MD). All power used by EKC is received from the fuel cells via General Electric Company (GE) interface connections. The distribution, switching and use of various power types are described in the following paragraphs.

4.9.1.1 Primary Power. Primary power (unregulated) in the range of 22.5- to 31-v dc (28-v nominal) is supplied by GE to the LM power unit (LMPU) and the processor in the LM and to the MM power unit (MMPU) in the MM. A d-c power bus is supplied at the PP/GE interface for each PP switched power function. In addition, each mission-critical function except environmental control (that is, alignment, launch locks, camera, film handling, and focus) is supplied with a back-up bus at the interface.

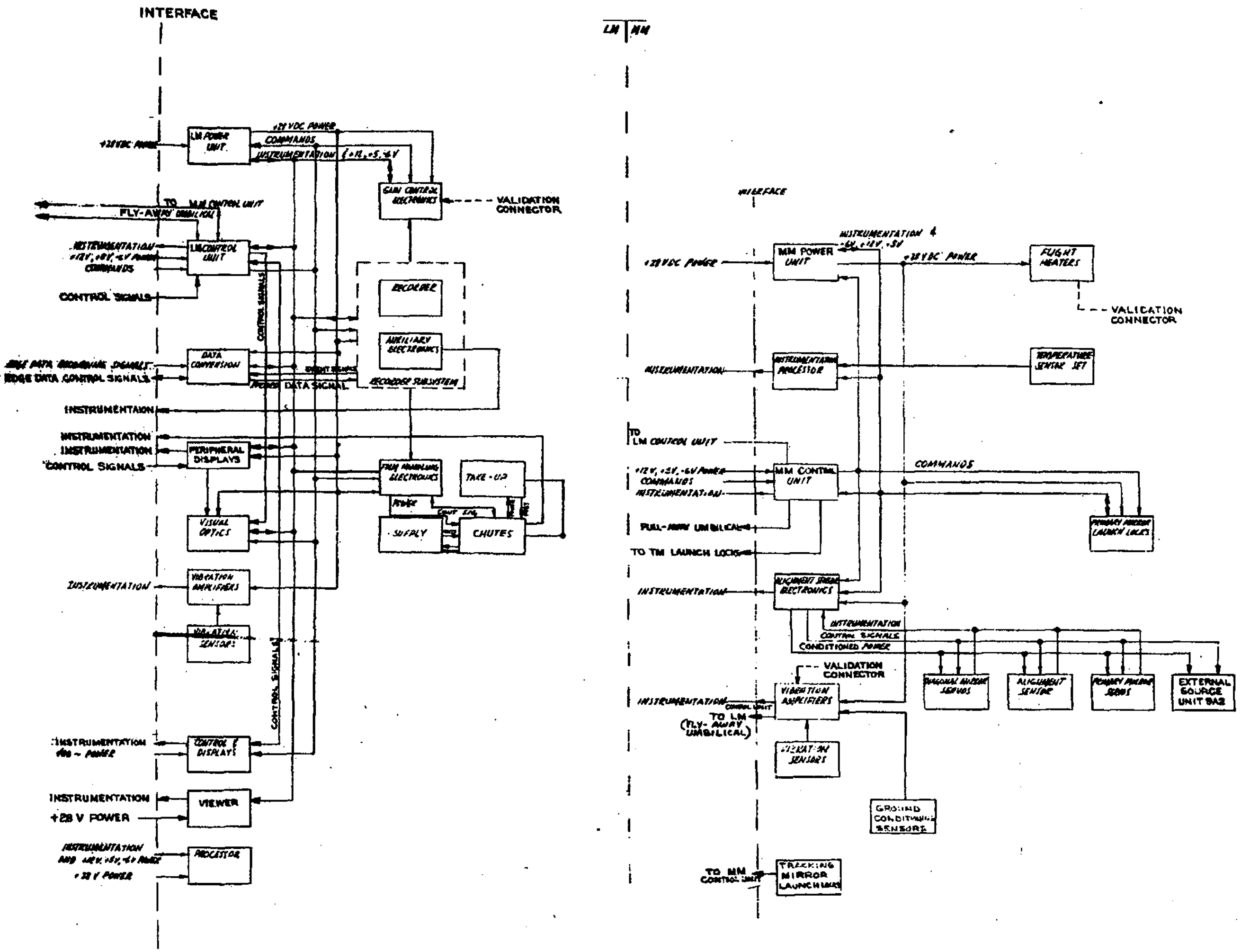


Figure 4.9-1. Electrical System Block Diagram

The environmental control system is supplied with multiple buses such that the failure of a single bus will not be critical. All units receiving primary power at the EKC/GE-AFE interfaces provide transient-suppression networks, voltage-level instrumentation, and manual and/or computer-commandable bus switching.

The power switching technique consists of a transistor switch in parallel with the contacts of a power relay. The transistor is turned ON (or OFF) with a controlled rise (or fall) time by a power command, such that the contacts of the power relay make (or break) the saturation voltage of the transistor, rather than the full line voltage. This technique controls the generation of EMI with minimal use of in-line components such as filters.

In addition to manual switches on the controls and displays panels and processor, the LMPU and MMPU provide independently commandable power switches for the following busses:

Laboratory Module Power Unit (LMPU)

a. (1) LM launch and boost bus (provides power for launch instrumentation).

b. (1) Camera prime bus

(2) Camera back-up bus (provides camera power in case of prime bus failure).

c. (1) Film handling prime bus (also actuates the data conversion unit bus).

(2) Film handling back-up bus (provides power in case of prime bus failure).

d. (1) Focus prime bus (provides power to focus sensor and focus control electronics)

(2) Focus back-up bus (provides power in case of prime bus failure)

Mission Module Power Unit (MMPU)

a. (1) MM launch and boost bus (provides power for launch instrumentation)

b. (1) Unlock prime bus (TM and PM launch locks prime servos)

(2) Unlock back-up bus (TM and PM launch locks back-up servos)

c. (1) Alignment bus

(2) Alignment back-up bus

d. (1) Environmental buses (3 separate buses)

These buses are separated in the above manner to improve reliability and limit power drain.

4.9.1.2 <u>Instrumentation Power</u>. Regulated power, to be used for instrumentation (except launch instrumentation), is provided at the LM control unit (LMCU) and the processor in the LM and at the MM control unit (MMCU) in the MM. The instrumentation power is provided at three levels, +5-v dc, +12-v dc and -6-v dc. The +5-v dc is isolated from the +12-v dc to provide redundancy for critical instrumentation.

4.9.1.3 Alternating-Current (ac) Power. The main LM lighting is an associate contractor responsibility and is powered by an a-c 400 Hz supply. This supply is used for indicator illumination and panel 1-C. Voltage level is controlled by an associate contractor's master dimmer switch which controls all LM lighting.

4.9.1.4 Fusing. Fuses are used in the buses supplying power for launch instrumentation, individual launch instrumentation amplifiers, and in individual environmental heater controllers to minimize the possibility of tripping a main circuit breaker feeding critical equipment because of the failure of a nonmission-essential unit. The VO power bus will be fused to provide protection for wiring from the LMPU to the VO assembly.

4.9.1.5 Estimated Energy and Peak Power Requirements. The PP average power is estimated to be 264 watt-hours per hour.* Of this amount, approximately 67 watt-hours per hour is used operationally; the remaining 197 watt-hours per hour is consumed by environmental equipment. The peak power requirement occurs during the photographic phase and is estimated to be 1143 watts.

* This estimate does not include film viewer or peripheral display.

4.9.2 Commands

Commands for control of PP equipment originate from ground control at the Mission Control Center (MCC), the on-board computer, or the flight crew. Set-up commands to the camera are generated by the on-board computer from prestored equations, current ephemeris data, vehicle attitude data, and TM gimbal angles. Photographic sequences can be revised by the flight crew (see paragraph 2.3) but cannot be initiated by the flight crew unless target data and photography requirements have been prestored in the computer. The current PP command list is shown in Appendix C. Command relay configurations are shown in Figure 4.9-2.

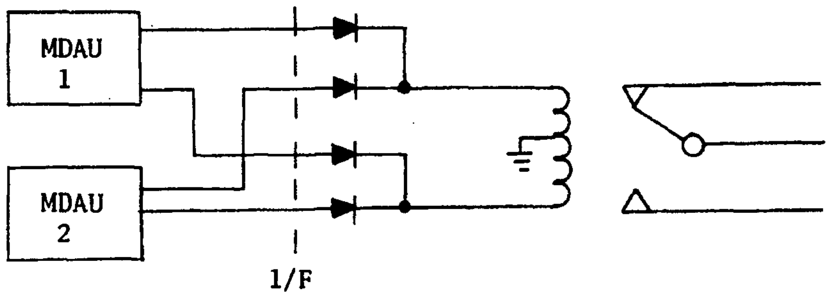
Command transfer is accomplished by the actuation of latching relays in the LMCU, the MMCU, and the film handling electronics. Contacts on these relays are used as command inputs by various PP units. The voltage and current switched by each set of contacts is limited by EMI considerations to 5v at 5 milliamperes or less.

Additional sets of contacts on the relays are used to provide command-transfer instrumentation signals.

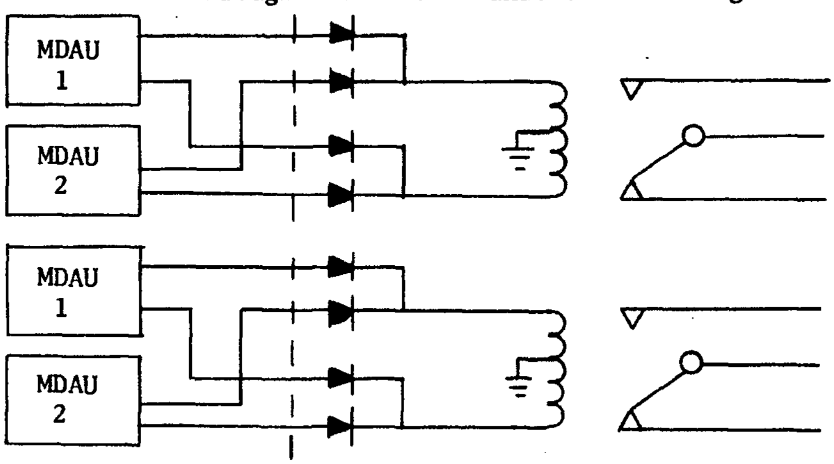
4.9.3 Instrumentation

Instrumentation of the PP provides information on the functional status of various payload components during test, prelaunch, launch, powered flight, and orbital phases of the mission. The primary purpose of this information is to ascertain payload health.

Configuration I. 1 nonredundant relay used to command the majority of primary and backup functions.



Configuration II. 2 relays provide primary and redundant commands for 1 function. Redundancy carried from the interface through the control unit to the using unit.



Configuration III. 3 relays provide primary and redundant commands for functions which require a 3-wire input. Redundancy is carried only from the interface to the control unit.

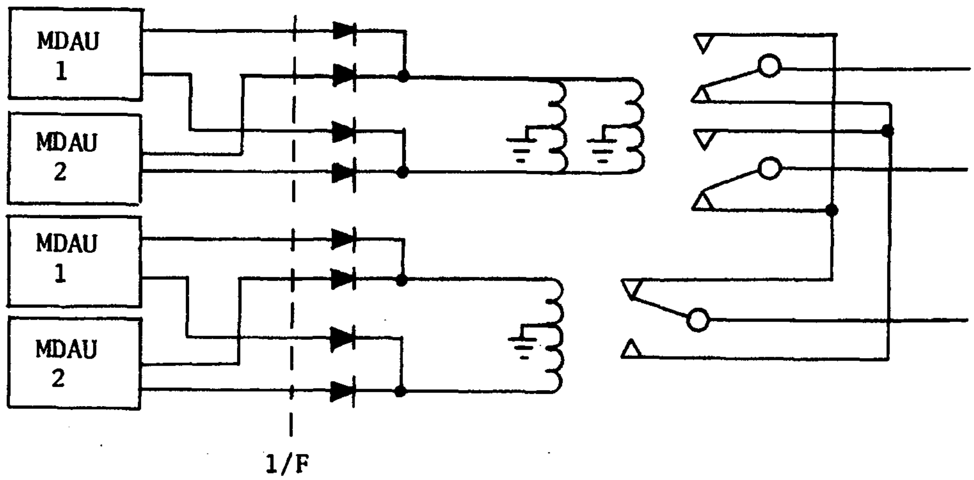
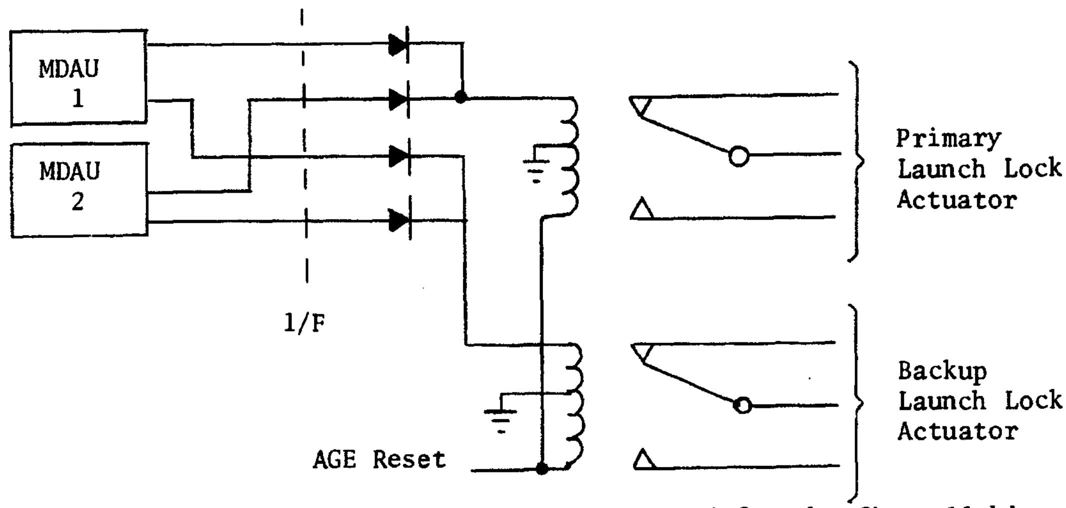
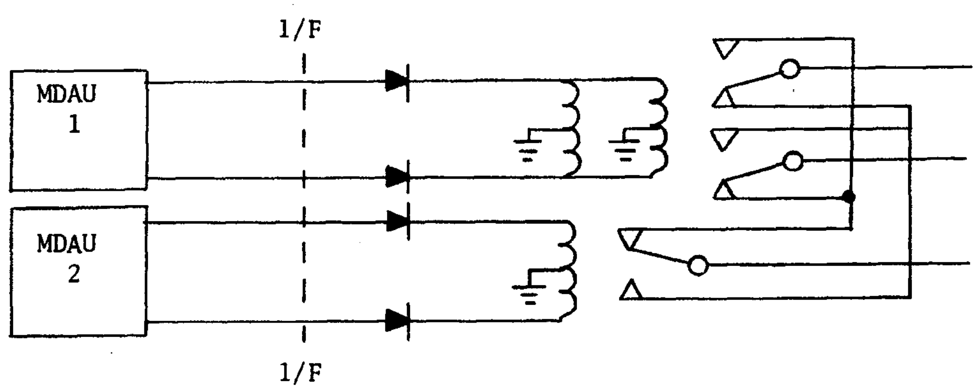


Figure 4.9-2(1). Command Relay Configurations

Configuration IV. Special Case 2 relays provide commands for primary and back-up launch-lock actuators with an AGE reset



Configuration V. Special Case This configuration is used for the first 11 bits of the 23-bit command. Total capability is not available from both MDAU's



Configuration VI. Special Case 2 relays wired in parallel to command two functions simultaneously

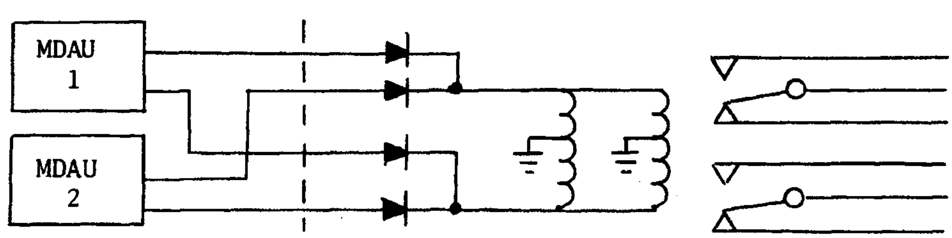


Figure 4.9-2 (2). Command Relay Configuration

Instrumentation interconnections between PP units are shown in Figure 4.9-1. Instrumentation category definitions and a list of the points for the M/A mode are contained in Appendix C. Instrumentation transducers and sensing circuits are located in all PM MM units and throughout the MM. Processing of the instrumentation signals is accomplished in several of the PP units, depending primarily on the type and location of the instrumentation sensor. These processing functions are described in succeeding paragraphs.

4.9.3.1 Mission Module Instrumentation. The block diagram shown in Figure 4.9-1 identifies the interfacing units which provide the conditioned electrical signals to the associate contractor and the manner in which these units are interconnected with the payload sensors. The following is a brief description of the signals developed at each interface unit.

4.9.3.1.1 Vibration Amplifiers. The vibration amplifiers process signals from three uniaxial accelerometers mounted in the MM and connected to the amplifiers by coaxial cables. The vibration amplifiers are powered during launch and ascent and their outputs are telemetered via the FM telemetry system. The vibration amplifiers were modified because of a reduction in the number of FM telemetry channels available for EKC use from eleven to four (three in the MM and one in the LM). Ground conditioning instrumentation was added to the MM and is processed by circuits included in the vibration-amplifier package. These circuits sense relative humidity, pressure, and air velocity. Outputs of these circuits are connected to the flyaway umbilical for monitoring during the prelaunch phase of the mission.

4.9.3.1.2 Alignment Sensor Electronics. The alignment sensor electronics collects all alignment subsystem instrumentation signals. Output data provides information regarding alignment-sensor error signals, alignment-servo positions, alignment-servo drive signals, and alignment light sources. The alignment-error signals and servo positions are instrumented redundantly.

4.9.3.1.3 Mission Module (MM) Control Unit and Power Unit. The MM control unit and power unit instrumentation consists of command verification, and voltage and current measurements. Each command relay is instrumented to verify response to command signals. Voltage and current instrumentation on each unregulated power bus is used to determine power-switch status and enable power-profile information to be obtained. The MM control unit is also used as a function box for instrumentation from the tracking mirror and primary mirror launch locks.

4.9.3.1.4 Instrumentation Processor. The instrumentation processor conditions the environmental temperature instrumentation derived from temperature probes (thermistors and resistance thermometers) located throughout the MM.

The following is a summary of temperature instrumentation points located in the MM:

Range	Quantity Processed	Use
+3, -1 F (Differential)	10	Mirror - ΔT
60 to 80 F	36	Mirrors, COA structure
40 to 90 F	9	A-frame/COA mount point
-150 to 250 F	18	A-frame/MM shell mount MM shell and aft bulkhead

4.9.3.2 Laboratory Module Instrumentation. Figure 4.9-1 shows the electrical system configuration for the LM units providing instrumentation outputs to the interface. The following is a brief description of the signals developed at each interface unit.

4.9.3.2.1 Vibration Amplifiers. A single vibration amplifier monitors launch and ascent acceleration loads sensed by a transducer located at the camera/Ross corrector interface. The transducer is similar to those described in 4.3.1.

4.9.3.2.2 Camera Auxiliary Electronics. The camera instrumentation is derived from sensors located throughout the camera assembly. Processing is accomplished in both of the camera auxiliary electronics units. All major camera functions are instrumented.

4.9.3.2.3 Laboratory Module Control Unit and Power Unit. The LM control unit and power unit instrumentation consists of command verification, and voltage and current measurements. Each command relay is instrumented to verify response to command signals. Voltage and current instrumentation on each unregulated power bus is used to determine power switch status and enable power-profile information to be obtained. The LM control unit is used as a function box for instrumentation signals from the focus control electronics, VO, data conversion, and film handling electronics. The LM control unit also processes most of the LM temperature instrumentation.

4.9.3.2.4 Controls and Displays. The controls and displays consist of two panels (Panel 1-C and a film transfer panel) as shown in Figures 4.9-3 and 4.9-4. The panels contain control switches, status lights, and meters necessary to provide the flight crew with adequate information to allow them to participate in focus, alignment, film transfer, and VO control. The controlled functions are instrumented at the controls and displays unit to provide information pertaining to the status of each control switch. The displayed functions are instrumented at the originating unit; for example, the focus control electronics for focus signals.

4.9.3.2.5 Processor. The processor provides instrumentation outputs giving environmental and operational information. The environmental information includes processing and drying temperatures and pressures. The operational information includes processor mode (standby and operate) and voltage/current values.

4.9.3.2.6 Chute Set Electronics. The chute set electronics unit collects and processes instrumentation signals from the film handling chutes and the supply and take-up assemblies. The instrumented functions include primary film quantity information, primary film tension, supply brake status, and component temperature information.

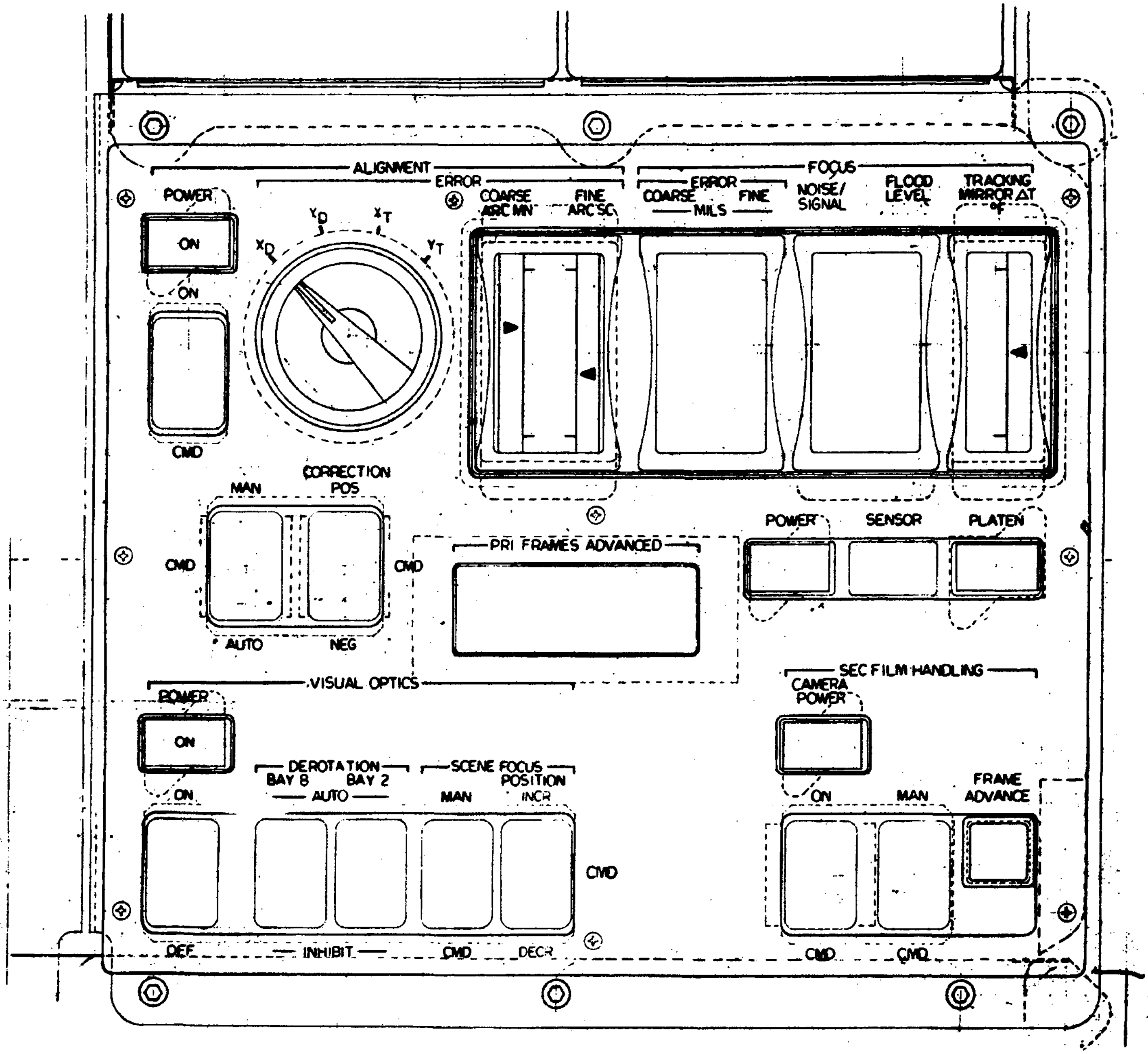


Figure 4.9-3. Panel 1-C

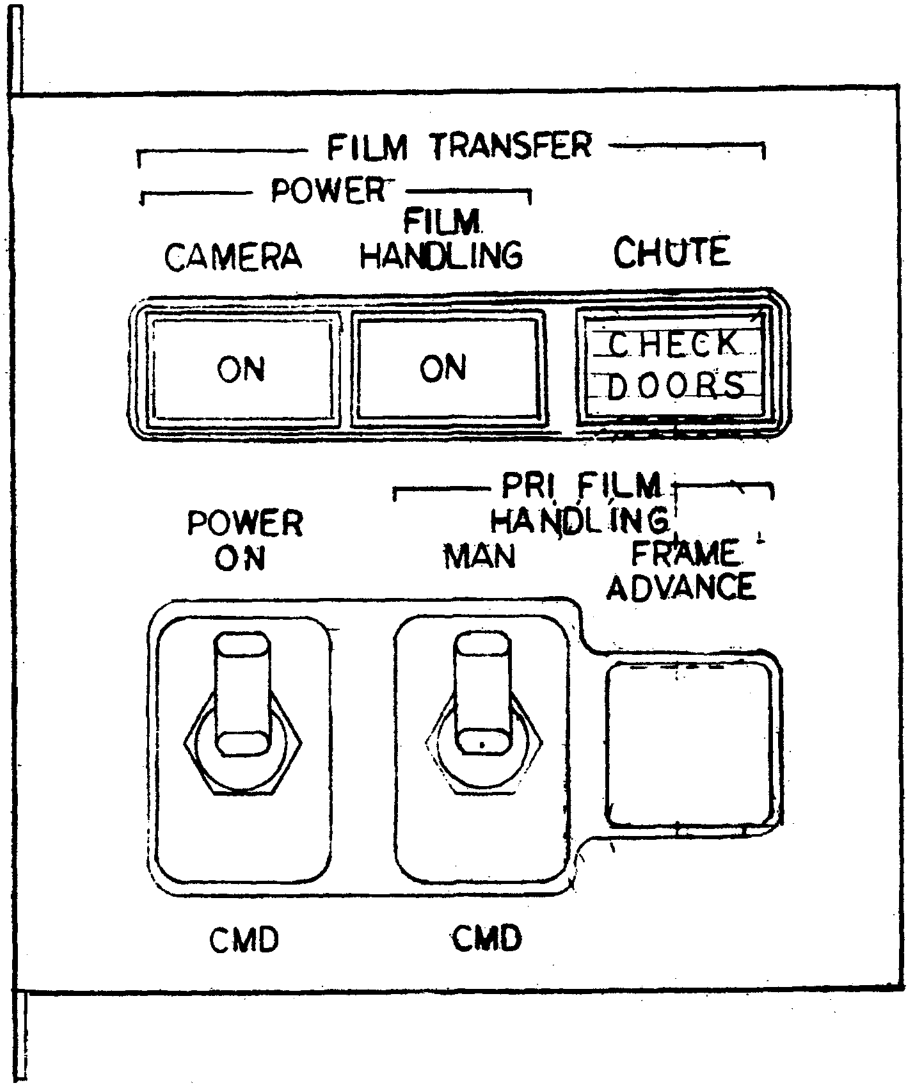


Figure 4.9-4. Film Transfer Panel

4.9.4 Electromagnetic Compatibility (EMC)

EMC requirements are set forth in SSD Exhibit 64-4, General Specification for Electromagnetic Compatibility Requirements for Manned Spacecraft, as amended by an EKC Addendum (reference F-004736-OH). The basic requirement of the EMC program is to produce a vehicle having a 6 decibel (db) or better electromagnetic interference (EMI) safety margin factor. Achievement of this requirement will result in a system in which the interference generated therein is not more than 50 percent of the level which the system can withstand without malfunctioning.

The design approach for control of generated interference is to:

a. Limit ON-OFF switching of primary power within components to a rate-of-current-change of less than 30,000 amperes per second.

b. Limit ON-OFF switching of primary power by bus-enabling switches to less than 30,000 amperes per second during the controlled-rate-of-current-change phase. During the bypass-relay operation phase, the hard-switched voltage/current will be less than 1.75v and 1.75 amperes.

c. Limit interference levels, within components, generated by sources such as command, instrumentation and microelectronic circuitry to that which corresponds to hardswitched 5 volts and 5 milliamperes.

d. Use appropriate EMI filters and shielding to control interference generated by circuits/parts whose nature of operation requires rates-of-current-change higher than that which will meet the required EMI limits.

e. Restrict in-rush currents to components at the time of power application.

f. Establish bonding requirements for interfaces.

Status of EMI design will be monitored by means of EMI tests on component breadboards during the component design phase.

Susceptibility will be controlled by:

a. Designing electromagnetic safety margins which are as high as practical.

b. Decoupling networks on power-supply lines as required.

d. Selection of the routing path and grouping of cables.

4.9.5 Edge-Data Recording Control

Supplemental data are recorded in the corner of both the primary and secondary film formats by use of the on-board computer, the DCU, and data recording heads mounted in the camera.

4.9.5.1 Method of Operation. Two data recording heads are mounted in the camera such that recording of data is accomplished when the film is in the post-platen position. One head is used for recording on primary film; the other is used for recording on a secondary film. Each data recording head is an avalanche-luminescent diode array consisting of 18 columns and 32 rows. Signals are sent from the camera conditioned by the DCU, and sent to the on-board computer at frame start, frame center, and frame end. These signals cause information pertinent to the frame being exposed to be placed in an unformatted storage area in the on-board computer. Immediately after completion of the exposure, the frame of film is advanced to the post-platen position. When the advance is completed and the data head is clamped in position, the camera sends an initiate signal to the DCU which sends an initiate output signal to the computer. The initiate output signal commands the computer to format the first column of edge data to be recorded and transfer this data to a formatted storage area within the computer. There are two initiate signals; one for primary film and one for secondary film. In order for this data to be transferred from computer storage to DCU storage and recorded on film, a sequence of events must take place (refer to Figure 4.9-5).

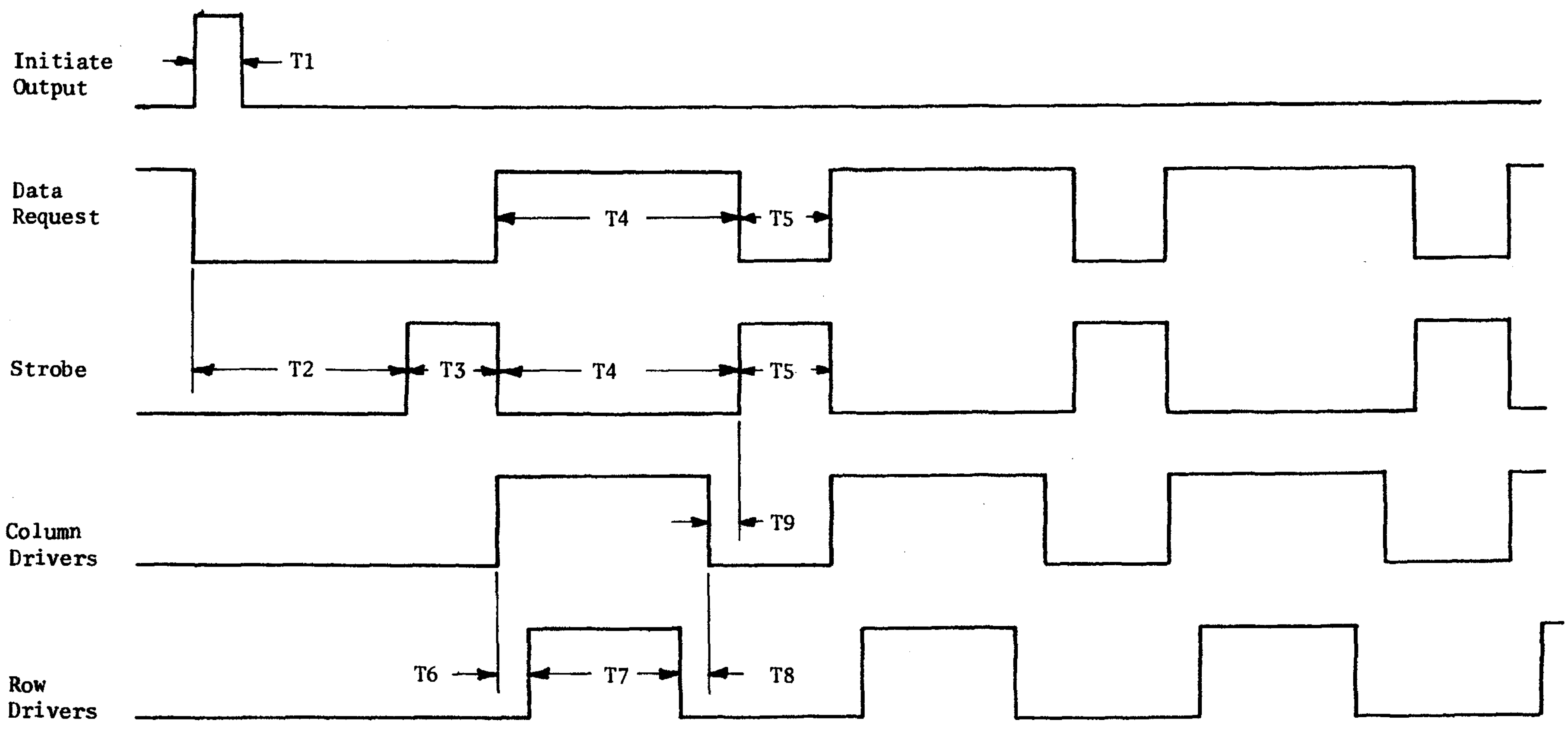
a. The data request signal (generated by the DCU) drops to a low level upon transmission of the initiate output signal to the computer.

b. When the first column of edge data has been formatted, the computer sends a high-level strobe signal to the DCU.

c. The concurrence of a low-level data request and high-level strobe enables the DCU input gates and the formatted edge data is taken into DCU storage.

d. Two hundred microseconds after the DCU received the leading edge of the strobe signal from the computer, the data request returns to a high level. This signals the computer to format the next column of edge data and remove the strobe signal.

e. When the data request signal goes to a high level, the first column driver is turned ON.



$T1 = 10\mu s$
$3MS \leq T2$
$T3 = 200\mu s$
$5MS \leq T4 \leq 10.6\ MS$
$T5 = 200\mu s$

$T6 = 200\mu s$
$T7 = 10\mu s$
$T8 = 200\mu s$
$T9 \geq 200\mu s$

Time Durations Not to Scale

T7 - Time to Record one column of data at 32 bits/column

T3 and T5 - Time for data transferral

Figure 4.9-5. Data Word Timing

f. Two hundred microseconds after the column driver is turned ON, each of the 32 row drivers, for which the corresponding bit in DCU storage is a binary one is turned ON. The ON time for the row drivers is the actual data-recording time. For primary film the recording time is ten milliseconds per column; for secondary films, the recording times are less than ten milliseconds per column.

g. Two hundred microseconds after the row drivers are turned OFF, the column drivers are turned OFF.

h. If the row drivers are ON for more than five milliseconds, the data request will drop to a low level of two hundred microseconds after the column drivers are turned OFF. If the row drivers are ON for less than five milliseconds, the drop of the data request will be delayed a sufficient amount of time to provide at least five milliseconds between successive drops of the data request. The five millisecond period allows the on-board computer to format the next column of data for transfer to the DCU.

4.10 CURRENT MASS PROPERTIES VALUES

The total PP weight for the M/A mode is 5772 lb. Table 4.10-1 contains the contract weight budget summary. The weight breakdown for PP components is shown in Table 4.10-2.

Approximately 67 percent of these weights are actual, an additional 31 percent are calculated, and the remainder are estimated. Centers of gravity and moments of inertia for PP equipment are given in Table 4.9-3.

These data are updated in the mass properties report issued monthly.

TABLE 4.10-1

CONTRACT WEIGHT BUDGET SUMMARY

		M/A Mode
Total contract weight July 1966		5583
Negotiated weight June 1967 (CCN No. 14)		23
	Revised contract total	5606
Negotiated weight October 1967 (CCN Nos. 15, 19)		108
	Revised contract total	5714
Negotiated weight May 1968 (CCN Nos. 11, 20, 24 30 and revised film and BIMAT weight)		58
	Current contract total	5772

BIF-008-[redacted]-68
(Control Number)

TABLE 4.10-2

PHOTOGRAPHIC PAYLOAD WEIGHT BREAKDOWN

			M/A (lb)
1.	COA Components		-
	a. COA structure and mount assembly		724
	b. Primary mirror assembly		1097
	c. Primary reference rod set		35
	d. Diagonal mirrors and structure assembly		364
	e. Ross corrector assembly		298
	f. Thermal blankets and supports		256
	g. MM electronics		281
	h. Camera assembly		197
		TOTAL	3252
2.	Additional MM equipment		36
3.	Tracking Mirror		1278
4.	LM Components		-
	a. Primary film handling		172
	b. LM electronics		231
	c. Film		240
	d. BIMAT		50
	e. Processor		195
	f. Visual optics		163
	g. Miscellaneous assembly		131
	h. Viewer		*
		TOTAL	1182
	Primary DRC baseplates in Gemini		24
		TOTAL	5772

* Not negotiated

TABLE 4.10-3

MASS PROPERTIES DATA, MANNED/AUTOMATIC MODE

A. Summary Data:

Description	Center of Gravity (Inches from Reference Datum) X	Y	Z	Moments and Products of Inertia (Slug-Feet Squared) I_{xx}	I_{yy}	I_{zz}	I_{xy}	I_{xz}	I_{yz}
COA	242.26	0.10	-8.29	805.547	16066.492	15780.699	38.007	-1337.950	- 3.802
Additional MM Equipment	302.67	-0.17	-0.19	17.299	84.013	81.715	0.302	5.728	0.140
TM Assembly	445.03	0.0	12.76	129.960	104.692	174.762	-0.020	42.024	0.004
LM Equipment	560.00	-10.06	-17.33	424.346	598.974	413.497	43.330	-41.260	-66.300
DRC base-plates	885.33	0.0	-3.17	3.060	4.045	2.339	0.0	1.990	0.0
* Total PP	354.39	-1.96	-5.36	1533.318	40088.147	39571.277	-442.567	-1255.370	-40.121

* Includes all PP components oriented in a flight configuration.

TABLE 4.10-3 (Continued)

B. Detailed Data:

Description	Center of Gravity (Inches from Reference Datum) $\overline{X}$	$\overline{Y}$	$\overline{Z}$	Moment of Inertia (Slug-Feet Squared) Roll	Pitch	Yaw
1. COA Components						
a. COA structure and mount assembly	220.66	0.0	-.61	267.71	1967.39	1939.94
b. Primary mirror assembly	98.26	0.0	3.07	159.45	84.34	84.39
c. Primary reference rod set	233.51	0.0	7.79	8.43	39.14	39.10
d. Diagonal mirrors and structure assembly	388.94	0.0	-6.55	83.65	80.65	33.11
e. Ross corrector assembly	446.32	2.69	-39.62	4.66	65.93	67.96
f. Thermal blankets and supports	229.83	0.0	-3.46	58.87	731.43	698.95
g. MM electronics	282.54	-1.83	-27.19	51.73	564.62	550.69
h. Camera assembly	504.03	0.30	-38.79	4.10	5.20	4.47
2. LM Equipment						
a. Primary film handling	592.80	-0.74	-43.01	3.26	21.55	20.35
b. Stowed film handling equipment	543.44	7.90	-2.59	30.15	81.12	63.28
c. LM electronics	537.44	-32.14	-37.73	10.89	9.18	14.14
d. Film	596.04	0.0	-21.25	71.65	72.88	2.36
e. BIMAT	562.70	-28.87	35.80	0.2	0.11	0.11
f. Processor	545.45	-31.61	32.75	3.09	9.07	9.02
g. Visual optics	533.14	18.01	-38.55	11.31	29.22	34.82

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