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EXPERIMENTAL LAND OBSERVING DATA SYSTEM FEASIBILITY STUDY FINAL REPORT

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16. Abstract

This report presents the results of a study to define an end-to-end data system to support a Shuttle-based Multispectral Linear Array (MLA) mission in the mid-1980's. As an evolution of NASA's earth observation program, the Experimental Land Observing System (ELOS) will open new areas of remote sensing research including high-resolution multi-spectral imagery, stereo imagery, and off nadir bi-directional reflectance observations. Technology advances in the solid-state sensor, data processing, and applications analysis are also expected.

General Electric Company's Space Systems Division has defined a ground system that exploits NASA/GSFC institutional facilities and extensive assets from the Landsat-D Program to effectively meet the objectives of the ELOS Mission. The goal of 10 meter pixel precision, the variety of data acquisition capabilities, and the use of Shuttle are key to the mission requirements. Ground mission management functions are met through the use of GSFC's Multi-Satellite Operations Control Center (MSOCC). The MLA Image Generation Facility (MIGF) combines major hardware elements from the Applications Development Data System (ADDS) facility and Landsat Assessment System (LAS) with a special purpose MLA interface unit. Landsat-D image processing techniques, adapted to MLA characteristics, form the basis for the use of existing software and the definition of new software required.

The ELOS Data System concept as defined is feasible to meet identified performance requirements and can be developed at low risk to meet a mid-1980's ELOS mission.

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GLOSSARY

ADDS	-	Application Development Data System
ADS	-	Attitude Displacement Sensor
AP	-	Applications Processor
B/H	-	Base-to-height ratio
BASD	-	Ball Aerospace Division
BCH	-	BOSE-CHAUDHURI-HOCQUENGHEM
BER	-	Bit Error Rate
CCT	-	Computer Compatible Tape
CDR	-	Critical Design Review
CRT	-	Cathode Ray Tube
CSF	-	Control and Simulation Facility
DOMSAT	-	Domestic Satellite
DPCM	-	Differential Pulse Code Modulation
DRRTS	-	Data Receive, Record and Transmit Subsystem
EA	-	Electronics Assembly
ECI	-	Earth Centered Inertial
EDAC	-	Error Detection and Correction
ELOS	-	Experimental Land Observing System
FFBD	-	Functional Flow Black Diagram
FOV	-	Field of View
FS	-	Flight Segment
GCD	-	Geodetic Correction Data
GCM	-	Geometric Correction Matrices
GCN	-	Ground Control Neighborhood
GCP	-	Ground Control Point
GFE	-	Government Furnished Equipment
GS	-	Ground Segment
GSFC	-	Goddard Space Flight Center
HDDR	-	High Density Digital Recorder
HDT/HDDT	-	High Density Tape/High Density Digital Tape
I/O	-	Input/Output
IFOV	-	Instantaneous Field of View

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IR - Infra-red
JSC - Johnson Space Center
KM - Kilometer
KSA - K-Band Single Access
KSC - Kennedy Space Center
KUSP - Ku-Band Signal Processor
LAS - Landsat Assessment System
LOC - Lines of Code
LSD - Landsat D
MAP - Matrix Array Processor
ME - Map Errors
MGCP - Map Ground Control Point
MIGF - MLA Image Generation Facility
MLA - Multi-Spectral Linear Array
MMF - Mission Management Facility
MOR - Mission Operations Room
MSOCC - Multi-Satellite Operations Control Center
MSS - Multi-Spectral Scanner
Mbps - Mega-bits per second
NASCOM - NASA Communications
NCC - Network Control Center
NRZ-L - Non-Return to Zero - Level
NRZ-M - Non-Return to Zero-Mark
NRZ-S - Non-Return to Zero-Space
ORI - Operations Research, Inc.
PDR - Preliminary Design Review
POCC - Payload Operations Control Center
QL - Quick Look
QPSK - Quadrature Phase Shift Keying
S/C - Spacecraft
SBRC - Santa Barabara Research Corp.
SCD - Systematic Correction Data
SOM - Space Oblique Mercator
SOW - Statement of Work
SPIF - Shuttle Payload Interface Facility
SRR - System Requirements Review
STS - Space Transportation System
SWIR - Short Ware IR

TAC - Telemetry and Command

TDRSS - Tracking and Data Relay Satellite System

TIPS - Thematic Mapper Image Processing System

TM - Thematic Mapper

UTM - Universal Transverse Mercator

VF - Valley Forge

VIS/NIR - Visible/Near IR

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INTRODUCTION

SECTION 1
INTRODUCTION

This report presents a design approach to an end-to-end data system to support a Shuttle-based Multispectral Linear Array (MLA) mission in the mid-1980's. As an evolution of NASA's earth observation program, the Experimental Land Observing System (ELOS) will open new areas of remote sensing research including high-resolution multispectral imagery, stereo imagery, and off-nadir bi-directional reflectance observations. Technology advances in the solid-state sensor, data processing, and applications analysis are also expected.

General Electric Company's Space Systems Division has defined a ground system that exploits NASA/GSFC institutional facilities and extensive assets from the Landsat-D Program to effectively meet the objectives of the ELOS Mission.

In this study we first analyzed the characteristics of the ELOS shuttle mission and representative MLA technology to determine functional requirements for mission operations and image generation of the ground system. The goal of 10 meter pixels, the variety of data acquisition capabilities. and the use of shuttle are key to the requirements Mission management functions are met through the use of GSFC's Multi-Satellite Operations Control Center (MSOCC). The MLA Image Generation Facility (MIGF) combines major hardware elements from the Applications Development Data System (ADDS) facility and the Landsat-D Assessment System (LAS) with a special purpose MLA interface unit. Landsat-D image processing techniques, adapted to MLA characteristics, form the basis for the use of existing software and the definition of new software required.

The ELOS Data System concept as defined is feasible to meet identified performance requirements and can be developed at low risk to meet a mid-1980's ELOS mission.

SECTION 2
STUDY RESULTS

SECTION 2

STUDY RESULTS

This section summarizes the objectives, requirements, and results of the ELOS Data System Study. The summary is presented in the form of viewgraphs with a facing page of explanative text.

OVERVIEW

This section summarizes the study objectives, baseline requirements, scope and results.

OVERVIEW

- ELOS DATA SYSTEM STUDY OBJECTIVES
- STUDY BASELINE REQUIREMENTS
- DATA PROCESSING RESPONSIBILITIES
- STUDY RESULTS SUMMARY

STUDY OBJECTIVE

The objective of this study is to define an effective end-to-end data system for the first MLA Shuttle mission that makes maximum use of NASA's extensive Landsat assets.

The data system concept described herein is compatible with parallel GSFC ELOS studies that address definition of research objectives, technology goals, MLA sensor concepts and MLA/Shuttle accomodation.

The data system concept is flexible in that it allow upgrades for reflight missions,and incorporates processing capabilities that would evolve smoothly to support a free-flyer mission.

ELOS DATA SYSTEM STUDY

STUDY OBJECTIVES

DEFINE AN END-TO-END DATA SYSTEM FOR THE INITIAL ELOS SHUTTLE MISSION THAT MAKES MAXIMUM USE OF EXISTING LANDSAT ASSETS

- 1986 FIRST EXPERIMENT MISSION
- ANNUAL REFLIGHTS WITH UPGRADES
- PLANNED EVOLUTION TO FREE-FLYER

STUDY BASELINE REQUIREMENTS

Baseline requirements define a cost-effective research-oriented system using baseline Shuttle and TDRSS capabilities. The 48 Mbps Shuttle/TDRSS link rate forces compression or selection of the approximately 120 Mbps generated by a four band, 10/10/10/20 meter IFOV, MLA with a 60 km swath. The data system accommodates data decompression and error correction in special purpose MLA interface hardware, and data selection in the basic processing system. A processing rate of two scenes per day will handle the mission data set in one year (50% nominal cloud cover), and support annual ELOS reflight missions. This rate is achieved on a one-shift, five day per week basis, leaving significant capability for exansion, software development and system maintenance.

STUDY BASELINE REQUIREMENTS

- EXPERIMENTAL SHUTTLE MISSION IN LATE 1986
- 48 MBPS TDRS LINK
- ~800 SCENES (60 x 60 Km) ACQUIRED
- PROCESS 2 SCENES/DAY TO EXPERIMENTERS
- ADAPT LANDSAT-D IMAGE PROCESSING HERITAGE TO MLA DATA
- USE LANDSAT ASSESSMENT SYSTEM (LAS) AND APPLICATIONS DEVELOPMENT DATA SYSTEMS (ADDS) EQUIPMENT
- PERFORM MISSION MANAGEMENT FUNCTIONS AT GSFC USING MULTI-SATELLITE OPERATIONS CONTROL CENTER (MSOCC) AND SHUTTLE PAYLOAD INTERFACE FACILITY (SPIF)

DATA PROCESSING RESPONSIBILITIES

The scope and complexity of the ELOS Data System is strongly influenced by the experimental nature of the MLA shuttle mission. The basic data system will provide high quality processed data to allow experimenters to perform applications research, evaluate MLA technology areas, and generate special research products on off-line institutional facilities.

DATA PROCESSING RESPONSIBILITIES

ELOS DATA SYSTEM	EXPERIMENTERS
● ACQUIRE DATA AND LABEL	● CLASSIFICATION
● DECOMPRESSION AND ERROR CORRECTION	● INFORMATION EXTRACTION
● QUICK LOOK CAPABILITY	● ELEVATION EXTRACTION (STEREO)
● RAW DATA TAPE	● PRECISION OFF-NADIR CORRECTION (TERRAIN)
● RADIOMETRIC CORRECTION	● ROTATION/TRANSFORMATION TO DESIRED MAP FORMATS
● SYSTEMATIC CORRECTION DATA	● REGISTRATION WITH OTHER DATA SETS
● GEOMETRIC ANNOTATION (A-TAPE)	● MLA PERFORMANCE EVALUATION
● GEOMETRIC CORRECTION (P-TAPE)	● RADIOMETRIC CALIBRATION EVALUATION
PRODUCTS: CCT'S, FILM	● END-TO-END PRECISION EVALUATION
PRECISION: SUB-PIXEL ON NADIR IMAGES SEVERAL PIXELS OFF-NADIR	● DATA COMPRESSION EVALUATION

STUDY RESULTS SUMMARY

The results of this six-month study show that the ELOS data system will meet all mission requirements using existing GSFC and Landsat assets, with capability for evolution to follow-on mission.

Significantly, the same basic image processing approach and algorithms used on Landsat apply directly to nadir, off-nadir, and stereo ELOS data. Ground control point elevation data are used to generate very precise correction parameters for the scene in perspective, and features of terrain relief are preserved as displacements for eventual elevation data extraction by investigators.

We see no major development risks for the basic data system, and advanced technology augmentations can be readily accomodated for evaluation and demonstration as appropriate.

STUDY RESULTS SUMMARY

- ELOS/MLA MISSION REQUIREMENTS MET
- EFFECTIVE STANDARD APPROACH TO HIGH-PRECISION NADIR, OFF-NADIR, STEREO IMAGE PROCESSING
- HARDWARE DESIGN USES ADDS/LAS ASSETS PLUS SPECIAL PURPOSE MLA INTERFACE UNIT
- SIGNIFICANT TRANSFER OF SOFTWARE FROM LANDSAT-D
- USE OF MSOCC/SPIF FOR MISSION MANAGEMENT FEASIBLE
- LOW-RISK, COST EFFECTIVE IMPLEMENTATION FEASIBLE FOR 1986 MISSION

MLA SENSOR BASELINE

This section establishes baseline MLA parameters that relate to the ELOS data system for the conduct of this study. It comprises SOW requirements, derived requirements, ORI MLA accommodation study results and verbal inputs from the ELOS project.

MLA SENSOR BASELINE

- PARAMETERS BY BAND
- CONFIGURATION
- OPERATION
- IMAGE DATA
- COMMAND AND HOUSEKEEPING
- BASELINE SUMMARY

MLA PARAMETERS BY BAND

The MLA sensor for the first ELOS shuttle mission is baselined to have four bands, three in the visible/near-IR (VIS/NIR) and one in the short-wave IR (SWIR). Each of the visible/near-IR bands has 6144 detector elements, a few more than the 6000 nominal listed in the SOW, because detector array modules are often produced with a binary multiple number of elements (e.g., 1024, 2048). For this application 6144 detectors can be built up from three 2048 modules or six 1024 modules. Both SBRC and BASD have baselined 6144 elements per VIS/NIR band. The SWIR band then has half this number of detectors (3 x 1048).

The MLA contractors have developed ELOS sensor concepts capable of providing up to seven bands for future missions, four VIS/NIR (10m), two SWIR (20m), and one thermal IR (100m). This provides the potential for up to 162 Mbps raw data rate for operation at 350 km (an increase of 39% over the first mission). At 705 km altitude this seven-band sensor would produce 80 Mbps with a VIS/NIR ground resolution of 20 meters (pixel centers), and a swath width of 124 kilometers. For this study only the four band configuration at 350 km is considered.

MLA PARAMETERS BY BAND

BAND NUMBER	WAVELENGTH RANGE (μM)	IFOV (PITCH)* (M)	NUMBER OF DETECTORS	DETECTOR TYPE/SIZE (μM)	DWELL* (MS)	DATA RATE*(MBPS) @ 8 BIT QUANT
1	0.52 - 0.60 (VIS)	10	6144	Si/15	1.37	35.9
2	0.63 - 0.69 (VIS)	10	6144	Si/15	1.37	35.9
3	0.76 - 0.90 (NIR)	10	6144	Si/15	1.37	35.9
4	1.55 - 1.75 (SWIR)	20	3072	TBD $^+$/30	2.74	9.0
					TOTAL	116.7 (NO O/H)

* AT 350 KM ALTITUDE (61.5 KM SWATH)

\+ HgCdTe HYBRID AND Pd_2Si SCHOTTKY ARE PRIME CANDIDATES

MLA CONFIGURATION

The tranverse field of view (FOV) of an MLA with 6144 elements per line (10 meter centers at 350 km altitude) is 10.03 degrees. If the detector elements (VIS/NIR) are on 15 micron centers in the focal plane, then the effective focal length of the sensor at this altitude will be 525 millimeters.

To obtain a stereo base-to-height ratio (B/H) of 1.0 between fore and aft viewing, the MLA should point 25.1 degrees off-nadir in both directions at 350 km altitude (refer to Section 3.2). 26 degrees provides a B/H ratio of 1.04 at 350 km. Three of the four MLA contractors have baselined the use of mirrors for all off-nadir viewing from the shuttle.

For this study, it is assumed that all calibration processing (radiometric correction) is accomplished on the ground. The sensor is calibrated before flight and correction parameters are provided to the processing facility for use during the flight. Several calibration checks will be acquired by the sensor during the mission; after evaluation of these data, updated radiometric correction parameters will be provided to the ground facility for the balance of the image processing. The data system will be designed to accommodate the sensor calibration goals for intraband, interband and absolute accuracies (i.e., 0.5%, 1.0% and 5% respectively).

MLA CONFIGURATION

OPTICS
- 10° FOV
- 525 MM FOCAL LENGTH

POINTING
- ±25.1° ALONG TRACK (2 POSITION)
- ±30° CROSS TRACK (0.1° STEPS)
- NO COMBINATION
- MIRRORS PREFERRED

BAND SEPARATION (TBD)
- BEAM SPLIT/DICHROIC
- ADJACENT BANDS

$\left.\right\}$ EITHER

CALIBRATION
- PROCESSING ON GROUND
- LIMITED (2 OR 3 TIMES)
- 0.5% INTRABAND, 1% INTERBAND, 5% ABSOLUTE

MLA OPERATION

For this study, it is assumed the shuttle will operate at an altitude of 350 km. An MLA focal plane with 6144 detectors per line (VIS/NIR) and 10 meter ground resolution elements will provide a 61.5 km swath.

Because the shuttle data link is limited to less than 48 Mbps (ORI estimates 43 Mbps for raw data with overhead and error correction) and the MLA is capable of producing 117 Mbps of raw data, some means of data reduction is required. This can be accomplished by three methods:

1. reduction of swath width,
2. elimination of bands, and
3. data compression.

Pixel summing (averaging) is not considered for this mission because it reduces resolution.

The baseline for shuttle operation during MLA data acquisition is to eliminate as many disturbance torques as possible by controlling thruster firings, crew motions and other mechanisms.

MLA OPERATION

GEOMETRY

- 350 KM ALTITUDE
- 61.5 KM SWATH

FLEXIBILITY

- VARIABLE SWATH
- BAND SELECTION
- NO PIXEL SUMMING
- POINTING
- DATA COMPRESSION
- MODES WITH NO COMPRESSION
  - 20.5 KM SWATH ALL BANDS
  - 61.5 KM SWATH ONE BAND
  - OTHERS

STS CONSTRAINTS

- THRUSTERS
- CREW MOTIONS
- UNCOMPENSATED MOMENTUM

IMAGE DATA

If the MLA focal plane is divided into modules with 1024 or 2048 detectors each for the visible/near-IR bands (1024 for the SWIR band), then it becomes convenient to reduce the swath to one-third of its full value for some modes. This lowers the raw data rate to 39 Mbps with all four bands operating (43 Mbps is available).

Data compression is limited to the along-track dimension because cross-track compression requires on-board radiometric correction. For full sensor operation, compression by a factor of 2.7 (117/43) is necessary. Preliminary studies, including work reported by SBRC, indicate that one-dimensional compression techniques (e.g., DPCM and buffered DPCM) is limited to ratios of 1.8 or lower for active scenes with high statistical variation. Also, it may be desireable to have more than one compression ratio selectable to accommodate scenes with different statistics.

The multiplexing of image data can be accomplished in the MLA with a wide range of possible pixel grouping schemes. Interleaving single pixels from different bands minimizes the buffer memory burden in the sensor, whereas large pixel groupings assist the front-end processing in the ground system. Because computers handle and sort data in words (e.g., 32 bits), pixel grouping to this modest level (4 pixels) appears to be an effective compromise for the total system.

IMAGE DATA

RATES

- FULL SWATH, ALL BANDS: 117 Mbps
- 1/3 SWATH, ALL BANDS: 39 Mbps
- ADD OVERHEAD, ERROR CORRECTION, ETC.
- 8 BIT QUANTIZATION

DATA COMPRESSION

- ALONG TRACK ONLY
- DPCM (BUFFERED?)
- RATIO 1.8 - 2.7
- SEVERAL MODES POSSIBLE

MULTIPLEXING

- SENSOR HOUSEKEEPING
- SHUTTLE STATE VECTORS
- PIXEL GROUPING PREFERRED (BY WORDS)

COMMAND AND HOUSEKEEPING

Command and telemetry values were obtained from the ORI MLA Instrumentation Orbiter Accommodation Study. These values are practical assuming the sensor is intelligent and serial links are emphasized in the design. However, on Landsat-D both the Thematic Mapper and Multispectral Scanner have significantly more discrete commands and analog telemetry channels. Detailed requirements for the MLA cannot be established until the sensor is designed. In any case, these values do not directly affect the results of this study.

It is assumed that MLA mode sequences are accomplished by commands stored in the sensor. These sequences are initiated by timeline commands from the orbiter.

COMMAND AND HOUSEKEEPING*

COMMANDS

- 10 DISCRETE
- 1 SERIAL
- 1 Mbps, 1 Hz, 4 Bps CLOCKS
- 1 COMMAND WORD PER SECOND UPLINK

TELEMETRY

- 10 ANALOG
- 5 BI-LEVEL
- 1 SERIAL (PACKETS)

OPERATION

- MODE SEQUENCES BY MLA STORED COMMAND
- SEQUENCES SELECTED BY POCC
- UPLINK A FEW WORDS PER 5 TO 30 MINUTES

*ORI ESTIMATES. VALUES MAY BE SIGNIFICANTLY LARGER IF THE SENSOR PROCESSOR CAPABILITIES ARE LIMITED

MLA BASELINE SUMMARY

The shuttle MLA mission provides an opportunity to demonstrate solid-state array sensor technology and to investigate the utility of off-nadir and high-resolution imagery. The full benefit of this increased capability will be realized with the global and temporal coverage provided in a free-flyer mission.

MLA BASELINE SUMMARY

- 3 VIS/NIR (10M) AND 1 SWIR (20M) BANDS
- ALONG-TRACK AND CROSS-TRACK POINTING
- 61.5 KM FULL SWATH
- SELECTABLE SWATH AND BANDS
- 117 Mbps FULL DATA RATE
- ALONG-TRACK DATA COMPRESSION
- SENSOR-STORED COMMANDS

ELOS MISSION DESCRIPTION

This section describes the pertinent characteristics of the ELOS Shuttle mission.

ELOS MISSION DESCRIPTION

- ORBIT PARAMETERS
- DATA COLLECTION PARAMETERS
- DATA PROCESSING REQUIREMENTS
- MISSION OPERATIONS
- IMAGE REGISTRATION ACCURACY
- OFF-NADIR IMAGING GEOMETRY

ORBIT PARAMETERS

The orbit for ELOS has been defined to be 350 Km nominal altitude, plus or minus 25 Km. The launch will be north-east from the NASA Kennedy Space Flight Center, with a resulting orbit inclination of 40 to 57 degrees. The launch time is unspecified, so the sun angle during ascending/descending nodes is indeterminate. The ELOS data system is designed to accommodate this wide variety of orbital parameters. Some simplification of data processing parameters might be possible if daylight times could be restricted, or if repeat cycles could be specified. However, any such restrictions might limit flight opportunities, and since these restrictions do not substantially affect the data system it is better to be accommodating rather than restrictive.

ORBIT PARAMETERS

- ALTITUDE: 350 Km ± 25 Km
- LAUNCH SITE: EASTERN TEST RANGE
- INCLINATION: 40 TO 57 DEGREES
- SUN ANGLE: INDETERMINATE

DATA COLLECTION PARAMETERS

This chart describes the parameters that the space segment will provide in taking the data to be processed by the ELOS data system. Most of these parameters were defined at a meeting between the NASA-GSFC technical officer, GE and ORI, Inc. at a meeting in Silver Spring on April 16, 1982.

The 48 Mbps data rate is essentially an STS orbiter limiation. It could be surmounted, but it was judged not to be worth the expense, since only small improvements (to 50 Mbps) are envisioned; and this is still a long way from the raw sensor data rate of about 120 Mbps. It was decided this data rate must include whatever ancilliary data is needed to process the image data.

For stereo imagery, a base to height ratio of one half (for nadir to along track) or one (along track to along track) is considered appropriate. The calculation of this angle is discussed in Section 3.0. For the STS orbit altitude of 350 Km the angle is about 25.1 degrees, compared to 26 degrees previously considered at 705 Km. Across track, the ability to see about plus or minus three swaths from the present ground track, gives rise to the 30 degree cross track off nadir requirement.

The swath lengths were selected to be in the approximate range of six to twenty "scenes", where a scene is about 61 Km square. Because of concern for what ground control points may look like at very low sun angles, registration of images to maps may be very difficult and less accurate than Landsat-D; hence it was decided not to impose a system requirement for accurate image registration at low sun angles.

DATA COLLECTION PARAMETERS

- 48 Mbps DATA RATE - INCLUDING ANCILLARY DATA
- OFF NADIR POINTING - ± 25.1 DEG. ALONG TRACK: ± 30 DEG. CROSS TRACK
- DUTY CYCLE - 6 TO 20 SCENES (50 TO 170 SECONDS)
- SUN ANGLES 30° TO 90°
- DATA QUANTITY = 100 MIN ≅ 720 SCENES
- POINTING ACCURACY ± 1 DEG. ALL AXES
- POINTING KNOWLEDGE ± 0.5 DEG. ALL AXIS; RATE KNOWLEDGE ± 0.005 DEG/SEC

DATA PROCESSING REQUIREMENTS

The topics on this chart describe the data processing guidelines that were adopted for this study. In order to obtain 100 minutes of data, in bursts of 45 to 150 seconds each, an average of about 8 maximum length passes per day will be needed. Since there will be typically only about three daylight passes over CONUS daily, most of the data will be acquired from other parts of the world.

The data products will be similar to those of Landsat-D in appearance. However, they will be registered only to Map Ground Control Points (MGCP's), and not to each other.

The data quantity to be processed is set at two scenes per day. Considering the need for potentially developing additional MGCP's for the received image, two days are allowed for in process time. The storage time is a year for raw data, indefinitely for film products and the life of the media for AX and PX tapes.

DATA PROCESSING REQUIREMENTS

- DATA INGEST
  - UP TO 20 MIN PER DAY
  - UP TO 10 TIMES PER DAY
  - ANY TIME

- DATA OUTPUTS
  - QUICK LOOK VIDEO
  - RAW CCT
  - A-TAPE
  - P-TAPE
  - P-FILM PRODUCTS
  - 10-25 MGCP'S PER IMAGE (MSS = 8, TM = 22)

- THRU-PUT
  - 2 SCENES PER DAY
  - 48 HOUR LEAD TIME
  - QUICK LOOK 2 HOURS

- STORAGE
  - RAW HDDT'S 1 YEAR
  - FILM-FOREVER
  - MAGNETIC TAPES - TBD

MISSION OPERATIONS

In the pre-flight phase, it is expected that many suitable ground control points can be selected from thematic mapper (TM) images and correlated with maps, so that the image registration time in the post-flight period can be reduced. The process used to register images to maps will be very similar to that used to build the library of GCP's for Landsat-D.

During the flight, a ground operations control team will be in residence at the Payload Operations Control (POCC) on a round-the-clock basis. They will monitor instrument health, provide any needed commands for corrective action, and provide liasion between the science team and JSC to accommodate any adjustments to pre-flight plans occasioned by flight contingencies.

In the post-flight era, it is projected that flight and post-flight calibration data will be reviewed by the science team, who will then define the parameters that will be used to process the bulk of image data collected during the flight.

MISSION OPERATIONS

- PRE-FLIGHT PLANNING
  - PRE-SELECT SOME CONTROL POINTS

- FLIGHT OPERATIONS
  - HOUSEKEEPING
  - DATA ACQUISITION, REGULAR AND CALIBRATION
  - QUICK LOOK
  - IMAGE PROCESSING

- POST-FLIGHT
  - SENSOR & HOUSEKEEPING EVALUATION/REFURBISHMENT
  - CALIBRATION
  - IMAGE PROCESSING

IMAGE REGISTRATION ACCURACY

This chart presents a preliminary version of an image to map registration budget for ELOS. US map accuracy standards are a half millimeter for 1-to-24000 maps (the 7.5 minute series), or an error on the ground of 12 meters. This is a fundamental limitation on the best registration that can be obtained. To these must be added the map digitization and image correlation errors shown here.

In non-level terrain, mis-location of a ground control point relative to contour lines, compounds the registration error. Near nadir, the effect is small, as seen here, but at stereo or large cross track locations, the elevation effect becomes half or more of the simple location effect.

Several studies of the effects of DCPM data compression have concluded that many boundaries will exceed the "settling time" of the compression algorithm so much that about three pixels will be needed to establish correct radiance levels. Since edges are used for control point registration, this represents a systematic registration error (along track only) that must be added to the statistically independent errors.

This table has been updated from the May 18 briefing, based upon information received from Dr. Arch Park of GE, that photointerpreters routinely locate object edges to a fifth of the pixel IFOV. The data in the tables has been revised, based upon that understanding.

IMAGE REGISTRATION ACCURACY (PIXELS)

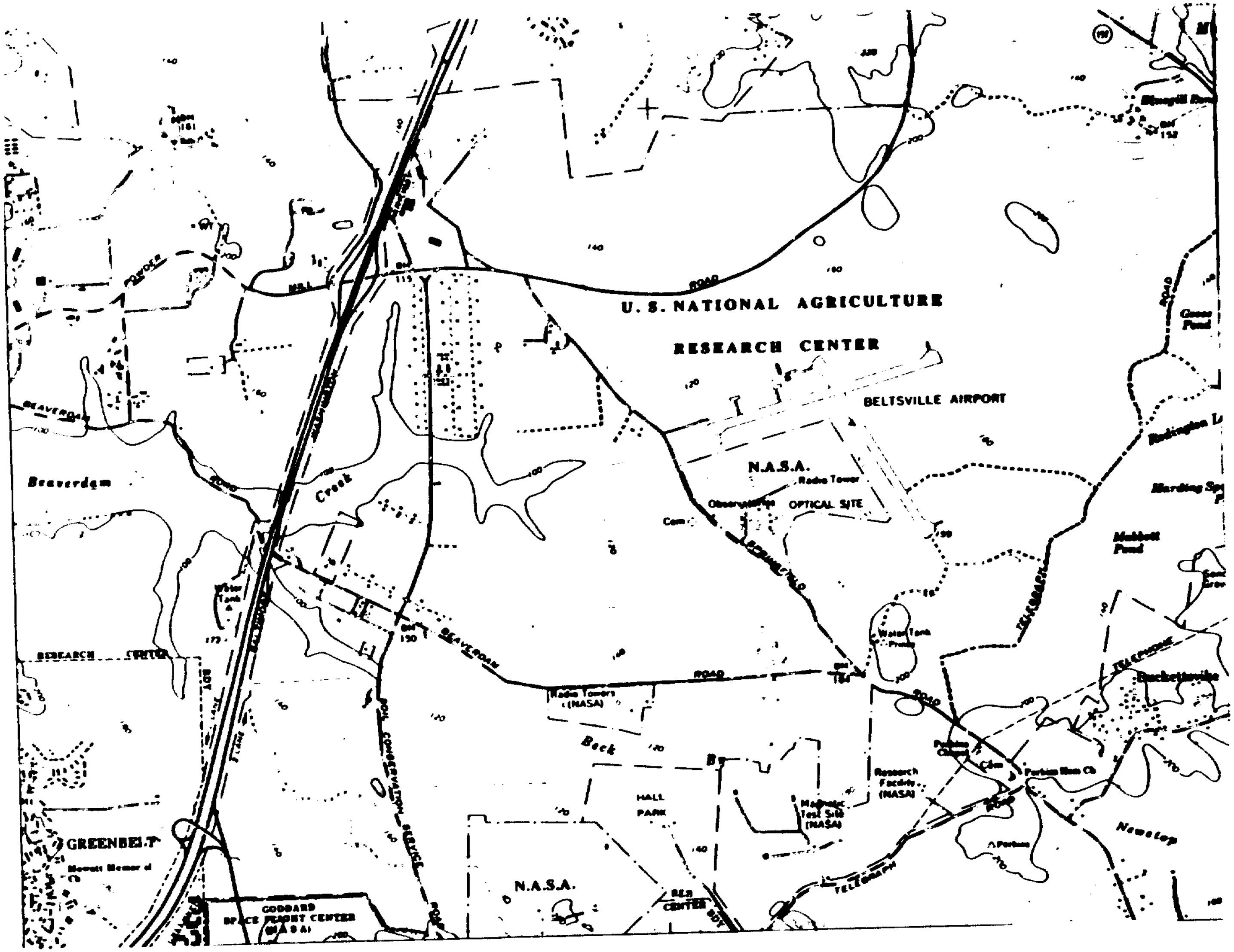
ERROR SOURCE	NADIR VIEW (5°)		ALONG TRACK (25°)		CROSS TRACK (30°)	
	X	Y	X	Y	X	Y
MAP ERROR	2	1.2	1.2	1.2	1.2	1.2
MAP DIGITIZATION						
-OPERATOR	.8	.8	.8	.8	.8	.8
-ELEVATION						
-FLAT	0	0	0	0	0	0
-ROLLING	.008	.008	.04	.04	.05	.05
-RUGGED	.08	.08	.4	.4	.5	.5
IMAGE CORRELATION						
-OPERATOR	.2	.2	.2	.2	.2	.2
-ELEVATION						
-FLAT	0	0	0	0	0	0
-ROLLING	.002	.002	.01	.01	.012	.012
-RUGGED	.02	.02	.1	.1	.12	.12
RSS						
-FLAT	1.5	1.5	1.5	1.5	1.5	1.5
-ROLLING	1.5	1.5	1.5	1.5	1.5	1.5
-RUGGED	1.5	1.5	1.6	1.6	1.6	1.6
DATA COMPRESSION	1.5	0	1.5	0	1.5	0
TOTAL						
-FLAT	3.0	1.5	3.0	1.5	3.0	1.5
-ROLLING	3.0	1.5	3.0	1.5	3.0	1.5
-RUGGED	3.0	1.5	3.1	1.6	3.1	1.6

U.S. NATIONAL AGRICULTURE RESEARCH CENTER

This section of a 7.5 minute section map will be familiar to people who know GSFC and the suburban DC area. It shows an example "super-site" in the form of the U.S. National Agriculture Research Center. Extensive records of weather and crop condition are available at this site to provide ground truth to support ELOS science objectives.

The Beltsville Airport, seen near the center of the chart is a feature typically used on ground control points; it is large, has clear edges, is distinctive in shape, and is flat.

U.S. NATIONAL AGRICULTURE RESEARCH CENTER



NITTANY MOUNTAIN

This well known feature near State College, Pennsylvania was [illegible] estimate what slopes will often be encountered in "rugged" te[illegible] [illegible]opes near McBride Gap and near the south-east summit as great as 64 d[illegible] [illegible]s can be found. A few miles away in a neighboring valley, slopes of four percent are common.

Based upon the study of several maps, of which the two shown here are only samples, it was concluded an error budget of sufficient granularity could be constructed using only three values - "flat", "rolling", and "rugged". Numerical values of 0, 0.1, and 1.0 were associated with these descriptions, and used to calculate the error budget (shown previously).

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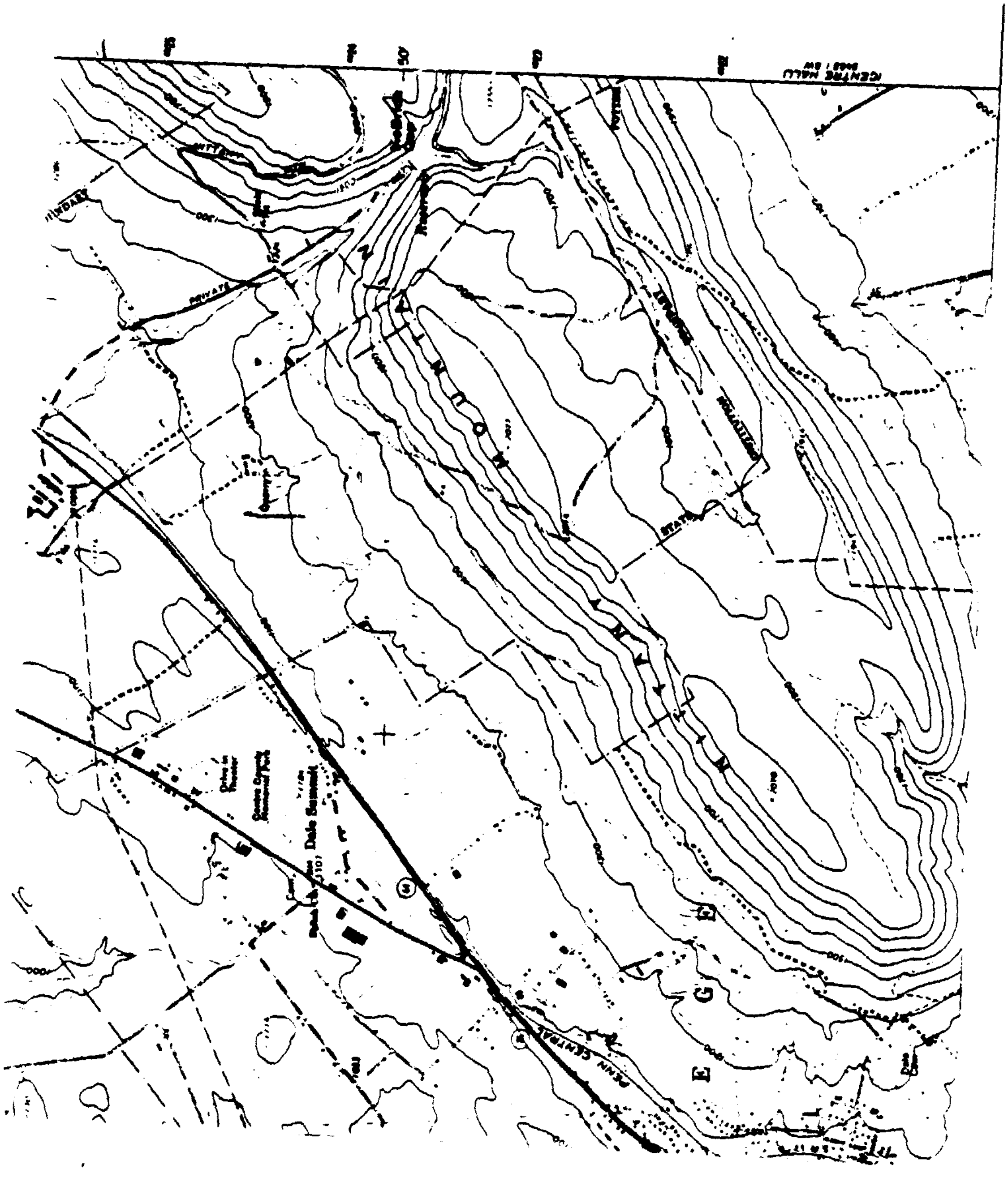


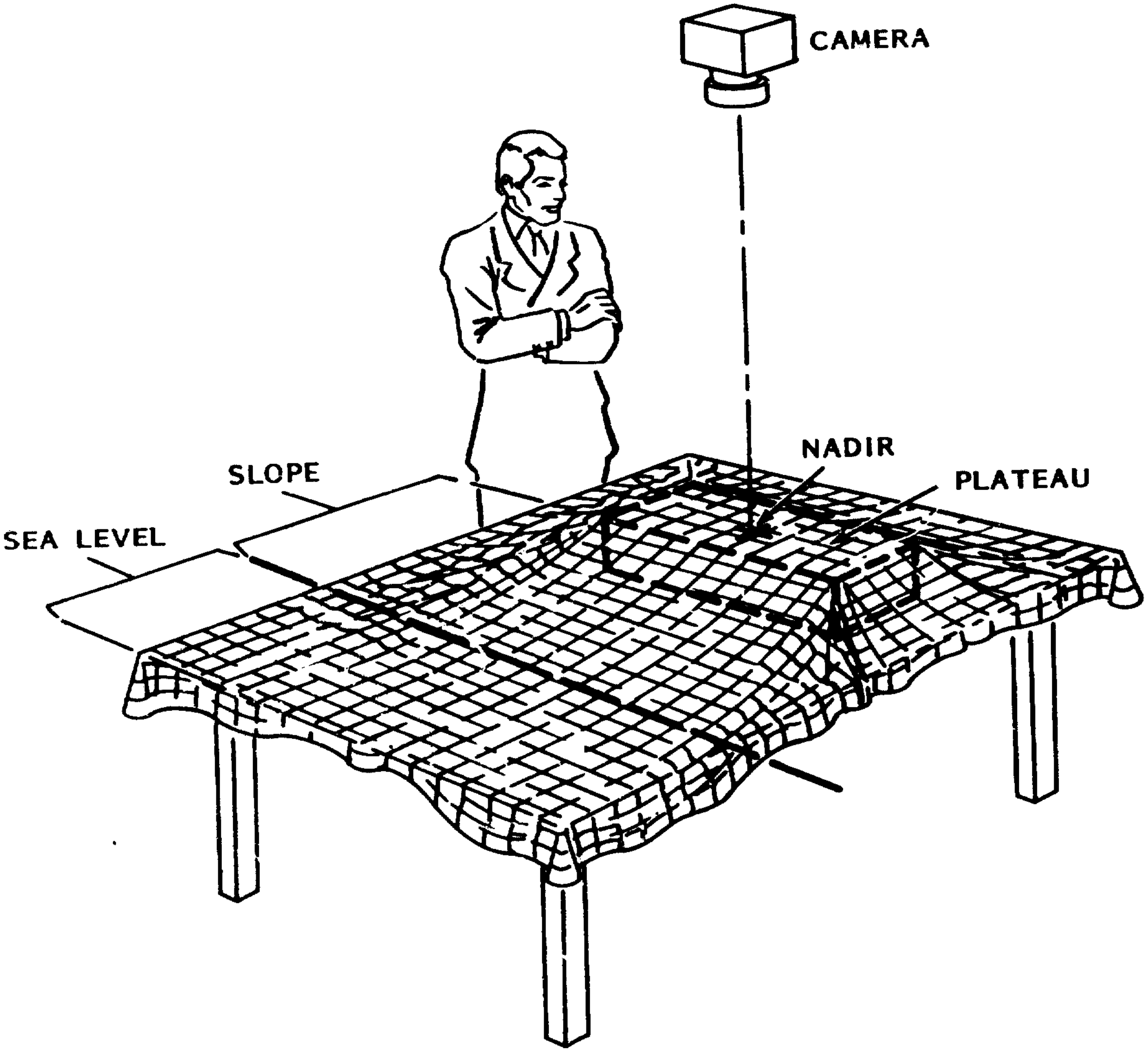
NITTANY MOUNTAIN

OFF- NADIR IMAGING GEOMETRY

The task of explaining how an off-nadir image will be visually different from a nadir scene has been a major difficulty throughout the study. In an attempt to make this visualization possible, we made some simple images with a film camera to illustrate the differences. A checkered tablecloth and some model railroad train scenery (HO gauge - 1/87th size) were set up and photographed from different directions. A rectangular box was placed under one end of the tablecloth to form a plateau and a one dimensional slope.

There are a couple of aspects of the photography that need to be understood in order to interpret the results. The first is that the images here were made with a frame camera, and not a line scanner. Hence these are plate scale changes away from the center of the field-of-view in both directions; in a scanner this effect would only appear cross track. The other effect here is that the field-of-view is much larger than the FOV planned for ELOS. (These pictures cover a field-of-view of about 33 degrees, compared to 10 degrees by .0016 degree for an MLA.) The consequence of this is that the off axis effects are quite significant.

OFF-NADIR IMAGE GEOMETRY



NADIR VIEW

In this image the approximate camera on-axis point is marked "nadir". Away from this point, the image includes a part of the "side" of objects as well as the "top". It is a useful visual aid to remember that the top of three dimensional objects is always in the direction <u>away</u> from the camera axis. See the "box" noted in the upper right of the picture for a good example of the effect.

Since this is a "nadir" view, it is visually like a "P" image product. Note that the squares are square, and that straight lines near nadir are straight, whether they are at "sea level", on the "plateau", or on the slope.

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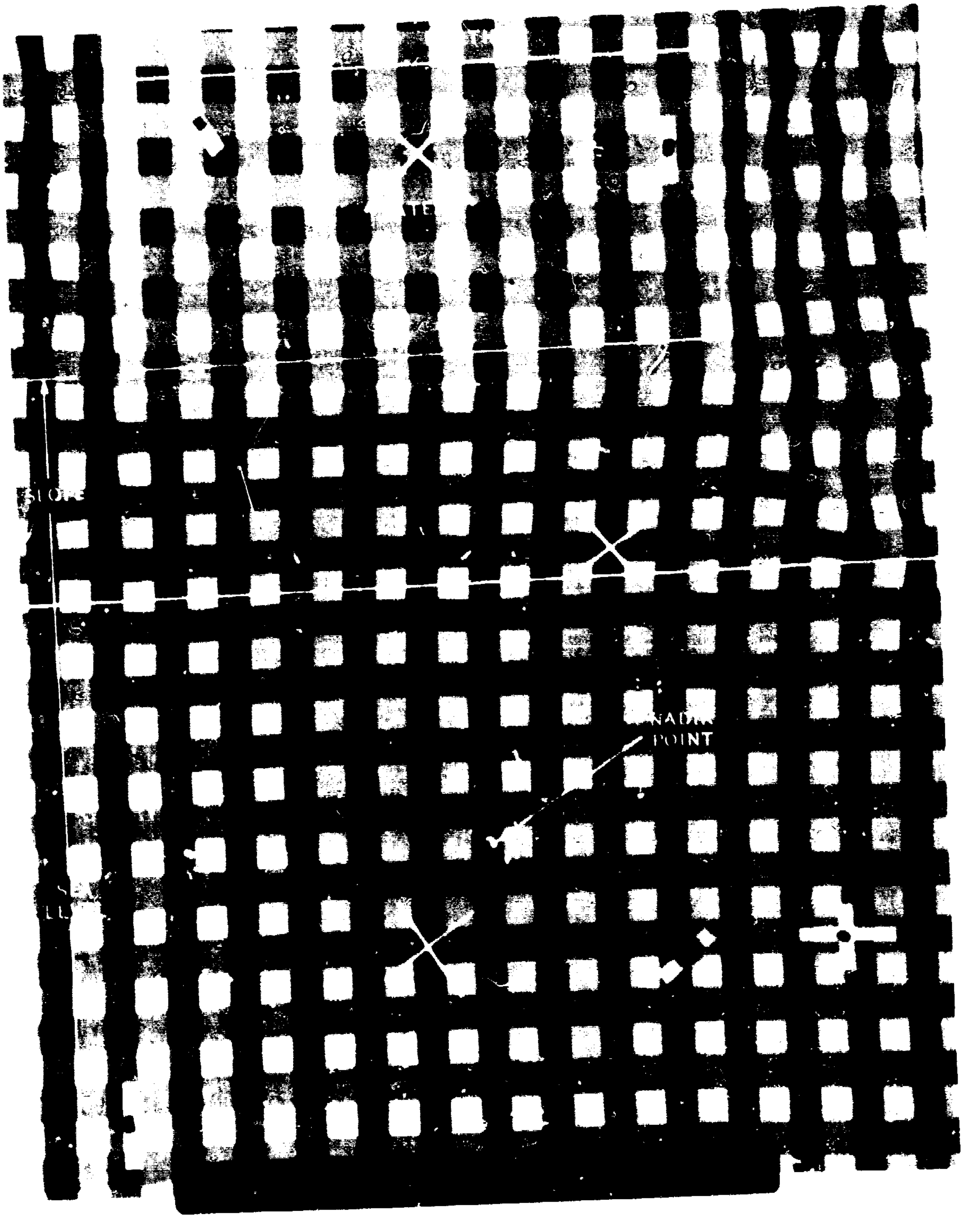
NADIR VIEW

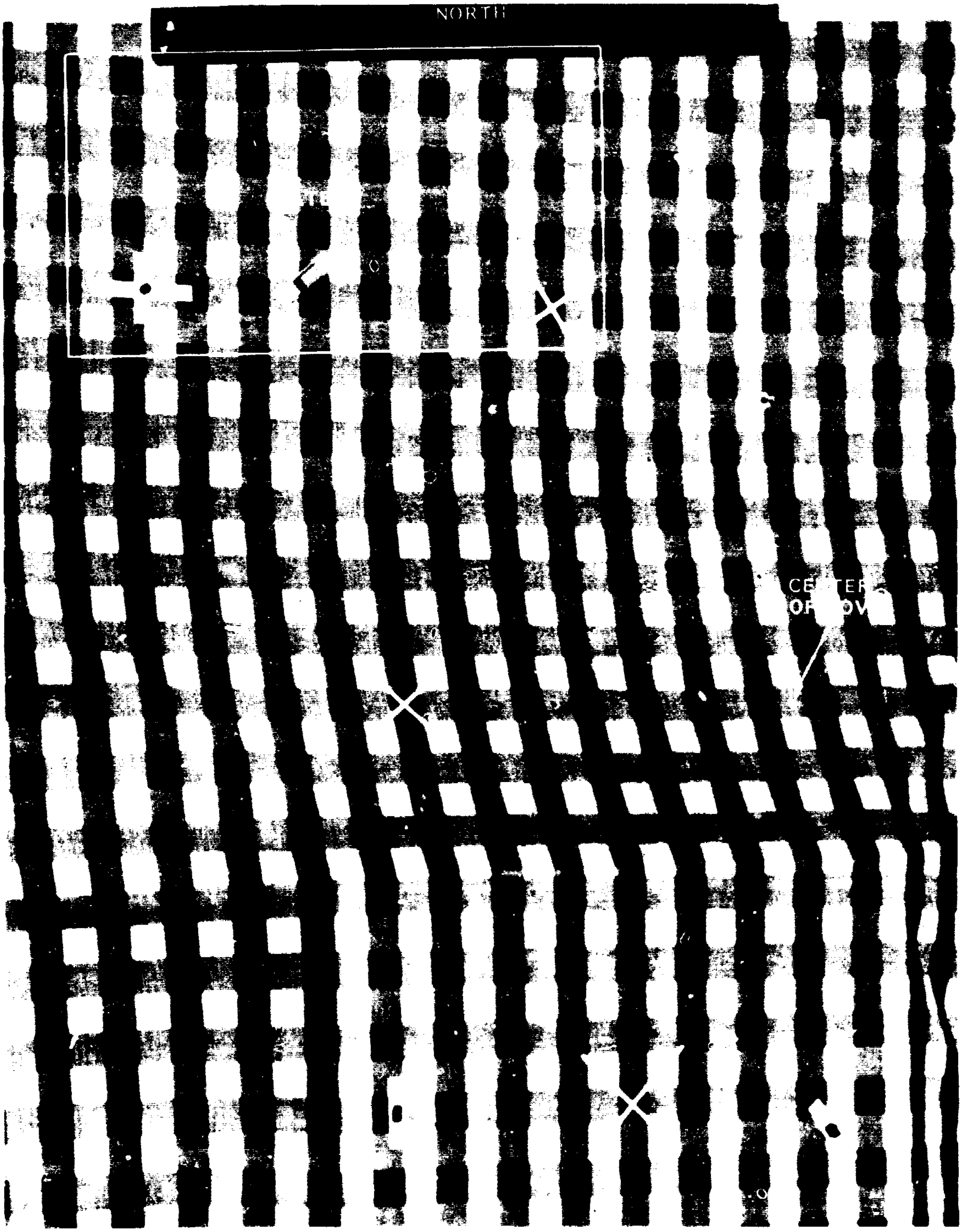


UNCORRECTED OFF-NADIR VIEW

This picture was taken at an angle of approximately 30 degrees off nadir. It is oriented here the same as the previous picture in that the "plateau" is on the left of the page. The center of the FOV is again designated on the chart with an arrow showing the look direction of the camera. Notice the pronounced effect of objects "leaning away" from the camera.

In this picture, the "fields" represented by the squares on the cloth are no longer square. (A pair of drafting dividers makes this easier to see.) Further, the lines on the slope are no longer straight. It is apparent that this image could not be registered with the previous one well enough to permit ground cover classification, for example.

UNCORRECTED OFF-NADIR VIEW



"CORRECTED" OFF-NADIR PHOTOGRAPH

This image was produced from the same film negative as the previous one. The only difference is that the enlarger base was tilted 30 degrees in the direction opposite to the angle introduced into the projection when the picture was taken. Now the square fields are again square, and a sea level field can be registered to a nadir field at the same elevation well enough that crop classification should be possible. By moving the image to account for the elevation difference, square fields on the plateau can also be registered for classification purposes. The amount of image motion needed to register higher elevation images is directly related to the magnitude of the elevation; i.e. the terrain level information contained in this image pair. Said another way, small sections of these images that have the same plate scale can be (and have been) viewed in a stereo viewer, and the stereo effect is present. The extraction of this terrain information is left to the user community, and is not performed by the ELOS data system.

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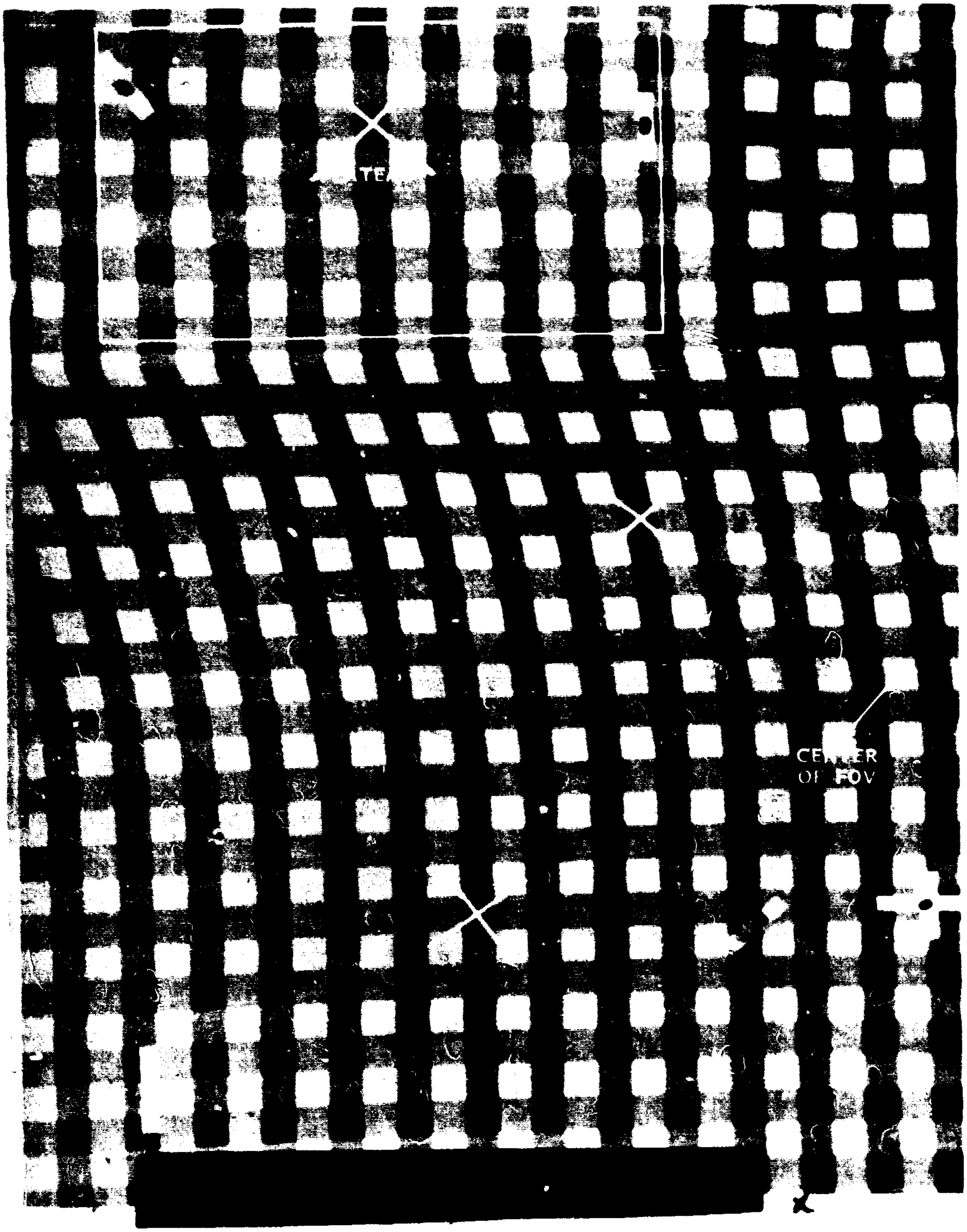
"CORRECTED" OFF-NADIR PHOTOGRAPH



ELOS/STS DATA SYSTEM

This section describes the ELOS/STS Data System. An overview of the end-to-end data system is provided as well as a detailed description of the technical baseline and image processing techniques.

ELOS/STS DATA SYSTEM

- OVERVIEW
- TECHNICAL BASELINE
    - PRELIMINARY HARDWARE CONFIGURATION
    - PRELIMINARY SOFTWARE CONFIGURATION
    - OPERATIONAL CONSIDERATIONS
- IMAGE PROCESSING
    - IMAGE GENERATION
    - MISSION PLANNING
    - QUICK-LOOK PROCESSING
- SUMMARY

OVERVIEW

This section provides an overview of the ELOS/STS end-to-end data system, defines major components in the Ground Segment and provides a high level data flow through the system.

OVERVIEW

- ELOS-STS END-TO-END DATA SYSTEM
- FUNCTIONAL DEFINITION OF ELOS/STS GROUND SEGMENT
- ELOS/STS GROUND PROCESSING FACILITIES

ELOS/STS END-to-END DATA SYSTEM OVERVIEW

Data acquired by the MLA sensor on board the shuttle is transmitted to the MIGF (MLA Image Generation Facility) at Goddard via TDRSS and DOMSAT. The raw image data will be processed after completion of the mission, in conjunction with the shuttle orbiter parameters received from JSC. Quick look data will be processed and evaluated immediately. The housekeeping data will be stripped out of the received data and sent to the POCC (Payload Operations Control Center) in Building 14 at Goddard, where it will be analyzed for anomalies. Any required modification in the mission will be accomplished by sending pre-canned commands from the POCC to the shuttle, via the Mission Control Center at JSC.

ELOS/STS END-TO-END DATA SYSTEM OVERVIEW

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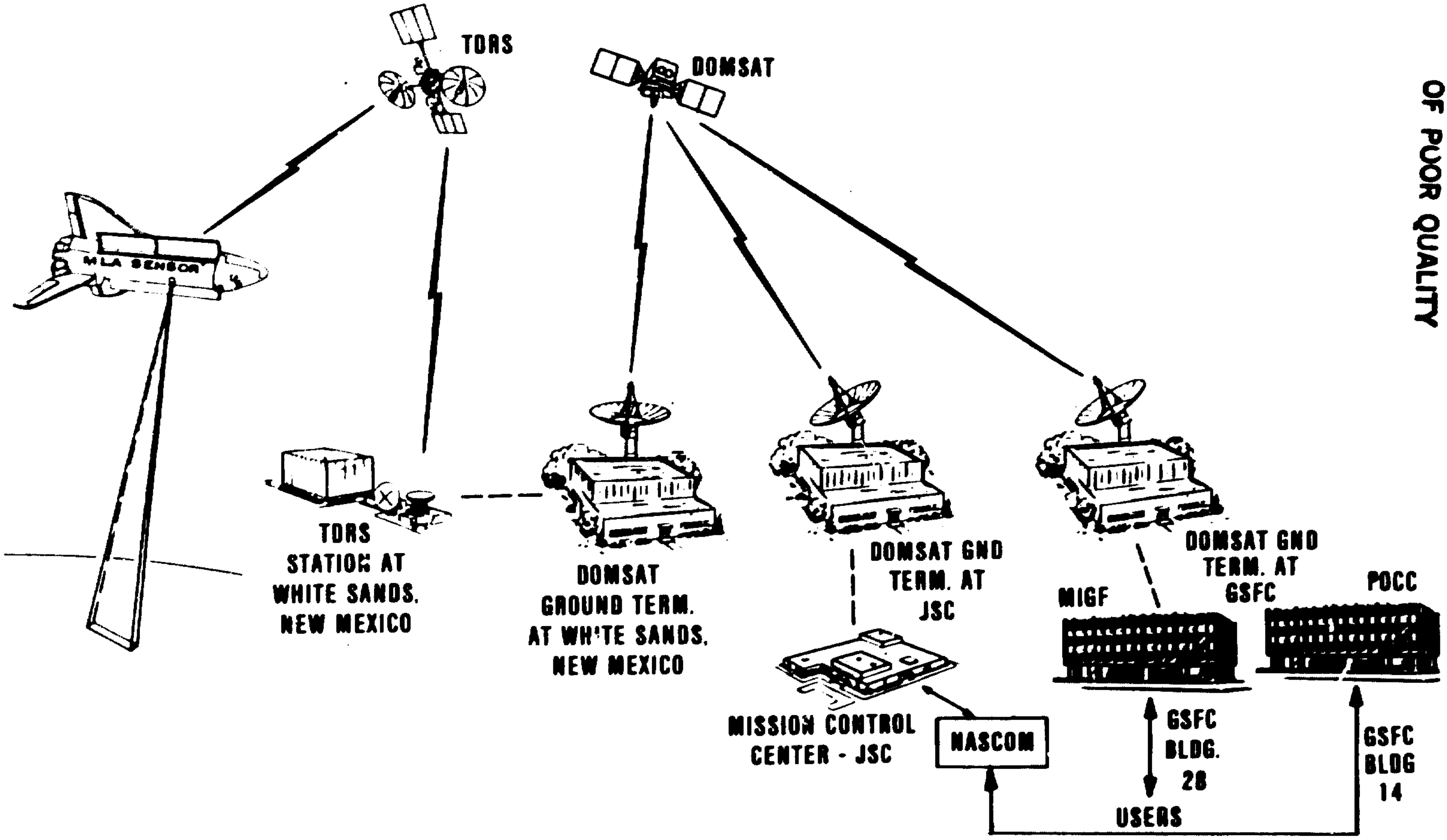
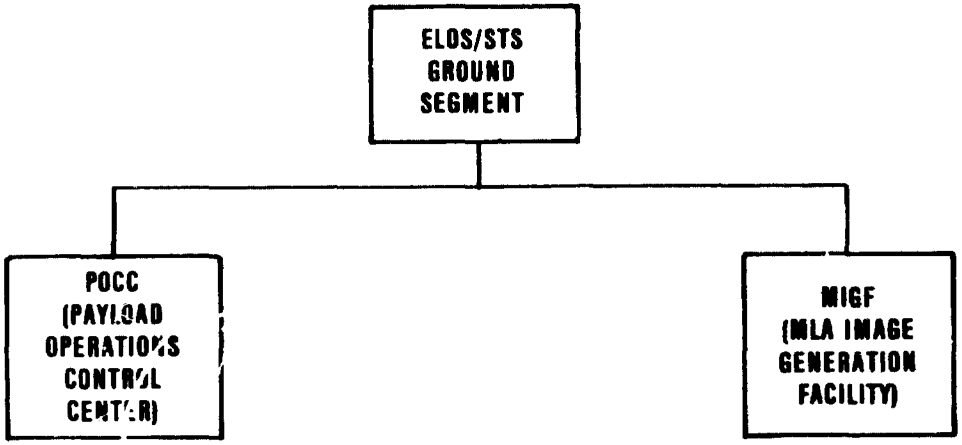


FUNCTIONAL DEFINITION of ELOS/STS GROUND SEGMENT

The ELOS/STS ground segment will consist of two major facilities, the POCC and the MIGF. The POCC will perform those functions related to planning the mission, commanding the MLA sensor (via pre-generated commands), and evaluating the MLA housekeeping data. The other functions shown are provided to allow the processes just described, to be carried out. An extrememly important function is that of data base management. The POCC data base will consist of those parameters concerned with the operation of the MLA sensor - that is - commands, sensor status, telemetry limits, constraints, etc.

The other major facility, the MIGF, is concerned with the actual processing of the image data. It consists of those functions necessary to acquire, process and generate corrected images from the raw sensor data. This includes off-nadir as well as nadir data. The MIGF also performs the function of quick-look processing to allow experimenters to make a quasi-realtime decision on the acceptability of the acquired data.

FUNCTIONAL DEFINITION OF ELOS/STS GROUND SEGMENT



POCC

- MISSION PLANNING
- MLA COMMAND GENERATION
- TELEMETRY EVALUATION
- DATA BASE MANAGEMENT
- KEYBOARD/DISPLAY PROCESSING
- EXTERNAL INTERFACES

MIGF

- DATA RECEIPT PROCESSING
- QUICK-LOOK PROCESSING
- IMAGE GENERATION
- STEREO/CROSS-TRACK PROCESSING
- PRODUCT GENERATION
- DATA BASE MANAGEMENT
- EXTERNAL INTERFACES

ELOS/STS GROUND PROCESSING FACILITIES

This chart shows the major ELOS ground facilities, their key hardware elements and the relationship that they have with each other. Raw image data acquired from DOMSAT is received in Building 28, via the Landsat-D DRRTS (Data Receive, Record and Transmit Subsystem), and recorded on a high density tape. That tape is hand carried to the MIGF, where a Quick-look function is immediately performed. Stripped out telemetry is delivered to the POCC, where it is evaluated via the TAC, AP and MOR. If anomalies are detected, and a modification in the mission is required, pre-canned commands are sent to JSC via the SPIF and NASCOM.

Upon completion of the mission, the raw MLA sensor data is processed at the MIGF, which uses a set of reconfigured hardware from the LAS (Landsat Assessment System) and the ADDS (Application Development Data System). The resultant products are made available to the users. They (the products) consists of computer compatible tapes of raw sensor data, radiometrically corrected data with geometric correction parameters appended, and geometrically corrected data. A set of geometrically corrected 241mm film products will also be generated.

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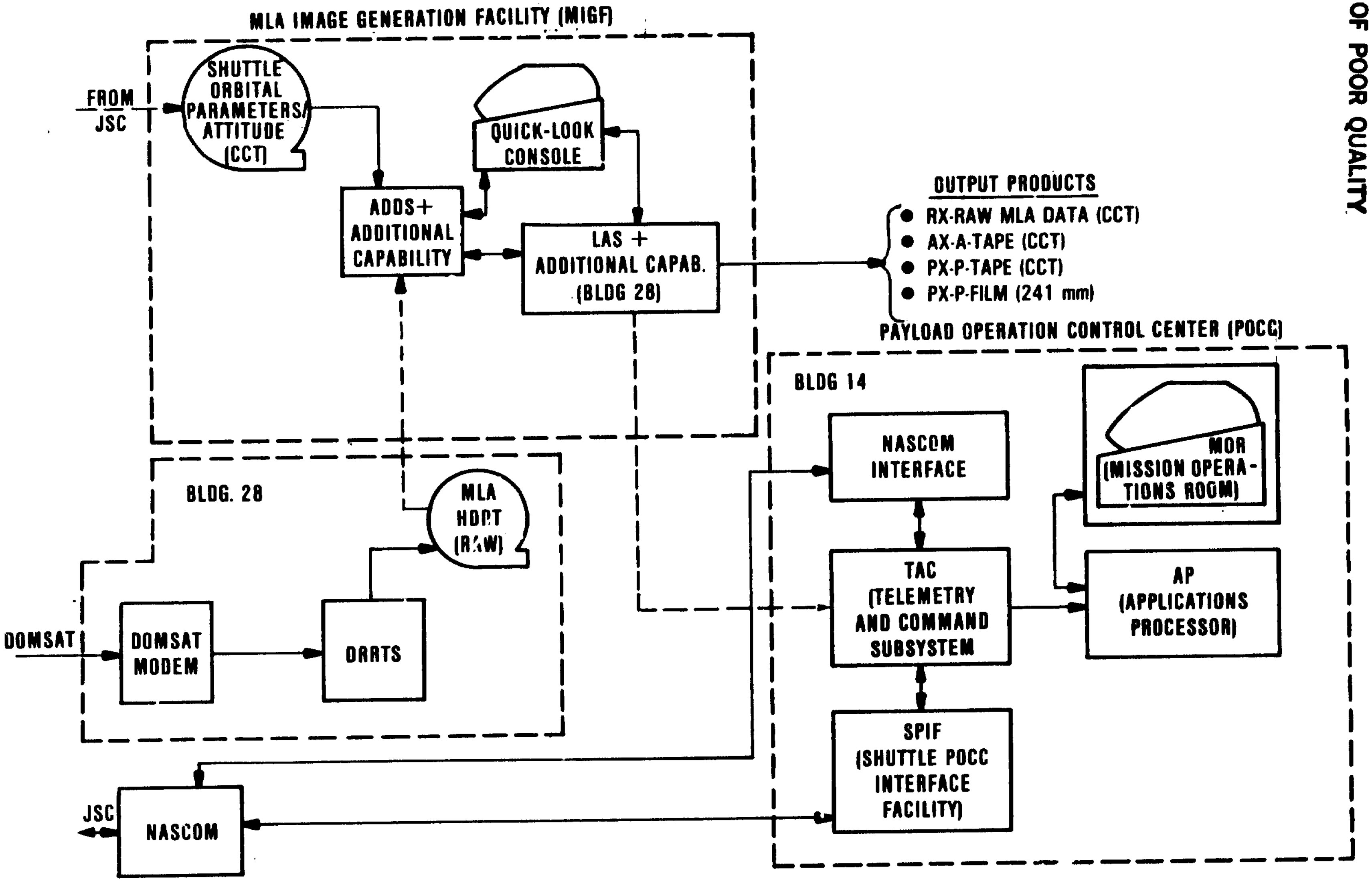
ELOS/STS GROUND PROCESSING FACILITIES



TECHNICAL BASELINE

This section describes the ELOS/STS Ground Segment. Hardware, Software and Operational aspects are discussed for the MLA Image Generation Facility as well as use of NASA's Multi-Satellite Operations Control Center. Staffing requirements are addressed.

TECHNICAL BASELINE

- MIGF PRELIMINARY HARDWARE CONFIGURATION
- MLA IMAGE GENERATION FACILITY
- MIGF SOFTWARE OVERVIEW
- TYPICAL MIGF TIMELINE
- MULTI-SATELLITE OPERATIONS CONTROL CENTER
- MANNING ESTIMATES

MIGF PRELIMINARY HARDWARE CONFIGURATION

The hardware resources of the Landsat Assessment System and the Advanced Development Data System can be combined to provide a single facility for processing MLA image data from High Density Tape to finished film products. The only new hardware design will install interface circuitry on a standard CSP, Inc. I/O Scroll card in the MAP 300 to support decompression and error correction/detection of the raw image data.

Using standarized components and data busses will facilitate installation of any new peripherals and utilizing array processors will support new implementation of current algorithms to investigate enhancements in image preprocessing.

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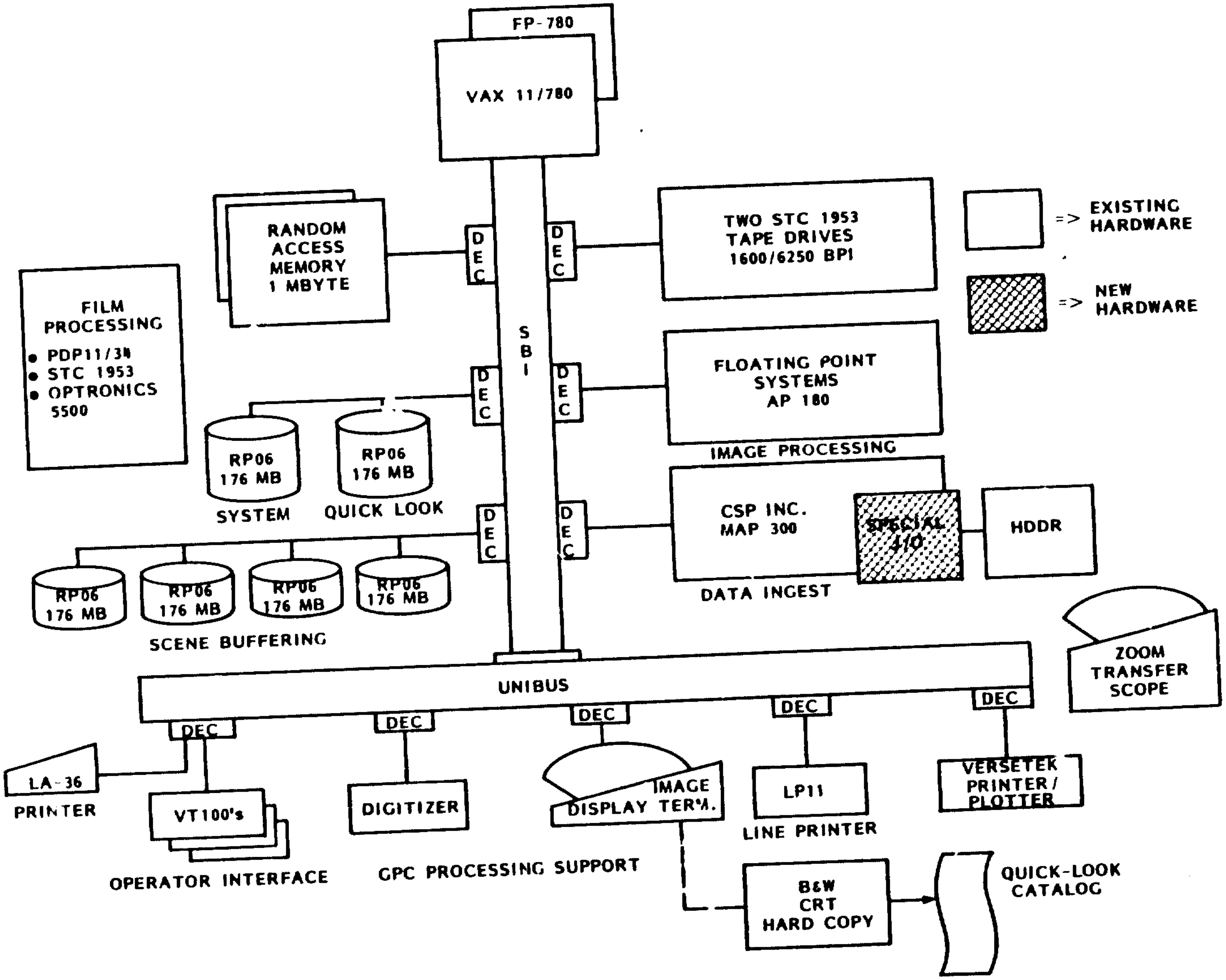
MIGF PRELIMINARY HARDWARE CONFIGURATION



MLA IMAGE GENERATION FACILITY

This table identifies the type and quantity of hardware items necessary to implement the MLA Image Generation Facility. With the exception of the Special I/O, all hardware can be procured off-the-shelf as standard equipment. It is presently planned that all hardware except the Special I/O and the CRT Hardcopy device could be provided GFE from existing Landsat-D resources. The Special I/O is special purpose hardware assembled on a CSP, Inc.'s I/O Scroll printed circuit board which is off-the-shelf hardware and is physically installed in and supported by the CSP, Inc. MAP 300.

MLA IMAGE GENERATION FACILITY

COMPONENT	QUAN.	FUNCTION	SOURCE	COMMENT
● VAX 11/780	1	GENERAL CONTROL AND PROCESSING	GFE	
● SPECIAL I/O	1	ERROR CORRECTION DECOMPRESSION	NEW HARDWARE	PROGRAMMABLE
● MAP 300 AND SBI I/O	1	DATA INGEST DECOMMUTATION	GFE	
● FPS AP180V	1	RADIOMETRIC CORRECTION RESAMPLING	GFE	USING THE AP180V ALLOWS SOFTWARE TRANSFER FROM MSS LANDSAT D.
● MASS STORAGE DISKS	6	● QUICK LOOK ● IMAGE GENERATION ● SCENE MANAGEMENT DATA BASE	GFE	450 MBYTES OF IMAGE DISK STORAGE IS REQUIRED FOR THE IMAGE GENERATION FUNCTION
● CRT HARDCOPY	1	QUICK-LOOK SCENE PREVIEW	NEW HARDWARE	
● CCT TAPE DRIVES	3	OUTPUT PROCESSING	GFE	1600/6250 BPI
● VT100	4	● CONTROL/MONITORING ● QUICK LOOK	GFE	
● IMAGE DISPLAY TERMINAL	1	● SCROLLING DISPLAY ● QUICK-LOOK ● GCP DESIGNATION	GFE	
● DIGITIZER	1	● GCP LOCATION DETERMINATION	GFE	
● FILM GENERATION	1	FILM GENERATION	GFE	OFF-LINE CCT INTERFACE
● HDDR	1	DATA INGEST	GFE	

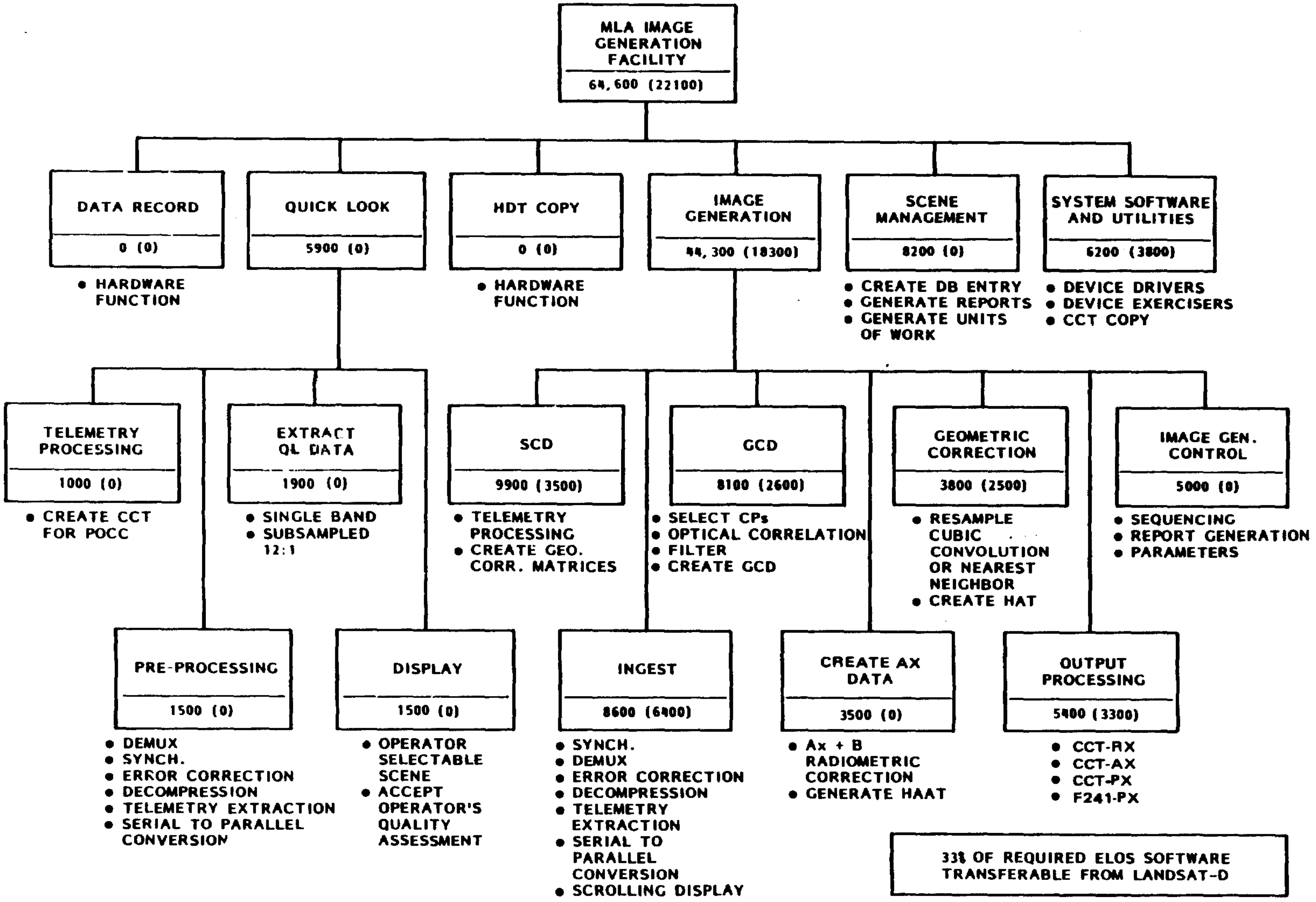
MIGF SOFTWARE OVERVIEW

The chart illustrates the MIGF software hierarchy. The numbers at the bottom of each box indicate the total number of lines of code required to implement the function, and the number of lines of code of that amount that are directly transferrable from Landsat D (in paranthesis). Note that approximately 33% of the MIGF lines of code can be transferred directly from Landsat D.

The lines of code estimates were derived by breaking each function down as much as practical, and then estimating the number of lines of code for each low level module. These numbers were then checked against Landsat D actual and projected lines of code figures for consistency.

Transferrability was assessed by a careful examination of each module, comparing its functions to similar Landsat D functions.

MIGF SOFTWARE OVERVIEW



- MLA IMAGE GENERATION FACILITY — 64,600 (22100)
  - DATA RECORD — 0 (0)
    - HARDWARE FUNCTION
  - QUICK LOOK — 5900 (0)
    - TELEMETRY PROCESSING — 1000 (0)
      - CREATE CCT FOR POCC
    - PRE-PROCESSING — 1500 (0)
      - DEMUX
      - SYNCH.
      - ERROR CORRECTION
      - DECOMPRESSION
      - TELEMETRY EXTRACTION
      - SERIAL TO PARALLEL CONVERSION
    - EXTRACT QL DATA — 1900 (0)
      - SINGLE BAND
      - SUBSAMPLED 12:1
    - DISPLAY — 1500 (0)
      - OPERATOR SELECTABLE SCENE
      - ACCEPT OPERATOR'S QUALITY ASSESSMENT
  - HDT COPY — 0 (0)
    - HARDWARE FUNCTION
  - IMAGE GENERATION — 44,300 (18300)
    - SCD — 9900 (3500)
      - TELEMETRY PROCESSING
      - CREATE GEO. CORR. MATRICES
    - INGEST — 8600 (6400)
      - SYNCH.
      - DEMUX
      - ERROR CORRECTION
      - DECOMPRESSION
      - TELEMETRY EXTRACTION
      - SERIAL TO PARALLEL CONVERSION
      - SCROLLING DISPLAY
    - GCD — 8100 (2600)
      - SELECT CPs
      - OPTICAL CORRELATION
      - FILTER
      - CREATE GCD
    - CREATE AX DATA — 3500 (0)
      - Ax + B RADIOMETRIC CORRECTION
      - GENERATE HAAT
    - GEOMETRIC CORRECTION — 3800 (2500)
      - RESAMPLE CUBIC CONVOLUTION OR NEAREST NEIGHBOR
      - CREATE HAT
    - OUTPUT PROCESSING — 5400 (3300)
      - CCT-RX
      - CCT-AX
      - CCT-PX
      - F241-PX
    - IMAGE GEN. CONTROL — 5000 (0)
      - SEQUENCING
      - REPORT GENERATION
      - PARAMETERS
  - SCENE MANAGEMENT — 8200 (0)
    - CREATE DB ENTRY
    - GENERATE REPORTS
    - GENERATE UNITS OF WORK
  - SYSTEM SOFTWARE AND UTILITIES — 6200 (3800)
    - DEVICE DRIVERS
    - DEVICE EXERCISERS
    - CCT COPY

33% OF REQUIRED ELOS SOFTWARE TRANSFERABLE FROM LANDSAT-D

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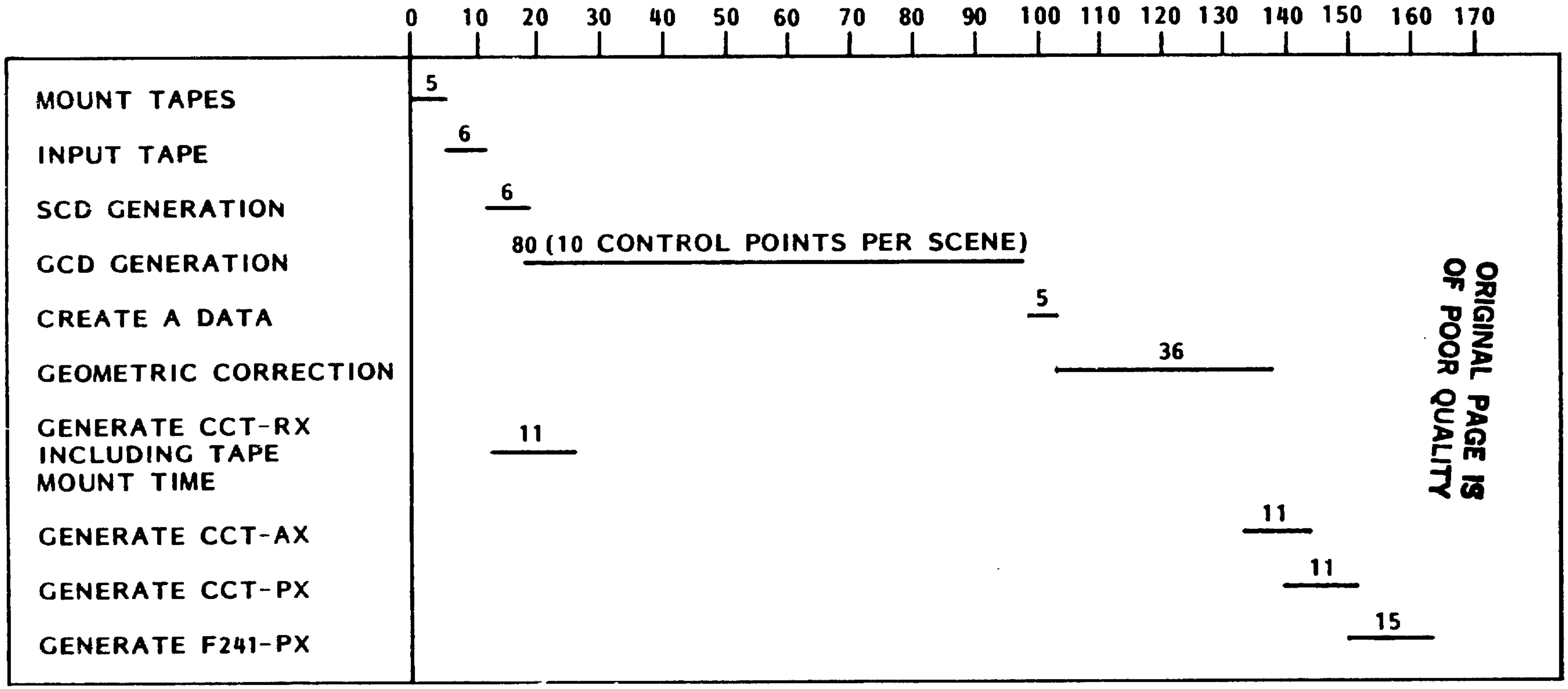
TYPICAL MIGF TIMELINE (1 SCENE)

The timeline is based on comparison to similar Landsat D functions. The two most significant times are the Control Point processing time and the resampling times.

The Control Point function is essentially a manual function. An operator locates the geodetic location of each control point and then optically correlates a map to the MLA imagery. Experience with the Landsat D Control Point Library Build function has shown that the operator requires approximately 8 minutes per point.

The geometric correction time is based on benchmarks derived for the Landsat D MSS Image Processing System.

TYPICAL MIGF TIMELINE (1 SCENE)



PROCESSING TIME = 85 MIN/SCENE + 8 MINUTES/CONTROL POINT

TOTAL TIME (10 CONTROL POINTS) = 165 MIN/SCENE = 2 HRS 45 MIN

MULTI-SATELLITE OPERATIONS CONTROL CENTER (MSOCC)

This chart depcits our understanding of the hardware configuration of the MSOCC, located in Building 14. It presently consists of 5 PDP11/34's (eventually expandable to 8) interfacing directly with NASCOM for receipt of telemetry data and transmission of commands. The received data goes from the TAC to an AP (PDP-11/70) via patching equipment, and from there to a number of Mission Operations Rooms, again, via patching equipment. The MOR will be staffed with contractor operations personnel during the entire 7 day mission.

It is anticipated that prior to and during the ELOS/STS mission, a TAC, AP and MOR will be available for exclusive use of the Operations personnel.

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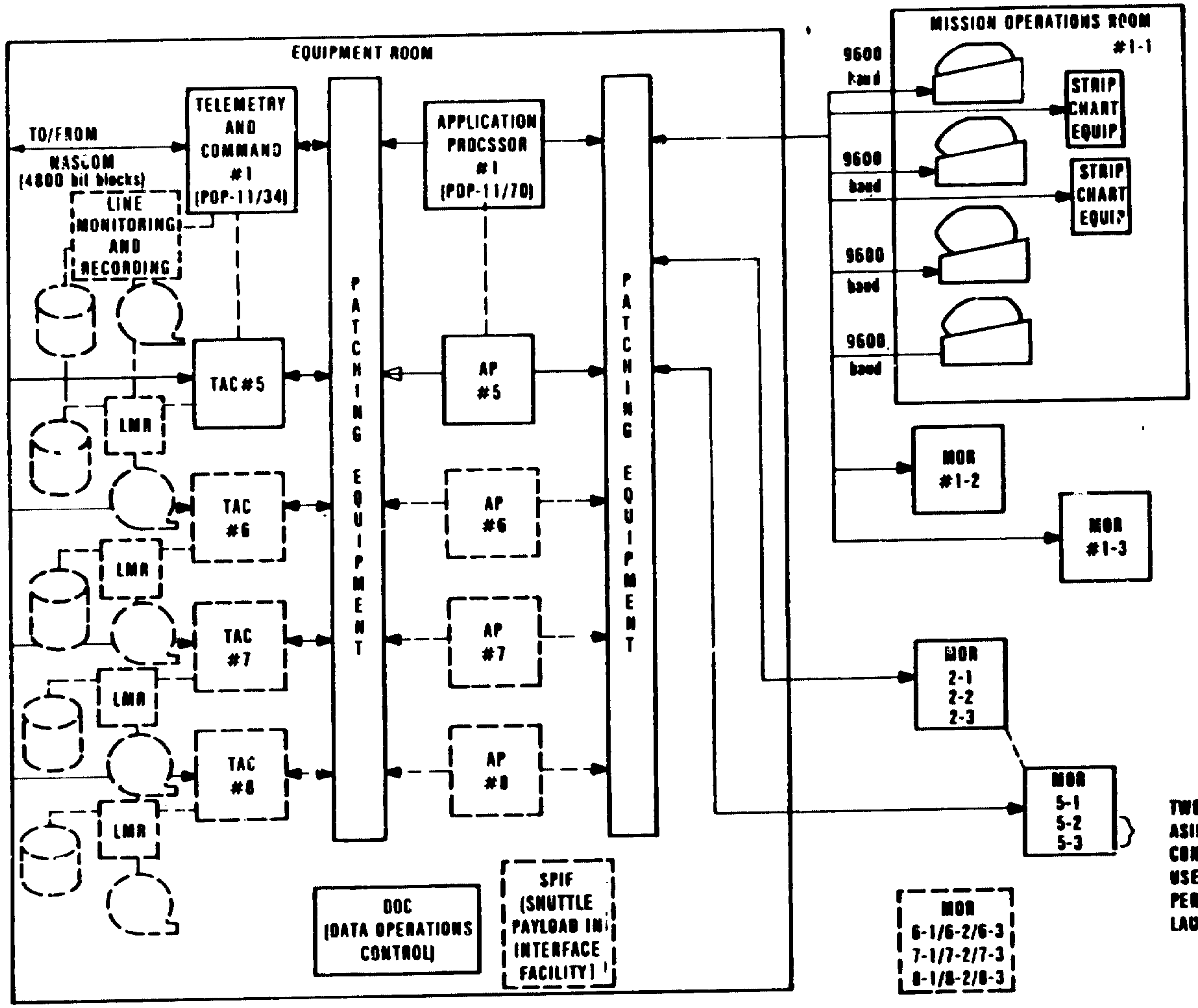
MULTI-SATELLITE OPERATIONS CONTROL CENTER (MSOCC)



TWO MOR'S ARE SET ASIDE AS LCR'S (LAUNCH CONTROL ROOMS) TO BE USED FOR ADDED OPERATIONS PERSONNEL REQUIRED DURING LAUNCH OPERATIONS

MANNING ESTIMATES

Personnel manning the POCC during the pre-mission and mission phases will not be required during the post-mission phase. MIGF personnel are assigned for the pre-mission, mission, and post-mission phases (Note - the pre-mission phase will be approximately 90 days in duration, the mission phase seven days, and the post-mission phase approximately one year). Also note that while there will be three shifts during the pre-mission/mission phases, there will be one shift during the post-mission phase.

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MANNING ESTIMATES

FACILITY	PRE-MISSION/MISSION (3 SHIFTS) (DURATION OF MISSION)	NO. PER SHIFT	POST MISSION (1 SHIFT) (CONTINUOUSLY)	NO.
POCC	• MISSION PLANNER • TELEMETRY EVALUATOR • COMMAND GENERATOR/ VERIFIER • EXPERIMENTER REPRESENTATIVE (+ POCC OPERATIONS PERSONNEL)	3 1 1 1		
MIGF	• MIGF SUPERVISOR • QUICK LOOK OPERATOR • MIGF OPERATIONS PERSONNEL • EXPERIMENT COORDINATOR	1 1 4 1	• MIGF SUPERVISOR • GCP OPERATORS • MIGF OPERATIONS PERSONNEL • DATA CLERKS • EXPERIMENTER COORDINATOR	1 2 8 2 1
MISSION CONTROL CENTER (JSC)	• EXPERIMENT COORDINATOR	1		

IMAGE PROCESSING

This section discusses the process of generating MLA images. Data flow through the MIGF, mission planning and quick look operations is defined and discussed. Significant processing operations such as error correction, radiometric correcton, and geometric correction are addressed.

IMAGE PROCESSING

- ERROR CORRECTION CODES
- MLA IMAGE PROCESSING
- IMAGE GENERATION DATA FLOW
- RADIOMETRIC CORRECTION
- GEOMETRIC CORRECTION PROCESS FOR MLA
  - SYSTEMATIC CORRECTION
  - GEODETIC CORRECTION
- MISSION PLANNING AND QUICK LOOK PROCESSING
  MISSION PLANNING
  - QUICK LOOK DATA FLOW

ERROR CORRECTION CODES

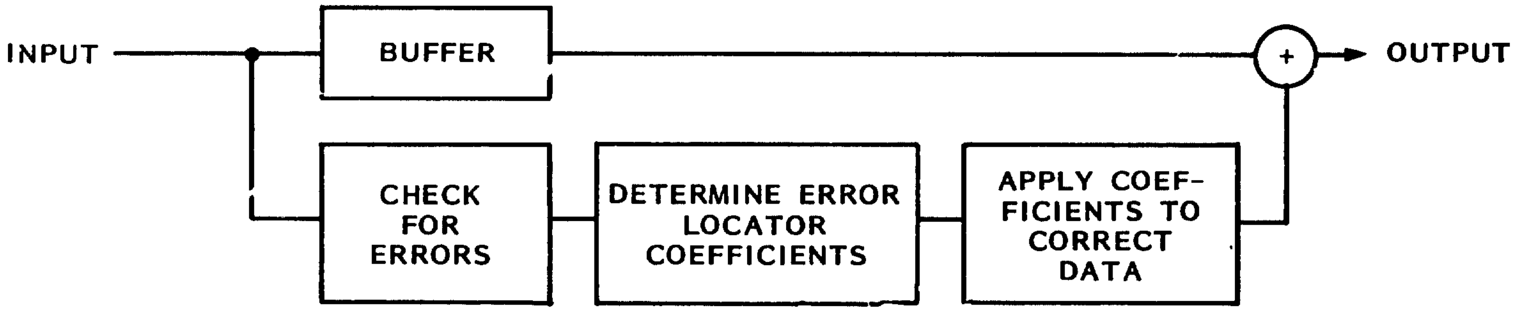
Both BCH and Reed-Solomon error detection and correction codes encode the input data block as a polynomial multiple of a fixed generator polynomial with coefficients in a specified symbol field. The symbol field for the (255, 231) BCH code is simply Z_2 whereas for the (255,233) Reed-Solomon code, it is the Galois field GF (2^8). The difficulty of on board encoding is directly related to the complexity of the symbol field. With the BCH code, each bit is a coefficient of the broadcast polynomial; the encoding is performed with simple circuitry using feedback shift registers with binary adders. The Reed-Solomon code associates each 8 bits with a coefficient of a polynomial over GF (2^8); the encoding arithmetic is then over the more complicated field GF(2^8).

Decoding both BCH and Reed-Solomon codes involves the three steps of:

1. finding the syndromes in the error location field,
2. computing the coefficients of the error locator polynomial (and the error evaluator polynomial for Reed-Soloman codes),
3. employing Chien Search to identify the erroneous symbols and then correct them.

The error locator field for both of the above codes is GF (2^8). The BCH code processes a block of 255 bits whereas the Reed-Solomon code processes a block of 255, 8 bit bytes.

ERROR CORRECTION CODES



OPTIONS	CHARACTERISTICS	IMPACT
BCH (BOSE-CHAUDHURI HOCQUENGHEM)	• (255,231) • BIT ORIENTED • CORRECTS 3 RANDOM BIT ERRORS	SIMPLER ENCODING/DECODING LOW ERROR CORRECTING CAPABILITY
REED-SOLOMON	• (255,223) • BYTE ORIENTED • CORRECTS 16 BYTE ERRORS	BURST ERROR CORRECTION COMPLEX ENCODING

MLA IMAGE PROCESSING

This chart depicts those functions involved in processing MLA sensor data. Previously error detected and corrected HDDT's are selected for demultiplexing, decompressing and processing. A raw CCT is produced, annotated with the appropriate shuttle parameters - that is, orbit, altitude, etc. In addition to the raw data CCT, the raw sensor data is radiometrically corrected. These data, along with appended geometric correction matrices, are used to produce an AX CCT. The geometric correction matrices are used to resample the radiometrically corrected data to produce a PX-CCT as well as a PX-241mm film product.

MLA IMAGE PROCESSING

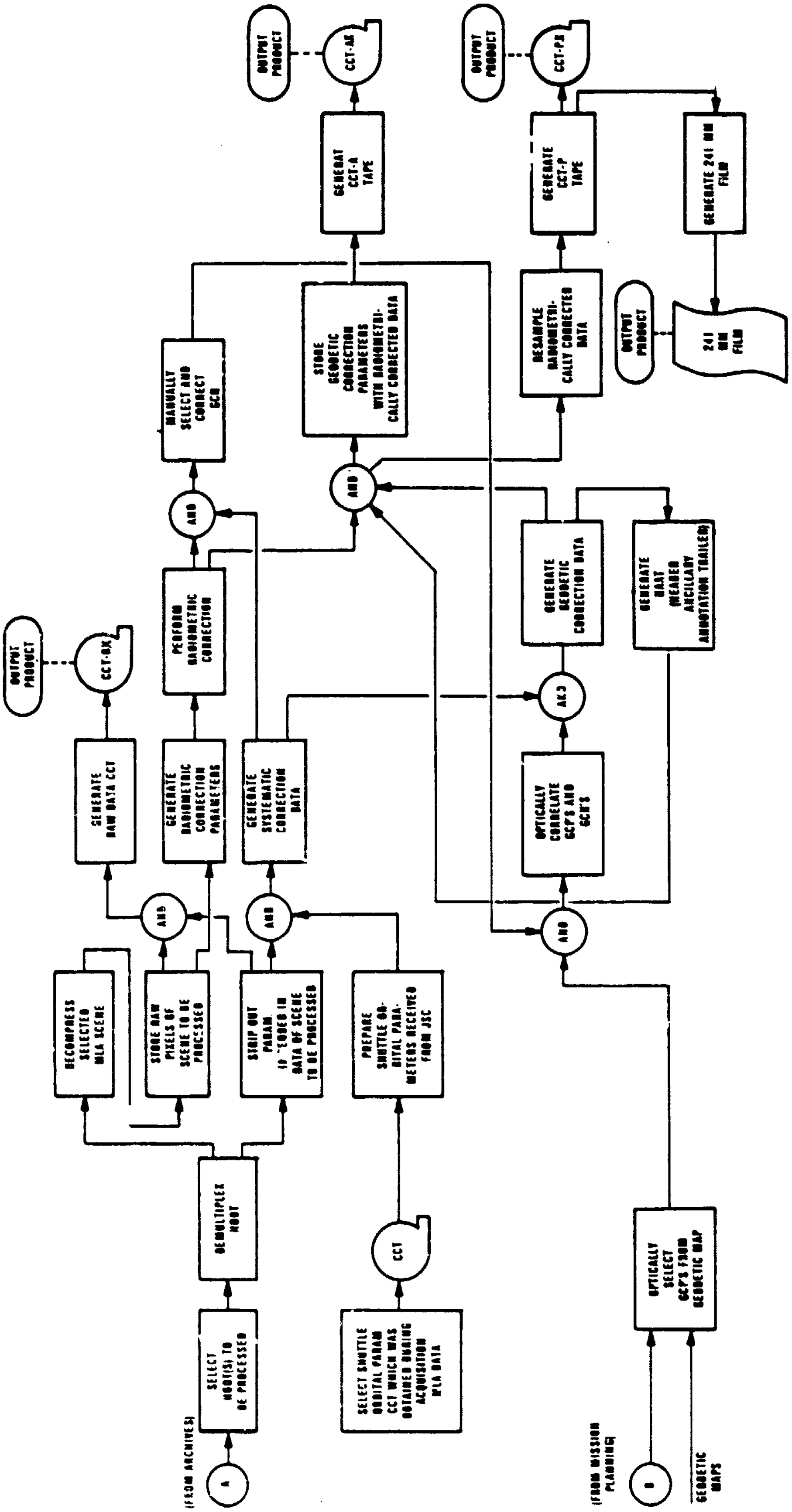


IMAGE GENERATION DATA FLOW

The Image Generation function ingests raw MLA data from HDT, performs the same preprocessing as the Quick Look Function and writes the raw data on disk. Systematic and Geodetic correction data are calculated using look point models, and ground control points respectively. These calculations are performed for all nadir and off-nadir scenes, providing correction for stereo and off track scenes.

AX data is created by applying predetermined radiometric correction functions to the raw image data and appending the geometric correction matrices. AX data is stored on disk.

PX data is created by resampling the AX data per the geometric correction matrices using an array processor. Output is again to a separate area on disk.

Output processing consists of creating CCTs from either the RX, AX or PX data on disk. Any or all types of CCTs may be made for a given scene.

High resolution film is created by reading a CCT-PX into the high resolution film film system and producing latent film.

IMAGE GENERATION DATA FLOW

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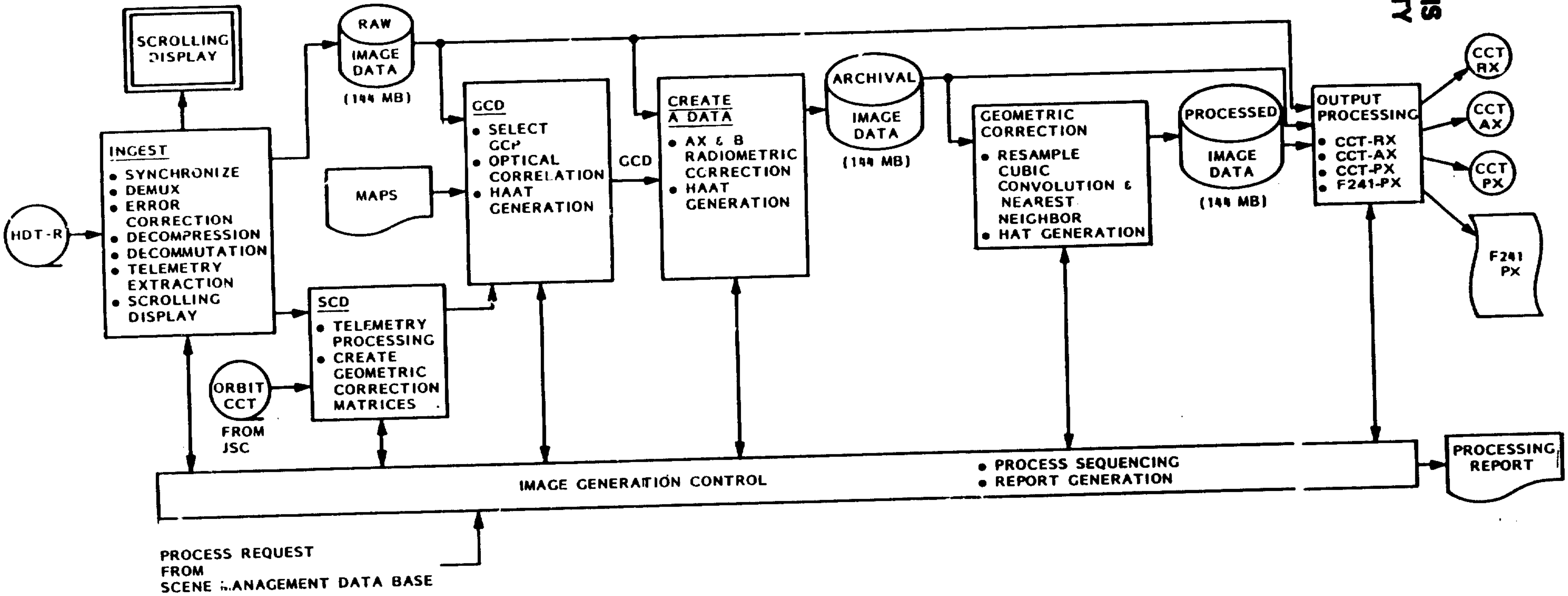
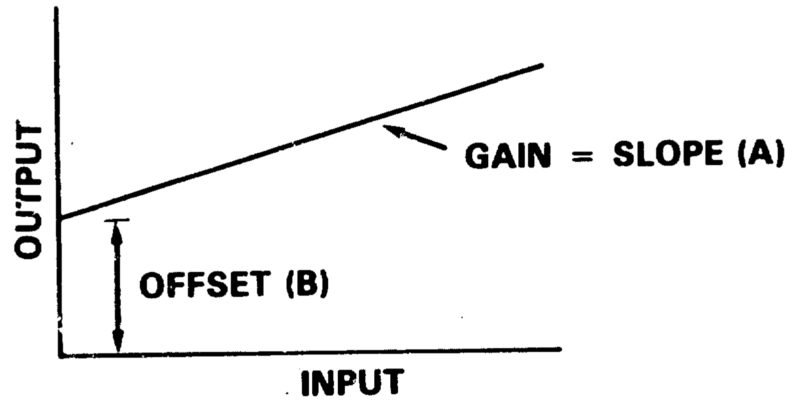


RADIOMETRIC CORRECTION

For this study, it is assumed that all calibration processing (radiometric correction) is accomplished on the ground. The sensor is calibrated before flight and correction parameters are provided to the processing facility for use during the flight. Several calibration checks will be acquired by the sensor during the mission; after evaluation of these data, updated radiometric correction parameters will be provided to the ground facility for the balance of the image processing. The data system will be designed to accommodate the sensor calibration goals for intraband, interband and absolute accuracies (i.e. 0.5%, 1.0% and 5% respectively).

A simple linear calibration curve (AX+B) is most likely adequate for each of the silicon VIS/NIR detections. However, the SWIR band may require more complex curves (e.g. combinations of several linear segments).

RADIOMETRIC CORRECTION



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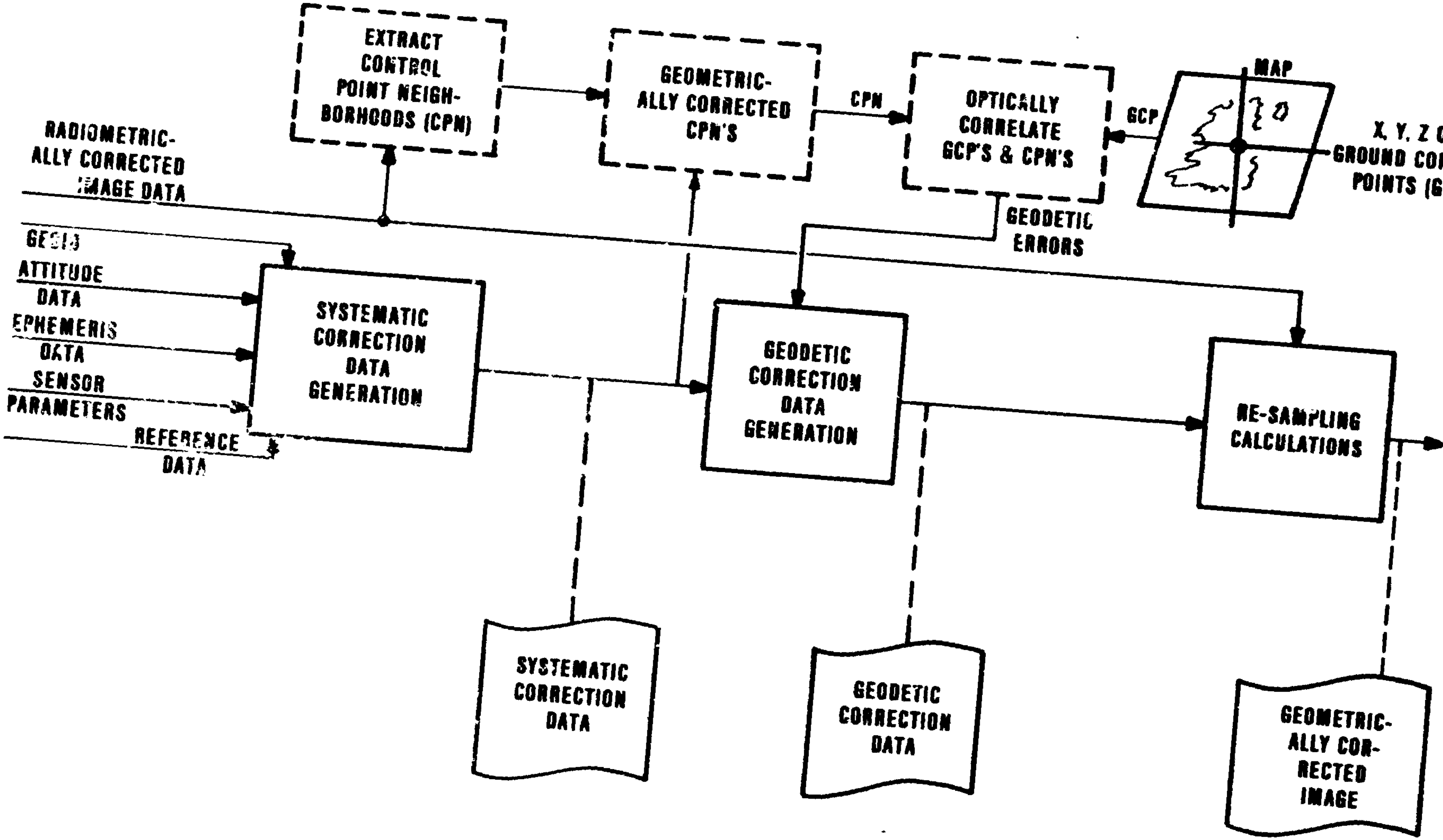
- APPLY INDIVIDUAL CORRECTION TO EACH DETECTOR
- USE GAIN AND OFFSET CORRECTION (AX + B)
- CALIBRATE MLA BEFORE FLIGHT (DERIVE PARAMETERS)
- ACQUIRE CALIBRATION UPDATES DURING FLIGHT
- PERFORM EXPERIMENTAL ANALYSIS AFTER FLIGHT
- UPDATE PARAMETERS BASED ON ANALYSIS

GEOMETRIC CORRECTION PROCESS FOR MLA

The steps required to produce a geometrically corrected image are shown on this chart. Using the Shuttle altitude and ephemeris parameters, as well as various sensor parameters, the Systematic Correction Data (SCD) functions performed. The SCD's are a set of matrices in which each pixel is corrected, based on measured Shuttle and sensor errors. Using the SCD's, in conjunction with the geodetic errors derived from correlating portions of a radiometrically corrected image and GCP's (Ground Control Points) derived from actual maps, results in a set of GCD's (Geodetic Correction Data). These GCD's are the parameters that are used for resampling the radiometrically corrected image, in order to produce a fully corrected image. These same parameters (i.e., GCD's) are the ones that are appended to the AX-CCT.

GEOMETRIC CORRECTION PROCESS FOR MLA



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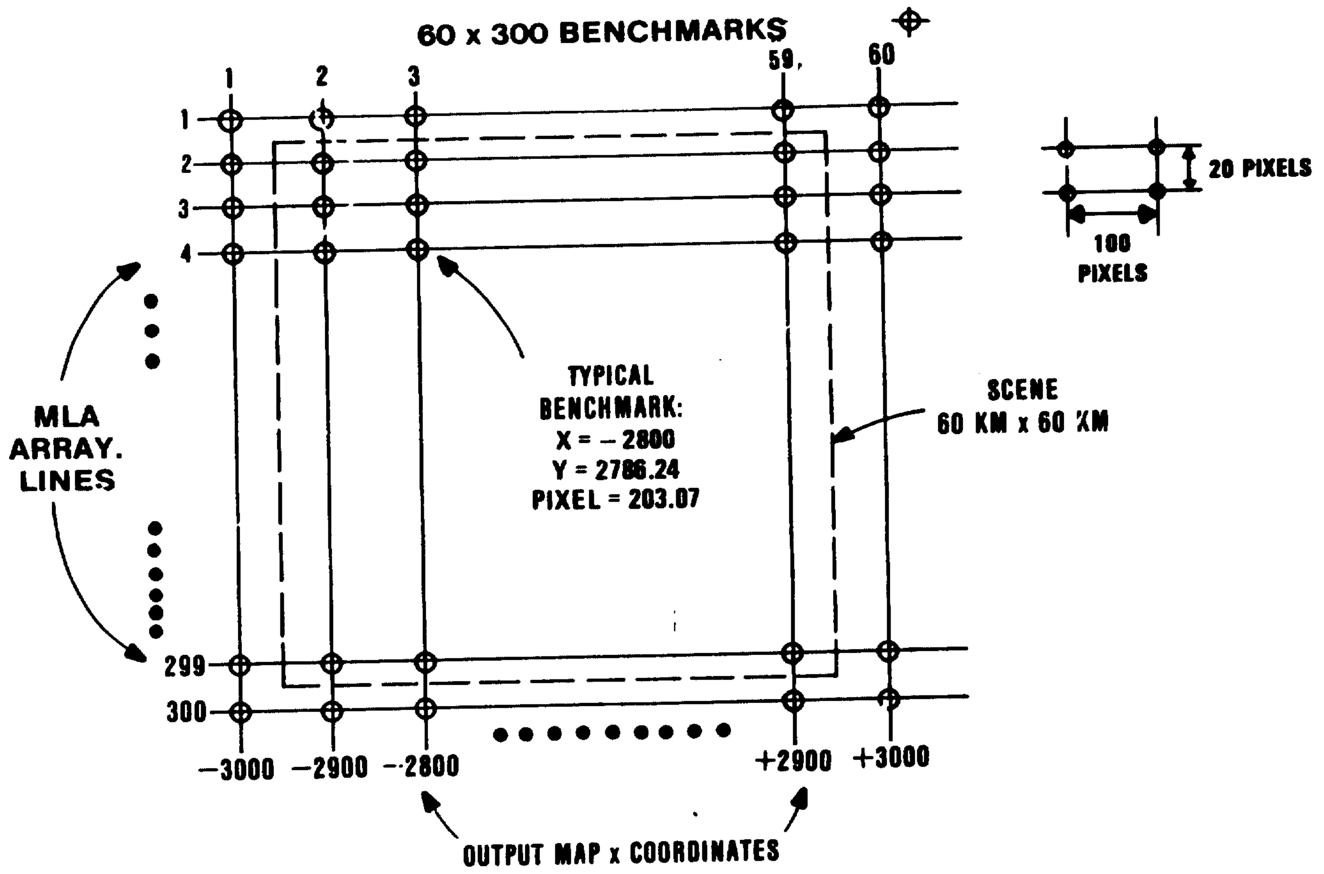
SYSTEMATIC CORRECTION

Systematic Correction is the process of calculating geometric transfer functions that will correct imagery for known physical, spacecraft, and sensor error sources such as earth rotation, earth curvature, spacecraft attitude and ephemeris variations. Systematic correction also includes mapping the output onto a standard grid. The output of the process is a benchmark matrix, representing the geometric transfer function, which can be used to resample the imagery.

The process by which Systematic Correction Data is generated, is shown on this chart. Each MLA line results in approximately 6000 pixels, for a 60 KM swath. 6000 of these lines result in a 60 KM x 60 KM scene.

The Y and pixel location of 5 equally spaced X-locations along every 20th MLA line are determined by a "look-point model". These 5 benchmarks per line are expanded to 60 per line using cubic interpolation resulting in 60 X 300 or 18000 points. Thus, the result of these calculations is an output map location and pixel location for each of the 18000 points. Interpolation will determine the location of each of the 36 x 10^6 pixels. Due to the parameters involved in these calculations and the look-point model, the new pixel location is such that it reflects all measured errors inherent in the data.

SYSTEMATIC CORRECTION



1. DETERMINE XY LOCATIONS OF 5 EQUALLY SPACED PIXELS ALONG ARRAY (VIA LOOK-POINT MODEL)
2. REPEAT EVERY 20th LINE
3. RELATE X, Y AND PIXEL NUMBER (VIA CUBIC EQUATION)
4. SOLVE FOR OUTPUT MAP LOCATION AND PIXEL NUMBER FOR EACH OF 300 SELECTED LINES (i.e. 18000 BENCHMARKS)

C-2

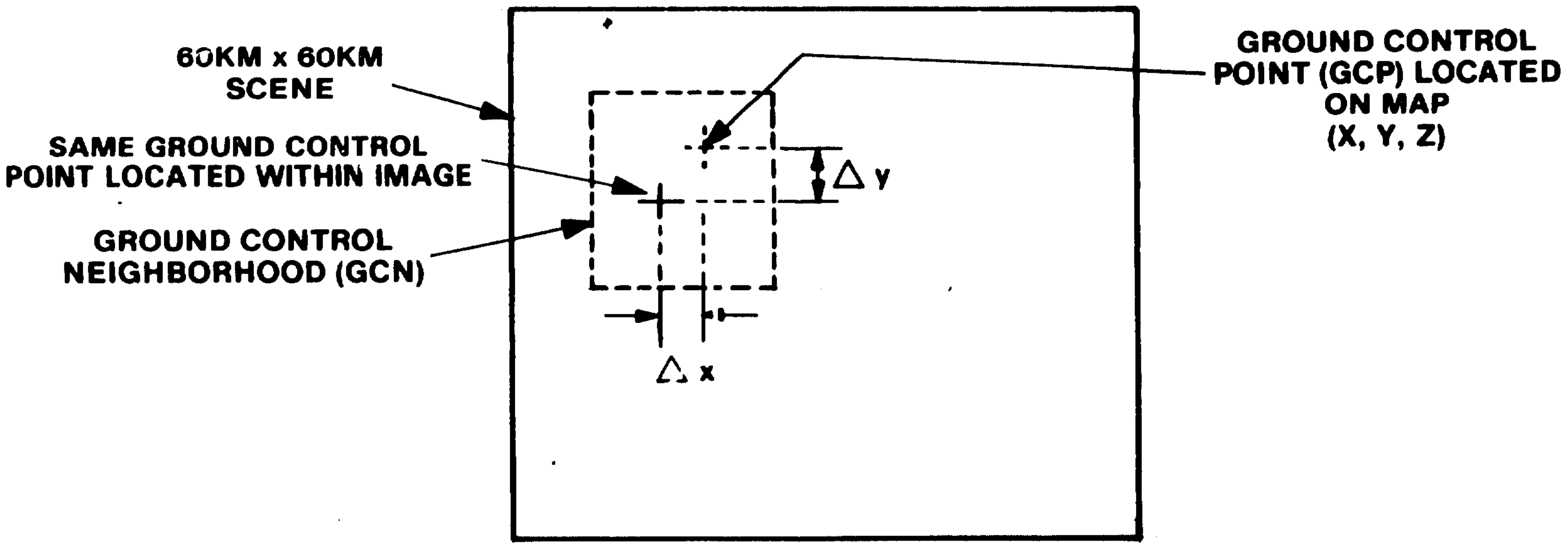
GEODETIC CORRECTION

Geodetic Correction is the process of updating the systematic correction benchmark matrix to reflect actual ground truth. This is performed by determining displacements of specific ground control points on maps and the representation of those points on systematically corrected imagery.

In the figure we see a simplified sketch of our 60 km scene with a Ground Control Neighborhood (GCN) outlined as a dashed square and containing a ground feature with an accurately known geodetic location called a Ground Control Point, GCP. The input scene is resampled in the general region of the GCP to produce a localized image containing the GCP. (Size of the resampled region, the GCN, is dependent upon how severe the shuttle pointing inaccuracies may be.) Then the known ground feature is optically correlated between its location in the output scene and where it actually occurs on a reference map. The difference in the GCP's location is measured in terms of ΔX and ΔY of the reference map, taking into account the topographical elevation of the GCP. These offset values are used to update ΔX, ΔY and ΔZ of the STS position and $\Delta\theta$, $\Delta\phi$, $\Delta\psi$ of the STS attitude. With the new updated parameters the Look Point Model and the Cubic Equations are rerun to recreate the 18,000 benchmarks, which now constitute the Geometric Correction Matrices (GCM).

Using the GCM's, the output scene is now created through cubic convolution or nearest neighbor resampling.

GEODETIC CORRECTION



- RESAMPLE GCN USING SYSTEMATIC CORRECTION DATA
- OPTICALLY CORRELATE GCP AND GCN
- MEASURE OFFSET BETWEEN CONTROL POINT ON THE MAP AND CONTROL POINT WITHIN IMAGE
- USE Δx, Δy, AND Δz TO UPDATE SHUTTLE POSITION AND POINTING
- "PLUG" UPDATED PARAMETERS INTO LOOK-POINT MODEL TO REGENERATE SYSTEMATIC CORRECTION MATRICES (NOW CALLED GEOMETRIC CORRECTION MATRICES)
- REGENERATE OUTPUT SCENE USING GEOMETRIC CORRECTION MATRICES

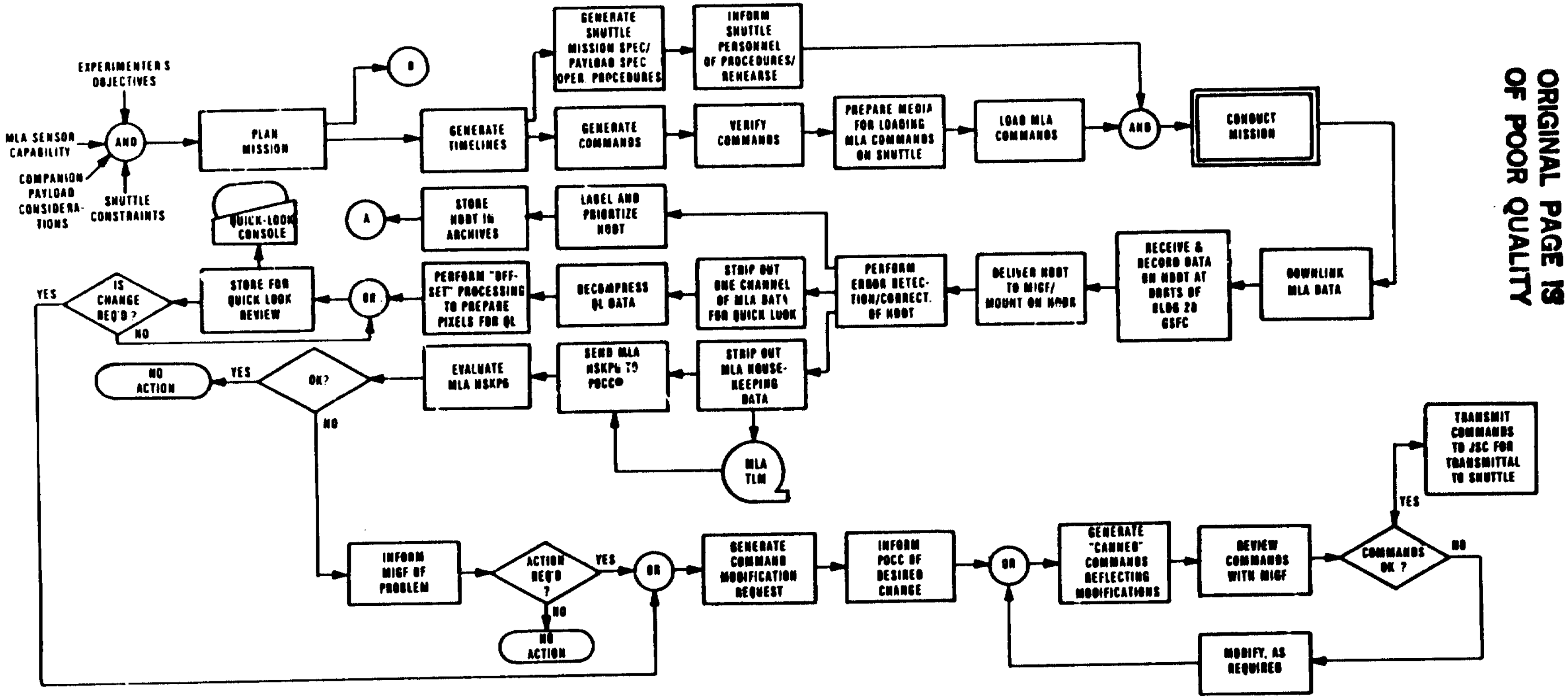
APPLICABLE TO NADIR, STEREO AND CROSS-TRACK SCENES

MISSION PLANNING AND QUICK LOOK PROCESSING

Prior to the mission actually starting, it must be planned. This chart depicts that process. The end result of the planning process will result in a set of commands, probably recorded on a CCT, to operate the MLA sensor. This tape will be delivered to KSC to be installed in the MLA, prior to launch. The planning process will also result in a set of procedures that must be followed by the On-board mission and payload specialists to operate the MLA.

During the conduct of the actual mission, the received image data will be recorded on high density tape, which will be immediately subjected to an error detection and correction process. Following this, a quick look review will take place. Housekeeping data will also be stripped out and delivered to the POCC, at this time. Any anomalies detected as a result of analyzing the telemetry or quick look data will trigger a process whereby a pre-determined set of Contingency Commands will be sent to JSC for uplink to the STS. These contingency commands will have been generated along with the primary commands during the mission planning process, and stored in the POCC data base.

MISSION PLANNING
AND
QUICK-LOOK PROCESSING



MISSION PLANNING

In order to plan a mission, a number of items must be produced and delivered to the appropriate agencies. This chart shows that process. Using various constraints, experimenter requests, policy directives, and other applicable data, a specific set of data collection parameters can be generated. Applying these parameters will allow a set of data collection timelines to be developed, which, in turn, will result in a number of deliverable products. These productes are as follows: first, a set of primary and contingency commands to operate the MLA in accordance with the data collection timelines, can be generated. Secondly, the procedures to be performed by the on-board personnel for operating the sensor can be defined. Finally, a communication request schedule for TDRSS and DOMSAT can be determined, and sent to the Network Control Center for approval. Accomplishment of all these activities will permit the mission to be performed with maximum efficiency and minimum problems.

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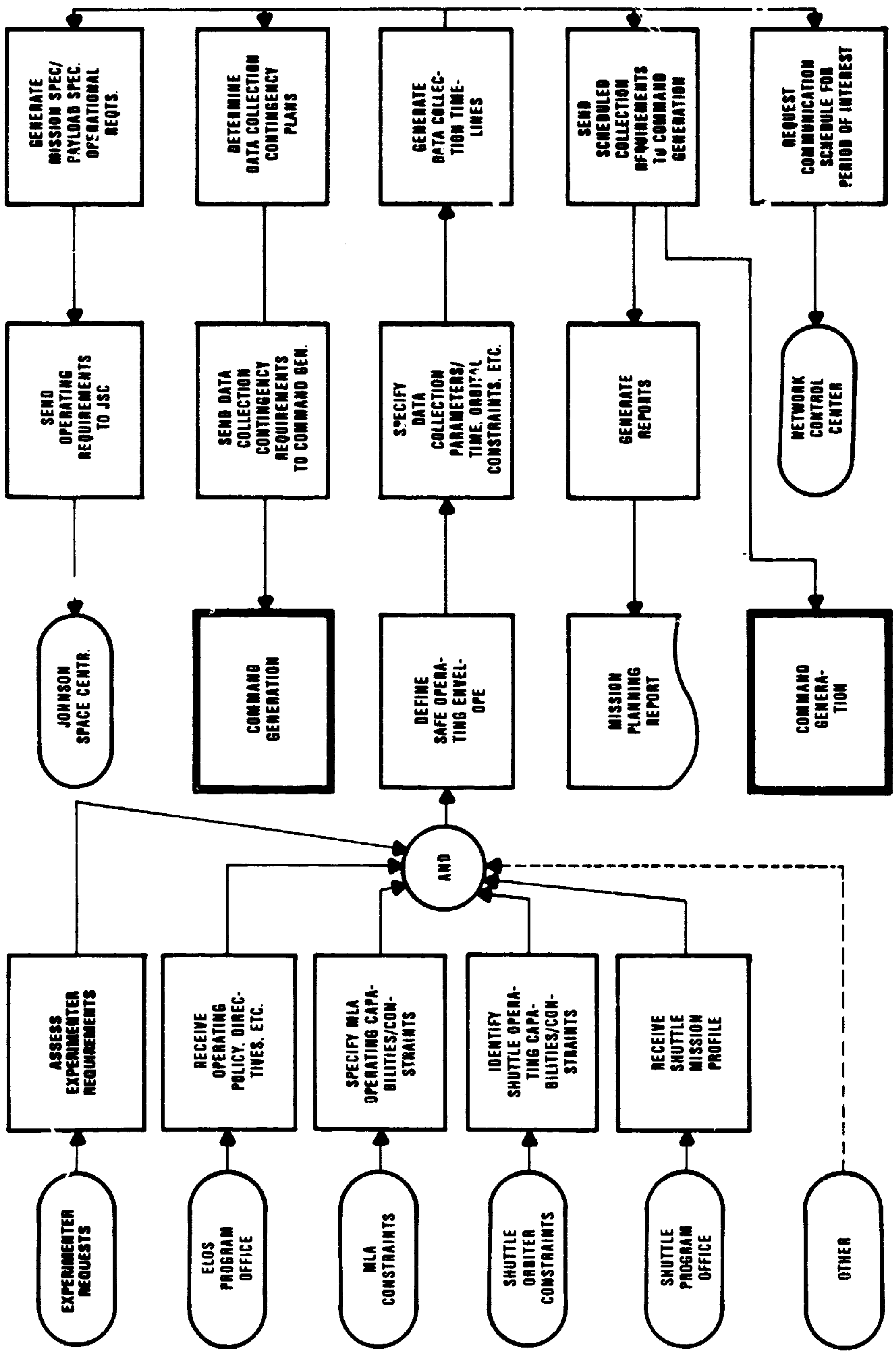
MISSION PLANNING



QUICK LOOK DATA FLOW

Raw data is ingested from HDT and is:

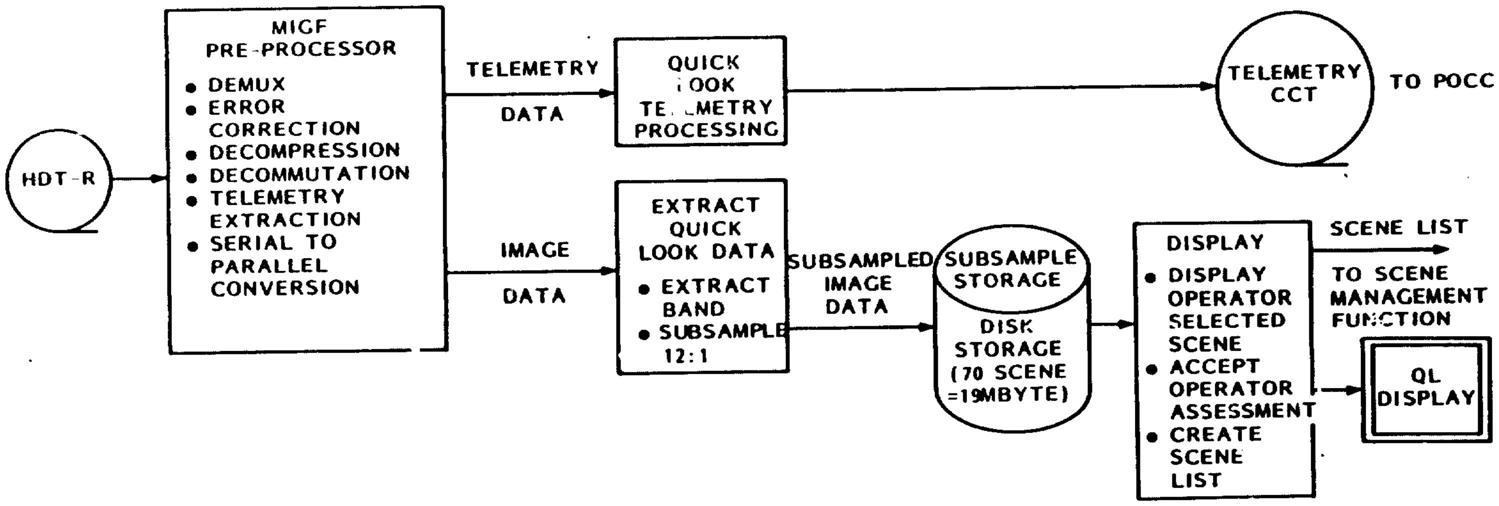
1. Demultiplexed
2. Error Corrected
3. Decompressed
4. Decommutated
5. Converted to a Parallel Format

The resulting image data is subsampled and stored on disk. Telemetry data is also temporarily stored. All data for an imaging interval is ingested before the operator viewing function is initiated.

When an interval of data is on disk, the operator sequentially views each scene, looking for anomalous sensor operation and other situtations. At this time the operator may define new scene boundaries.

A CCT containing telemetry data for the interval is also generated.

QUICK LOOK DATA FLOW



SUMMARY

The items shown on this chart summarize the key points that were discussed during this portion of the presentation.

SUMMARY

- LAS/ADDS HARDWARE DIRECTLY APPLICABLE
- APPROXIMATELY 1/3 OF REQUIRED SOFTWARE DIRECTLY TRANSFERABLE FROM LANDSAT D
- MIGF CAN MAINTAIN OPERATIONS ON A ONE SHIFT BASIS
- FLEXIBILITY OF CONFIGURATION PERMITS GROWTH
  - ADDITION OF OPTICAL DISC STORAGE
  - INCREASED CAPACITY OF DISC STORAGE DEVICES
  - TIE-IN TO "DRRTS TYPE" INGEST SUBSYSTEM

SECTION 3

TECHNICAL DEFINITION

SECTION 3

TECHNICAL DEFINITION

Contained within Section 3 are detailed technical descriptions and analyses to support the conclusions reached in the study. The results from these analyses are summarized on the viewgraphs shown in Section 2.

3.1 SYSTEM REQUIREMENTS

This section contains an analysis of the mission parameters that was performed to drive out the ELOS/STS system requirements.

3.1.1 DATA COLLECTION PARAMETERS

3.1.1.1 Orbit Parameters

The orbit parameters have been specified as 40 degrees to 57 degrees inclination, with altitudes from 325 to 375 kilometers. Table 3.1-1 shows the variation in orbital period, ground velocity, and the time to make one image 61.44km long.

(Note: 61.44 KM X 61.44 KM is the "scene" size used throughout this report. It is near 10 degree cross track field-of-view and is compatible with 6 chips of 1024 elements, 12 of 512, etc.)

Table 3.1-1. Parameters of Possible ELOS Orbits

CIRCULAR ALTITUDE (km)	INCLINATION (Degrees)	ANOMALISTIC PERIOD (Seconds)	NODAL PERIOD (Seconds)	GROUND VELOCITY (Km/Sec)	FRAME TIME (61.44 km) (Seconds)
325	40	5461.73	5450.93	7.3520	8.3570
325	57	5461.73	5460.23	7.3394	8.3712
350	40	5492.31	5481.53	7.3109	8.4039
350	57	5492.31	5490.82	7.2986	8.4181
375	40	5522.95	5512.19	7.2703	8.4509
375	57	5522.95	5521.46	7.2581	8.4651

3.1.1.2 Collection Parameters

The Orbiter/TDRSS return link and NASCOM ground station are both limited to 50 Mbps. The NASCOM link requires a 2 Mbps overhead, leaving 48 Mbps available for payloads. The 48 Mbps maximum rate available to the ELOS system must contain all of the system overhead. ORI estimated that a data rate of 43 Mbps would actually be available for image data. This estimate seems reasonable, and was used in this study. The ORI chart (Table 3.1-2) detailing this analysis is included for the readers convenience.

3.1.1.3 Duty Cycle

The technical officers' best judgement was that the number of contiguous scenes that should be taken would lie between 6 and 20. Based upon the scene rates given in paragraph 3.1.1.1, this results in MLA operation periods between 50 and 170 seconds. These numbers were checked against the data ingest capabilities. They do not impact any other part of the data system.

Table 3.1-2. MLA High Rate Data Format

- 43 Mbps of the 48 Mbps High Rate Through-Put is Available for the Compressed MLA Image Data
- Burdens on the 48 Mbps Return Link Include
  - About 100 Kbps for MLA Self-Contained Fine Attitude Determination Sensors and Gyros
  - About 10 Kbps for Orbiter and MLA Experiment Information Necessary for Data Reduction
  - About 10% Overhead for Burst Error Correcting Code
  - About 1% Overhead for Frame Sync and Other Header Information

3.1.1.4 Pointing Accuracy

The principle consideration in sensor pointing is being able to acquire the desired scientific data. It is expected that very specific and relatively small local targets will often be the subject of investigations. One potential mode of data rate reduction was to operate the sensor at a partial swath width The value of one third (1/3) has frequently been mentioned, since that would get data from all bands into the available data rate. At the partial swath width of three and a third degrees (3 $1/3^{o}$), the nominal two (2^{o}) degrees pointing error advertised as expected worst case shuttle performance is such a large fraction of the swath, that there is considerable risk that the desired target would be missed.

Based upon this reasoning, and upon early reports that shuttle orbiter structural distortions were less than expected, it was decided to base the ELOS data system on a one degree (1^{o}) pointing capability. This can probably be obtained by the shuttle system. In cross track operation, the instrument has fractional degree pointing capability, and this is the major concern in terms of targeting.

3.1.1.5 Pointing Knowledge

The effort required to register MLA images with maps is strongly dependent upon a priori information about pointing. The Shuttle state vector, which is embedded in the telemetry stream, provides information on slow rate attitude motions accurate to .078 degree. High frequency attitude disturbances are not measured in the space segment.

Preliminary data indicates that operation of the Shuttle in the free drift mode with restrictions on crew motions and other experiments will provide a stable platform free of significant high frequency attitude disturbances. Inaccuracies in the Shuttle state vector can be removed in the geodetic correction process with the use of control points.

An analysis of the number of control points required to correct such errors has not yet been performed, although Landsat-D experience indicates 10 to 25 control points may be necessary.

If, at some time in the future it is determined that estimates for attitude disturbances during imaging sequences will be greater than currently anticipated, the addition of more accurate attitude sensors such as those used on Landsat-D may be warranted. Control points can be used to correct these attitude disturbances, however the number of control points and the complexity of the correction algorithms increase exponentially with the complexity of the unmeasured attitude disturbances. Landsat-D experience indicates that the cost of developing complex modelling software and of generating control points far outweigh the cost of spring restrained gyros for precision low frequency and the attitude displacement sensor for high frequency attitude knowledge.

3.1.2 MISSION/SYSTEM/SHUTTLE ANALYSIS

This section contains some additional supporting analysis material generated during the study.

3.1.2.1 Calculation of Geometric Error Due To Off-Nadir Pointing

From the JPL Stereosat Report (5/30/79, pp 5-8), the relation between nadir angle and the angle off local vertical is given in Figure 3.1-1.

Assuming that the local verticals at points A and B are parallel, we may solve for the apparent displacement d of an object of height h' as shown in Figure 3.1-2. Table 3.1-3 presents the magnitude of displacements due to 10 meter elevation changes for various off-nadir points.

Table 3.1-3 shows that a 25 degree off-nadir view will produce feature displacements equal to one-half the height of the feature. Thirty degree off-nadir views will produce displacements equal to 0.6 times the height of the feature. These values were used in constructing the error budget in Section 2.

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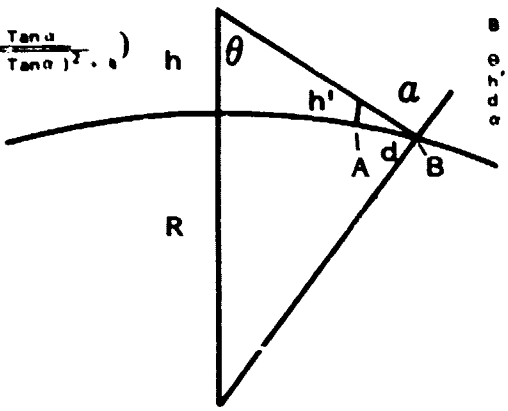
$$\mathrm{Sin}\,\theta = \frac{R}{R+h}\left(\frac{2\,\mathrm{Tan}\,\alpha}{\sqrt{(2\,\mathrm{Tan}\,\alpha)^2+1}}\right)$$



h = ALTITUDE OF ORBITER
R = RADIUS OF THE EARTH
A = ACTUAL GEODETIC LOCATION OF FEATURE
B = APPARENT GEODETIC LOCATION OF FEATURE
θ = OFF NADIR ANGLE
h' = HEIGHT OF FEATURE
d = DISPLACEMENT OF FEATURE
α = ANGLE OFF LOCAL VERTICAL

Figure 3.1-1. Off-Nadir Angle Calculation

$$d = h'\left(\left(\frac{R+h}{R}\,\mathrm{SIN}\,\theta\right)^{-2} - 1\right)^{-1/2}$$

Figure 3.1-2. Calculation of Feature Displacement Due to Off-Nadir Pointing

Table 3.1-3. Geometric Error Due to Off-Nadar Pointing

θ (OFF-NADIR ANGLE)	d (APPARENT DISPLACEMENT)[1, 2] (705 km)	(350 km)
35	8.27 M	7.5994
30	6.68	6.2081
25	5.32	4.9804
20	4.11	3.8684
15	3.00	2.8380
10	1.97	1.86330
5	0.973	0.923294

NOTES:

1. THE RESULTS SCALE LINEARLY FOR ANY ALTITUDE h' AS LONG AS THE ASSUMPTION OF PARALLEL LOCAL VERTICALS IS MAINTAINED
2. FOR 10 M ELEVATION
3. EDGE OF 185 KM SWATH

3.1.2.2 Capability Of NASA (JSC) To Refine An Already Flown STS Orbit(s)

Based on telephone conversations with personnel of the Mathematical Physics Branch (JSC), the following information was provided:

1. While the STS Orbiter is still in flight, orbit determination is accurate to within 25,000-30,000 feet, depending on the Orbiter attitude control/mission orbit requirements for that particular mission.

2. Based on the recorded Orbiter flight telemetry, the Mathematical Physics Branch prepares a Best Estimated Trajectory (BET) in about three months' time, which is accurate for the most part to 2000 feet (although minor part could be as bad as 10,000 feet - again depending on mission orbit requirements for that particular mission).

3. The unprocessed telemetry information can be provided by JSC anywhere from one week to a couple months after the Orbiter flight. JSC cautioned, however, that developing the unprocessed telemetry information without the JSC computer model might prove inaccurate.

4. JSC Mathematical Physics Branch commented that the processing time for a BET will not change much with the advent of the TDRS system in 1983, as the BET computer calculations will have to be done the same way regardless of the telemetry transmission mode. The mathematical Physics Branch also commented that part of the reason for the delay in preparation of the BET is that the Mathematical Physics Branch does not have immediate access to the telemetry data themselves.

5. A contact was provided in the STS Program Office (JSC) for either the BET or the unprocessed telemetry.

3.1.2.3 Shuttle Data Transmission

The payload data (2 Mbps to 50 Mbps) is routed from the payload to the Ku-Band Signal Processor by the payload station distribution panel. Data can be NRZ L,M or S. There is an advantage to having the input data NRZ M or S which will be discussed later. This data is routed to Channel 3 (as defined in the Space Shuttle Payload Data Handling and Communication Description and Performance Document, JSC 14241, Revision A) of the Ku-Band Signal Processor (KUSP).

When the system is operated in mode 1 (as defined in JSC 14241, Revision A), the 50 Mbps data is convolutionally encoded to 4 to 100 Mbps and sent to the Ku-Band Electronics Assembly (EA) where Channel 3 is summed with the QPSK squarewave subcarrier and sent to the Ku-Band displayed assembly where it is used to modulate the Ku-Band carrier. The input is power amplified and radiated to TDRS by the Ku-Band antenna.

The TDRSS satellite relays the signals to the TDRSS ground station where it is demodulated. Channel 3 (4-100 Mbps) data is sent to the KSA bit synchronizer and decoder. Mode 1 Channel 3 is bit synchronized and Viterbic decoded. Data is now NRZ-L 2-50 Mbps. If data was orginally NRZ-L, the conversion to NRZ-L may have bit inversion. If data was orginally NRZ M or S the conversion to NRZ-L will be without bit inversion. The data is converted to the original format NRZ M, S or L and transmitted to GSFC by use of DOMSAT.

3.2 MLA SENSOR INTERFACE

The baseline for the MLA sensor is presented in Section 2 with an emphasis on those parameters that relate to the ELOS data system. The information has been derived from SOW requirements, sensor analysis, ORI study results and inputs from the ELOS project. This section provides additional discussion of the MLA stereo off-nadir angle and alternate operation modes.

3.2.1 STEREO OFF-NADIR ANGLE

The MLA off-nadir pointing angle required to achieve a stereo base-to-height (B/H) ratio of 1.0 between fore and aft views varies with altitude due to earth curvature effects. Figure 3.2-1 shows the geometry for this calculation and a plot of the results. At 350 km the required sensor half-angle from nadir for a B/H ratio of 1.0 is 25.08 degrees; for 705 km this angle drops to 23.75 degrees.

If the off-nadir pointing angle is held fixed and altitude is varied, the B/H ratio changes. Figure 3.2-2 illustrates this effect for a 26 degree angle. An altitude of 350 km produces a B/H of 1.04 between fore and aft views.

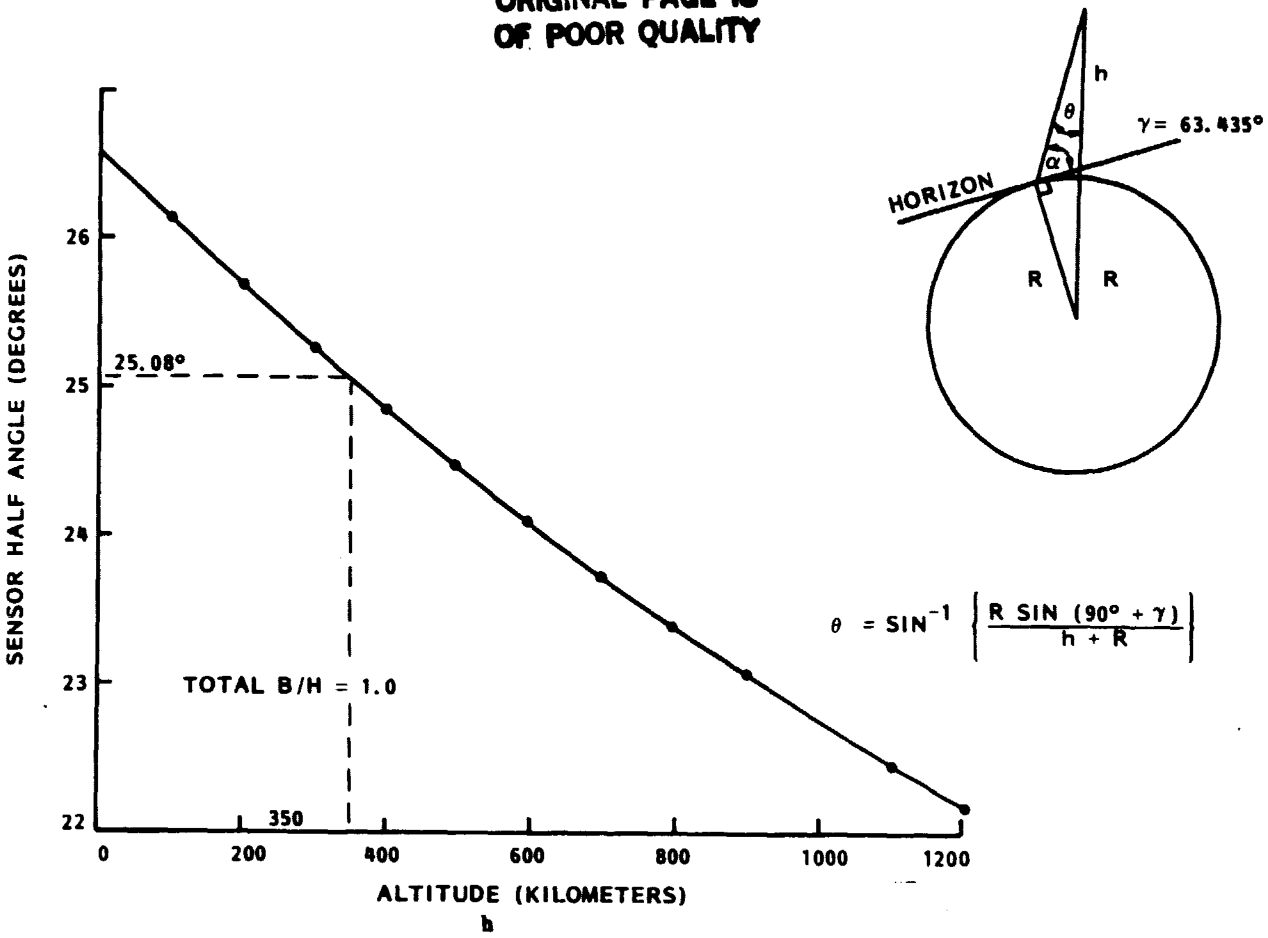


Figure 3.2-1. Sensor Off-Nadir Angle as a Function of Altitude for Total Base/Height Ratio of 1.0

3.2.2 ALTERNATE MLA OPERATION MODES

With overhead and allowance for error correction, ORI estimates that the useable raw data rate for shuttle operation is limited to 43 Mbps. Because the MLA baselined for this study can generate 117 Mbps, some means of data reduction is required. This can be accomplished by three methods:

1. reduction of swath width,
2. elimination of bands, and
3. data compression.

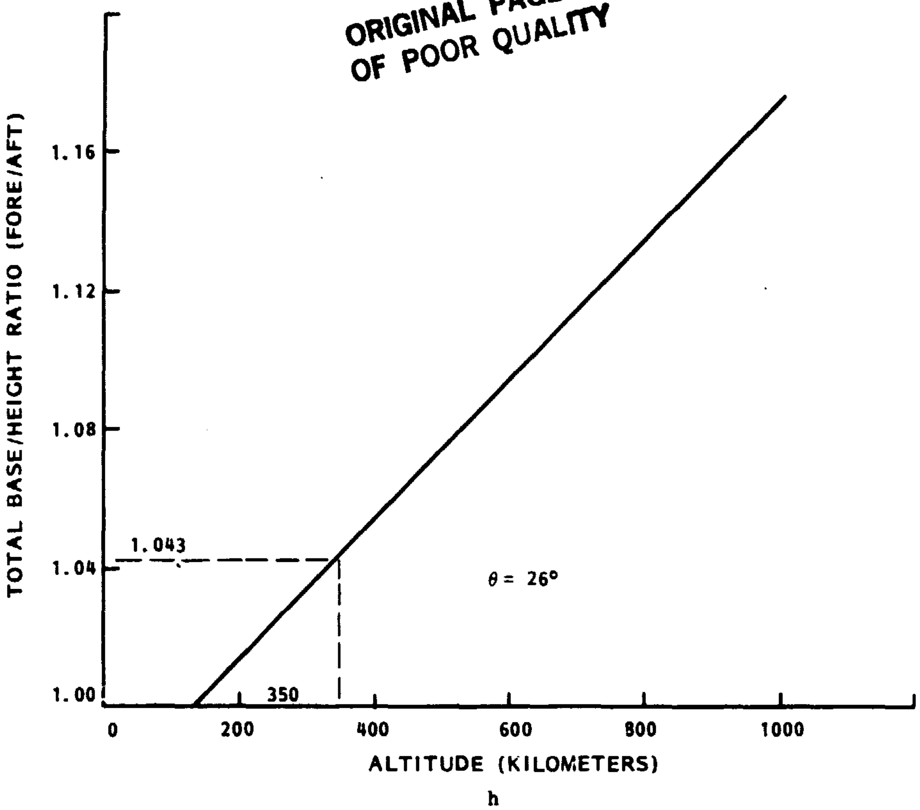


Figure 3.2-2. Base/Height Ratio as a Function of Altitude for a Sensor Half Angle of 26°

Because analysis of high-resolution imagery is one of the primary objectives of this mission, pixel summing (averaging) is not employed to reduce the data rate.

Table 3.2-1 lists several alternate operation modes possible for the baselined MLA. Modes A and B offer an image acquisition choice between one band with full swath and all bands with reduced swath without data compression. Modes C and D provide all bands with two-thirds swath at two different compression ratios. This choice allows for an evaluation of the effect of compression ratio on scene statistics. Finally, modes E and F provide an opportunity for direct comparison between compressed and raw data from the same image using different compression ratios.

Table 3.2-1. Alternate MLA Modes

MODE	COMPRESSION	BAND(S)	SWATH (km)	RAW DATA RATE (Mbps)	COMMENTS
A1, A2, A3	NONE	1, 2 OR 3	61.5 (FULL)	36	ONE BAND, MAX COVERAGE
B	NONE	ALL (4)	20.5 (1/3)	39	ALL BANDS, LIMITED COVERAGE
C	2.7	ALL (4)	61.5 (FULL)	43	ALL BANDS, MAX COMPRESSION
D	1.8	ALL (4)	41 (2/3)	43	ALL BANDS, LIMITED COMPRESSION
E1, E2, E3	NONE 2.7 } BOTH	1, 2 OR 3	41 (2/3)	24 9 } 33	COMPRESSION EVALUATION (MAX)
F1, F2, F3	NONE 1.8 } BOTH	1, 2 OR 3	41 (2/3)	24 13 } 37	COMPRESSION EVALUATION (LIMITED)

3.3 GROUND SEGMENT CONCEPT

A baseline for the ELOS/STS Ground Based Data System is shown in Figure 3.3-1. This Section will describe the operation of that baseline, as well as the manner in which data will flow through the system. Before describing that operation, however, several groundrules and assumptions will be addressed.

1. The ADDS (Advanced Development Data System) and LAS (Landsat Assessment System) blocks shown within the dashed area labeled "MIGF" (MLA Image Generation Facility) are intended to be used as resources only. That is, any additional equipment that must be added to generate the required output, will be. We are not to be constrained by the present ADDS and LAS configurations.

2. The DRRTS (Data Receive, Record and Transmit Subsystem) shown within the Bldg. 28 dashed lines are presently part of the Landsat D system. The baseline will assume its use for the reception of MLA data (via DOMSAT) and generation of MLA HDDT's. In order to assume its use for the ELOS/STS experiment, an arrangement will have to be made with NOAA. If such an agreement is not possible, a separate DRRTS type facility will have to be made part of the ELOS/STS Ground Data System.

3. HDDT's recorded by DRRTS will be "hand carried" to the MIGF, where they will be labelled and prioritized for future processing. Quick Look processing will be carried out immediately, prior to archiving the HDDT.

4. The MIGF will produce 2 scenes per day, with the following products generated for each scene:

   a. Raw MLA Data (CCT) - RX

   b. A-Tape (CCT) - radiometrically corrected with geometric correction parameters appended. - AX

c. P-Tape (CCT) - radiometrically and geometrically corrected. - PX

d. P-Film (241 mm) - PX film

5. If a stereo "pair" (consisting of 2 or 3 images) has been requested, it, and no other scenes, will be processed that day.

6. One channel (TBD) of the received MLA data will be selected as the "Quick Look" channel for review in the MIGF.

7. The 120 Mbps data rate out of the MLA sensor (image, telemetry, and overhead) will be compressed on-board to 48 Mbps and sent to the TDRSS downlink.

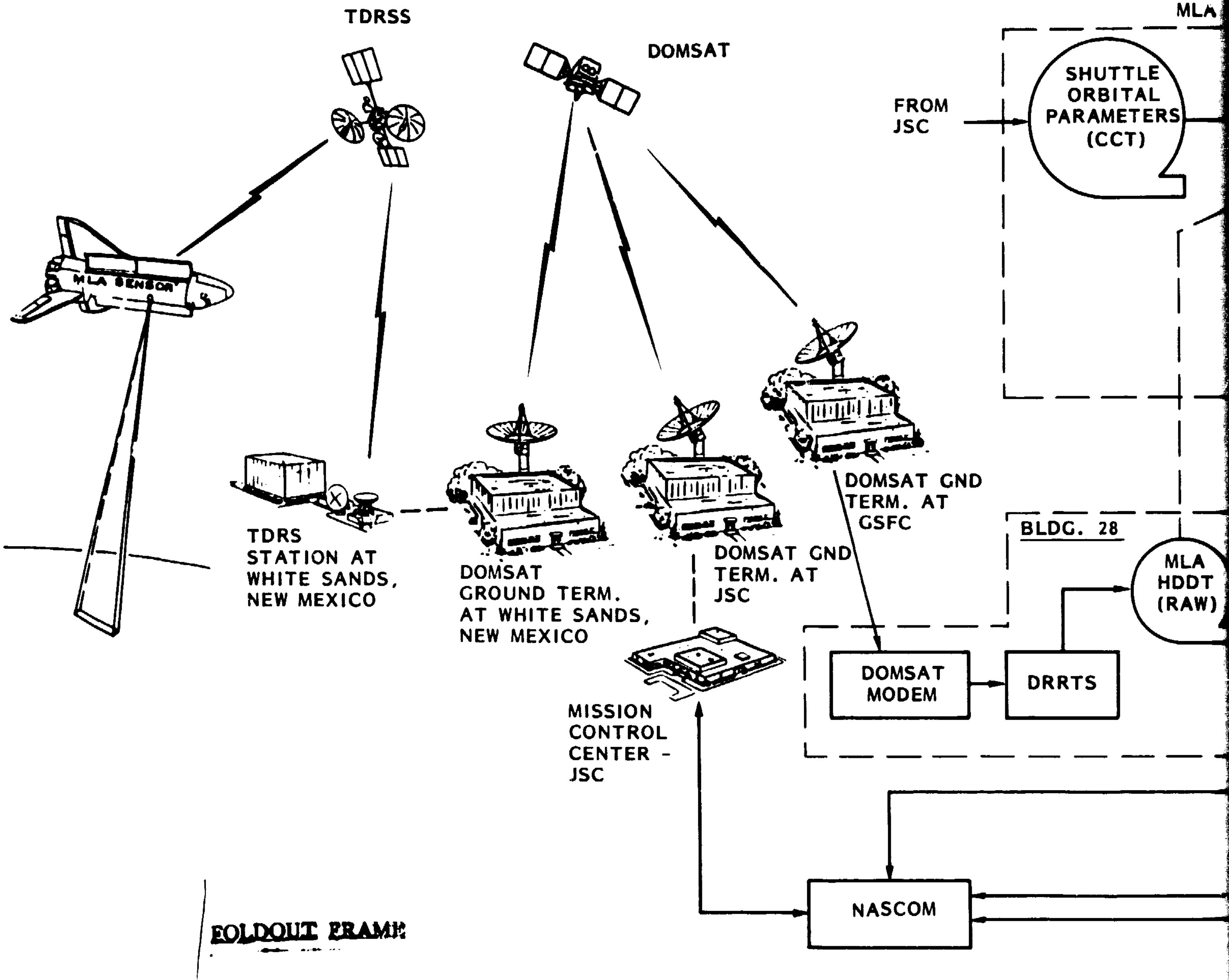
Operation of the ELOS/STS Data System is as follows: Mission planning will have previously taken place in the POCC (Payload Operations Control Center), and a set of commands for operation of the MLA generated. These commands will be installed in the MLA Payload Processor on board the Shuttle prior to launch. During actual operations, based on the mission timeline, the Shuttle based MLA will acquire earth resources data, be "combined" with both Shuttle Orbital data, MLA housekeeping data and error correction codes, compressed to produce 48 Mbps, formatted in accordance with a pre-determined format and transmitted to the GSFC (Goddard Space Flight Center) via the following path:

Shuttle --➡TDRSS -➡TDRSS ground station at White Sands -➡DOMSAT -➡ both DOMSAT ground stations at JSC (Johnson Space Center) and GSFC.

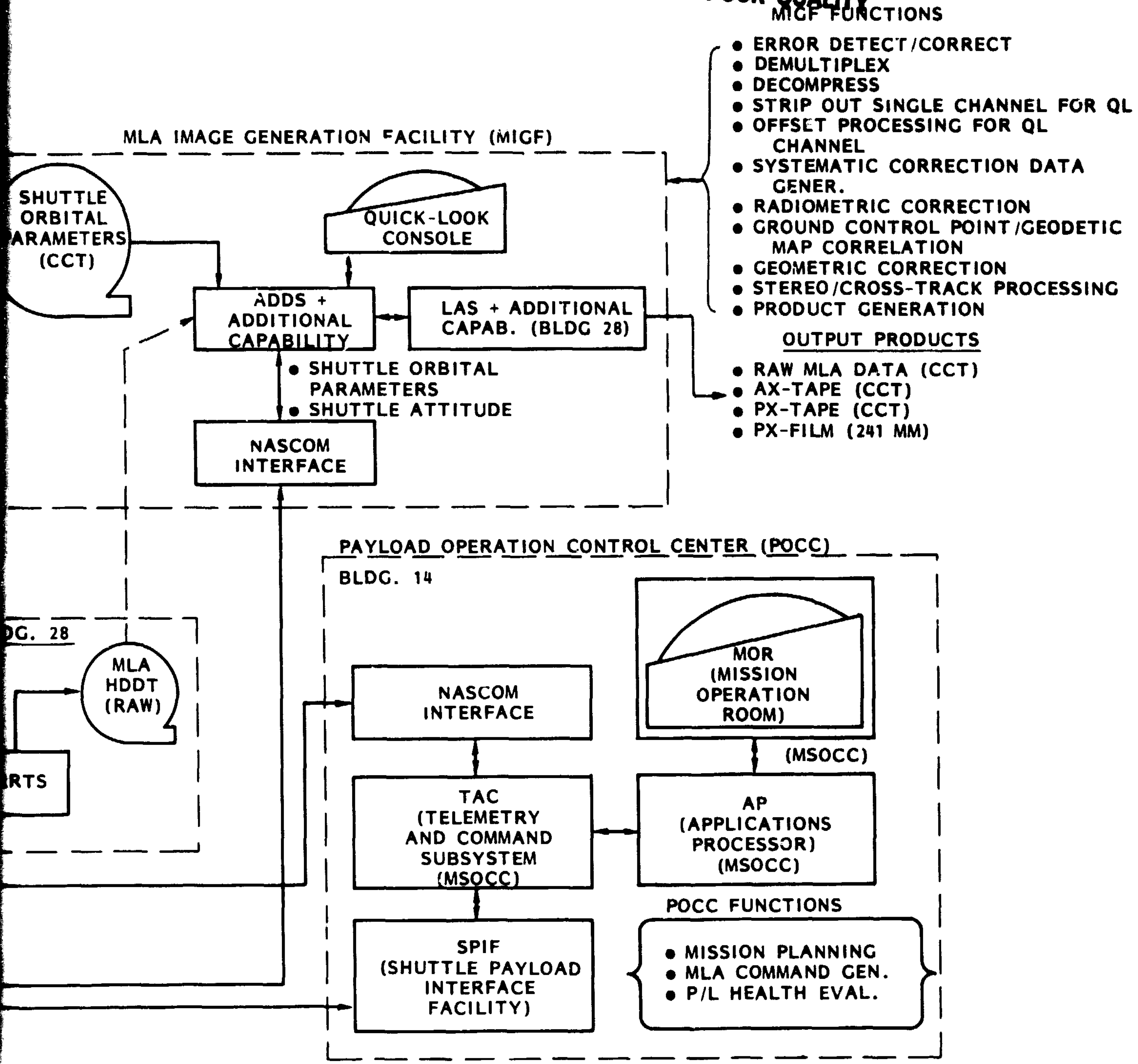
JSC will strip out the required Shuttle housekeeping, orbital parameters and other data and prepare a CCT of refined Shuttle orbit. (Note that these same data could be transmitted from JSC to the MIGF at GSFC via NASCOM, where it would be recorded for SCD (Systematic Correction Data) generation.

The 50 Mbps MLA data (including NASCOM overhead) received at Goddard will be recorded on HDDT's via the DRRTS at Bldg. 28. They will then be manually transported to the MIGF, where the following processes will take place:

1. Immediately upon receipt of the HDDR at the MIGF, it will be labeled and subjected to an error detection and correction process to eliminate/reduce transmission errors; the HDDR will then be decommutated to obtain the following:



FOLDOUT FRAME



2 FOLDOUT FRAME

Figure 3.3-1. Overview of ELOS/STS Ground Data System

   a. the single channel selected for Quick Look processing

   b. MLA housekeeping data

   c. imbedded shuttle orbital parameters

2. The MLA housekeeping data and imbedded shuttle orbital parameters will be sent to the POCC for MLA housekeeping TLM analysis. Any anomalies will be immediately reported to the MIGF.

3. The channel selected for Quick Look processing will be decompressed and "corrected" by modifying all pixels by a single pre-determined offset value. The resultant data will be stored in some storage type device where it will be made accessible for display on the QL console and for use in preparing a Quick-Look Catalog.

4. The HDDT will be labeled with a processing priority, based on user requests, scenes acquired, etc. It will then be archived prior to further processing.

5. If, when viewing the Quick Look data, the operator decides to "modify" the data collection process, he/she generates a Command Modification Request message, which is transferred to the POCC.

6. The POCC (via the operator at the MOR (Mission Operations Room) "generates" a set of pre-determined canned commands for transmission to the MLA instrument on board the Shuttle.

7. After coordinating with the operator at the MIGF to insure that a correct set of commands has been generated, the MLA commands are transmitted to the MCC at JSC via NASCOM.

8. JSC will transmit the commands to the Shuttle at the proper time.

When the time arrives to process a particular 60 km x 60 km scene, the following processes will occur:

1. The proper HDDT will be selected from the archives. If this scene is one of a stereo "pair", the other related scenes will also be selected.

2. The HDDT will be demultiplexed, stripping out the following data:

   a. The raw pixels involved in the selected scene(s).

   b. The payload correction data which was imbedded in the raw MLA data.

   The stripped data will be written onto a separate media for further processing.

3. The raw MLA data will be decompressed.

4. A CCT of the raw MLA data will be generated.

5. Systematic correction data parameters will be generated using the payload correction data stripped out of the HDDT and the Shuttle orbital parameters received from JSC, if available.

6. The pixels of the selected scene will be radiometrically corrected. If this is one of 2 (or 3) scenes of a stereo pair, CCT's will be prepared at this time. No further processing will be performed on this tape.

7. Using the SCD parameters and the radiometrically corrected pixels, a set of geometric correction parameters will be generated, based on optical correlation of a portion of the MLA image and geodetic maps. The GCP's (Ground Control Points) will be used in the generation of the geodetic correction parameters.

8. A CCT of the radiometrically corrected scene will be generated. The geodetic correction data, along with other pertinent header data, will be appended to the same tape. This product (i.e., AX-Tape (CCT)) will become one of the output products.

9. The geodetic correction data will also be used to resample the radiometrically corrected image, and the resulting pixels will also be recorded on a CCT. This tape (i.e., PX-Tape (CCT)) will also become one of the output products. In addition, it will be used to generate a 241 mm film.

3.3.1 FUNCTIONAL REQUIREMENTS

3.3.1.1 Functional Description of the Mission Planning and Image Generation Process

The processes required to carry out the ELOS/Shuttle mission are depicted in, the Functional Flow Block Diagram (FFBD's) of Figures 3.3-2 and 3.3-3. Figure 3.3-2 contains those functions required to plan a mission and perform Quick Look processing, while Figure 3.3-3 is concerned with the processing of an image derived from the MLA sensor on board the spacecraft. This Section will describe those functions in sufficient detail so as to provide the reader with an understanding of the processes involved. The FFBD for MLA image processing relates to both nadir and off-nadir scenes.

3.3.1.1.1 Mission Planning Phase

The first phase to be addressed will be that of mission planning. Refer to Figure 3.3-2 for the ensuing discussion. The data to be collected during the mission is determined by taking into consideration the objectives to be

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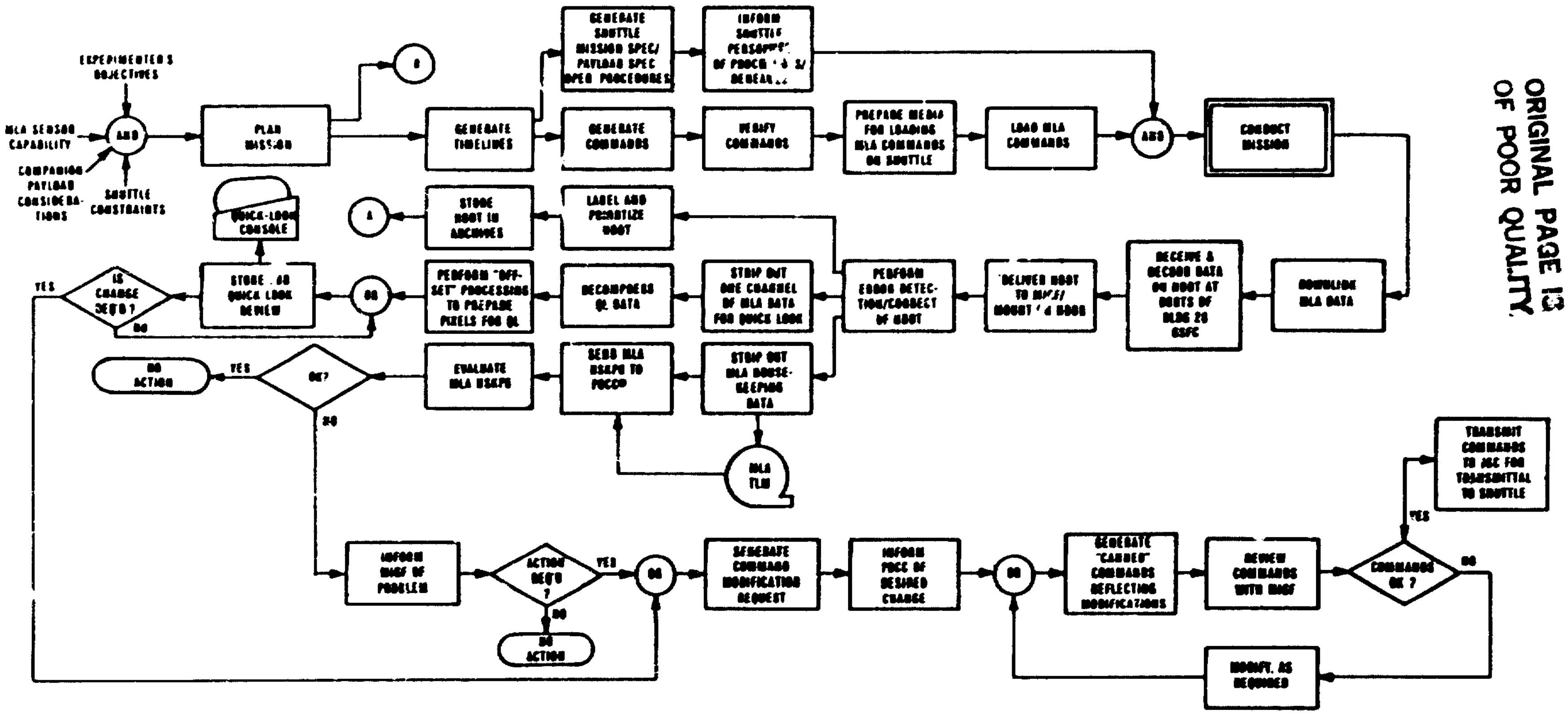

Figure 3.3-2. Functional Flow Block Diagram -
Mission Planning and Quick Look Processing

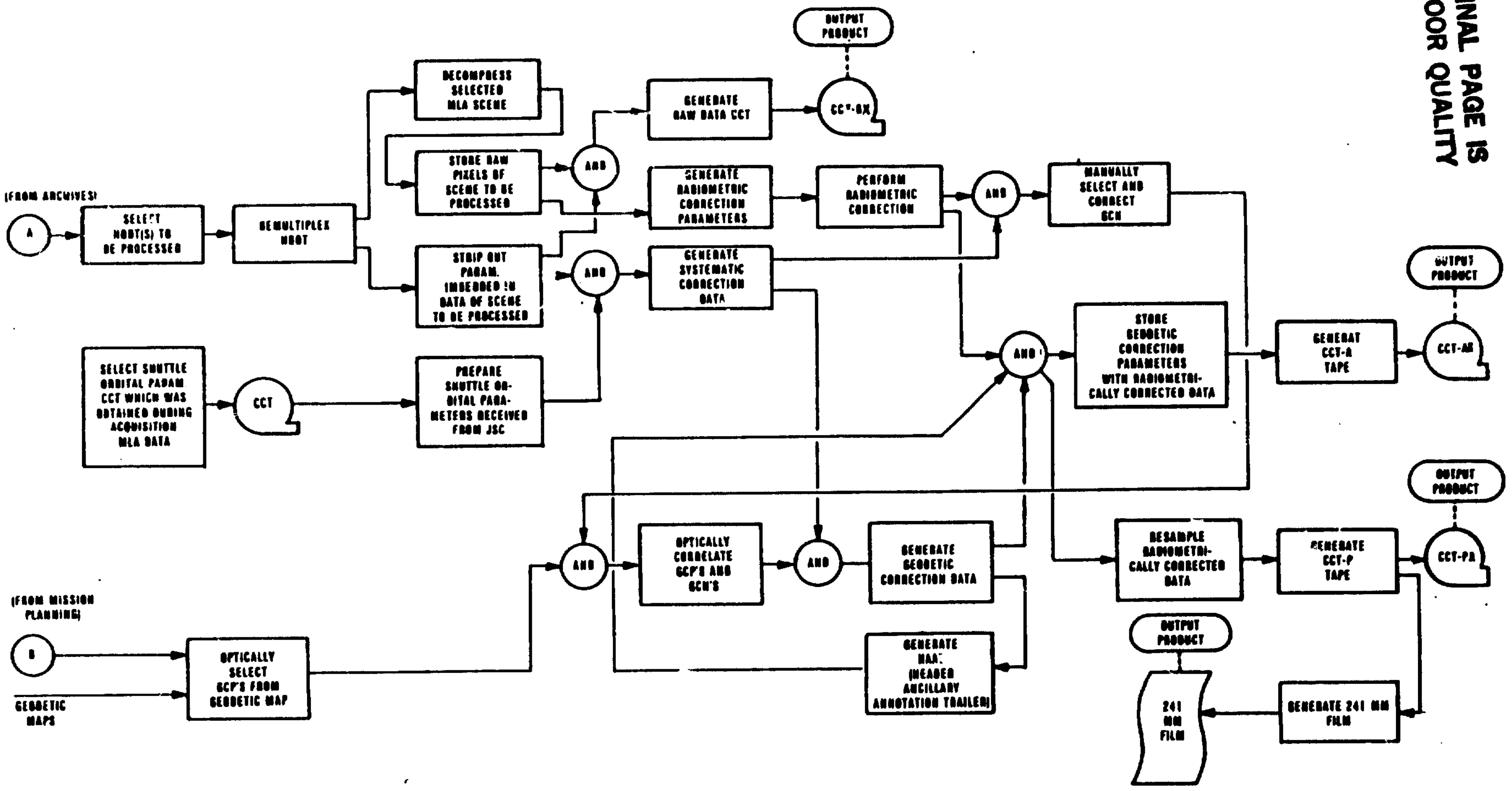

Figure 3.3-3. Functional Flow Block Diagram - MLA Image Processing

achieved by the experimenters, the capability of the MLA sensor, the constraints imposed by the Shuttle itself, and any other considerations imposed by other payloads that may be flying at the same time. These determinations are then adjusted by the orbit, attitude, sun angle, and any other mission considerations that have to be taken into account, and a timeline for this payload is generated. A set of MLA commands required to perform the mission is then generated, and after being verified, is stored on the proper media for eventual loading on board the Shuttle.

Simultaneously with the generation of MLA commands, operational procedures for the Mission Specialist and/or payload Specialist are developed. These specialists are informed of the procedures to be carried out, and along with their other training, rehearse the tasks to be carried out in operating the MLA on board the Shuttle.

Obviously, all these activities are carried out prior to launch. The next phase, i.e., Quick Look Processing, will occur during the actual conduct of the mission.

3.3.1.1.2 Quick Look Processing

During the conduct of the mission, a 50 Mbps data stream (including NASCOM overhead) will be received at Bldg. 28 - GSFC via TDRSS and DOMSAT. The data stream will consist of the following data:

1. MLA sensor data
2. MLA housekeeping telemetry
3. Imbedded shuttle parameters (i.e., orbiter state vector, attitude, etc.)
4. Error correction codes
5. Overhead

This data stream will be recorded at the DRRTS (Data Receive, Record and Transmit Subsystem) - Bldg. 28 on High Density Digital Tape (HDDT). Upon completion of the recording session, the tape will be rewound and delivered to the MIGF (MLA Image Generation Facility). It will be mounted on an HDDR (High Density Digital Recorder) where an error detection and correction of the entire tape will be performed. At the conclusion of the error detection/correction exercise, the HDDT will be labeled, prioritized and archived for future processing.

While the tape is being error checked, the following data will be stripped out:

1. One pre-selected channel for Quick Look (QL) observation
2. MLA housekeeping telemetry

The MLA housekeeping data will be sent to the POCC (Payload Operations Control Center) where it will be recorded and evaluated for anomalies (i.e., limit checking, etc.). If an anomaly is identified, the MIGF will be so informed. If the MIGF determines that corrective action should be taken, it will generate a "Command Modification Request Message," informing the POCC of the desired action. The POCC will proceed to generate a "pre-canned" set of commands reflecting the changes requested by the MIGF. These commands will be sent to JSC (Johnson Space Center) via NASCOM, where they will be transmitted to the Shuttle at the appropriate time.

During the time that the telemetry analysis is going on, the stripped out Quick Look data will be "decompressed" and made ready for review. This will involve a simple "offset processing" to make the displayed data appear "correct". It will involve modifying each pixel with some pre-determined value to reduce the known bias errors. The QL data will then be stored and, at the appropriate time, displayed on a QL console for operator assessment. If a change to the collection strategy is required, and the change fits within the mission timeline, the MIGF will inform the POCC via a "Command Modification Request Message". The same activities that occurred between the two facilities during the MLA housekeeping telemetry evaluation process will now be repeated.

3.3.1.1.3 MLA Image Processing (Figure 3.3-3)

When a specific scene is due for processing (at the rate of two per day), the HDDT containing that scene will be removed from the archive. If this particular scene is one of a two (or three) scene stereo "pair", both (or all three) HDDT's will be also removed from the archives. After mounting the HDDT on the HDDR, the tape is demultiplexed and the raw MLA data of the scene to be processed, is stored. These data are then decompressed and made ready for generation of a CCT-RX (Computer Compatible Tape - Raw). Also recorded on that same tape are the Shuttle parameters that were imbedded in the data of the scene being processed. The CCT-RX is one of the four basic ELOS output products. The other three are:

1. CCT-AX (a computer compatible tape on which the MLA data has been radiometrically corrected and the geometric corrections parameters appended).
2. CCT-PX (a computer compatible tape on which the MLA data has been radiometrically and geometrically corrected).
3. 241-PX (a 241 mm film image of the radiometrically and geometrically corrected MLA data).

In addition to being recorded, the raw MLA sensor data is radiometrically corrected. After generation of the geometric correction parameters and other HAAT (Header, Ancillary, Annotation, Trailer) data, a CCT-AX is prepared.

The geodetic correction parameters are derived in the following manner:

Using the Shuttle parameters imbedded in the data of the scene to be processed and the Shuttle orbital parameters received from JSC (either via a CCT prepared by JSC and delivered to the MIGF or via NASCOM), Systematic Correction Data (SCD) are generated. The SCD are used to correct several GCN (Ground Control Neighborhoods) manually selected from the radiometrically corrected MLA data. The GCN's are optically correlated with the MGCP's (Map Ground Control Points) and used to "correct" the SCD's, to produce geodetic correction data (GCD). These GCD's, along with the HAAT, are stored on the same CCT containing the radiometrically corrected pixels, to produce the CCT-AX. In addition, the GCD's are also used to resample the radiometrically corrected MLA data to produce a CCT-PX tape. This tape may also be used to generate the 241-PX (241 mm film) product.

The Map Ground Control Points (MGCP's) that were used in the optical MGCP/GCN correlation were produced as follows:

Using a geodetic map and the areas from which data is to be collected (as derived during the mission planning process), MGCP's are optically selected and the coordinates are manually entered. The MGCP's are stored in preparation for geodetic correction of the MLA scenes. (Note that this storage does not constitute a library, since the likelihood of that same MGCP being used again is quite small).

3.3.1.2 Functional Description of the ELOS/STS POCC (Payload Operation Control Center)/SPIF (Shuttle Payload Interface Facility)

Since the duration of an ELOS/STS mission will be relatively short (i.e., 7-10 days), and it will occur no more frequently than once or twice a year, a dedicated mission management or operations control facility is unwarranted. Therefore, our concept makes use of the MSOCC (Multi-Satellite Operations Control Center) in Bldg. 14 at GSFC, as a POCC. Goddard is planning on adding a SPIF to the MSOCC which will enable them to interface with JSC on shuttle related payloads that are "controlled" by GSFC. Thus, the POCC/SPIF combination is probably ideally suited for control of the MLA payload. The method by which that may be accomplished will be the subject of this discussion.

As illustrated on Figure 3.3-4, there are three major functions that will be performed in the ELOS/STS POCC. They are: "Plan Mission," "Generate Commands" and "Evaluate Telemetry". The other two functions shown on this figure, i.e., "Perform Quick Look" and "Process MLA Data" were addressed in Section 3.3.1.1 "Functional Description of the Mission Planning and Image Generation Process" and will therefore not be discussed any further. The three POCC functions, are addressed below.

3.3.1.2.1 Plan Mission (see Figure 3.3-5)

In order to plan the ELOS/STS mission, at least the sources and constraints shown on Figure 3.3-5 must be considered. Taking into consideration the Experimenters' requirements, the operating policies and directives of the ELOS Program Office, the constraints imposed by the MLA itself and those imposed by the Shuttle Orbiter, as well as the planned shuttle mission profile, an "operating envelope" can be developed. This envelope will define those limits

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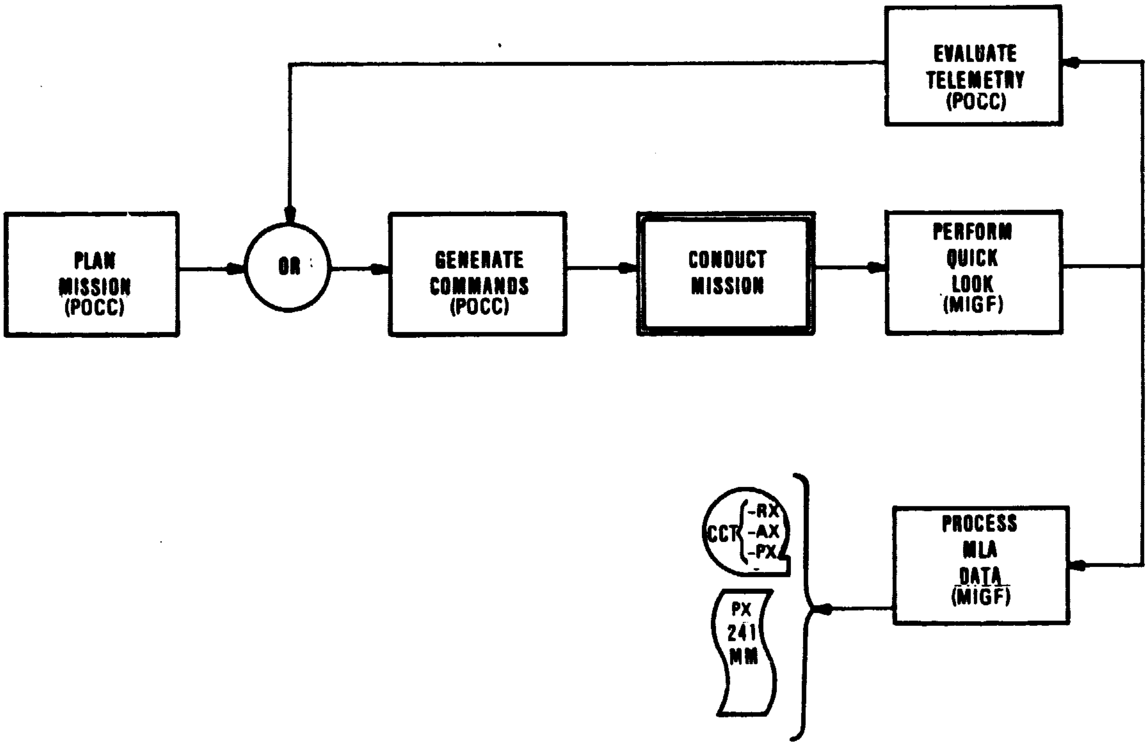

Figure 3.3-4. Functional Flow Block Diagram of ELOS/STS Ground System

within which it is both possible and desirable to collect MLA data. Converting the operating space into a set of data collection parameters, data collection times, orbital parameters, etc. will permit a set of unique mission timelines to be generated. The timelines will define what data can be collected, and when. Both the data collection requirements and the timelines ar dispersed to several locations and will be used for various purposes.

First, they will be used to generate a set of Mission Specialist operational requirements. These will be sent to the Johnson Space Center where they can be used to inform the Shuttle Orbiter crew when the instrument should be turned on, the procedures by which the MLA sensor should be operated, etc. The MLA operational procedures will be factored into the overall shuttle mission timeline.

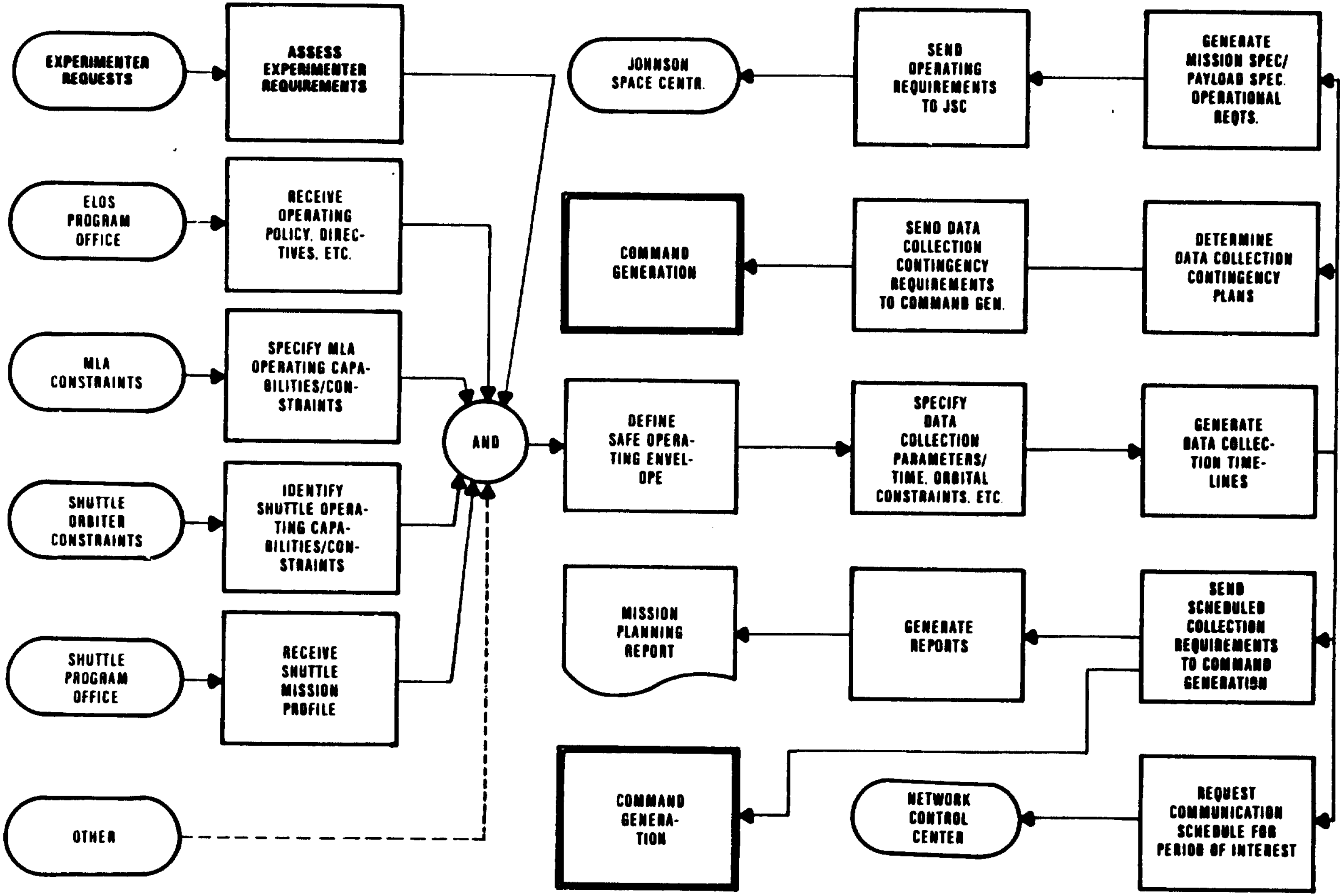

Figure 3.3-5. Functional Flow Block Diagram of ELOS/STS Mission Planning

The next use to which the data collection parameters are put is to permit the generation of the specific commands required to operate the MLA sensor. This is true for both the normal operating mode and the contingency operating mode. The data collection parameters are "sent" to the command generation function, where both "normal" and "contingency" commands are generated.

The final use to which the data collection parameters are put is to inform the NCC (Network Control Center) of the desired data collection schedule. This will be done so that the NCC can schedule the proper communiation facilites (i.e., TDRSS, DOMSAT) for our use at the proper time. They (the NCC) will inform the POCC as to the availability of these facilities when requested, or suggest a modification to the schedule. If the original requested schedule is modified, a re-planning cycle will have to occur.

At the conclusion of the Mission Planning cycle, a Mission Planning Report will be prepared. This report will document the data collection requirements, schedules, timelines, etc.

3.3.1.2.2 Command Generation (see Figure 3.3-6)

Upon receipt of both the normal and contingency data collection requirements by the command generation function, the following actions take place:

1. Normal MLA Commands. The data collection requirements are examined to determine the specific functions required by the MLA sensor. These functions are then time-ordered so the commands will be executed in the proper sequence. Using a prestored MLA command list, a set of commands is generated. After verification that all commands are correct, they are time ordered and recorded on some media (CCT) for loading into the MLA sensor prior to launch. The storage media is delivered to KSC, where the MLA commands will be loaded.

2. Contingency MLA Commands. The contingency commands are handled in a similar fashion, except instead of being recorded onto a storage media for delivery to KSC, they are stord in the POCC. When a "Command Modification Request Message" is received from the MIFG, the proper contingency commands are extracted from storage, time ordered in the manner required for the contingency mission and sent to JSC through the SPIF, via NASCOM. JSC will send those commands to the shuttle at the proper time. (Note that the operation may be such that JSC merely acts as a "bent pipe" and the contingency commands could conceivably go directly to the shuttle from the POCC.)

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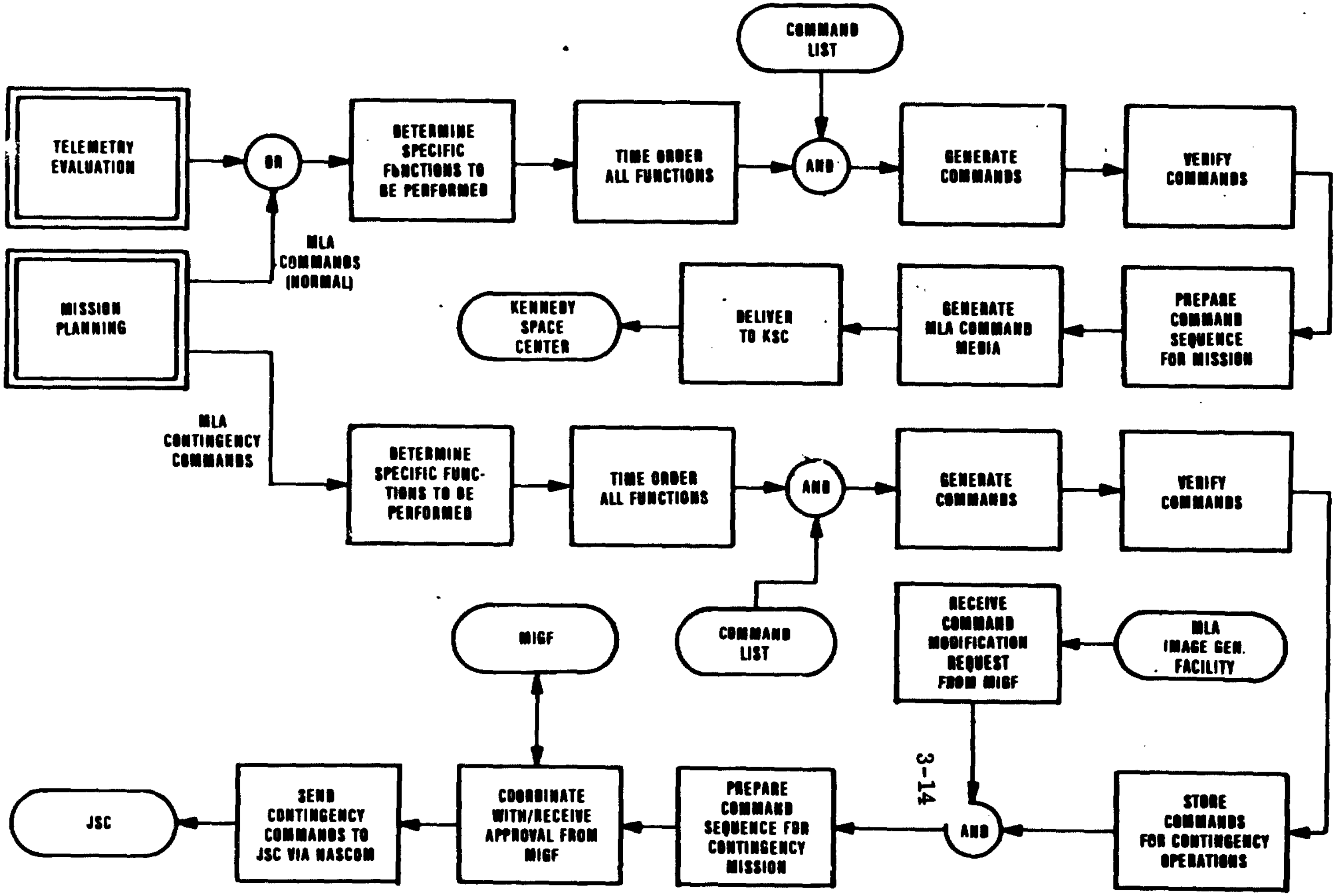

Figure 3.3-6. Functional Flow Block Diagram of Command Generation

3.3.1.2.3 Telemetry Evaluation (see Figure 3.3-7)

As the mission is being conducted, and MLA housekeeping telemetry is made available to the POCC, it will be recorded and undergo the following processing: each measured telemetry point will be compared to a set of pre-determined limits. If the value falls within limits, no action is taken. However, if a value falls outside of those limits, an alarm will be sounded. The particular anomaly will be assessed to determine its potential impact, and the MIGF will be informed. If it is jointly determined that the anomaly could cause a potentially serious problem, the Command Generation function is so informed (where a set of contingency commands will be generated - see Figure 3.3-6).

In addition to monitoring the MLA housekeeping telemetry during a mission, certain MLA points will also probably be monitored during non-operating periods. During those periods of time, a reduced set of voltages within the instrument will be "ON". The measured parameters will be sent to the POCC for evaluation, just as occurred during a normal mission.

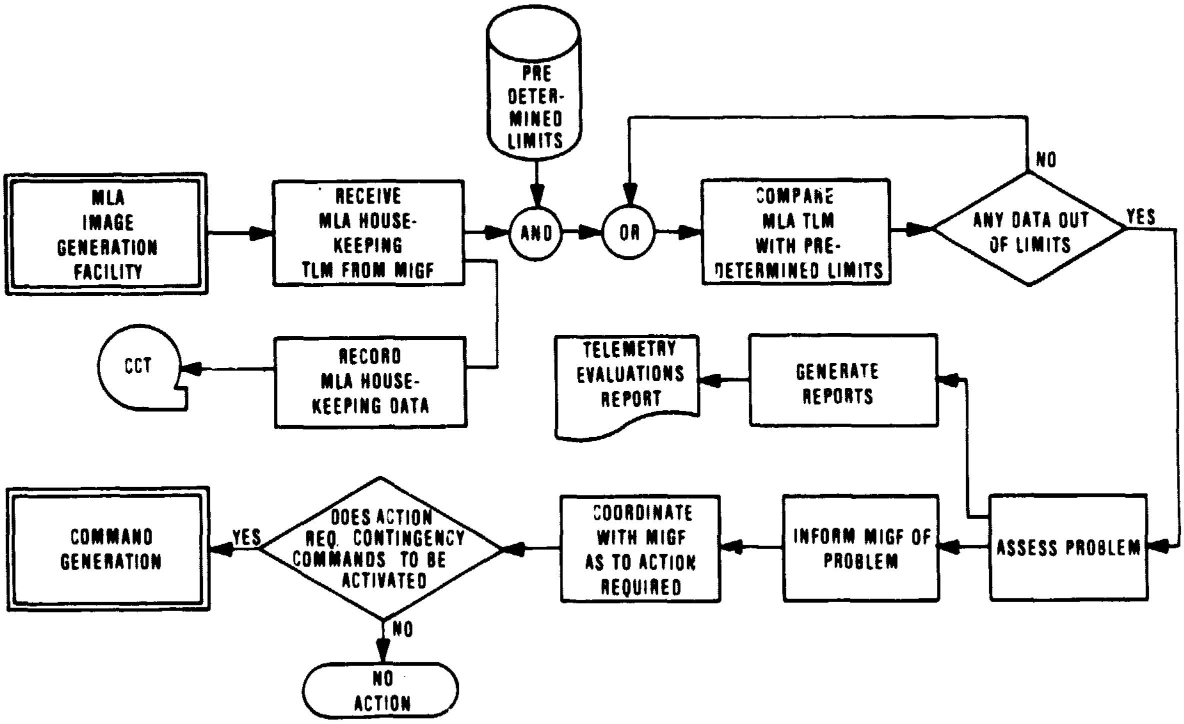

Figure 3.3-7. Functional Flow Block Diagram of Telemetry Evaluation

Upon completion of the mission, an in-depth evaluation of both the telemetry and output products would aid in performing the mission planning function for the next shuttle mission.

3.4 HARDWARE REQUIREMENTS and ARCHITECTURE

3.4.1 INTRODUCTION

This Section describes the ground based data processing facilities required to support an earth viewing Multi Spectral Linear Array (MLA) sensor carried by the Space Transportation System (shuttle). The topic of expansion is addressed in Section 3.7.

3.4.1.1 MLA Image Generation Facility (MIGF)

The architecture of the MIGF is driven by four primary requirements:

1. It must accommodate the maximum of Landsat resources, both in hardware and software.
2. It must operate as a standalone facility capable of processing raw sensor data to radiometrically and geometrically corrected images.
3. It must accommodate a sensor with bandwidth of approximately 120 Mbps over an effective 48 Mbps data link.
4. It must accommodate expansion in throughput, storage capacity and operator interfaces to support a MLA sensor aboard a free flyer.

The third and fourth requirements are driven by the sensing instrument, the MLA, while the first and second are the result of the desire to minimize the procurement of new components while still providing completely processed images.

The two primary sources of hardware are the Landsat Assessment System (LAS) and the Advanced Development Data System (ADDS). The former is a VAX 11/780 based system estalished to support R&D and product assessment efforts on the Landsat-D Thematic Mapper. The latter system is also VAX 11/780 based, but it contains a MAP 300 array processor. Its purpose is to investigate advanced data system architecture, to support future Goddard design requirements. The two facilities are participating together to process Landsat-D TM imagery prior to the availability of the Thematic Mapper Image Processing System

(TIPS). This system is will process one Thematic Mapper image a day. Another Landsat resource is the software utilized to support the multi-spectral scanner. This software operates on a VAX 11/780 based system, which utilizes the Floating Point System AP180 array processor. These three resources have been utilized to achieve an effective MLA Image Generation Facility.

Figure 3.4-1 depicts the data processing system configuration. It is VAX 11/780 based and has both the Floating Point Systems AP180 and the CSPI's MAP 300 as peripheral array processors. With the exception of the MAP 300, black and white CRT hardcopy, and the special I/O, all components are presently part of the Landsat Assessment System and require no reconfiguration of the LAS. The MAP 300 is borrowed from ADDS with its interface to the Synchronous Backplane Interconnect (SBI) of the VAX 11/780. The new hardware is the "special I/O". This "new" hardware is presently envisioned to be a standard I/O Scroll card available from CSP, Inc. which will fit in optional card slots of the MAP 300. It was chosen because it provides direct access to the MAP 300 internal bus, is software configurable and has spare integrated circuit sockets available for customizing interfaces.

The purpose of the "special I/O" card is to handle the downlink data error correction/detection and with the support of the MAP 300, derive baseband data from the already compressed (~ 2.7:1) data stream, and decommutate the image data to achieve properly formatted data on the mass storage devices controlled by the VAX 11/780.

The VAX 11/780 then uses the Floating Point System's AP180 to perform geometric correction prior to outputing the final processed image.

The digitzer and zoom transfer scope are used in a background mode to identify and locate ground control points to support generation of the geometric correction matrices necessary to perform geodetic correction of the image data. The hard copy device attached to the image display terminal will provide hard copy printouts of unprocessed imagery (i.e., not geometrically corrected) to establish a scene catalog from which scenes can be chosen for full processing. In this sense, a "quick-look" is taken of all scene images by the MLA during its seven day mission.

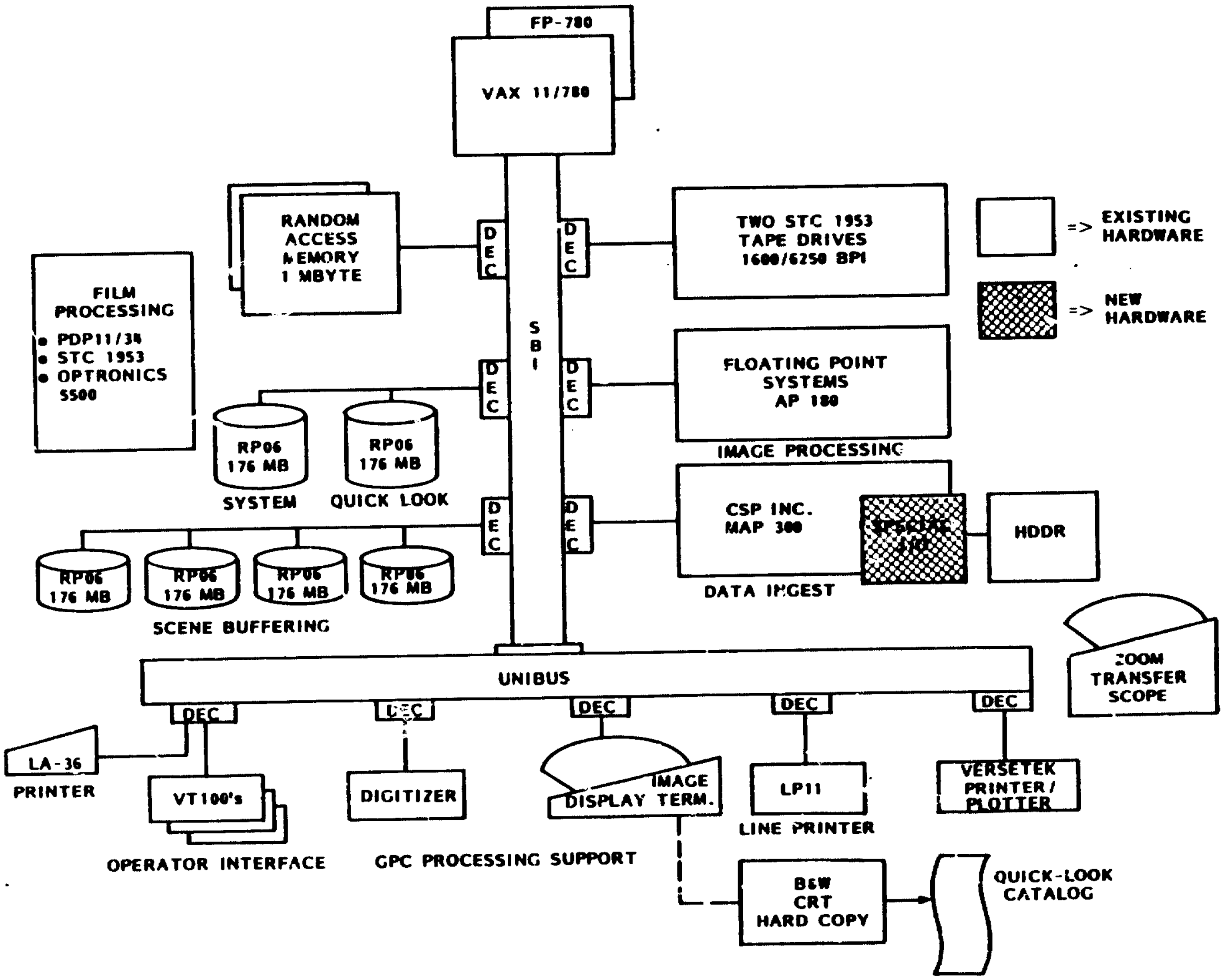

Figure 3.4-1. MIGF Preliminary Hardware Configuration

3.4.1.2 Payload Operations Control Center

The Payload Operations Control Center (POCC) will make use of GSFC's Multi-Satellite Operations Control Center (MSOCC). The MSOCC (see Figure 3.4-2) is an existing facility containing computers, displays, software and other equipments, located on the top floor of Bldg. 14 at the Goddard Space Flight Center. It consists of one Equipment Room (staffed, maintained and operated by NASA, with subcontractor support) and a number of MOR's (Mission Operations Rooms) staffed and operated by Project (contractor) personnel. The equipment Room presently contains five (5) "processing lines", with each processing line containing one TAC (Telemtry and Command - PDP-11/34) and one AP (Applications Processor - PDP 11/70). The software for the TAC was designed and "built" by Ford Aerospace in Houston, while the AP software was designed and coded by Westinghouse. The capability presently exists to increase the number of "processing lines" in the Equipment Room from 5 to 8.

In addition to the Equipment Room several MOR's are also part of the MSOCC. Each "processing line" in the Equipment Room can drive up to three (3) MOR's, for a total of fifteen (15) MOR's (24 MOR's when the Equipment Room gets expanded to eight (8) "processing lines"). A single MOR contains four (4) terminal devices (CRT + keyboard) plus two (2) racks of strip chart equipment.

Specific points concerning both the Equipment Room and the MOR's are described below:

Equipment Room

1. Equipment Room hardware and software is maintained and operated by NASA personnel (via a subcontract)
2. Each TAC is capable of handling a data rate of up to 600,000 BPS on three (3) decommutation channels.
3. Each TAC is a PDP 11/34 computer which interfaces with NASCOM.
4. The TAC performs the functions of decommutating received telemetry, stripping out communication from sync bits and passing a properly registered and error corrected 4800 bit format to the AP. Conversely, it formats commands for transmission to the satellite, via NASCOM.

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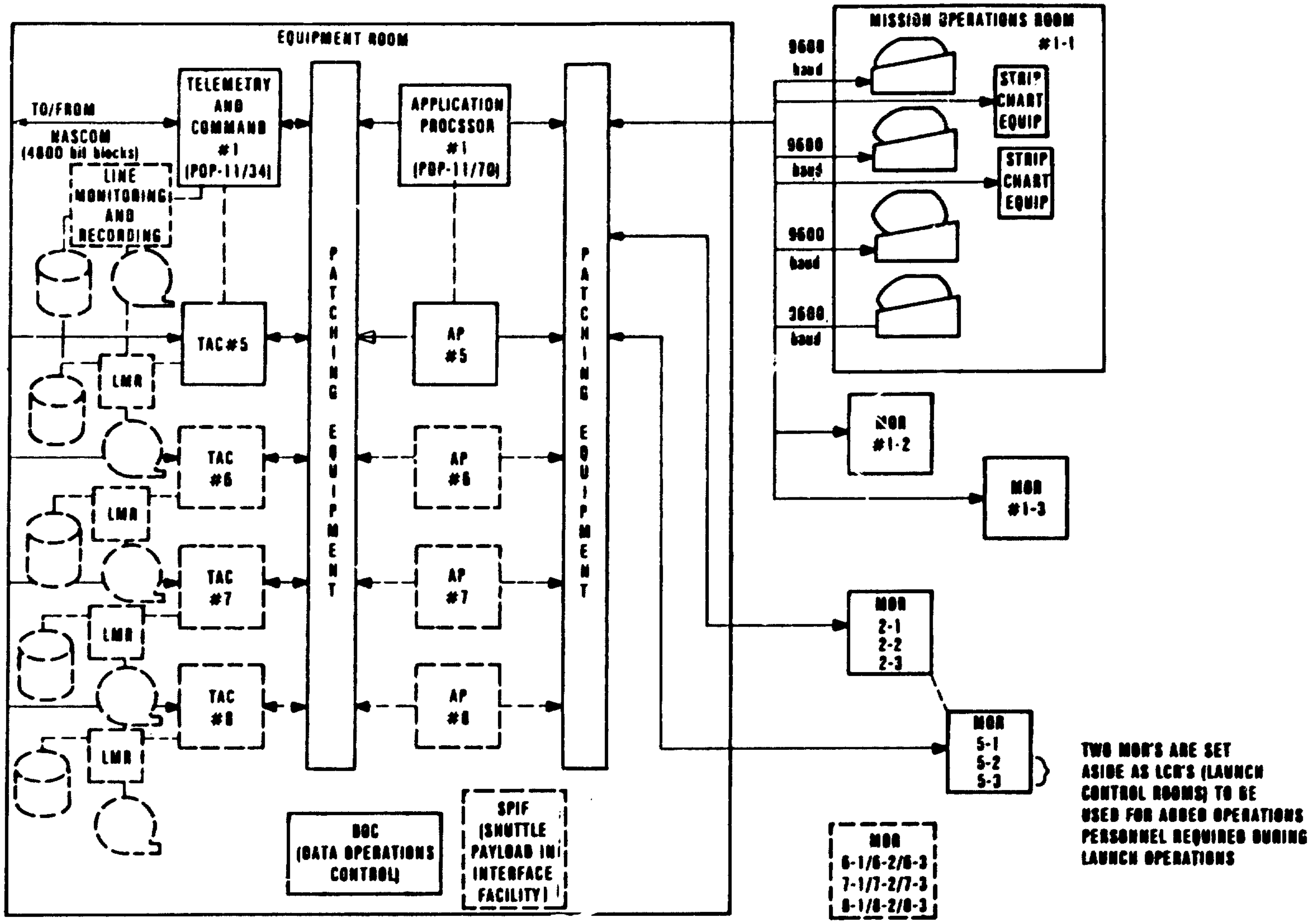

Figure 3.4-2. Multi-Satellite Operations Control Center

5. NASA is considering trying an LMR (Line Monitoring and Recording) subsystem to each TAC. The LMR will contain tape drives and disc files to record raw data as it is received from NASCOM.

6. DOC (Data Operations Control) - that part of MSOCC that operates the Equipment Room. DOC schedules the use of TAC's and AP's, assigns them to various space projects, operates the system, etc.

7. SPIF (Shuttle Payload Interface) - a future capability reserved for interfacing with payloads that are launch aboard the Space Shuttle. It will also probably be a PDP-11/34.

8. NCC (Network Control Center) - it is very likely that one of the eight (8) TAC/AP combinations will be assigned to the NCC function, when TDRSS becomes operational. The NCC "processing line" will also interface with NASCOM.

9. NASA is in the process of determining wheter a TAC should have a "store and forward" capability.

10. Each AP is a PDP-11/70 with 3/4M bytes memory, a small swapping disc and a large 88M byte moving head disc.

11. Each AP contains three (3) types of software:

    a. ● Commercial Software (provided by vendor).

    - operating system (RSX-11M)
    - Compiler (FORTRAN IV)
    - Data Base Management System (DBMS 11)
    - Utility Software (i.e., assemblers, editors, file handlers, etc.)

    b. ● Standard Software (mostly provided by Westinghouse).

    - STOL (Standard Test and Operating Language)
    - Telemetry Software
    - Commanding Software
    - Display Software
    - Data Base describing spacecraft (provided by spacecraft contractor)

    c. ● Application Software (provided by each contractor for his specific project).

12. Input data rate into each AP is 30-40 Kbps (GSFC feels that 40 Kbps is max for a real time system).

13. The Equipment Room is operated 24 hours per day, seven days per week.

Mission Operations Room (MOR)

1. The MOR is staffed by Project personnel.

2. Each MOR contains four (4) alpha-numberic terminals plus two (2) sets of Strip Chart Recording equipment. More than one MOR can be requested for a single project, if required.

3. Each display in the MOR is driven by a 9600 baud line - it gets updated approximately once every 10 seconds.

4. At least two (2) MOR's are set aside to serve as LCR's (Launch Control Rooms) for those times when a spacecraft is launched and additional personnel are requied.

5. The Equipment Room patching facilities provide the flexibility to patch any "processing line" into any MOR.

Based on the above considerations, our initial assessment indicates that no additional hardware or software is required to use the MSOCC as a POCC for the ELOS/STS mission. The only effort required, in additional to planning the mission and operating the MOR, is that necessary to define and populate the data base.

3.5 SOFTWARE REQUIREMENTS AND ARCHITECTURE

3.5.1 INTRODUCTION

During the discussion of the MIGF software, the following topics will be addressed in detail:

1. A summary of the software requirements and constraints.

2. An analysis of the applicability and transferability of Landsat D software.

3. A description of the software structure and flow.

4. An analysis of the software sizing estimates.

3.5.2 MLA PARAMETERS INFLUENCING SOFTWARE ARCHITECTURE

The MLA consists of four linear arrays (bands), each responding to different spectral frequencies. Bands 1, 2, and 3 contain 6144 sensors each, with a resolution 10 meters while band 4 contains 3072 sensors with 20 meter resolution. The MLA images the earth by simultaneously loading the radiance values detected by all 21504 sensors into a buffer memory. The contents of the buffer is then shifted out serially for transmission to the ground.

Although the MLA does not use moving mirrors while imaging, it does contain two mirrors which can be used to point the instrument off nadir in either the along or cross track directions. The along track mirror is capable of pointing the MLA 26 degrees forward or backward; the cross track mirror is capable of pointing the MLA up to 30 degrees off nadir in .5 degree increments.

It is assumed that MIGF will be supplied with radiometric correction functions for each detector.

3.5.3 SOFTWARE DESIGN

The ELOS mission is a two phase mission. The first phase occurs during the flight of the shuttle. During this seven day period, the MLA sensor will acquire data and transmit it to the ground station. The ground station will record this data and provide a quick look capability to monitor the health of the sensor and to determine which scenes to process further.

Sometime after the seven day shuttle mission, the NASA project office will determine a processing priority for the scenes acquired. Processing requests will be entered into the scene management system, which will generate work orders for the image generation function. The image generation function will produce CCT-RX, CCT-AX, CCT-PX, and high resolution film products. The scene management function will record the medium identifiers for all CCT products generated.

Figures 3.5-1 and 3.5-2 illustrate the MIGF data flow and the software structure respectively. The following paragraphs will describe the during flight and post flight processes in detail.

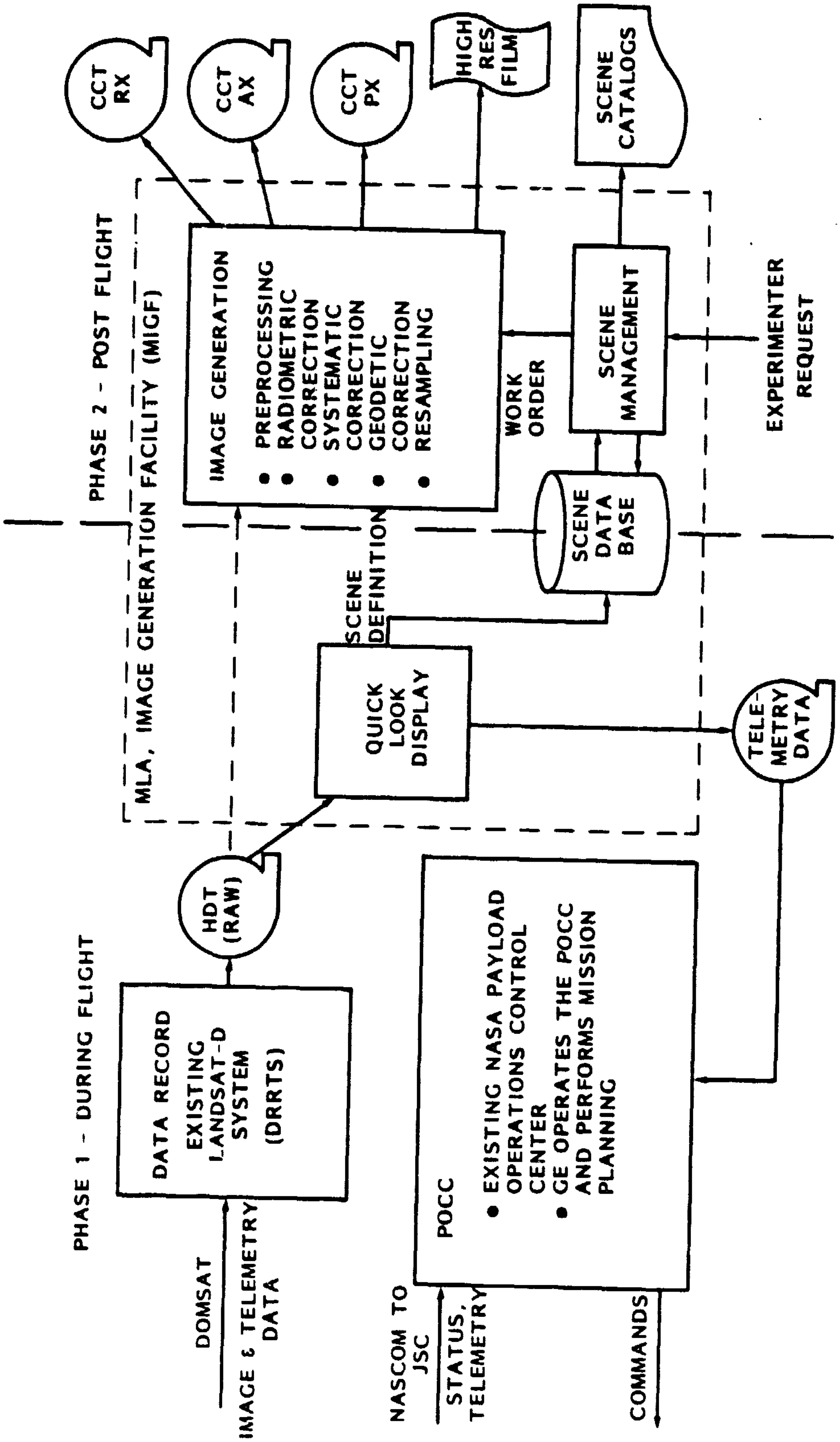

Figure 3.5-1. ELOS Ground Segment Data Flow

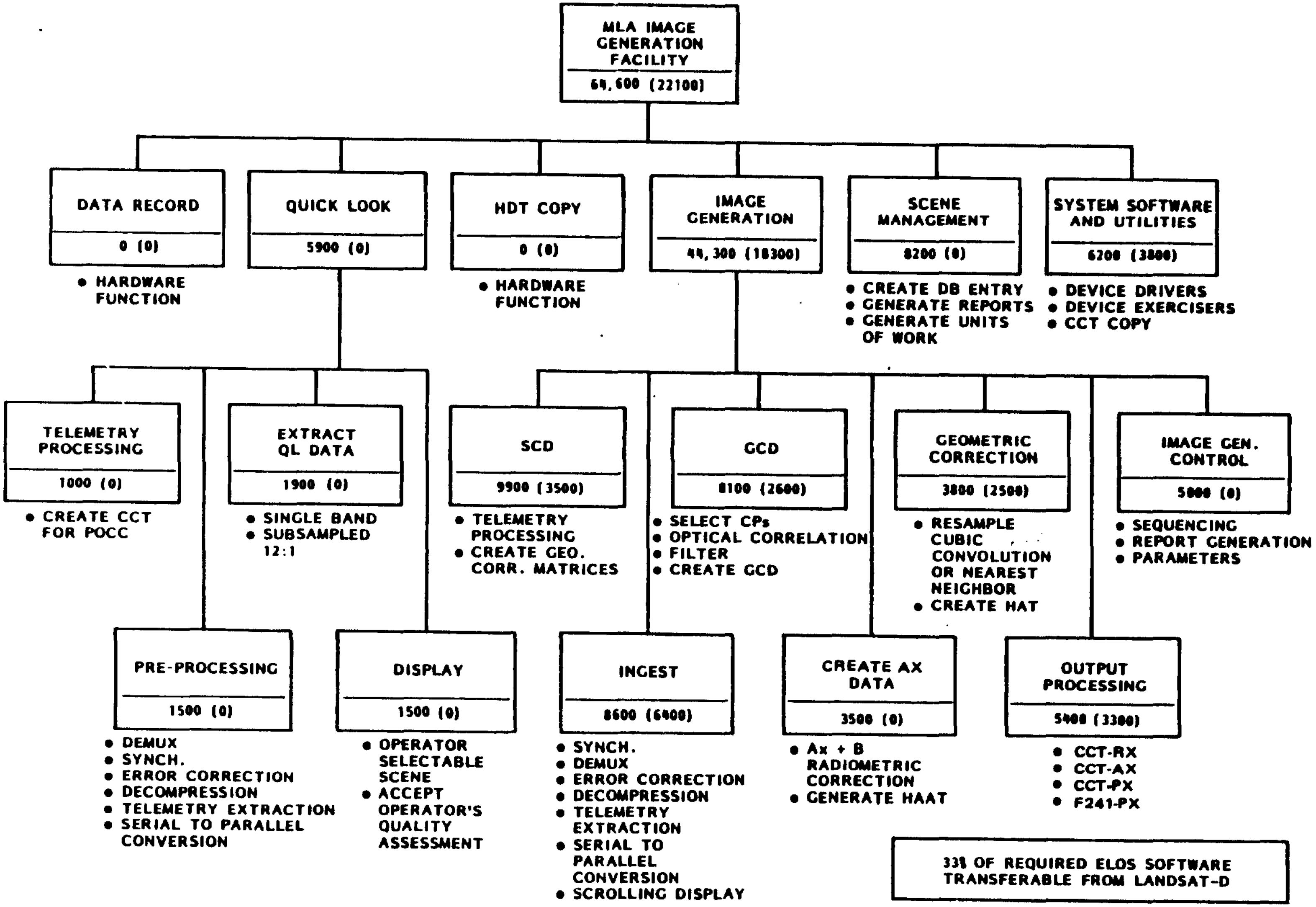

Figure 3.5-2. MIGF Software Overview

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3.5.3.1 During Flight Functions

3.5.3.1.1 Data Record and HDT Copy Functions

The data record function is a hardware function of the Landsat-D DRRTS. The DRRTS operator coordinates with White Sands and Domsat for the transmission of MLA data verbally via telephone. When a transmission is arranged, the DRRTS operator connects a 28 track to the HDDR Domsat modem via manual controls on the matrix switch. The compressed MLA data is recorded directly on a HDT. Upon completion of the transmission, the DRRTS operator reconfigures the matrix switch (via the manual controls) to perform the HDT copy function. The operator then operates the HDDR to produce a backup HDT.

3.5.3.1.2 Quick Look

The quick look process performs several functions. First, it allows a technician to visually review the image data acquired by the MLA sensor in a near real time mode. If anomalies are discovered during the review, mission analysts can evaluate the data and determine if changes in the sensor command sequence are required. Secondly, the quick look function provides data for a scene catalog. This data includes hard copies of quick look displays and a scene index, which is used to create the scene data base. Finally, during the quick look process, telemetry data is stripped from the HDT and written onto CCT for evaluation at the POCC. Figure 3.5-3 illustrates the quick look process.

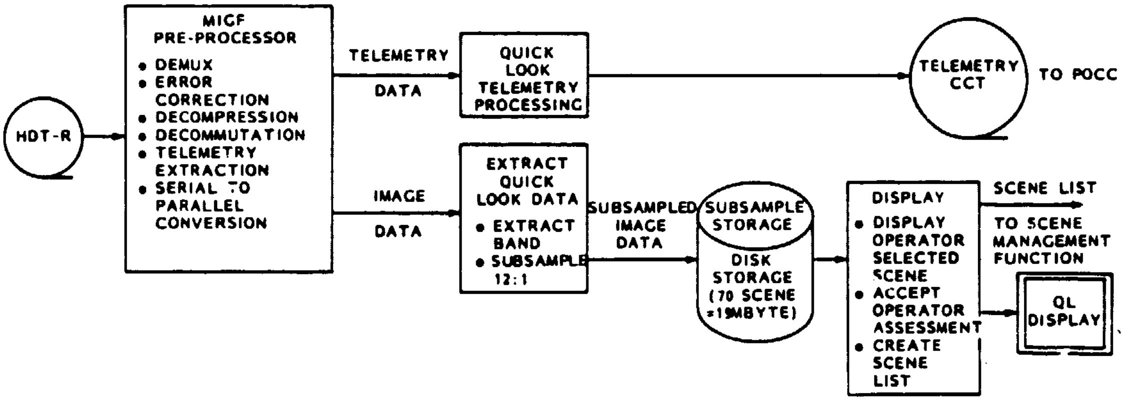

Figure 3.5-3. Quick Look Data Flow

The quick look process is initiated when an HDT is recorded in DRRTS and delivered to the MIGF. The HDT is mounted on the HDDR and a read operation initiated. The special IO board in the MAP 300 array processor synchronizes the data and converts it from a serial bit stream to parallel. Software in the MAP performs error detection, error correction, and data decompression. Decompressed data is transferred to the VAX where telemetry data is stripped out and the image data subsampled at a 12 to 1 ratio. Telemetry data and subsampled image data are stored on disk. This operation continues until all data on the HDT is ingested. In order to create scene index data, the IRIG time of the first and last valid data is saved, as well as the start and end spacecraft time. The ingest operation operates at approximately 2.8 Mbps, or approximately 2 minutes, 20 seconds per scene.

After an entire interval of ELOS data is ingested, the stripped telemetry data on disk is formatted and written to CCT.

The subsampled image data on disk is divided into scenes, each scene representing approximately 60 KM by 60 KM. This division is based strictly on an even division of the imaging interval. Each scene is then displayed to the operator for inspection. Anomalies identified by the operator are brought to the attention of the mission analyst for off-line investigation. At the time of viewing, the operator may redefine the boundaries of a scene. The redefinition may be used to include more useful data in one scene or to elimate scenes which contain little useful data (e.g., scenes with total cloud cover.) When the operator is satisfied with a scene definition, a hard copy of the display is produced. The hardcopy includes image data and annotation, identifing spacecraft time.

After all scenes in the interval are viewed, a file containing the scene center time and calculated IRIG start and stop time, is created.

3.5.3.1.3 Create Scene Management Data Base

The scene management process maintains a data base of all MLA scenes, their current processing status, and a cross reference to the physical media (i.e., HDT, CCT-RX, CCT-AX, and CCT-PX) which contain the scene. During the mission, the function of the scene management process is to create data base entries for each scene defined in the quick look process. This is accomplished by obtaining the scene file created by the quick look process, and storing each scene (keyed by scene center time), the start and stop IRIG time for each scene, and the identification of the HDT containing the scene in the data base.

3.5.3.2 POST FLIGHT FUNCTIONS

.1 Image Generation

[illegible] generation includes radiometric and geometric correction of each MLA [illegible] production of CCT and film products. The process is initiated by a w [illegible] from the scene management system and operates on one scene at a time. [illegible] input for the process is image and telemetry data on HDT, ephemeris data on CCT from JSC (if available), and standard USGS maps. Figure 3.5-4 illustrates the data flow for the image generation function. The following paragraphs describe each subfunction in detail.

3.5.3.2.2 Image Generation Control

The process is initiated by a work order from the scene management process. The work order specifies the input HDT and the CCT products desired. One work order may specify any combination of the three types of CCT products for a scene. The image generation control accepts work orders and determines the sequence of processes that must be invoked to produce the desired products. After processing is complete for the work order, the image generation control process generates feedback for the scene management function.

3.5.3.2.3 Ingest Raw Data

All processing sequences begin with HDT ingest. This process positions the HDT to the beginning of the data for the scene (based on start IRIG time from the work order) and initiates the transfer of data from the HDT to the VAX. The transfer occurs via the MAP in the same manner as quick look data ingest. As in the quick look process, the MAP performs error detection, error correction, and data decompression. Telemetry data is also stripped from the data stream in the map and transferred to the VAX. The VAX receives image and telemetry data and stores it in a standard format on disk. Additionally, the image data is subsampled and output to the image display device, allowing the operator to preview the scene in process.

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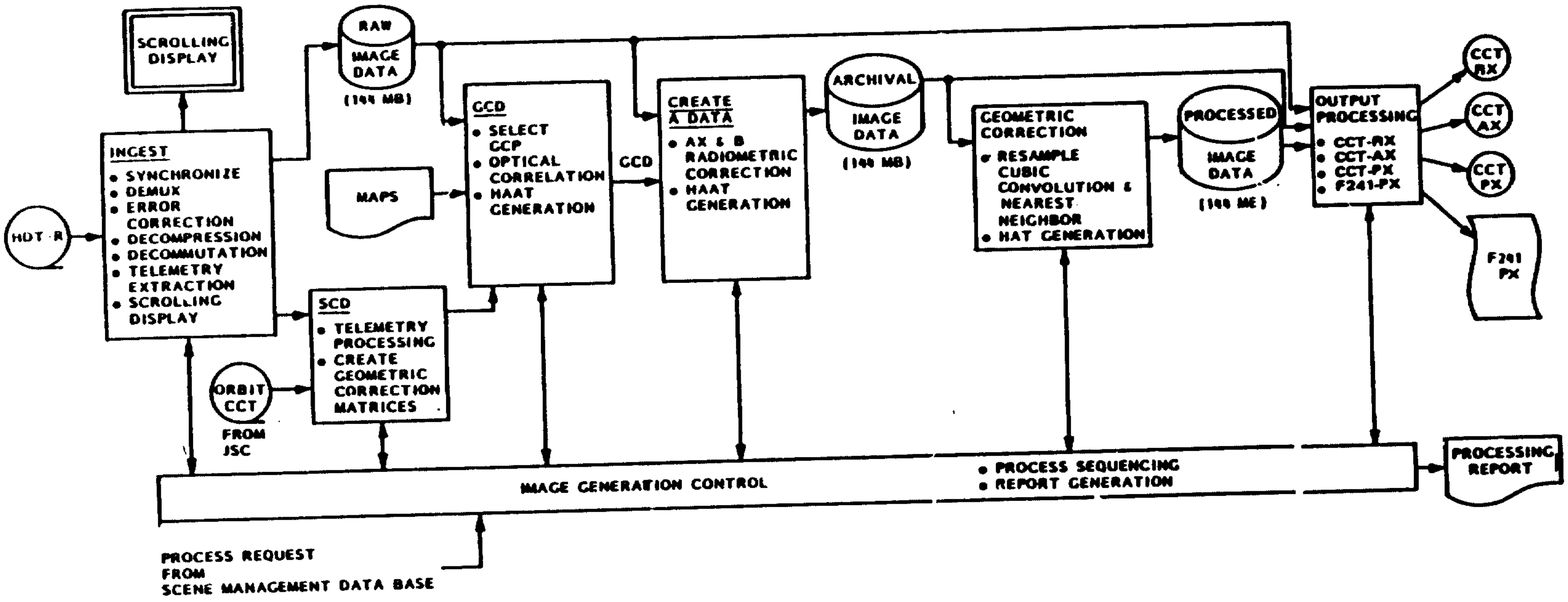

Figure 3.5-4. Image Generation Data Flow

control point. Optical correlation consists of resampling small portions of the MLA imagery around the control point (using systematic correction data) and displaying the corrected imagery on the image display device. Using the zoom transfer scope, the operator optically overlays the map on the image data. Once a satisfactory overlay is achieved, the operator positions a cursor over the control point. The line and pixel location of the control point, along with the precise latitude and longitude, is then stored.

When approximately 10 control points have been located and correlated in one scene, the differences between the SCD predicted locations of the control points, and the actual correlated locations of the control points, are modeled. These data are related back to errors in the modeled attitude and Ephemeris data, from telemetry processing. Based upon these modeled errors, the geometric correction matrices are updated.

3.5.3.2.6 Create AX Data

After the GCD is generated, the AX format data is created.

The radiometric correction functions are assumed to be simple linear relationships between raw pixels and corrected pixels, represented by a single gain and offset for each detector. These gains and offsets are stored in the MIGF parameter data base and can be modified when experimenters determine more accurate gains and offsets.

3.5.3.2.7 Geometric Correction

Geometric correction consists of resampling the AX data to the SOM projection as per the geometric correction matrices and sensor parameters. The large number of computations involved in the resampling process dictates use of an array processor. Floating Point Systems AP180 array processor is used to perform the resampling. Benchmarks for the process indicate that resampling one MLA scene requires approximately 40 minutes using the AP180.

The geometric correction process also includes creating the header, annotation, and trailer (HAT) data for the scene. This process consists mainly of copying selected records from the HAAT data in the AX scene, and modifing selected fields in those records.

3.5.3.2.4 Systematic Correction Data Generation

Systematic Correction Data (SCD) generation calculates geometric correction parameters using telemetry data and sensors constants. The process includes attitude and ephemeris processing, look-point calculations, image framing, and SCD parameter generation. Attitude processing consists of combining the attitude data from several sensors using a digital filter, and then modeling the result of that combination. Ephemeris processing models the Ephemeris data. Ephemeris data may be obtained from one of two sources. First, the shuttle's state vector is included in the telemetry data. This data is readily available, however its accuracy is reduced because long term smoothing has not been done. More accurate ephemeris data can be obtained from JSC in the form of a CCT; however it will not be available until approximately 13 weeks after the mission is complete. The work order will specify which ephemeris source is to be used. The look-point model calculates the precise location of each pixel in the output space using the attitude and ephemeris models, and nadir and off-nadir scenes. Finally, the look point model and image framing data is used to produce geometric correction matrices.

3.5.3.2.5 Geodetic Correction Data Generation

Geodetic Correction Data (GCD) generation refines the geometric correction matrices produced in SCD generation by registering the imagery to standard US Geological Survey (USGS) maps. This process is accomplished by selecting a set of control points for each scene, and optically correlating these control points with the image data. Control points are points on the earth whose geodetic location is known to a high degree of accuracy and which are close to features that are readily identifiable on both standard maps and MLA imagery. The GCD generation process consists of locating control points, optically correlating the standard maps and imagery around the control points, and modeling the results of the correlations.

Locating control points consists of previewing maps looking for features that are likely to be visible in the MLA imagery. For each such feature found, a notation is made on the map. This notation represents the control point. The next step is to precisely identify the geodetic location of the control point. This is done by placing the map on the Sonic Digitizer and specifing the X-Y position of the control point and the surrounding reference points on the map. The latitude and longitude of the reference points are entered and the computer interpolates to find the precise latitude and longitude of the

3.5.3.2.8 Output Processing

Output processing reads data in RX, AX, or PX format from disk and produces CCT's. Output processing also includes producing fully corrected high resolution film.

Any or all of the output products can be made for a scene from a single work order. All CCT products consist of two physical CCT reels, written at 6250 bits per inch, in a standard format.

High resolution film is generated by the LAS stand alone film generation system. This system reads MLA image data from CCT-PX and produces high resolution film.

3.5.3.2.9 Scene Management

In the post mission era, the scene management function consists of accepting experimenters requests to process scenes, generation of work orders for the image generation function, update of the data base based on processing feedback, and generation of scene catalogs. A high level data flow of the post mission scene management function is shown in Figure 3.5-5.

Update of the data base based on processing feedback consists of making entries in the data base for each CCT type created and linking those entries to the scene record.

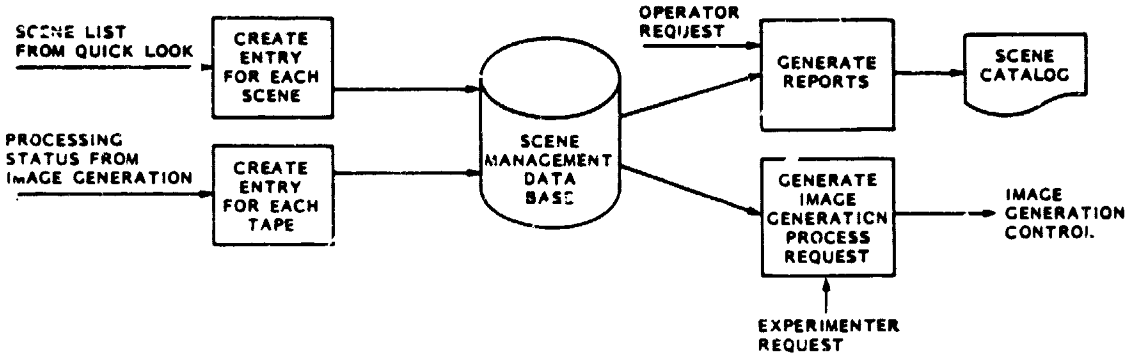

Figure 3.5-5. Scene Management Data Flow

Generation of scene catalogs is the same function as described in the during mission section. The catalog contains a scene identification and a list of the tapes (both HDT and CCT) that contain the scene.

3.5.3.3 System Software

System software consists mainly of the vendor supplied operating system and device drivers and exercisers written for the special purpose hardware in the system. Since the MIGF is configured from existing hardware, the operating system and most special purpose device drivers and exercisers are available and can be used without modification. A device driver and exerciser for the special input output board that handles synchronization of the MLA, data is the only new system software.

Also included in the system software category is CCT copy software. Since CCT's are the main product medium, software to create backup CCT's is required.

3.5.3.4 Software Lines of Code (LOC) Estimates

The ELOS software LOC estimate was developed by preparing a conceptual design for the software , breaking the design down to the module level, estimating the size of each module, and estimating the complexity of each module.

The estimation of lines of code and complexity of each module were determined by evaluating the task to be performed in each module, preparing initial estimates based on this evaluation, and checking the estimates against similar functions in the Landsat-D image processing system. Each Landsat-D MSS and TM function used for comparison was analyzed to assure realistic comparisons.

Table 3.5-1 shows the module breakdown for the MIGF software and the lines of code estimate for each module. The estimates are divided into two columns, lines of code that can be transferred directly from Landsat-D to ELOS, and lines of code that must be written.

Of the 64000 lines of code estimated for the MIGF, 22000 (nearly one third) can be directly transfered from Landsat-D. Although transfer of software does have an associated cost this use of Landsat-D assets will produce a significant cost savings. Many of the algorithms embodied in the new code are very similar to Landsat-D algorithms even though the code is not directly transferable.

Table 3.5-1. MIGF Software LOC Estimate

	Loc Trans. From LSD	New Loc
I. QUICK LOOK		
A. Preprocessing		
Synchronize (Hardware)		
Serial-Parallel Conv. (Hardware)		
Demultiplex (Hardware)		
Decompression (MAP)	0	600
Error Correction (MAP)	0	600
Telemetry Extraction (MAP)	0	300
	0	1500
B. Telemetry Processing		
Format Telemetry Data	0	500
Write Telemetry CCT	0	500
	0	1000
C. Extract Quick		
Read Image Data	0	800
Subsample Image Data	0	300
Create List of IRIG vs S/C Times	0	800
	0	1900
D. Display Quick Look Data		
Display List of S/C Times	0	400
Accept Operator Commands For Display	0	300
Display Subsampled Image data	0	300
Format Feedback for Scene Manager	0	500
	0	1500
Total For Quick Look	0	5900
II. IMAGE GENERATION		
A. Ingest Raw Data		
Accept Unit of Work	0	500
Interact with Operator	0	300
HDT Control Software (HCS)	2300	400
Preprocessing (Same as Quick Look)		
Read Image Data (Same as Quick Look)		
Scrolling Display (ODP)	1800	300
Write Image Data to Disk (MDKIO)	2300	400
	6400	2200

Table 3.5-1. MIGF Software LOC Estimates (Cont.)

	LOC TRANS. FROM LSD	NEW LOC
B. Systematic Correction Data		
Read Housekeeping Telemetry (Same as Quick Look)		
Read JSC Telemetry CCT	0	400
Attitude And Ephem. Processing	0	3000
Image Framing	0	1000
Look-Point Calculation	2000	500
Calculate SCD Matrices	1500	1500
	3500	6400
C. Geodetic Correction Data		
Digitizing	1500	300
Lat. Long. to I, J calculation	300	200
Extract CPN	0	300
Correct CPN (Systematic Correction)	0	600
Display CPN	300	100
Operator Interaction	0	500
Model Att. And Ephem.	0	2500
Create Geodetic Correction Matrices	500	500
Generate QA Data	0	500
	2600	5500
D. Create AX Data	0	3000
Generate HAAT Data	0	500
Apply Radiometric Correction (AP180)		
Disk I/O (MDKIO)		
	0	3500
E. RESAMPLING		
Extract Geometric Correction Data	0	400
Calculate Resampling Parameters	0	400
Resample Data (AP180 Like MSS)	2500	300
Calculate HAT	0	100
Disk I/O (MDKIO)		
Control Software	0	100
	0	100
	2500	1300
F. Create CCT's (RX, AX, AND PX)		
Control	0	600
Format Data	0	300
Write CCT's	0	600
	0	1500

Table 3.5-1. MIGF Software LOC Estimates (Cont.)

	LOC TRANS. FROM LSD	NEW LOC
G. Control		
Accept Process Request	0	500
Schedule	0	500
Accept status from other modules	0	500
Processing Summary	0	1000
Prepare Feedback	0	500
	0	3000
H. Parameter Manipulation	0	2000
	0	2000
I. Film Generation		
Read CCT	500	200
Write to Disk	1000	0
Write Film	1800	400
	3300	600
Total For Image Generation	18300	26000
III. SCENE MANAGEMENT		
A. Initialize Data Base	0	500
	0	500
B. Create Scene Entries		
Accept scene def from quick look	0	300
Build scene entries in DB	0	800
	0	1100
C. Determine Processing Requirements		
Print Scene Catalog	0	2000
Accept user requests	0	1000
Generate processing requests	0	800
	0	3800
D. Update DB After Processing		
Accept Feedback	0	1000
Update Data Base	0	800
Create Tape ID Data Base	0	1000
	0	2800
Total Scene Management	0	8200

Table 3.5-1. MIGF Software LOC Estimates (Cont.)

	LOC TRANS. FROM LSD	NEW LOC
IV. System Software		
A. Device Drivers/Exercisers		
DSM type device	0	1500
Comtal (plus Fortran callable routines)	1000	0
TSU/HDDR	1800	0
SPI	1000	0
	3800	1500
B. CCT Copy		
Operator Interaction	0	500
Copy	0	400
	0	900
Total System Software	3800	2400
TOTAL MIGF SOFTWARE	22100	42500
TOTAL NEW AND TRANSFERED	64600	

3.6 OPERATIONS

The manning estimates and responsibilities for the ELOS POCC are shown in Table 3.6-1. It should be pointed out that all POCC personnel mentioned in the table are temporarily assigned for the pre-mission/mission phases. Most POCC personnel will be manning the Mission Operations Room.

The manning estimates and responsibilities for the MIGF are shown in Table 3.6-2. MIGF personnel are assigned for the pre-mission, mission, and post-mission phases.

3.7 GROWTH CAPABILITIES

Anticipated system enchancements fall mainly in the areas of increasing throughput (to support more frequent or possibly free flying missions) and providing alternate archival media. Each of these enhancements are discussed below.

Table 3.6-1. ELOS POCC Manning Estimates and Responsibilities

POSITION/OPERATOR	NO. REQUIRED DURING MISSION		RESPONSIBILITIES
	NO/SHIFT	TOTAL	
1. MISSION MANAGER (NASA)	-	1	● DEFINE CURRENT MISSION PROFILE ● COORDINATE ALL MSOCC OPERATIONS ● INTERFACE WITH NASA ELOS PROGRAM OFFICE ● INTERFACE WITH GE ELOS PROGRAM OFFICE ● SUPERVISE ELOS OPERATIONS SCHEDULING ● PROVIDE INPUT DATA TO MISSION PLANNER
2. MISSION PLANNER	2	6	● DEVELOPE AND MAINTAIN CURRENT MISSION PLAN ● INTERFACE WITH ORBIT COMPUTATIONS GROUP ● MAINTAIN CURRENT ORBIT DEFINITION ● MAINTAIN CURRENT OBC CONFIGURATION ● MANAGE MISSION PLANNING MODULE OF AP ● PROVIDE INPUT DATA TO COMMAND OPERATOR ● COORDINATE/MAINTAIN ORBIT DEFINITION DATA TAPES
3. COMMAND OPERATOR	1	3	● MAINTAIN ELOS DATA BASE ● MANAGE DATA BASE MGT MODULE OF AP ● PREPARE COMMAND LOADS ● MANAGE ELOS COMMAND AND CONTROL MODULE OF AP ● MONITOR AND VERIFY COMMAND TRANSMISSIONS/EXECUTION ● PROVIDE COMMAND PLAN TO PERFORMANCE MONITOR ● MAINTAIN COMMAND HISTORY REPORTS
4. TELEMETRY EVALUATOR	1	3	● MONITOR ELOS STATUS/HOUSEKEEPING DATA ● VERIFY COMMAND EXECUTION BY ELOS PERFORMANCE EVALUATION ● MANAGE TELEMETRY EVALUATION MODULE OF AP ● MAINTAIN PERFORMANCE REPORTS ● COORDINATE PERFORMANCE DATA WITH GE ENGINEERS ● REPORT ANOMALIES TO MISSION MANAGER
5. EXPERIMENTER REPRESENTATIVE	1	1	● PROVIDE QUICK-LOOK EVALUATION OF EXPERIMENT DATA ● INTERFACE WITH EXPERIMENT COMMUNITY ● COORDINATE WITH MISSION MANAGER ON EXPERIMENT REQUIREMENT IMPACTS ON OVERALL MISSION PROFILE

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Table 3.6-2. MIGF Manning Estimates and Responsibilities

POSITION/OPERATOR	NO. REQUIRED DURING MISSION		NO. REQUIRED POST MISSION TOTAL	RESPONSIBILITIES
	NO/SHIFT	TOTAL (NOTE 1)		
1. MIGF SUPERVISOR (NOTE 2)	1	3	1	• MANAGE ALL MIGF OPERATION AND MAINTENANCE ACTIVITIES • ESTABLISH MIGF PERSONNEL SCHEDULES • COORDINATE HARDWARE AND SOFTWARE MAINTENANCE SUPPORT REQUIREMENTS • COORDINATE IMAGE PROCESSING AND PRODUCT QUALITY • COORDINATE MIGF PERSONNEL MANAGEMENT
2. QUICK LOOK OPERATOR (NOTE 3)	1	3	1	• SUPPORT DATA ACQUISITION, PROCESSING, AND RELAY OPERATIONS • PERFORM OPERATOR LEVEL PREVENTIVE MAINTENANCE TASKS • MOUNT, DISMOUNT, AND LABEL REELS • OPERATE TAPE REWIND AND DEGAUSSING EQUIPMENT
3. SYSTEMS ENGINEER	-	1	1	• MAINTAIN TECHNICAL COGNIZANCE OVER MIGF SYSTEMS • COORDINATE ROUTINE MAINTENANCE SCHEDULES FOR MIGF HARDWARE • REPRESENT THE MIGF IN PROBLEM REPORT ACTIVITIES • COORDINATE IGF SYSTEM CONFIGURATION • PROVIDE TRAINING ACTIVITIES TO MAINTAIN MIGF PERSONNEL CAPABILITIES • SUPPORT THE MISSION ENGINEER AND ANALYSTS IN INTERPRETING MIGF PERFORMANCE • SUPPORT THE SYSTEM ANALYST IN MONITORING IMAGE PROCESSING ALGORITHM INTERACTION WITH SENSOR DATA
4. SYSTEMS ANALYST	-	1	1	• MAINTAIN COGNIZANCE OVER IGF PROCESSING ALGORITHMS • ANALYZE STATISTICAL PERFORMANCE DATA • CORRELATE SENSOR, DATA RELAY, PROCESSING AND OUTPUT PRODUCT EVALUATION DATA • PERFORM SPOT-CHECK EVALUATIONS OF GEOMETRIC AND RADIOMETRIC CORRECTIONS • SUPPORT THE MISSION ENGINEER AND THE QUALITY ASSURANCE MANAGER IN RESPONDING TO DATA-RELATED INQUIRIES
5. PROGRAMMER (NOTE 4)	1	3	2	• ENTER CARD DECKS, REMOVE HARD COPY PRINT-OUTS AND INITIATE PROCESSING FUNCTIONS AS REQUIRED • COORDINATE OPERATIONS WITH THE QUICK-LOOK OPERATOR • PERFORM OPERATOR LEVEL PREVENTIVE MAINTENANCE TASKS • MAINTAIN CONSOLE LOGS FOR ALL PROCESSING STRING OPERATORS
6. EQUIPMENT OPERATOR (NOTE 4)	1	3	2	• COORDINATE AND SUPERVISE ALL MIGF DATA PROCESSING OPERATIONS • DIRECT THE PRODUCTION CONTROL SPECIALISTS AND STAGING CLERKS • MAINTAIN COGNIZANCE OVER PRODUCTION PROCESSING CAPABILITY STATUS • MAINTAIN PRODUCTION LOGS • PROVIDE ON-SHIFT SUPERVISION OF ALL MIGF OPERATOR AND PRODUCTION SUPPORT PERSONNEL
7. SOFTWARE MANAGER	-	1	1	• MAINTAIN EXPERTISE IN MIGF COMPUTER SYSTEM EXECUTIVE SOFTWARE • ASSIST THE MIGF SYSTEM ENGINEER IN MAINTAINING SYSTEM DOCUMENTATION • ASSIST THE LOAD ANALYST IN REACTING TO PROBLEM REPORTS • MODIFY/UPDATE OPERATING SYSTEM SOFTWARE
8. SECRETARY	-	1	1	• PROVIDE ADMINISTRATIVE AND CLERICAL ASSISTANCE
9. GCP OPERATOR	1	3	2	• OPERATE THE GCP ENTRY PROCESSING ELEMENT OF THE MIGF • PERFORM OPERATOR INTERACTION FUNCTIONS DURING THE LOAD PROCESS • MAINTAIN GCP LIBRARY RECORDS AND STATUS INFORMATION • SUPPORT THE MIGF SYSTEM ENGINEER IN ANALYZING PROCESSING ALGORITHM EFFECTS RELATIVE TO GCP DATA
10. EXPERIMENT CORDINATOR (NASA)	1	3	1	• PROVIDE QUICK-LOOK EVALUATION OF EXPERIMENT DATA • COORDINATE WITH MISSION MANAGER ON EXPERIMENT REQUIREMENT IMPACTS ON OVERALL MISSION PROFILE

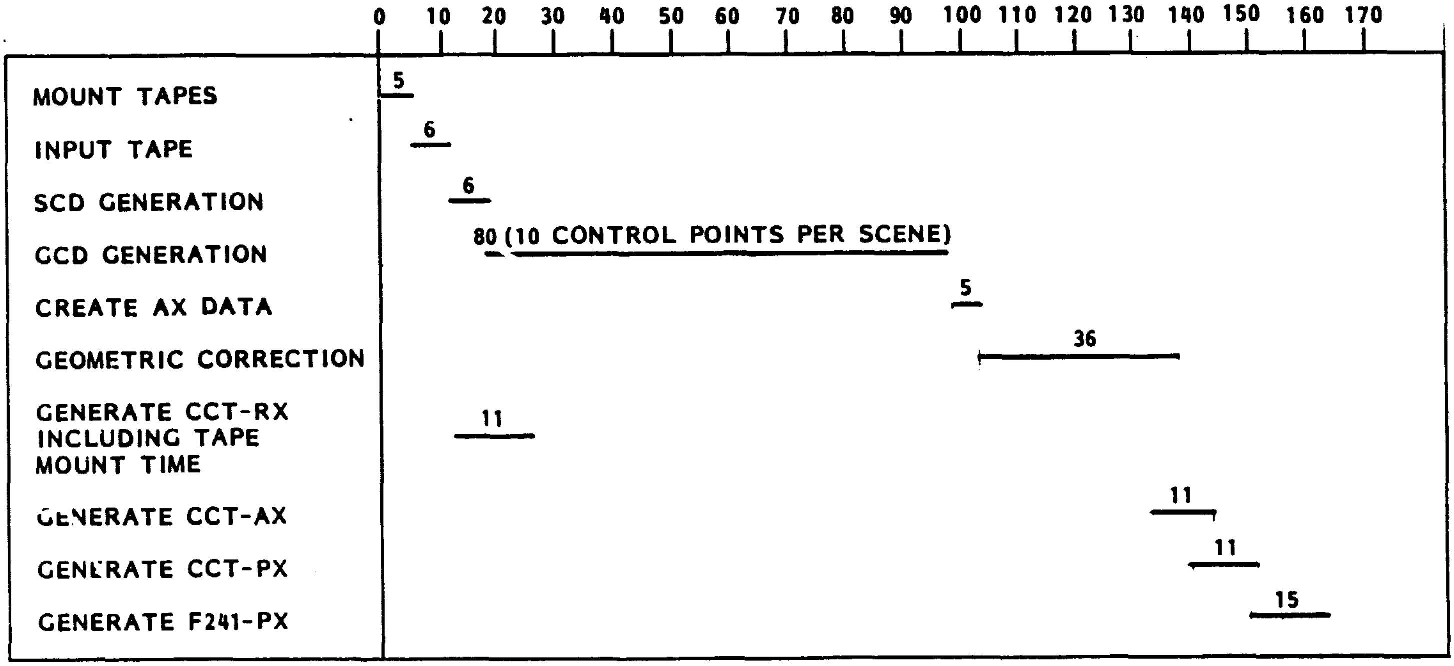
NOTES:

1. 3 TEAMS, 3 SHIFTS
2. 2 SUPPLIED TEMPORARILY FROM FACTORY (GE-VF)
3. ALL SUPPLIED TEMPORARILY FROM FACTORY (GE-VF)
4. 1 SUPPLIED TEMPORARILY FROM FACTORY (GE-VF)

3.7.1 INCREASED THROUGHPUT

The MIGF was designed to support a two scene per day processing load. Based upon this requirement, a relatively simple system design was defined. This design includes less complex and less costly software and hardware than would be required for a high throughput system There are however several areas where enhancements would significantly improve throughput. In order to identify these areas, the time required for each MIGF function must be examined.

Figure 3.7-1 illustrates a timeline for processing one scene through the MIGF. Assuming 10 control points are used in the GCD generation function, 165 minutes is required to process one scene. This timeline clearly shows that control point processing and resampling require the most computer time. The most dramatic improvements in throughput can be obtained by addressing these areas. After these areas are optimized, additional improvements can be obtained by addressing the SCD process and by increasing disk transfer rates.



PROCESSING TIME = 85 MIN/SCENE + 8 M'NUTES/CONTROL POINT
TOTAL TIME (10 CONTROL POINTS) = 165 MIN/SCENE = 2 HRS 45 MIN

Figure 3.7-1. Typical MIGF Timeline (1 Scene)

3.7.1.1 Control Point Processing

Control point processing requires 80 of the 165 minutes required to process a scene, and is limited by manual operations by the operator. This time can be reduced in two ways. First, precision geodetic registration may not be required for all scenes. The accuracy of the geodetic registration for scenes is related to the number and distribution of control points in the scene. Relatively few control points eliminate most of the SCD inaccuracies. A large number (10 to 20) are required for precise registration. Performing precision registration on a small number of scenes could potentially double the system's throughput.

Secondly an automatic control point processing system could be used. In the Landsat D system, manual control point processing performed in the control point library build process requires approximately 8 minutes per point. Automatic control point processing in the archive generation processes requires approximately 5 seconds per point. Therefore, the time required to process ten control points could be reduced from 80 minutes to less than 1 minute. Automatic control point processing can only be performed if a data base of control point information is available. In 1986, a TM control point data base will exist. It may be possible to reformat and resample TM control points for use in the ELOS system. Alternatively, an ELOS control point data base could be built. Building an ELOS control point library would be a manual process and would only be feasible during a free flying mission where the same area on the ground would be imaged many times.

3.7.1.2 Resampling

Resampling performed in the AP180 requires approximately 36 minutes per scene. This number can be reduced in two ways. First, several array processors could be used to resample in parallel. Four array processors might be used, one operating on each band of MLA data.

Secondly, a special purpose device could be built to perform the resampling. Similar devices currently available are capable of performing the resampling in approximately 8 minutes, and the possibility of using several such devices in parallel exists.

The lower limit on the resampling process will eventually be determined by disk transfer rates. This lower bound is expected to be on the order of 5 minutes per scene.

3.7.1.3 SCD Calculations

SCD calculations are expected to require 6 minutes per scene. Since these calculations depend only upon telemetry data, they could be performed prior to the image processing sequence, possibly in the quick look function.

3.7.1.4 Disk Rates

Finally, replacing the RP06 disk drives with faster disks would improve overall system performance. Using RP07 disks, a 100 percent improvement in transfer rates can be achieved. This disk transfer rate improvement would yield an overall improvement of 5 minutes to the scene processing time.

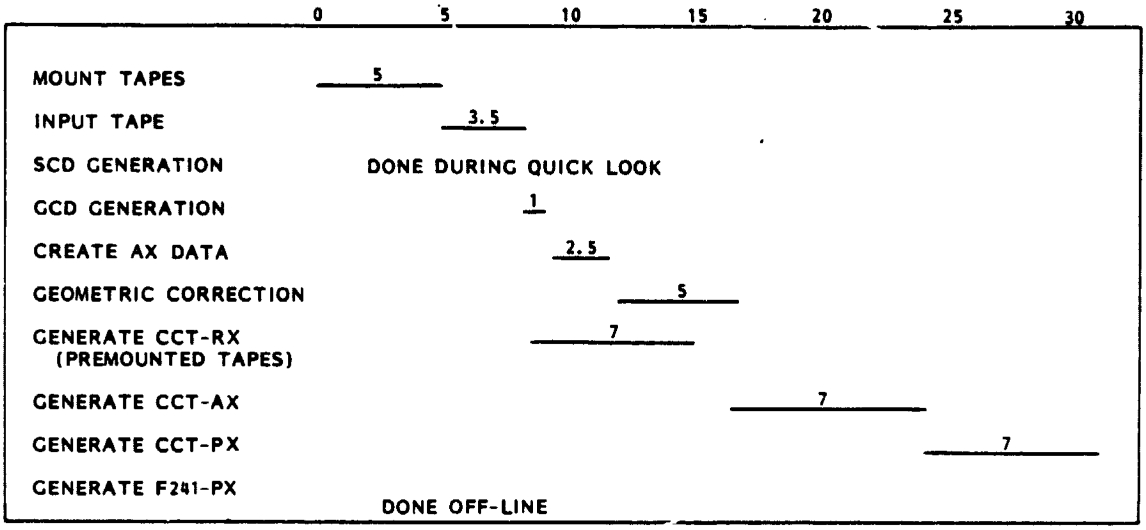
3.7.1.5 Potential Throughput

If the above enhancements were implemented, the expected processing time for an MLA scene would improve from 155 minutes per scene to 31 minutes per scene (the film generation function can be removed from the timeline since it occurs on a standalone subsystem of the Landsat Assessment System.) Figure 3.7-2 shows the enhanced timeline. In terms of scenes per day (assuming one shift operation), throughput would increase from 3 scenes per day to 14 scenes per day. Higher throughputs can be achieved by using two shifts per day and by using multiple processing strings.

3.7.2 ALTERNATE ARCHIVAL MEDIA

The MIGF design is oriented towards disk systems as the primary storage medium. Image data is written to disk in RX, AX, and PX format once, and then read as many times as required. Image data is archived on the original HDT, or on CCT.

Since the image data is written once, and read many times, a permanent storage system such as optical disks could replace the RX, AX, and/or PX image disk areas in the MIGF. Optical disks would allow simple, efficient, and long term archival of image data in any of the three data formats. Since the MIGF design is disk oriented, use of optical disks would have minimal impact on applications software.



PROCESSING TIME = 31 MINUTES

Figure 3.7-2. Enhanced MIGF Timeline (1 Scene)

3.7.3 SUPPORT FACILITIES

In addition to producing images, there are several functions and facilities which are required to support a free-flyer, but not required for a shuttle launched payload. Due to the much longer mission duration (years as opposed to days), mission operations becomes a continuous round the clock activity. The probable use of an OBC (On-Board Computer) on the spacecraft would necessitate a simulation facility on the ground. This facility would be used to verify OBC loads prior to installing or uplinking them to the free-flyer. Finally, the increased image processing loads would require a larger and more sophisticated capability for keeping track of, and processing user requests. Landsat-D performs these functions through the use of a Control and Simulation Facility (CSF) and a Mission Management Facility (MMF). A similar capability would have to be provided for an ELOS free-flyer.

SECTION 4
RISK ANALYSIS

SECTION 4
RISK ANALYSIS

Our study has defined a data system approach which can be implemented with minimal technical risk. No technology breakthroughs are required. While the basic system is configured using existing hardware and well understood software, it has the capability to incorporate advanced technologies as demonstration experiments or for follow-on growth. Therefore, this Risk Analysis addresses areas of requirements baseline that could change, thereby requiring additional capability to be added to the system at additional cost. None of these areas represents a major risk element to the overall ELOS concept.

Several key assumptions have been made to allow an expeditious definition of a system to support a shuttle based Multi-spectral Linear Array sensor. The programmatic risk in implementing this system is proportional to the probability of the assumptions being valid.

Review of these risks has been organized in Table 4-1 which defines each assumption, rates its feasibility, identifies implementation alternatives which reduce the necessity of making the assumption and defines an impact to the system as presently conceived.

Each assumption has been evaluated for its feasibility and criticality to project success on a scale of 1 to 10. An assumption with a feasibility rating of 10 is most feasible, almost guaranteed; criticality rating of 10 means the validity of the assumption is most critical to project success. Therefore, assumptions which are not too feasible (1-5) but very critical (6-10) present the highest risk to project success and, therefore, should be compensated for in project planning and execution.

All of the assumptions have been plotted versus feasibility and criticality in Figure 4-1. Boundaries have been selected to indicate high, moderate and low risks. There are 3, 9 and 9 assumptions per level respectively. Most assumptions tend to be very feasible (7-10).

Three assumptions (9, 11, 14) appear to have a high criticality/feasibility factor, and should be confirmed in detail prior to program initiation:

Number 9: Availability of sensor simulator during integration. A high fidelity simulator is vital to the development and integration of the system, particularly in view of the need to reliably monitor and verify MLA performance during the brief seven day mission.

Number 11: Experimenter support in analyzing performance of the ground processing system. Roles and responsibilities for system evaluation must be clearly assigned to experimenters, MLA developers, and ground system implementers in Program planning to assure that all demonstration/research objectives are considered.

Number 14: Availability of DRRTS while Landsat-D is still operating. This is an institutional issue that must be resolved when firm project schedules are established. Many feasible approaches exist for the MLA data capture function.

Boundaries for risk quantification can be moved and the levels of feasibility and criticality can be readjusted as the project is initiated. However, it appears now that the design presented within this report presents a fairly conservative effort driven by the Shuttle seven day mission and the low throughput post mission scene processing levels.

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Table 4-1. Evaluation of Assumptions

	Assumption	1-10 Feasibility	1-10 Criticality	Alternative	Impact
1.	Radiometric correction consists of applying a slope and intercept for each detector.	9	2	Histogram to develop calibration curves	Off line processing
2.	Availability of LAS/ADDS hardware in the planned mission timeframe.	6	7	Procure standard hardware	Cost
3.	Use and operation of the MSOCC.	9	10	JSC Facilities	TBD
4.	Support of LAS/ADDS software.	5	3	Develop necessary support software	Cost
5.	Receipt of complete data via the MSOCC for complete image processing.	8	10	More telemetry data in MLA raw data stream	More overhead
6.	Selection of the correct data compression/error correction technique.	6	5	Modify scheme through availabile flexibility	None
7.	Shuttle platform stability to ± 1°.	9	9	Attitude sensors on MLA	Cost, instrument Complexity
8.	Quick look provides adequate scene definition to select scene to fully process.	7	2	None	
9.	Availability of sensor simulator during integration.	4	9	Perform only subsystem level testing	Cost and schedule
10.	Required throughput of two scenes per day post mission.	8	7	Background processing to provide more processor time	None
11.	Experimenter support in analysing performance of the ground processing system.	3	9	Self contained quality assesment function	Cost; Landsat-D transfer feasible
12.	Development resources provided GFE for software development.	8	9	GE resources used	Cost

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Table 4-1. Evaluation of Assumptions (Cont.)

	Assumption	1-10 Feasibility	1-10 Criticality	Alternative	Impact
13.	POCC and MIGF available 20 days prior to launch.	6	8	Mock flight rehersals	Probability of mission success decreases
14.	Availability of DRRTS while Landsat-D is still operating (now over TDRSS).	4	9	Procure high density tape drive and install in DRRTS	Cost
15.	Processing of off-nadir imagery similar to processing nadir imagery.	9	8	None	System throughput
16.	Number of control points is achievable per scene.	6	7	None	Geometric registration accuracy
17.	Ratio of nadir and off-nadir imagery is accurate (70/30)	9	6	None	System throughput
18.	Projected processor throughput requirement and estimation is reasonable.	9	7	None	System throughput
19.	Level of transfer of Landsat-D software is reasonable.	8	10	Generate new code	Cost
20.	Shuttle launch date remains fixed at 4th quarter, 1986.	4	4	Slippage of date	Cost
21.	GSFC to provide computer facilities area.	8	10	New facility	Cost

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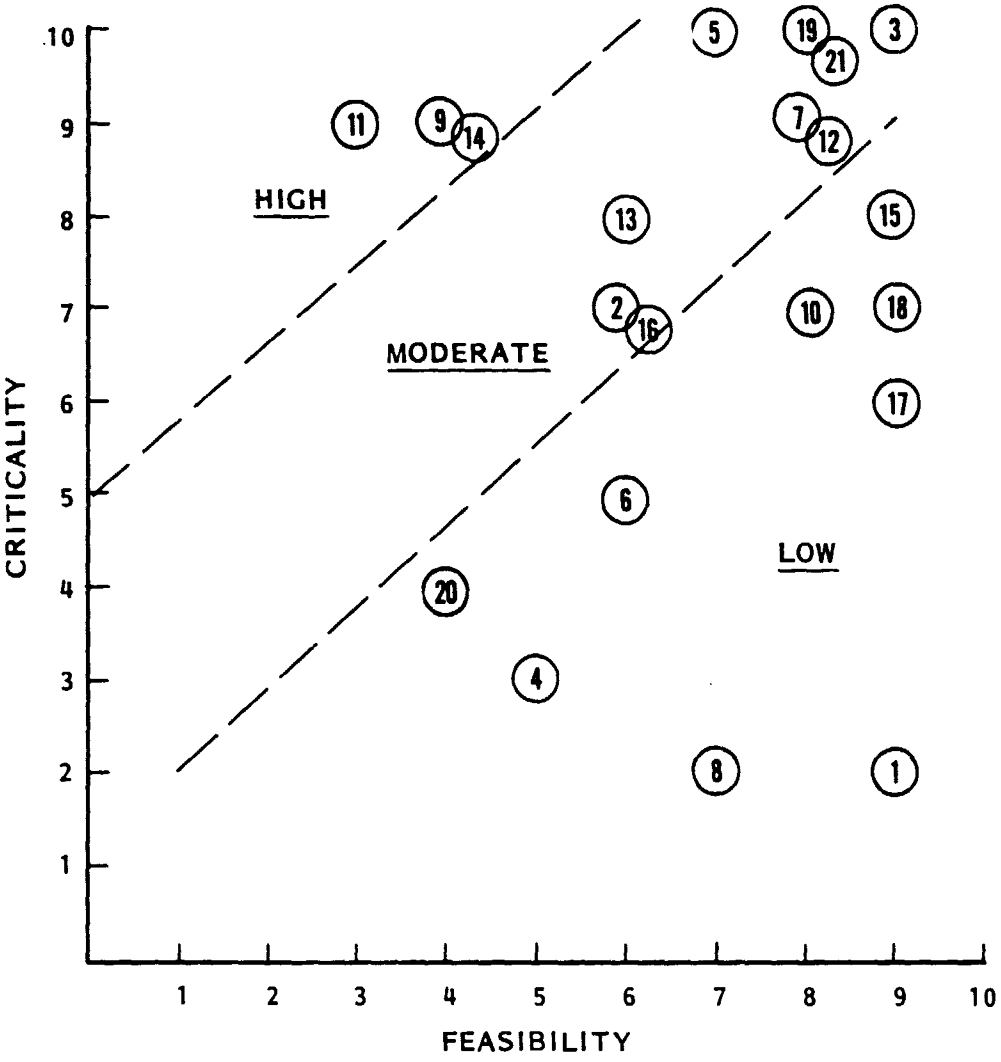


Figure 4-1. Risk Qualification

SECTION 5
IMPLEMENTATION SCHEDULE

SECTION 5

IMPLEMENTATION SCHEDULE

The ELOS program schedule is structured to support a fourth quarter 1986 launch date. This schedule is achievable only because of the extensive utilization of Landsat hardware, software, documentation, and procedures. The Landsat experience base is a critical element that underlies the success of the schedule and the overall approach to ELOS.

Figure 5-1 illustrates the key activities and events in the program. These include:

1. Project Plan. Beginning directly after contract award in the first quarter of 1984, this activity includes the planning, scheduling, and resource allocation functions performed by the project manager.

2. Requirements Definition. This activity begins during the first quarter and continues through the third quarter of 1984. A detailed analysis of system requirements will be performed, drawing upon experience with other ground segments and discussions with NASA and the mission contractor.

3. System Design. THe top level functional design activity will begin in the second quarter of 1984 and run into the first quarter of 1985. Basic functional designs will be developed from mission requirements and tradeoff analyses.

4. Specifications. The preparation of interface control documents and system specifications will begin as different aspects of the system design are completed. All specifications and control documents will be complete by the end of the third quarter of 1985.

5. New Hardware Development. Design and fabrication of the special I/O board that enables the MAP 300 to read raw data will begin at the end of the first quarter of 1985. Integration of the special I/O board into the MAP 300 will be complete by the end of 1985.

6. Software Development and Test. The MIGF software will be designed, implemented and tested over an 18 month period beginning at the end of the first quarter 1985. The first four months of this effort consists of developing a detailed design, and does not require the MIGF hardware resources. The last two months are dedicated to supporting system integration and test efforts.

7. MIGF Configuration. This activity includes configuring the MIGF from the GFE. MIGF hardware resources must be available to support software development and integration of the special I/O board by the third quarter of 1985. The final MIGF configuration, including the special I/O board, must be in place by the end of 1985.

8. System Integration and Test. System level test plans designed to verify system requirements will be developed during the second quarter of 1986. The integration tests themselves continue through the third quarter of 1986.

9. Mission Planning. Mission planning includes an analysis of the shuttle orbit and mission parameters to determine the initial spacecraft command sequence. Contingency command sequences, to be used in case of cloud cover or other anomalous conditions, will be developed. This activity begins in the second quarter of 1985 and continues into the third quarter of 1986.

10. Ground Control Point Identification. Potential ground control points will be selected from standard United State Geological Survey maps and the geodetic location of MLA scenes. This activity begins in the third quarter of 1986, at least three months before launch. This pre-selection of control points will facilitate the geodetic registration process during image generation operations.

11. Training. A three month training period for the mission facility and the MIGF staff is scheduled for the third quarter of 1986.

12. Mission Staffing. The POCC and the Quick Look segment of the MIGF will be staffed throughout the fourth quarter of 1986. This includes the three month period prior to the seven day mission.

12. Post Mission Facility Staffing. MIGF operations personnel will produce two fully corrected MLA scenes per day for a period of one year after launch.

13. Project Management. Project management activities continue throughout the program.

14. Design Reviews. The following design reviews will be conducted:

    a. System Requirements Review (SRR)

    b. Preliminary Design Review (PDR)

    c. Critical Design Review (CDR)

    d. Launch Readiness Review

    e. Post Mission Review (DD250)

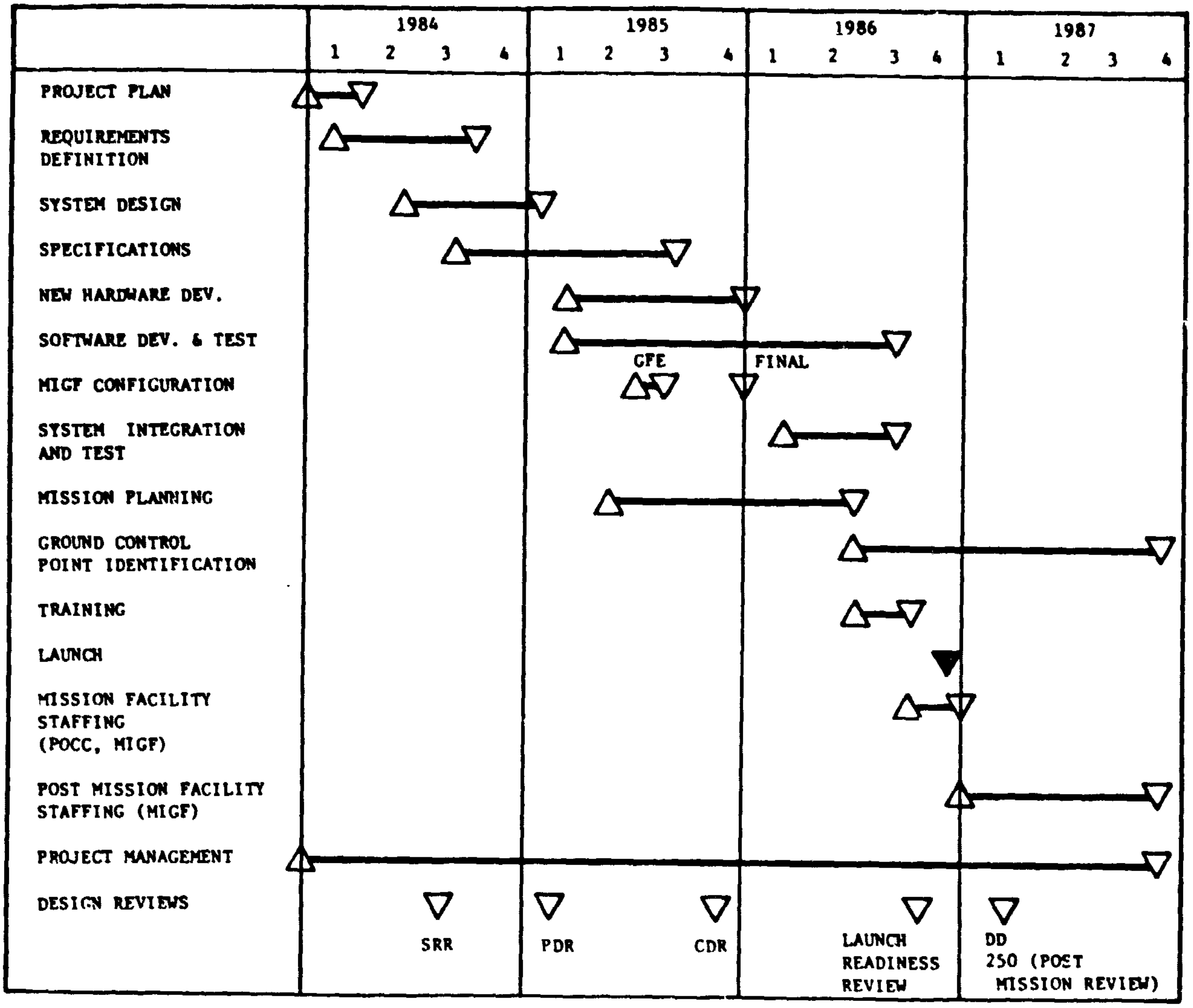


Figure 5-1. ELOS Ground Segment Implementation Schedule

SECTION 6

NEW TECHNOLOGY

SECTION 6
NEW TECHNOLOGY

No "Reportable Items" as defined by the New Technology Clause were developed during the performance of the Experimental Land Observing Data System Study contract.

APPENDIX A

IMAGE GENERATION/CORRECTION

IMAGE GENERATION/CORRECTION

Introduction

The main function of the ground processing software is to take raw data from the MLA sensor, radiometrically correct it, geometrically correct it and produce an output image. After correction, the data can be copied to CCT or onto 241 MM laser beam recorder film for assessment. Radiometric correction means calibration of each individual detector so that the data response of each detector will yield the same intensity level when viewing identical ground sources. Geometric correction means the process by which each pixel sampled by the MLA is allocated to a unique ground latitude and longitude in the output scene. Radiometric correction is a standardized process for all scanners and will not be discussed further. Geometric correction of MLA scenes is more straightforward than is the case for Landsat type multispectral scanners using dynamic mirrors to produce the cross scan. In addition, certain characteristics of the MLA geometries may be exploited which will provide a more simplified ground processing approach.

Geometric Correction

In order to register each input pixel with its corresponding ground source, it is necessary to determine the point on the ground which a particular MLA detector sees at the time it is sampled. A comprehensive geometric model containing all the parameters which influence the look point will be constructed called the "Look Point Model". It will be an adaption of the Look Point Model currently being used on LSD for the Thematic Mapper. It will model the stepping scan mirror positions, focal plane arrays, optical geometrics, sensor alignments and sampling rates of the MLA sensor system. With the foregoing knowledge, it only becomes necessary to know where the MLA is located in inertial space and how it is oriented relative to the earth so that we can determine the direction of the optical axis of the instrument and any particular detector of any band on-board.

The orientation of the MLA sensor in space is dependent upon its alignment relative to the Space Shuttle control axes as well as the orientation of the Space Shuttle with respect to earth local vertical. For these reasons the Look Point Model will contain the time history of pitch, roll and yaw of the STS and if necessary, the time history of any vibrations of the sensor itself.

Location of the MLA in space is of course the STS location which is known through NASA ground station tracking and post mission orbit analysis. At any instant of time, the XYZ position of STS is known in terms of an Earth Centered Inertial (ECI) frame of reference system.

The geoid of the earth's surface is also described in XYZ within the same ECI system. Knowing the orientation and position of the MLA within the ECI system an equation can be written describing the line of sight of any detector of any band within the MLA and determine its intersection (the "look point") with the earth's geoid. Using the Greenwich Mean Time corresponding to the same time and the look point coordinates, one can directly obtain the latitude and longitude of the look point.

At this point, one of two output maps may be selected upon which the final processed image is to be impressed. The choices are a Universal Transverse Mercator, UTM, or a Space Oblique Mercator, SOM. The grid map size is selected as 10 meters and the center of the map is selected to fall within the 3072th array line. By entering the latitude and longitude of the look point into a subroutine which models the maps, we are returned the XY map coordinates of the look point:

When this process is completed we have the following set of information for each lookpoint:

Sample Time

Band Number

Detector Number (Pixel Number)

Earth Latitude

Earth Longitude

Output Map X Coordinate

Output Map Y Coordinate

It takes approximately 10 ms to generate the above data for one pixel. To locate all the pixels of a band in one scene (36,000,000 pixels) by repeating the look point calculation would take 10 hours of computer time.

Benchmarks

Obviously there is a simpler approach. Since the MLA array for each band has detectors physically located in a linear array and since samples are taken at known discreet intervals, it can be safely assumed over small scene segments, 200 meters along track and 1 kilometer across track that all pixels maybe considered to be spaced linearly with respect to one another. Thus it only becomes necessary to locate the pixels at the corner boundaries of our segments and then by interpolation all interior pixels may be found. The quieter the operation of the MLA in terms of vibrational frequencies, the larger the scene segments that may be chosen for linear interpolation of pixel locations. For the entire scene 60 KM x 60 KM we will have 60 KM x 60 KM scene area)/(1/5 KM x 1 KM segment area) = 18,000 scene segments or 18,000 scene segment boundaries. A scene segment boundary is defined as a benchmark point.

Once again, the look point model could be used to directly calculate the 18,000 benchmarks but a 10 ms per point, this would take 3 minutes per band or 12 minutes for all 4 bands. A quicker approach that is sufficiently accurate is to calculate only 5 look points along the array line and use a cubic interpolation formula to find any intermediate pixel locations along the array line.

Since the benchmarks are spaced every 1/5 KM or every 20 pixels along track then every 20th array line out of 6000 array lines per scene the 5 look points must be determined. Thus we must run the look point model (5 points/array line) * (300 array lines) = 1500 times.

For one scene, representing one band of the MLA, a total of 1500 look points would be calculated. Since each scene is sensed by 4 bands and each benchmark takes 10 milliseconds to compute, the running time for the look point model is approximately 1 minute per scene.

In Figure A-1 the curved line is an exaggerated curved representation of an MLA array line at a given sample time as it is projected onto the surface of the earth relative to the vertical output grid of our selected map. Notice that we find the look point solution at 5 equally spaced points along the X direction of the map. At each point we have found the input pixel number given as a integer plus fraction and the Y coordinate given as an integer plus fraction.

Given the 5 known points along the array line, we solve for 60 intermediate pixel locations exactly spaced on the output grid every X = 100 as in Figure A-1.

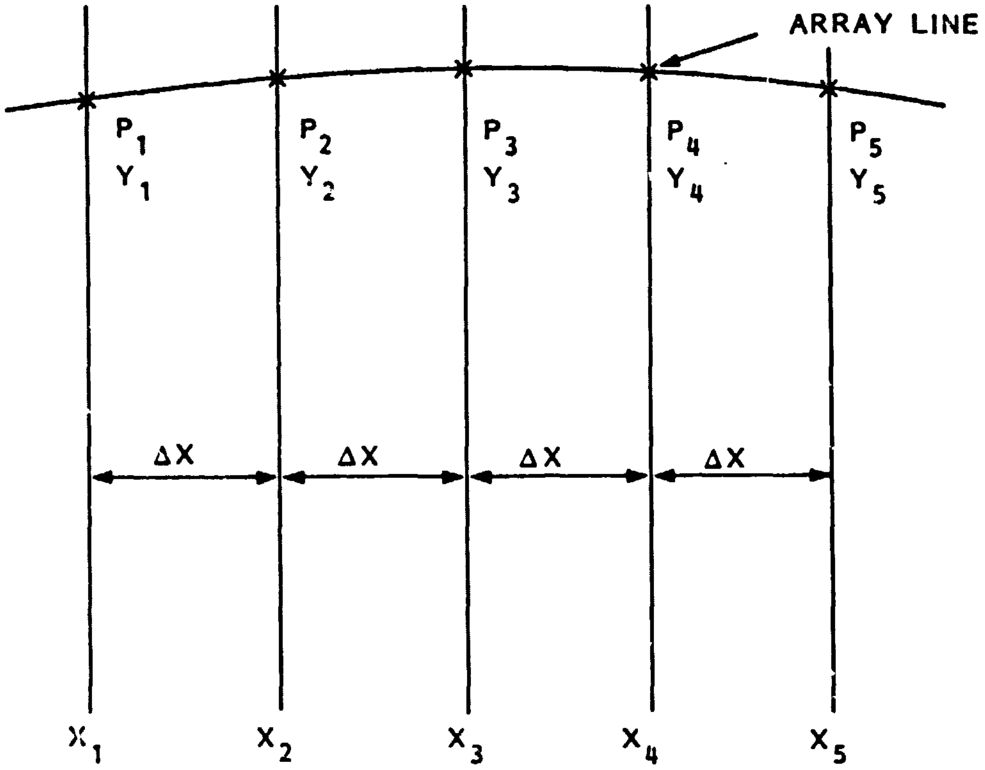
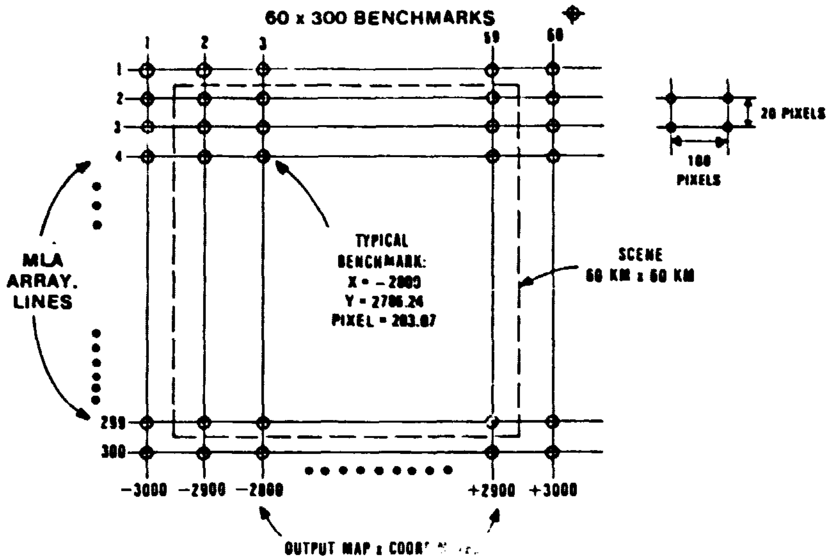


Figure A-1. Cubic Interpolation Formula for Finding P and Y Along Array Line

Because it greatly simplifies ground processing of the image it is important that the map XY coordinates are rotated so that at the center of the scene, the MLA array projects onto the map surface parallel to the X axis of the map.

In Figure A-2, labeled systematic correction, we see our output scene as a dashed line square 60 KM x 60 KM. Each small circle represents a benchmark located on a horizontal array input line. Vertical lines represent constant values of the output map X coordinate. Notice that the array input lines are perpendicular to the X coordinate lines because of our rotation of the output map coordinates. By using a cubic equation we have solved for 60 benchmarks along the array input line. Similarly every 20th array line, we solve for 60 more benchmarks. Since there are 6000 array lines to a scene, we need to repeat this process for 300 array lines making a total of 60* 300 = 18,000 benchmarks per band per scene.



1. DETERMINE XY LOCATIONS OF 5 EQUALLY SPACED PIXELS ALONG ARRAY (VIA LOOK-POINT MODEL)
2. REPEAT EVERY 20th LINE
3. RELATE X, Y AND PIXEL NUMBER (VIA CUBIC EQUATION)
4. SOLVE FOR OUTPUT MAP LOCATION AND PIXEL NUMBER FOR EACH OF 300 SELECTED LINES (i.e. 18000 BENCHMARKS)

Figure A-2. Systematic Correction

The benchmarks are spaced 20 x 100 pixels in the input scene. A typical benchmark will contain the pixel number as an integer plus a fraction, the Y coordinate as an integer plus a fraction and the X coordinate as an integer. Resampling of the input scene to produce the output scene has historically been accomplished between integer values of X.

For each band there will be 18,000 benchmarks representing the Systematic Correction Data for that band.

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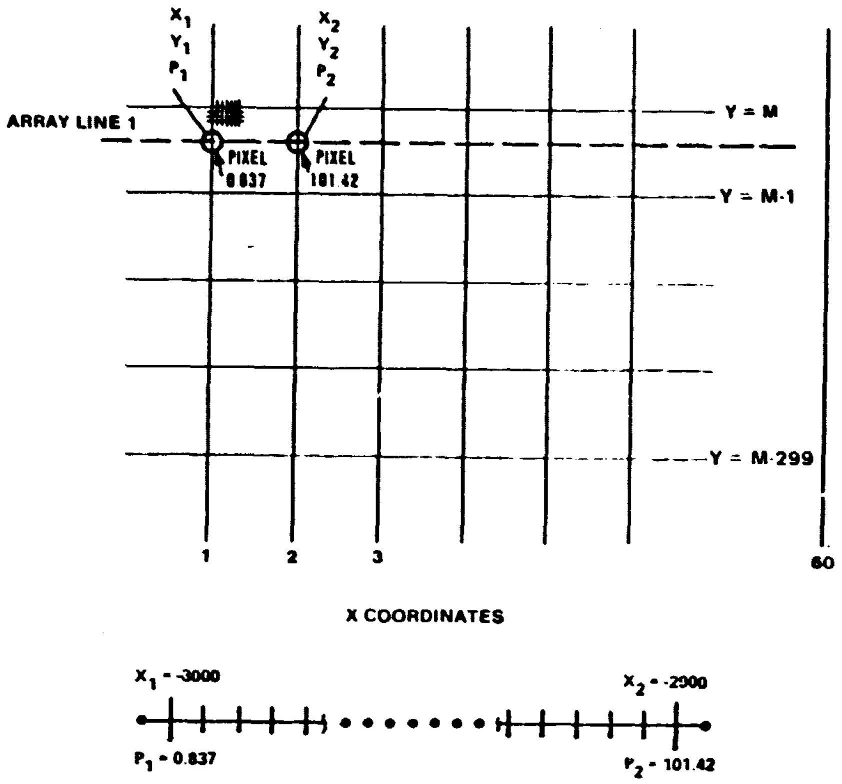


Figure A-3. Output Scene Generation

Pixel Locations

In order to resample the input scene and generate the output scene through cubic convolution or nearest neighbor resampling, it is necessary to know the output map XY location of every input pixel. This is accomplished by simple linear interpolation between the benchmark points as shown in Figure A-3, output scene generation.

Running across the topmost grid cells between the XY coordinates of the output map is a dashed line representing the first MLA line of input pixels for one sample time. The two benchmarks shown are separated by approximately 100 pixels or 1 kilometer and have found through the use of the cubic equation discussed previously. Notice that the benchmark pixels falling on the X coordinates are floating point numbers, P_1 = 0.837 and P_2 = 101.42, so that the actual center point location XY of any integer input pixel, P is given by the proportionalities:

$$X = X_1 * \left\{ \left(\frac{P-P_1}{P_2-P_1}\right) (X_2-X_1) \right\}$$

$$X = Y_1 * \left\{ \left(\frac{P-P_1}{P_2-P_1}\right) (Y_2-Y_1) \right\}$$

where X_1, Y_1, P_1, and X_2, Y_2, P_2 are the respective values for benchmark 1 and benchmark 2.

Benchmark Computation Time

Figure A-4 summarizes the calculation times for 18,000 benchmark points and 36 x 10^6 pixels. At the top of the figure we see the cubic equation which gives any input pixel p, as a function of its output Map X coordinate. Values P_i and Y_i for $i = 1-5$ have already been found from the Look Point Model. The equation for p within the interval X_2 to X_3 is:

$$P(Z) = AZ^3 + BZ^2 + CZ + D$$

$$Z = X - (X_2 + X_3)/2$$

$$A = (-P_1 + 3P_2 - 3P_3 + P_4)/6\Delta X^3$$

$$B = (P_1 - P_2 - P_3 + P_4)/4\Delta X^2$$

$$C = (P_1 - 27P_2 + 27P_3 - P_4)/24\Delta X$$

$$D = (-P_1 + 9P_2 + 9P_3 - P_4)/16$$

Similarly, the equation for Y within the interval X_2 to X_3 is:

$$Y(Z) = EZ^3 + FZ^2 + GZ + H$$

$$Z = X - (X_2 + X_3)/2$$

$$E = (-Y_1 + 3Y_2 - 3Y_3 + Y_4)/6\Delta X^3$$

$$F = (Y_1 - Y_2 - Y_3 + Y_4)/4\Delta X^2$$

$$G = (Y_1 - 27Y_2 + 27Y_3 - Y_4)/24\Delta X$$

$$H = (-Y_1 + 9Y_2 + 9Y_3 - Y_4)/16$$

	VAX TIMES			
	4.2 μsec ADD	4.2 μsec SUB	6.0 μsec MULT	10.6 μsec DIV
① $p(Z) = AZ^3 + BZ^2 + CZ + D$	3	0	6	0
② $Z = X - (X_2 + X_3)/2$	1	1	0	1
③ $A = (-p_1 + 3p_2 - 3p_3 + p_4)/6\,\Delta X^3$	1	2	3	1
④ $B = (p_1 - p_2 - p_3 + p_4)/4\,\Delta X^2$	1	2	2	1
⑤ $C = (p_1 - 27p_2 + 27p_3 - p_4)/24\,\Delta X$	1	2	3	1
⑥ $D = (-p_1 + 9p_2 + 9p_3 - p_4)/16$	1	2	0	1

ASSUME 5 LOOK POINTS PER ARRAY LINE (DERIVED FROM LOOK-POINT MODEL)

EQUATIONS ③ ④ ⑤ ⑥ ARE SOLVED ONCE WITHIN EACH ΔX INTERVAL FOR p AND ONCE WITHIN EACH ΔX INTERVAL FOR Y (THERE ARE 4 ΔX INTERVALS)

COMPUTATION TIME FOR 1 ARRAY LINE
$= (2)(4\ \Delta X\ \text{INTERVALS})\ \{(3)(4.2) + (8)(4.2) + (8)(6.0) + (4)(10.6)\}$
$= 1122.2\ \mu\text{sec}$

EQUATION ② IS SOLVED (60-5) = 55 TIMES
COMPUTATION TIME $= 55\ \{(1)(4.2) + (1)(4.2) + (1)(10.6)\}$
$= 1045\ \mu\text{sec}$

EQUATION ① IS SOLVED 55 TIMES FOR p AND 55 TIMES FOR Y
COMPUTATION TIME $(2)(55)\ \{(4)(4.2) + (6)(6.0)\}$
$= 5808\ \mu\text{sec}$

TOTAL COMPUTATION TIME PER ARRAY LINE:

EQUATIONS ③ ④ ⑤ ⑥	1122.2 μsec
EQUATION ②	1045.0 μsec
EQUATION ①	5808.0 μsec
	7977.2 μsec

TOTAL COMPUTATION TIME OVER 300 ARRAY LINES FOR p AND Y:
\# POINTS = (60 POINTS/ARRAY LINE)(300 ARRAY LINES)
= 18,000 POINTS

COMPUTATION TIME = (300 ARRAY LINES)(7977.2 μsec/ARRAY LINE)
= 2.39
≈ 2.4 sec

TIME TO COMPUTE: 36,000,000 p's AND 36,000,000 Y's
= (36,000,000)(2)(2.4 μsec PER ADD OR SUBTRACT)
= 172.8 sec (VAX)
≦ 35 sec (APS-120, 5 TIMES FASTER THAN VAX)

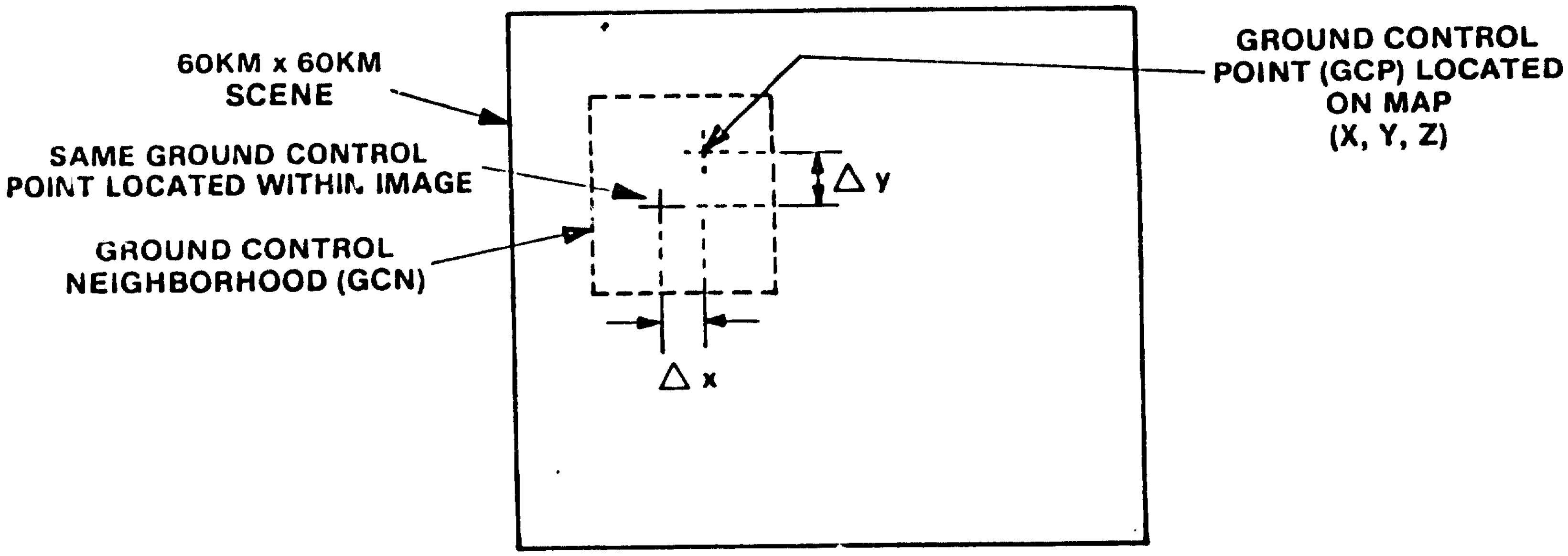
Figure A-4. Calculation Times for 18,000 Benchmark Points and 36 x 10^6 Pixels

These equations are solved for 60 benchmarks across each of 300 array lines. As shown in the figure, the computation time to obtain the 18,000 benchmarks will be only 2.4 seconds.

Geodetic Correction

At this point, if the input scene were to be resampled it would be found to be self consistent and error free within its own boundaries but slightly shifted with respect to its true earth location. This shift is due to unknown and unaccounted for errors in the Systematic Correction process. Therefore, the scene must undergo a final geodetic correction to locate it properly on the earth.

In Figure A-5 we see simplified sketch of our 60 KM x 60 KM scene with a ground control neighborhood (GCN) outlined as a dashed square and containing a ground feature with an accurately known geometric location called a ground control point GCP. The input scene is resampled in the general region of the GCP to produce a localized image containing the GCP. (Size of the resampled region is dependent upon how severe the Shuttle pointing inaccuracies may be.) Then the known ground feature is optically correlated between its location in the output scene and where it actually occurs on a reference map. The difference in the GCP's location is measured in terms of X and Y of the reference map taking into account the topographical elevation of the GCP. These offset values are used to update X, Y and Z of the STS position and θ, ϕ, ψ of the STS attitude. With the new updated parameters the look point model and the cubic equations are rerun to recreate the 18,000 benchmarks which now constitute the geometric correction matrices (GCM). Using the GCMs, the output scene is now created through cubic convolution or nearest neighbor resampling.



- RESAMPLE GCN USING SYSTEMATIC CORRECTION DATA
- OPTICALLY CORRELATE GCP AND GCN
- MEASURE OFFSET BETWEEN CONTROL POINT ON THE MAP AND CONTROL POINT WITHIN IMAGE
- USE Δx, Δy, AND Δz TO UPDATE SHUTTLE POSITION AND POINTING
- "PLUG" UPDATED PARAMETERS INTO LOOK-POINT MODEL TO REGENERATE SYSTEMATIC CORRECTION MATRICES (NOW CALLED GEOMETRIC CORRECTION MATRICES)
- REGENERATE OUTPUT SCENE USING GEOMETRIC CORRECTION MATRICES

APPLICABLE TO NADIR, STEREO AND CROSS-TRACK SCENES

Figure A-5. Geodetic Correction

APPENDIX B

SHUTTLE BASED ERRORS FOR ELOS

APPENDIX B

SHUTTLE-BASED ERRORS FOR ELOS

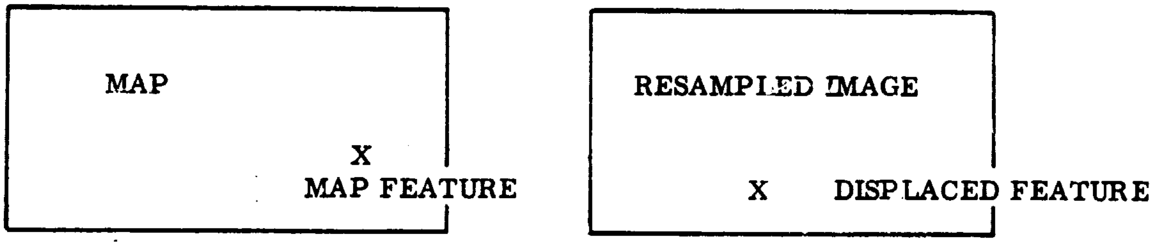
The anticipated error environment for the multilinear array (MLA) is presented for the case of a shuttle mounted sensor. The MLA is assumed to be a 10 meter sensor with fore-aft and cross-track capabilities.

Included is an overall error conceptual philosophy leading to a way of presenting the error budget in the context of error correction.

One major conclusion is that, from our preliminary results, locational errors on standard maps will limit the absolute geodetic accuracy achievable to one or two pixels.

B.1 ERROR BUDGET CONCEPT

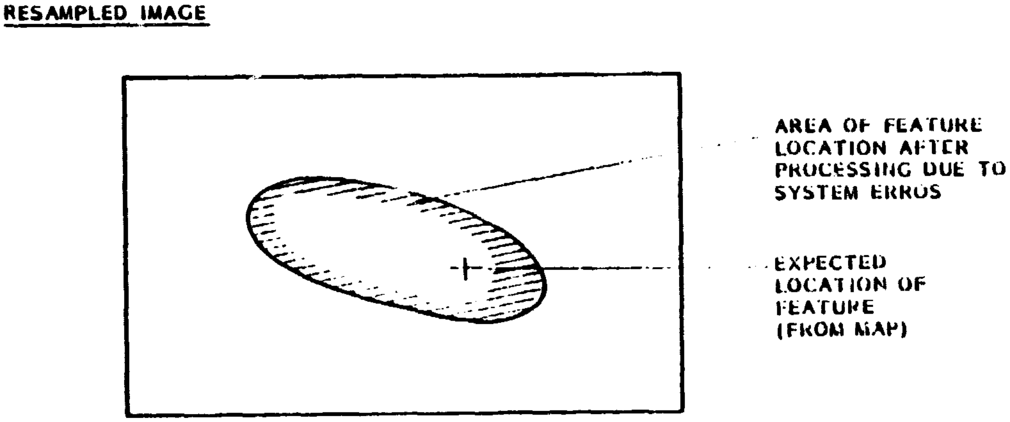
We are concerned primarily with geodetic errors, that is deviations from known map features. consider a map with a specific feature illustrated below:



If estimates of spacecraft position, altitude and sensor orientation are provided then it is possible to relate sensor pixels to map locations. If a display grid of pixels is constructed in the map projection from the given sensor pixels the image is said to be resampled. The position/attitude information is used to accomplish the resampling. The resampled image of course should display the map feature. Our knowledge of position, etc., however, may contain errors which result in the feature occurring elsewhere rather than the expected location as seen on the map.

If repeated passes are made over the same region, then it is assumed that the resampled feature would vary in location to form a distribution of positions in the resampled image. This pattern may, but not necessarily,

ERROR BUDGET



include the expected location. It is reasonable to assume that the errors are a mixture of slowly varying and rapid fluctation noise sources. Although the removal of these errors is not the primary concern of this report some of the techniques will be outlined. This provides a basis for structuring the error budget.

The relationship between sensor and display pixels is accomplished by means of a mesh of benchmarks over the sensor or display (or a mixture for that matter) region. Each benchmark is a mapping point, i.e.,

$$(\underbrace{i, j}_{\text{sensor pixel location}}, \underbrace{x, y}_{\text{output or display pixel location}})$$

It is necessary to interpolate between these mesh points to obtain the mapping elsewhere. Usually the points are spaced close enough to use a simple linear or quadratic interpolation.

Two major inputs to the benchmarks are spacecraft position and attitude. Particularly in the case of attitude, the system must sample attitude information at a sufficiently high rate to capture higher frequencies. For Landsat-D it is necessary to use additional sampling sensors to recover errors up to 100 Hz.

In addition, the spacing of the benchmarks must be fine enough to provide for rapid interpolation using simple algorithms and at the same time provide sufficient precision to model the mapping nonlinearities.

Slowly varying errors, notably orbit prediction, can be removed by observing known map locatable features in resampled imagery and filtering the location errors using a mathematical model of error dynamics.

B.2 TOP LEVEL ERROR IDENTIFICATION

Both flight segment (Shuttle, payload) and the Ground Segment contribute to the resampled feature errors. Some of the major sources are identified in Figure B-1.

The distribution of $\Delta\xi$ forms a pattern or errors which are controlled by the error correction process. System requirements are given by:

at least P% of n observed features must satisfy

$$|\Delta\xi_j| \leq \text{specified tolerance}$$

where

P is usually 90 or close to this value.

Error Definitions

- Control Point Designation. Locating a feature on a subsequent swath of imagery. This feature may be a unique topographical structure identifiable on a standard map.
- Systematic Correction Data Generation. The process of incorporating known error sources into a model which provides for adjusting imagery to conform to specified map projections.
- Interpolation. Using systematic correction (SCD) to determine adjustments between SCD points. SCD's are usually arranged in a grid over the swath of imagery. Spacing is selected to economize on processing time and yet satisfy necessary precision.
- Resampling. The actual process of adjusting imagery according to correction data. This involves the rearrangement and pixel value modifications to a specified map projection.
- Geodetic Correction Data Generation. The adjustment of SCD to account for errors detected in the process of locating known features (control point designation).

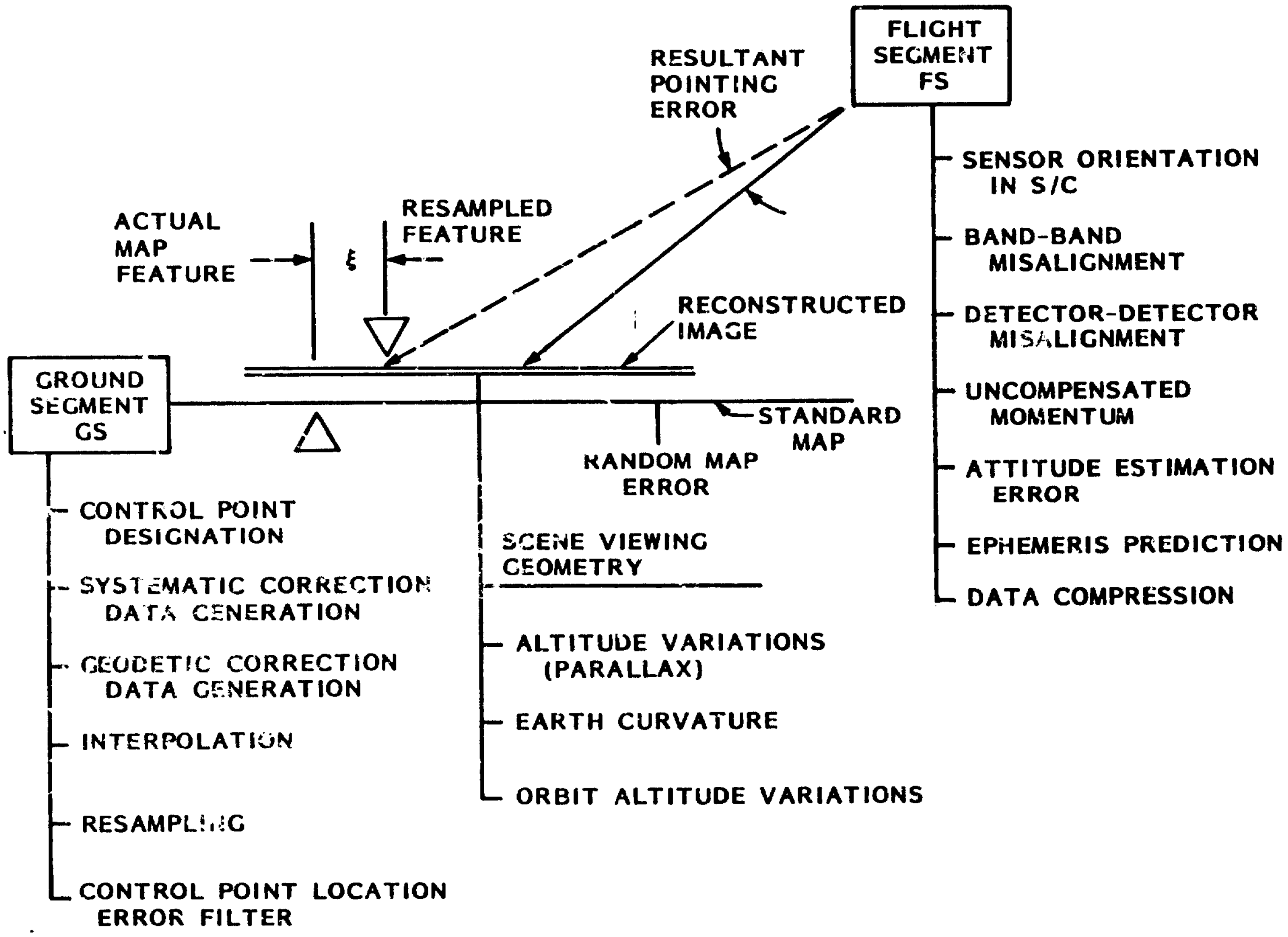


Figure B-1. Error Identification

- Control Point Location Error Filter. The technique used to determine the adjustments required to form Geodetic Correction Data (GCD). The filter uses measured dislocations of map features and SCD corrected imagery.
- Filter Residual. Errors not removed by the Filtering process. The size of the residual depends on the adequecy of the filter error models, measurement errors and initial uncertainty of the state estimates.
- Random Map Error. The inherent errors contained in standard reference maps. Features will be shifted in nondeterministic directions in a statistical manner.
- Altitude Variations. Local departures from the assumed earth shape. The assumed earth shape is used in look point models in the construction of SCD.
- Earth Curvature. Error in displaying the earth on a flat projection equal distances on the curved surface may become unequal on the flat projection.
- Orbit Altitude Variations. Relatively small variations in altitude of the spacecraft not modeled by the orbit model or ephemeris propagator.
- Sensor Orientation in S/C. Tolerance limits in the known positioning of the sensor with respect to the S/C structure.
- Band-Band Misalignment. Tolerance limits on the relation of the groups of detectors representing different wavelengths.
- Detector-Detector Misalignment. Tolerance limits on the relation of one detector with another (within bands).
- Uncompensated Momentum. Torques which are not balanced or cancelled by opposing torques to neutralize resulting rotational motion.
- Attitude Estimation Error. On-board systems measure the orientation of S/C body axes with respect to inertial space. The errors in the estimates reflect in SCD inaccuracies.
- Ephemeris Prediction. The inability of orbit models to exactly establish S/L position in inertial space. This is also the error in real-time location if dynamic filters are used in conjunction with measurement system.
- Data Compression. Reduction of wideband data volume by removing unneeded or less valuable portions of the data stream. Errors occur in the reconstruction process. These errors occur in track (function of time) and are not randomly associated with other error sources.

The top level error budget is an allocation of remaining errors after all corrections are applied. These errors will, in a statistical manner, cause a resampled feature to deviate from a given map location. Error sources can be divided into three categories as follows:

I. Top Level Errors Sources (e_j, j = 1, . . ., 8)

Flight 1. Residual high frequency errors in flight segment

Segment 2. Detector to detector variability (unmodeled)

3. SCD (Systematic Correction Data) or benchmark generation

4. GCD (Geodetic Correction Data) generator (after filtering)

Ground 5. Interpolation of GCD correction data

Segment 6. Resampling using GCD correction data

7. Map Errors

8. Filter Residue

II. Initial State Estimate Variability

1. Orbit position
2. Orbital velocity (augmented variables)
3. Attitude
4. Attitude rates (augmented variables)
5. Alignment
6. Alignment rates (augmented variables)

III. Measurement Errors (effecting measured feature location errors)

1. Residual FS high frequency errors
2. Detector to detector variability (remaining after modeling)
3. SCD Generation
4. Interpolation
5. Resampling
6. Cross correlation (map vs CPU)
7. Random map errors
8. Compression (smears sharp edges)

The first five affect the location of the resampled feature in a neighborhood sufficiently large to account for anticipated large slowly varying biases.

The sixth source is basically human and optical device error while aligning map and image. Item eight may affect the correlation process since it could blur sharp edges of a feature.

The next section contains preliminary estimates with sources identified by reference number (References follow this report). For comparative purposes, corresponding Landsat-D values are included. Do not consider the LSD data as official, but the values should, in most cases, be resonably close to the latest estimates.

B.2.1 PRELIMINARY ESTIMATES (NADIR POINTING)

Some early estimates were made for the three categories. In some cases more than one may be available.

One Sigma Error Budget Estimates

	Category	LSD Source (Ref)	ELOS Source (Ref)
I 1	Residual FS high frequency	2.42×10^{-6} rad (4)	TBD
I 2	Detector-detector variability	--	TBD
I 3	SCD Generation	1 meter (2), (4)	1/2 meter
I 4	GCD Generation	1 meter (2), (4)	1/2 meter
I 5	Interpolation	1 meter (2), (4)	1/2 meter
I 6	Resampling	1 meter (2), (4)	1/4 meter
I 7	Map Errors	--	7.3 meter (1:24000)
I 8	Filter Residual	6 meters (2)	TBD
II 1	Orbit Position Error	(two day predict)	(one revolution propagate)
	Along Track	506 meters (4)	260 meters (8)
	Cross Track	100 meters (4)	130 meters (8)
	Radial	33 meters (4)	150 meters (8)
II 2	Orbital Velocity	(two day predict)	(one revolution propagate)
	Along Track	0.163 meters/sec (4)	0.05 meters/sec (8)
	Cross Track	0.0065 meters/sec (4)	0.2 meters/sec (8)
	Radial	0.065 meters/sec (4)	0.433 meters/sec (8)

Category	LSD Source (Ref)	ELOS Source (Ref)
II 3 Attitude	(Gyro drift)	(deadband system)
Roll	1.745×10^{-4} rad (4)	2.057×10^{-3} rad (8)
Pitch	1.745×10^{-4} rad (4)	2.057×10^{-3} rad (8)
Yaw	1.745×10^{-4} rad (4)	2.057×10^{-3} rad (8)
II 4 Rates	(Gyro drift)	(limit cycle)
Roll	3.878×10^{-7} rad/sec (4)	5.818×10^{-5} rad/sec (8)
Pitch	3.878×10^{-7} rad/sec (4)	5.818×10^{-5} rad/sec (8)
Yaw	3.878×10^{-7} rad/sec (4)	5.818×10^{-5} rad/sec (8)
II 5 Alignment	(Thermal bending)	
Roll	6.06×10^{-4} rad (4)	1.164×10^{-2} rad/sec (8)
Pitch	1.212×10^{-3} rad (4)	1.164×10^{-2} rad/sec (8)
Yaw	1.212×10^{-3} rad (4)	1.164×10^{-2} rad/sec (8)
II 6 Alignment Rates		
Roll	8.096×10^{-7} rad (4)	TBD
Pitch	8.096×10^{-7} rad (4)	TBD
Yaw	8.096×10^{-7} rad (4)	TBD
III 1 Residual high frequency	2.42×10^{-6} rad (4)	TBD
III 2 Detector-Detector	--	TBD
III 3 SCD Generation	1 meter (2), (4)	1/2 meter
III 4 Interpolation	1 meter (2), (4)	1/2 meter
III 5 Resampling	1/2 meter (2), (4)	1/4 meter
III 6 Cross Correlation (designation)		
1:24000	24 meters (7)	Same
1:50000	TBD	Same
III 7 Map Errors		
1:24000	7.3 meters (7)	Same
1:50000	15.2 meters (7)	

The shuttle system includes a deadband system with a 0.01 deg/sec ($3\ \sigma$) limit cycle. There is a free drift mode (Ref 8) with an initial rate of 0.001 deg/sec ($3\ \sigma$). However, this rate is affected subsequently by uncompensated momentum and transients related to mission specific disturbances.

The limit cycle itself is estimated to be 0.1° (3 σ) but should be slowly varying so that it could be filtered.

Reference (1) contains smaller pointing (attitude and alignment) error values.

Reference (6) indicates a need to compress the wideband data rate from 120 Mbps (8 bit) to 43 Mbps. This may introduce an additional error in Category III affecting the correlation process and related measurement errors. The nature and dynamics of this error tend to blur sharp edges but not affect feature location directly. Consequently, in this report it is tentatively considered only a Category III item.

From Reference (1) the pointing error knowledge is given as ± 0.5° (assumed 3 σ) for all three axes. It is assumed that this is a combination of alignment and attitude error sources.

From References (2) and (4) the Landsat-D estimates and ELOS compare as follows:

σ^2 Pointing Errors (Attitude and Alignment) (Rad)

		LSD	ELOS
1.	Roll	3.976×10^{-7}	8.46×10^{-6}
2.	Pitch	1.499×10^{-6}	8.46×10^{-6}
3.	Yaw	1.499×10^{-6}	8.46×10^{-6}

Not much is known for the STS ELOS about orbit errors, but if the LSD data for two day predict is used

$$\sigma_{11}^{2} = 2.5604 \times 10^{5} \text{ meters}$$

$$\sigma_{22}^{2} = 1 \times 10^{4} \text{ meters}$$

$$\sigma_{33}^{3} = 1.089 \times 10^{3} \text{ meters}$$

The resulting pointing and ephemeris effect is

$$\sigma_{h_1}^{2} = 2.56 \times 10^{5} \text{ meters}$$

$$\sigma_{h_2}^{2} = 1.0 \times 10^{4} \text{ meters}$$

B.2.2 OFF-NADIR ERRORS

Various MLA configurations involve along and cross track pointing as mission options. The along track pointing accommodates stereo viewing. The MLS views fore about 25° and later aft about 25°, as illustrated in Figure B-2.

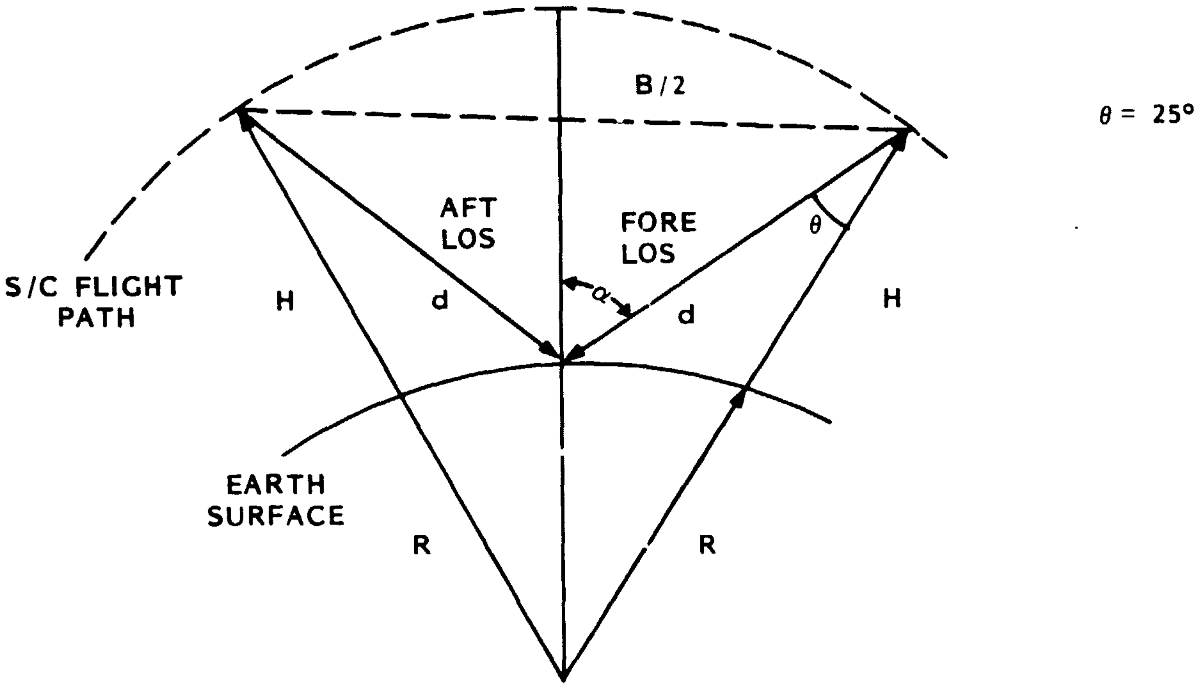


Figure B-2. MLA Views

For H = 350 km, R = 6378 and $\theta = 25^{0}$ the base height ratio is B/H = 2 tan σ.

$$\frac{\sin(\pi - \alpha)}{R + H} = \frac{\sin\theta}{R}$$

$$\sin\alpha = \left(\frac{R + H}{R}\right) \sin\alpha$$

$$\alpha = \text{arc sin}\left[\left(\frac{R + H}{R}\right) \sin\theta\right]$$

$$B/H \approx 1$$

The cross track viewing angle is set for the MLA at $\theta = 30^{0}$. Also the nadir viewing geometry can reach a cross track angle of roughly 5^{0}. The primary effect of this is to cause a parallax depending on the object elevation. A relatively simple way to assess the effect is to determine the range of location errors for a fixed spacecraft location for varying heights up to 1 km.

$$\frac{\sin(\pi - (\theta + \xi))}{R + H} = \frac{\sin\theta}{R}$$

and

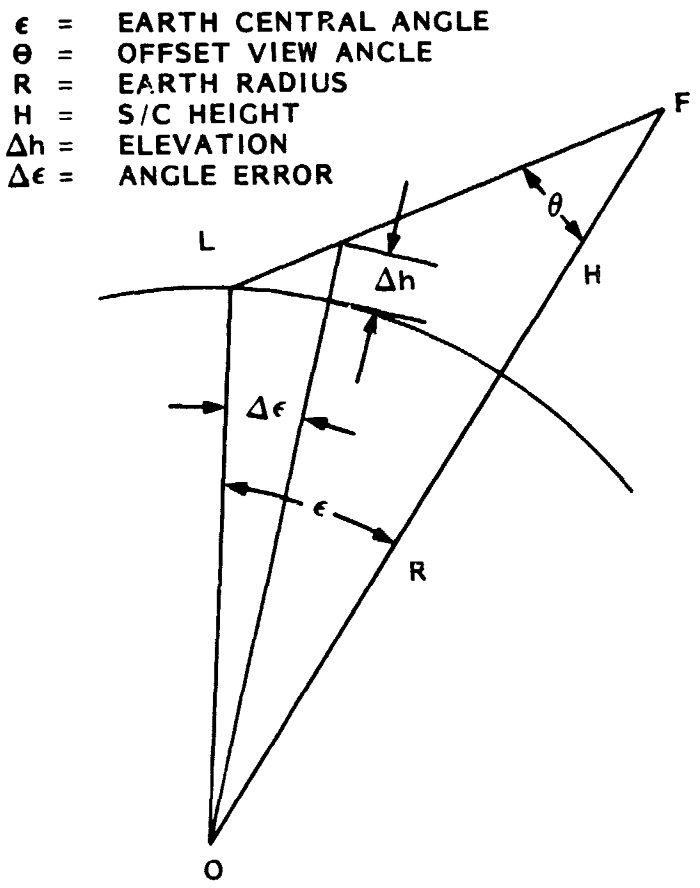
$$\frac{\sin(\pi - (\theta + \xi - \Delta\xi))}{R + H} = \frac{\sin\theta}{R + \Delta h}$$

$$\frac{\sin((\theta + \xi) - \Delta\xi)}{R + H} = \frac{\sin\theta}{R + \Delta h}$$

$$\Delta\xi = (\theta + \xi) - \text{arc sin}\left[\left(\frac{R + H}{R + \Delta h}\right) \sin\theta\right]$$

Distance error

$$R\Delta\xi = R\left\{\text{arc sin}\left[\left(\frac{R + H}{R}\right) \sin\theta\right] - \text{arc sin}\left[\left(\frac{R + H}{R + \Delta h}\right) \sin\theta\right]\right\}$$



$\Delta h(m)$	$\theta = 25^{o}$ $R\Delta\xi(m)$	$\theta = 30^{o}$ $R\Delta\xi(m)$	$\theta = 5^{o}$ $R\Delta\xi(m)$
0	0	0	0
100	49.80	62.08	9.23
200	99.60	124.15	18.46
300	149.40	186.23	27.69
400	199.20	248.30	36.92
500	248.99	310.37	46.16
600	298.79	372.44	55.39
700	348.58	434.51	64.62
800	398.37	496.57	73.85
900	448.16	558.63	83.08
1000	497.95	620.69	92.31

Estimated $\sigma_{\Delta l} \approx$ 144 179 27 (based on uniform distribution)

These errors must be accounted for to reduce control point correlation errors to acceptable levels. Standard maps therefore must have elevation contours. However, it is not known, at this time, the tolerance limits for the standard maps.

B.3 FLIGHT SEGMENT ERRORS

The effects of FS errors on the resampled feature location is estimated with the help of a measurement matrix. The matrix consists of elements which are partial derivatives of location error with respect to position error, attitude error, etc. (Reference 4, pp. 55-59). For nadir viewing this matrix is described below.

$$B = \begin{bmatrix} 1 & 0 & -\tan\alpha & 0 & h_0 & h_0 \tan\delta \\ 0 & 1 & -\tan\delta & -h_0 & 0 & -h_0 \tan\alpha \end{bmatrix}$$

Orbit Position
Along Track
Cross Track
Radial

Alignment +
Attitude (roll, pitch, yaw)

α = Along Track Look Angle

δ = Cross Track Look Angle

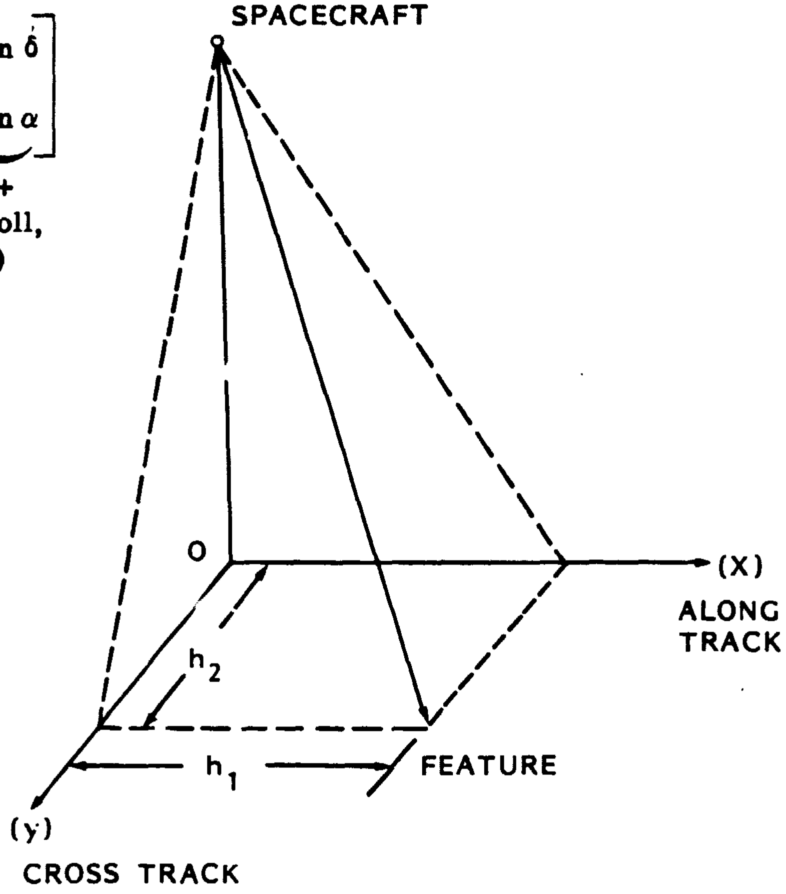
h_0 = Nominal Attitude

h_1 = AT distance to feature

h_2 = CT distance to feature

If $V_{FS} = (\sigma_{ij}^2)$ is the matrix of orbit position and attitude variances (to be covered below) the AT and CT error variances become

$$H = B V_{FS} B^T$$



or

$$\text{AT variance} = \sigma_{h_1}^2 = \sigma_{11}^2 + \sigma_{33}^2 \tan^2\alpha + \sigma_{55}^2 h_0^2 + \sigma_{66}^2 h_0^2 \tan^2\delta$$

$$\text{CT variance} = \sigma_{h_2}^2 = \sigma_{22}^2 + \sigma_{33}^2 \tan^2\delta + \sigma_{44}^2 h_0^2 + \sigma_{66}^2 h_0^2 \tan^2\alpha$$

where

σ_{11}^2 = AT ephemeris error variance

σ_{22}^2 = CT ephemeris error variance

σ_{33}^2 = Radial error variance

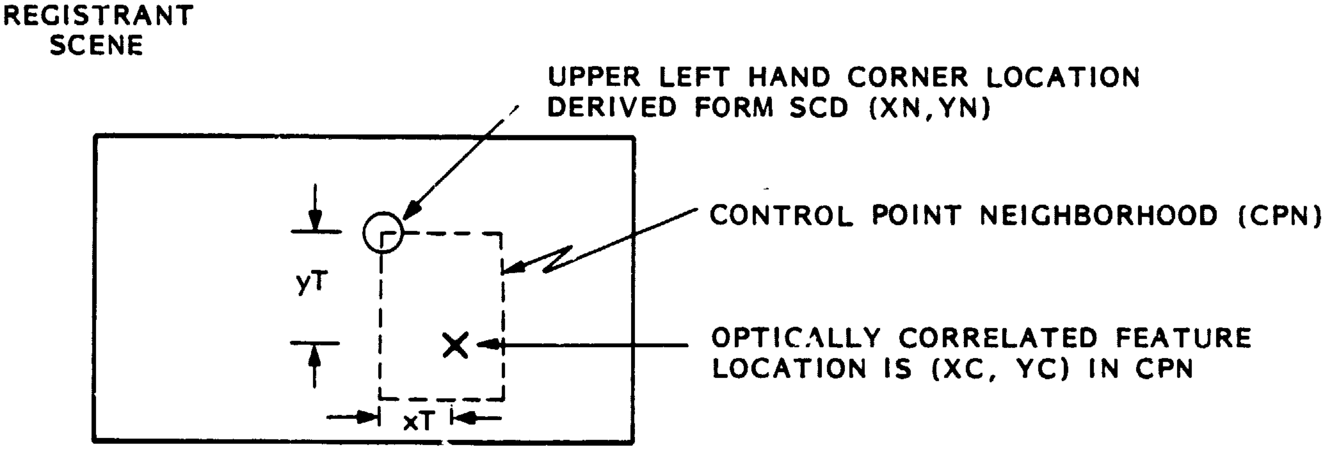
σ_{44}^2 = Roll error variance

σ_{55}^2 = Pitch error variance

σ_{66}^2 = Yaw error variance

B.4 MEASUREMENT ERRORS

Measurement errors include sources both within the FS and GS which affect the estimated location error when manually correlating CPN's and CPC's. The ELOS correlation process will most likely involve an optical device which provides for visual overlay. From Reference 4 the process is depicted below:



The CPN is chosen large enough to account for (primarily) the attitude, ephemeris error expected in the SCD.

The CP location error is:

$$\Delta X = X_c - \hat{X}$$

$$\Delta Y = Y_c - \hat{Y}$$

true (correlated) - predicted

The 'predicted' location is given by, for example,

$\hat{X} = X_T - X_N$ = location of correlated feature with respect to upper left hand corner of CPN.

B.5 FILTERING/SMOOTHING

Systematic Correction Data is designed to remove most errors, leaving a residue which we label in this report as Category I. Earlier these we estimated to be for both along and cross track.

Source			1σ Estimate (ELOS)
FS	1.	Residual high frequency attitude errors	TBD (probably small)
FS	2.	Detector - detector variability	TBD (probably small)
GS	3.	SCD Generation	1/2 meter
GS	4.	GCD Generation	1/2 meter
GS	5.	Interpolation	1/2 meter
GS	6.	Resampling	1/4 meter
GS	7.	Map Errors (ME)	7.3 meters 1:24000 15.2 meters 1:50000

The RSS of those errors is 7.36 meters for ME = 7.3 and 15.23 meters for ME = 15.2, so that the map effect overwhelms the other sources.

There is one more error source which is the residual from filtering the low frequency (mostly ephemeris and attitude) errors. The filter performs the task of reducing the residual error to the system requirement level as discussed earlier.

If the same limit is imposed on STS ELOS as Landsat-D, the residual errors, even without the residual filter errors, are too large.

The Landsat-D requirement = 1/2 pixel 90% of the time. However, if the requirement is placed on the system exclusive of map errors then

$$\sigma_T = 0.90 \text{ meters both along and cross track}$$

If the requirement is placed on along and cross track directions, then the filter must perform as follows:

$$\text{Along Track} = \sigma_{AT} = \sqrt{(3.03)^2 - (0.90)^2} = 2.89 \text{ meters}$$

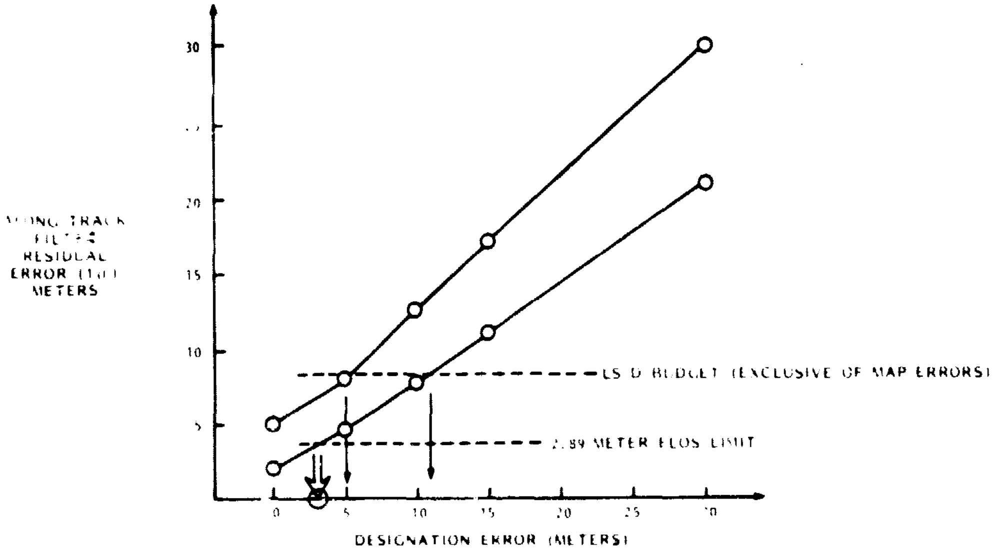
$$\text{Cross Track} = \sigma_{CT} = \sqrt{(3.03)^2 - (0.90)^2} = 2.89 \text{ meters}$$

The critical question is whether the filter can drive the ephemeris/attitude residual down to this level.

Unfortunately the measurement errors (both levels) now will include map errors and the suspected highly variable cross-correlation errors.

At this point a covariance analysis should be performed to judge the feasibility of a filter requirement of 2.89 meters. Our educated guess is that this is not likely to be feasible.

For example, an early LSD study (Reference 5) resulted in the sensitivity curves for ΔT = 60 seconds between control points for 10 control points shown below:



The two curves represent bounds for the residual error (based on extrapolated and smoothed results at the final (10th) control point.

The designation errors must be for Landsat-D somewhere in the 5-10 meter range to satisfy the 8+ meter budget limit with the error budget as conceived at the time of that study.

As a crude first guess, using these curves, the ELOS designation error (the error introduced when the operator optically correlates maps to imagery) would have to be below 3 meters, certainly unlikely from our listed cross correlation error estimates.

B.6 REFERENCES

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APPENDIX C

DATA COMPRESSION, ERROR CORRECTION AND STEREO PROCESSING

APPENDIX C

DATA COMPRESSION, ERROR CORRECTION, AND STEREO PROCESSING

This appendix addresses the three issues of data compression, error correction coding and stereo processing and their impact on the ground processing of MLA data for the ELOS mission.

C.1 DATA COMPRESSION

The MLA sensor collects data in four spectral bands at a net rate of 116.7 Mbps but must downlink this data, for the ELOS mission, though a shuttle to TDRSS link which is limited to 48 Mbps. This will require compressing the raw sensor data by a factor of 2.3 to 2.5, depending on the information rate of whatever error correcting code is employed and the amount of overhead.

Any kind of data compression scheme requires the three basic processing elements of mapping, quantizing and coding (See Figure C-1). Mapping is a method of exploiting the internal correlation of the video signal by transforming the input data stream into another stream with tighter signal statistics. The simplest mapping technique is along track, one dimensional differencing of either the actual 8 bit successive pixel values or the new pixel value and the previous quantized pixel value . This method exploits the favorable statistics of the pixel differences but, depending on the quantization and encoding schemes, may suffer degradation in edge response. This difficulty can be partially remedied, at the expense of increased memory

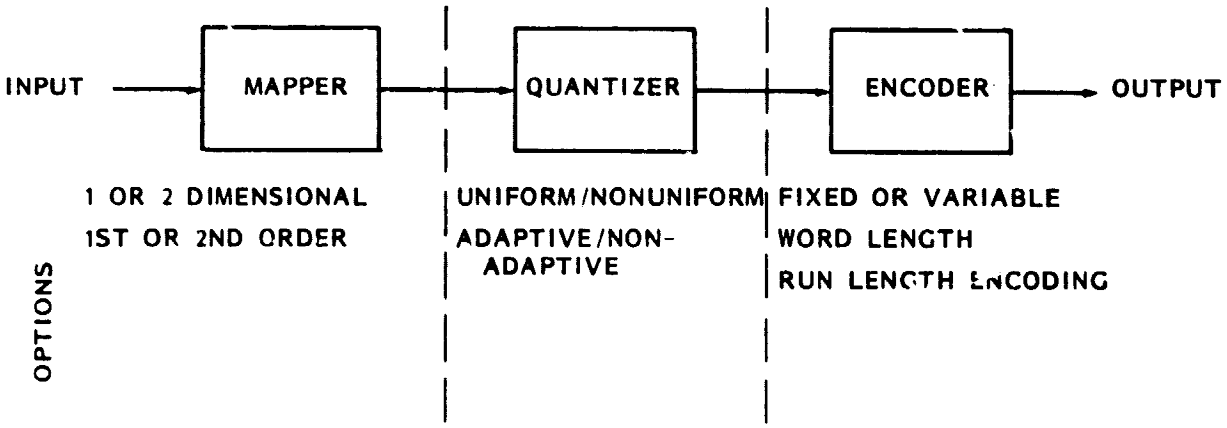

Figure C-1. Data Compression

requirements, by predicting a given pixel value by both along track and across track neighbors and then differencing the actual value with the predicted value. This two dimensioned Differential Pulse Code Modulation also requires incorporating on-board calibration information which is another difficulty. Another possibility is to map the input data stream into second differences either along track alone or both along and across track.

The second stage of data compression is quantization of the 8 bit data (or 9 bit differences) down to a smaller number of bits. This quantization may truncate the mapped signal stream to a uniformly or non-uniformly spaced staircase of step values and the truncation scheme may or may not adapt itself to the actual spread of each block of data.

Finally, the output of the quantizer is encoded for transmission in either fixed or variable length words. Each mapped and quantized pixel value may be encoded individually or a more complicated run length encoding or contour encoding scheme may be utilized.

Uncompressing the data stream requires only the two steps of decoding and inverse mapping. There is no inverse quantizer since truncation error is irretrievably lost during the data compression process. Neither of these steps presents much of a processing burden if only two scenes per day are to be processed. Decoding will be a simple table look-up for fixed word length encoding but will require a descending binary tree search if a more complicated variable word length encoding scheme is used. Inverse mapping requires first demultiplexing the four bands of video data and then inverting whatever transformation was performed during the mapping process. If, for example, along track DPCM is employed, then incoming pixel differences need only be added to the previous along track pixel intensity. If fixed word length encoding is used, the whole decompression process can be efficiently performed with array processors. However, since decoding a variable word length code requires a binary tree search which is not particularly suitable for an array processor, a special purpose interface board will probably be necessary if this kind of scheme is employed.

We understand that the current baseline design calls for simple one dimensional along track DPCM data compression using first differences for mapping, non-uniform quantization and fixed word length encoding. The advantage of this simple design is the ease of onboard processing, the minimal memory requirements and the fact that bit errors in the downlink only result in one dimensional streaks in the image which can only be averaged out during post processing. The prime disadvantage is the up to three IFOV degradation in the edge response caused by the fixed 3 bit word length. A more powerful (and difficult) design which is also being considered calls again for along track DPCM but with across track, possibly adaptive, Huffman encoding of the along track signal differences. The Huffman code must by matched to the scene statistics so as to reserve short words for the most likely signal differences and long words for the least likely ones. If the Huffman code is properly designed, which is no mean job since it must be adapted to variable scene statistics, then this scheme reduces the edge response blur to zero. However the price for this is greatly increased onboard processing complexity and two dimensional holes in the image whenever there is a bit errors in the downlink rather than the easily remedied one dimensional streaks which occur with the baseline design.

C.2 ERROR DETECTION AND CORRECTION (EDAC)

The ELOS product is a 60 km by 60 km scene with 10 meter resolution in the two visual bands and the near infrared band and 20 meters resolution at the short wave infrared band. If the 8 bit/pixel data is compressed to 3 bits/pixel, then the full four band scene contains (3 visible and NIR bands) x 3 bits/pixel x 36 x 10^6 pixels + (1 SWIR band) x 3 bits/pixel x 9 x 10^6 pixels = 351 x 10^6 bits of information. If the bit error rate (BER) of the Shuttle to TDRS to ground data link is 10^{-5}, then each 4 band scene contains, on average, 3510 bit errors. In the case of simple, along track DPCM, for example, each of these bit errors results in a one dimensional streak half as long, on average, as the number of pixels between update words. The across track, Huffman coding scheme results in more drastic triangular holes in the imagery. 3510 is clearly an unacceptable number of blemishes per picture and so some form of error detection and correction scheme is necessary to improve the effective BER of the downlink.

Suppose that the $M = 351 \times 10^6$ raw data bits are encoded with an EDAC code whose efficiency is e and block size is N and which corrects T or fewer errors within each block. Let E_c and E_{NC} denote the expected number of errors after the M bits are transmitted when EDAC is and is not employed, respectively, and let P_{BER} denote the bit error rate of the downlink. Then

$$E_{NC} = M x \; P_{BER}$$

$$E_C = \frac{M}{eN} P_{BER} \left[N - \sum_{i=1}^{T} \binom{N}{i} i \; P_{BER}{}^{i-1} (1-P_{BER})^{N-i} \right]$$

This latter formula is derived by noting that the expected number of bit errors in the M/e transmitted bits of data is equal to the expected number of N bit blocks which contain T+1 or more errors times the expected number of bit errors per block, given that the block has at least T+1 errors. We can interpret this formula as saying that the effective BER as a result of error detection and correction is improved to

$$P_{EFF} = \frac{E_c}{M}$$

$$= \frac{P_{BER}}{eN} \left[N - \sum_{i-1}^{T} \binom{N}{i} i \; P_{BER}{}^{i-1} (1-P_{BER})^{N.i} \right]$$

The efficacy of EDAC encoding is clearly demonstrated by the following table which shows a few numbers for the Bose-Chaudhuri-Hocquenghem (BCH) linear cyclic code of block length $2^8-1 = 255$.

N	T	e	P_{EFF}	$E_C = M.P_{EFF}$	P_{BER}
255	1	.969	$2.62 \cdot 10^{-8}$	9.2	10^{-5}
255	2	.937	$3.42 \cdot 10^{-11}$	$1.2 \cdot 10^{-2}$	10^{-5}
255	3	.867	$7.38 \cdot 10^{-12}$	$2.6 \cdot 10^{-3}$	10^{-5}

Even single error detection radically improves the effective BER; with double error correction, only one full band scene in a hundred is flawed by a single error. Notice also that there is a diminishing improvement in performance when we correct 3 errors per block. If the bit errors were truely random and independent, the above simple table would suggest that a two bit error correcting 255 block length BCH code would be a satisfactory solution to the bit error problem. However, the TDRS data link employs NRZM phase shift keying and therefore errors arrive in at least two bit bursts. For this reason, we understand that some consideration is also being given to burst error correcting codes, for example Reed-Solomon codes, in addition to random bit error correcting BCH codes.

At error correcting, 1 bit symbol field, BCH code of block length $M = 2^m-1$ encodes a $K = M-mt$ bit block of data into an M bit block. It does this by identifying the K input bits with a polynomial of degree K-1 with coefficients in the two element field Z_2 and then encoding the data as a polynomial multiple of a fixed generating polynomial. This generating polynomial is the least common multiple of the irreducible polynomials of $\alpha, \alpha,^2 \ldots, \alpha^{2t}$, where α is a primitive (ie generator) of the Galois field GF (2^m). It's degree is always < mt. These generating polynomials for various BCH codes are tabulated in numerous books. Let g (x) denote the generating polynomial and i (x) the input data. The broadcast code block is typically found by first using the division algorithm to write $x^{mt}\ i(x) = q(x)\ g(x) + p(x)$, where deg p (x) < mt. The encoded block is then $c(x) = x^{mt}i(x) - p(x) = x^{mt}\ i(x) + p(x)$. There are other ways of encoding i(x) as a multiple of g(x) but this one has the advantage that the first K bits down the channel are the actual data bits, possibly with errors, and the last mt are the parity check bits. The main operational advantage of 1 bit BCH codes is that circuitry to perform the binary polynomial division implied by the above encoding is relatively simple and does not require a lot of memory.

The above BCH code is also relatively easy to decode, especially in software. Since $\alpha, \ldots, \alpha^{2t}$ are all roots of the generating polynomial and since any code word is a multiple of the generating polynomial, $c(\alpha^j) = 0$, $j = 1,\ldots 2t$, for any code word polynomial c(x). If the received word, r(x), consists of c(x) corrupted by noise errors, n(x), then $r(\alpha^j) = c(\alpha^j)+n(\alpha^j) = n(\alpha^j)$, $j = 1,\ldots, 2t$. The 2t numbers $Sj = n(\alpha^j)$, $j = 1, \ldots, 2t$, all elements of the Galois field GF (2^m), are called the syndromes of the received word. However, rather than evaluating $r(\alpha^j)$ for each $j=1,\ldots,$ 2t, the syndrome is usually calculated by dividing r(x) by the minimal polynomial of α^j, p_j; so that $r(x) = h_j(x)\ p_j(x) + q_j(x)$, where the degree of $q_j(x)$ is less than the degree of $P_j(x)$. Then $r(\alpha^j) = h_j(\alpha^j)\ p_j(\alpha^j) + q_j(\alpha^j) = q_j(\alpha^j)$; the syndrome is therefore $s_j = q_j(\alpha^j)$.

Suppose now that the received word has errors at bit locations i_1, $i_2 .., i_p$, where $p \leq t$ (and assume that the indexing starts off at 0).

Then

$$n(x) = \sum_{k=1}^{P} X^{i_K}$$

and the error locations $i_1, \ldots, i_p$ satisfy the 2t equations

$$S_j = \sum_{k=1}^{P} (\alpha^j)^{i_k}, \ j = 1, \ldots, 2t$$

It should be emphasized that these are equations in the field $GF(2^m)$. There are, in general, many solutions to this set of equations. A maximum likelihood decoder wants to find a solution with the least number, P, of error locations. This is accomplished by using the 2t syndromes to determine the coefficients of the error locator polynomial, $\sigma(x)$, whose roots are the reciprocals of the field elements corresponding to the error locations. The degree of $\sigma(x)$ will, of course, be $\leq t$. The process of finding these coefficients is the hardest part of BCH decoding; the solution procedure uses a tricky recursive scheme which will not be described here. However, the results for t=1, 2 and 3 are the following:

$$t = 1 \quad \sigma(x) = 1 + S_1 x$$

$$t = 2 \quad \sigma(x) = 1 + S_1 x + (S_1^{\ 2} + S_3/S_1) X^2$$

$$t = 3 \quad \sigma(x) = 1 + S_1 x + [\ (S_5 + S_1^{\ 2} S_3)/(S_3 + S_1^{\ 3})\ ]\ X^2 + [\ S_1^{\ 3} + S_3 + (S_1 S_5 + S_1^{\ 3} S_3)/(S_3 + S_1^{\ 3})\ ]\ X^3$$

Once the error locator polynominal, $\sigma(x)$, has been found, it can be evaluated at successive powers, α^j, $j = 0, \ldots, 2^m - 2$, of the primitive element to determine if the (j+1) st bit is in error. If $\sigma(\alpha^j) = 0$, then the polarity of the (j+1) st bit should be reversed. This decoder is summarized in the flow diagram of Figure C-2.

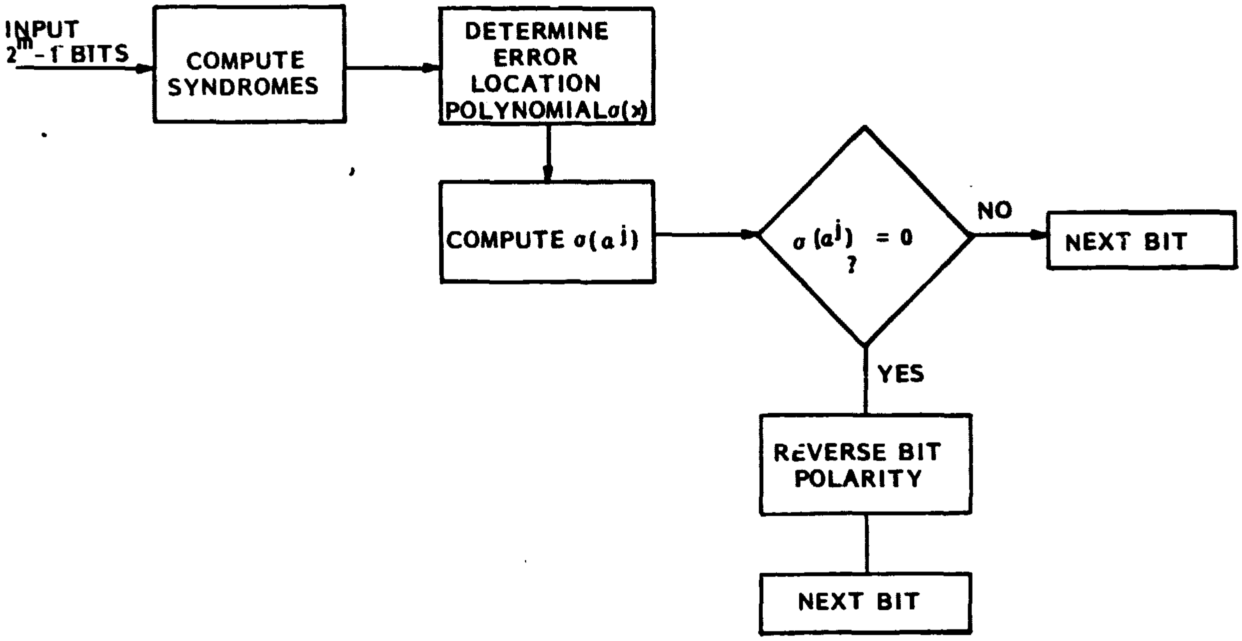

Figure C-2. BCH Decoder

Although the error locations of the above BCH code are discovered by solving equations in GF(2^m), the actual code word is still just a binary polynomial of degree $\leq 2^m-1$. In the terminology of the subject, GF (2^m) is the error locator field and Z_2 is the symbol field. This simple symbol field has the advantage of easy on board encoding but the disadvantage that it can only treat burst errors as random errors. A BCH code with a one bit symbol field and with T=3 would not be able to correct even two errors on the TDRS downlink since each error would actually have two bit errors.

This can be remedied by increasing the number of bits in the symbol field. A t error correcting BCH code with a k bit symbol field and block length $M=2^m-1$ encodes K k bit bytes into M k bit bytes. Each k bit byte is identified with an element of GF (2^k) and the K bytes, in turn, are associated with a polynomial of degree K-1 whose coefficients are in GF (2^k). Let α be a primitive element of GF ($(2^k)^m$) and let g(x) be the least common multiple of the irreducible polynomials of α, $\alpha^2, \ldots \alpha^{2t}$ over the field GF (2^k). The legal code words are then the multiples of g(x). K is M minus the degree of g(x). The on board encoding is done just as for the 1 bit symbol field except that now the polynomial division is over the more complicated field GF (2^k) rather than Z_2. The circuitry is therefore correspondingly more complicated.

Decoding is still performed as outlined in Figure C-2. The error locator field is now GF (2^{km}) and the syndrome and error locator polynomials are calculated in that field. There is now an additional twist, however, since once a k bit byte has been identified as in error, it is not as simple to correct the error as it was when the symbol field was just Z_2. Nonetheless, this difficulty can still be resolved by the use of another auxiliary polynomial called the error evaluator polynomial. The details will not be described here.

We understand that there is some interest in using Reed-Solomon encoding for the ELOS mission. This just corresponds to the above case where m=1 and is unique in that the error locator field is the same as the symbol field. Although there must be formidable on board encoding problems, this choice of encoding would only impact the ground processing through some increased complexity in the software for decoding. Since the production rate is only two scenes per day, it will not impact performance.

C.3 STEREO PROCESSING

The purpose of the ELOS stereo experiment is to utilize high resolution, MLA stereo imagery to obtain information on terrain elevation, slope and slope direction. This is accomplished, of course, by triangulation using the two stereo looks as shown in Figure C-3.

Suppose that the imagery is registered in the x-y plane and that a terrain feature located at $\vec{p}$ is registered at the points $\vec{r}_1$, and $\vec{r}_2$ for the fore and aft looks, respectively. The actual values for $\vec{r}_1$ and $\vec{r}_2$ are determined from the Shuttle location and attitude and knowledge of the relative position of each sensor element. If the shuttle positions at the times of the fore and aft looks are $\vec{v}_1$ and $\vec{v}_2$, then

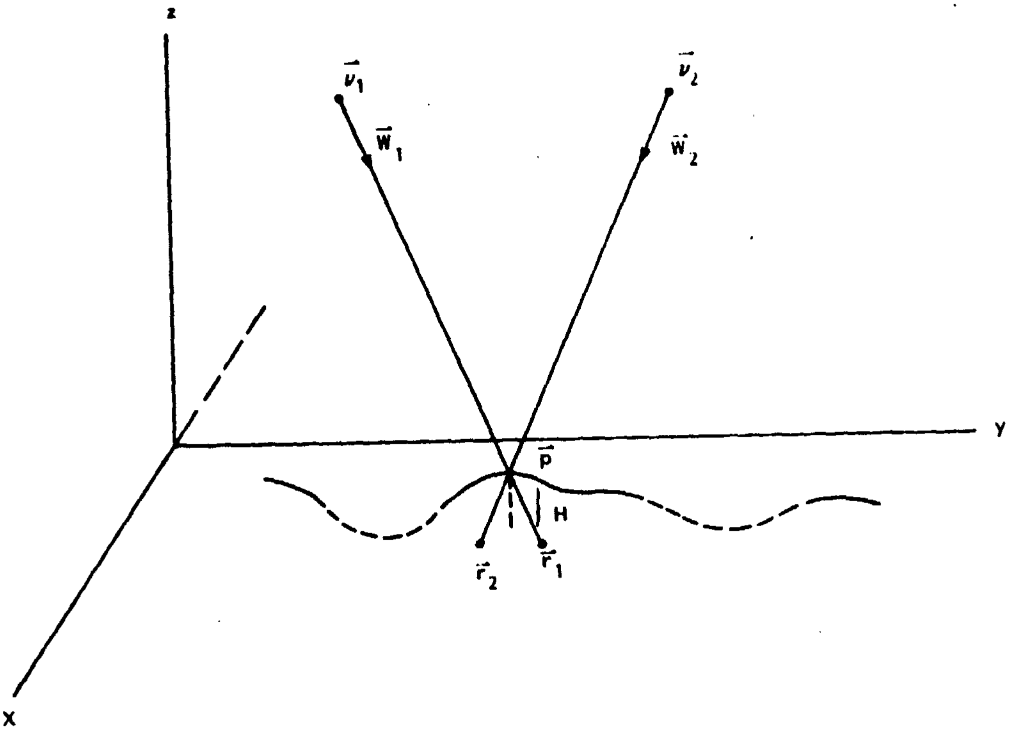

Figure C-3. Stereo Triangulation

$$\vec{p} = \vec{v}_1 + s\,\vec{w}_1 = \vec{v}_2 + t\,\vec{w}_2$$

where

$$\vec{w}_1 = (\vec{r}_1 - \vec{v}_1) / \mid \vec{r}_1 - \vec{v}_1 \mid$$

$$\vec{w}_2 = (\vec{r}_2 - \vec{v}_2) / \mid \vec{r}_2 - \vec{v}_2 \mid$$

The elevation of the terrain feature at p can thus be determined by taking the Z coordinate of the solution of the overdetermined system of 3 equations in two unknowns

$$(\vec{w}_1 - \vec{w}_2) \begin{pmatrix} s \\ t \end{pmatrix} = \vec{v}_2 - \vec{v}_1$$

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That this system has a unique solution is guaranteed by the compatibility equation

$$(\vec{w}_1 \times \vec{w}_2) \cdot (\vec{v}_2 - \vec{v}_1) = 0$$

which just says that the two lines intersect.

The planned registration method for the ELOS imagery is into a Space Oblique Mercator (SOM) coordinate system, which is just like a normal Mercator projection but with the equator replaced by the Shuttle orbit ground trace. This is especially suited to the ELOS mission because of the minimal distortion from a local flat earth model in the vicinity of the Shuttle ground trace where all of the imagery is, of course, taken. Once a ground feature has been correlated between the fore and aft images, all of the information necessary to triangulate for its elevation is available from the SOM coordinate of the terrain feature in the two images together with Shuttle ephemeris information.

The method of correlation of the individual terrain features in the two stereo images is the prerogative of the experimenter. The SOM registered data can be viewed in a stereoscope to gather qualitative information or scene features can be manually correlated to determine their altitude. Furthermore, current estimates for the net effect of errors in systematic and geodetic correction data, interpolation and resampling is less than a meter. The largest single error source is the external map error which is irrelevant to the problem of correlating two scenes with each other. Thus, except possibly for a uniform shift between the two stereo images which can be taken out manually, the epipolar condition will be satisfied and the SOM registered imagery can be processed by automated one dimensional correlators which require this epipolarity condition.