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INTEGRATED PAYLOAD AND MISSION PLANNING, PHASE III

FINAL REPORT

VOLUME III

Ground Data Management Analysis and Onboard Versus Ground Real-Time Mission Operations

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

MCDONNELL DOUGLAS CORPORATION

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INTEGRATED PAYLOAD AND MISSION PLANNING, PHASE III

FINAL REPORT, VOLUME III
Ground Data Management Analysis and Onboard Versus Ground Real-Time Mission Operations

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PREPARED BY:
W. J. WHITE
TASK LEADER

APPROVED BY:
R. P. DAWSON
STUDY MANAGER

APPROVED BY:
F. C. RUNGE
PROGRAM MANAGER
SPACE PAYLOADS

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-WEST

5301 Bolsa Avenue, Huntington Beach, CA 92647

PREFACE

This report documents the results of a study conducted by the McDonnell Douglas Astronautics Company (MDAC) from 1 June 1976 to 31 March 1977 for the NASA George C. Marshall Space Flight Center (MSFC) related to integrated payload and mission planning for Space Transportation System (STS) payloads. This Phase III effort is a continuation of the Shuttle payload planning studies initiated by NASA/MSFC in October 1974.

An executive summary of this phase is reported in MDC-6740. Final detailed technical results of this study phase are reported in the following volumes of MDC G6741:

- Volume I - Integrated Payload and Mission Planning Process Evaluation
- Volume II - Logic/Methodology for Preliminary Grouping of Spacelab and Mixed Cargo Payloads
- Volume III - Ground Data Management Analysis and Onboard Versus Ground Real-Time Mission Operations
- Volume IV - Optimum Utilization of Spacelab Racks and Pallets

This Volume III presents the results of two principal study tasks related to data management and mission control. Part I contains the results of a study to analyze Spacelab payload real-time onboard versus ground mission operations support. A cost relationship of three assumed cases of onboard versus ground capability was developed. Part II contains the results of a study to analyze the Spacelab experiment-operations ground-data management problem and to establish an effective approach for ground data processing to support real-time operations as well as postflight analysis. Information in the Appendixes includes a brief review of lessons learned from major programs involving payload integration and a checklist that would help to minimize integration-related problems.

Requests for additional information should be directed to the following personnel:

- Mr. R. E. Valentine, Study COR
  NASA George C. Marshall Space Flight Center
  Huntsville, Alabama 35812
  Telephone: 205-453-3437

- Mr. R. P. Dawson, Study Manager
  McDonnell Douglas Astronautics Company
  Huntington Beach, California 92647
  Telephone: 714-896-3205

- Mr. R. D. Nichols, Field Office Representative
  McDonnell Douglas Astronautics Company
  Huntsville, Alabama 35812
  Telephone: 205-881-0611

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ACRONYMS AND ABBREVIATIONS

AFD	aft flight deck
AMPS	atmospheric, magnetospheric, and plasmas in space
AO	Announcement of Opportunity
ATL	Advanced Technology Laboratory
ATP	Authority to Proceed
BPS	bits per second
BU	backup
C&D	control and display
C&W	Caution and Warning
CCD	charge-coupled devices
CCT	computer-compatible types
CCTV	closed-circuit television
CDMS	Command and Data Management System
CDR	Critical Design Review
CFE	Customer-furnished equipment
CMD	command
CPU	central processing unit
CRT	cathode-ray tube
DDU	data display unit
DDU/KB	data display unit/keyboard
DMA	direct memory access
DOMSAT	Domestic Satellite
DRS	data reformatting system
ECL	emitter-coupled logic
ESA	European Space Agency
EUV	extreme ultraviolet
EVA	extra-vehicular activity
EVAL	Earth Viewing Applications Laboratory
EXPMT	experiment
FMEA	Failure Mode and Effects Analysis
FY	fiscal year

GE	General Electric Company
GET	ground elapsed time
GFE	Government-furnished equipment
GMT	Greenwich Mean Time
GPC	general purpose computer
GSE	ground support equipment
GSFC	Goddard Space Flight Center
Hα	Hydrogen Alpha
HDRR	high data rate recorder
HDT	high-density tape
HK	housekeeping
HRM	high-rate multiplexer
IAC	instrument analysis centers
IC	integrated circuit
IF	intermediate frequency
I/O	input/output
IP&MP	Integrated Payload and Mission Planning
IPS	Instrument Pointing System
IR	infrared
ITP	Instrument Telemetry Packet
IUS	Interim Upper Stage
JSC	Johnson Space Center
K OPS	thousands of operations per second
KSA	Ku-band frequency, single access
KSC	Kennedy Space Center
KUSP	Ku-band signal processor
Lα	Lyman-Alpha
LaRC	Langley Research Center
LED	light-emitting diode
LIDAR	light detection and ranging
LLL TV	low-light-level television
LOS	loss-of-signal
LSI	large-scale integration
MCC	Mission Control Center
MDAC	McDonnell Douglas Astronautics Company
MDM	multiplexer/demultiplexer

MET	mission elapsed time
MILA	Merritt Island Launch Area
MOCR	Mission Operations Control Room
MOS	metal-oxide semiconductor
MPM	miniaturized pointing mount
MPS	Miniature Pointing System
MS	Mission Specialist
MSFC	Marshall Space Flight Center
MSS	multispectral scanner
MTU	master timing unit
MUX	multiplexer
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications Network
NRZ	non-return-to-zero
NSP	network signal processor
OEDSF	onboard experiment data support facility
OPS	operations
OSF	Office of Space Flight
OSS	Office of Space Sciences
OTDA	Office of Tracking and Data Acquisition
OWS	Orbital Workshop
PCC	payload control center
PCM	pulse code modulation
PCMMU	pulse code modulation master unit
PDR	Preliminary Design Review
PE	processing elements
PI	Principal Investigator
PLD	payload
POCC	Payload Operations Control Center
PPDB	Payload Planning Data Bank
PROM	programmable read-only memories
PS	Payload Specialist
PSS	Payload Specialist Station
QPSK	quadriphase phase shift key
RAAB	remote amplifier and advisory box

RAM	random access memory
RAU	remote acquisition unit
ROM	rough order of magnitude
RT	real time
SAR	synthetic aperture radar
SC	scientific
SIO/S_c	silicon dioxide/silicon (silicon-gate process)
SNR	signal-to-noise ratio
SPRAG	STS Payload Requirements and Analysis Group
SSA	S-band frequency, single access
SSPD	STS payload descriptions
STDN	Space Flight Tracking and Data Network
STS	Space Transportation System
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TM	telemetry
TM	thematic mapper
TTL	transistor-transistor logic
TV	television
UV	ultraviolet
VFI	Verification Flight Instrumentation
VFT	verification flight test
VHRDR	very high-rate data recorder
WLC	white-light coronagraph
WPS	words per second
XUV	x-ray ultraviolet

PART I

ONBOARD VERSUS GROUND REAL-TIME MISSION OPERATIONS

(TASK 2.2C)

PART I — SUMMARY

The payloads tentatively planned to fly on the first two Spacelab missions were analyzed to examine the cost relationships of providing mission operations support from onboard vs the ground-based Payload Operations Control Center (POCC).

Cost relationships were determined for three assumed cases of onboard vs ground capability. The three cases were defined as follows:

- Case 1 — A full data-and-command centralized POCC with minimum onboard control, display, and data processing.
- Case 2 — A voice-only centralized POCC with maximum onboard control, display, and data processing.
- Case 3 — Data and command systems added to a voice-only centralized POCC to permit mission feasibility or significantly reduce overall costs. Complementary onboard equipment will be used as required.

Initially, Case 3 was to be limited to ground display of minimum payload-system data. However, early in the study it was discovered that display of scientific data was cost effective for many payloads and the Case 3 POCC configuration was revised accordingly.

The study was conducted by performing an individual analysis of each experiment to define its operating modes and support requirements for each of the three cases. These individual experiment operating plans were then integrated and revised as necessary to assure overall mission compatibility. The onboard and ground support requirements, including hardware, software, and support personnel were then identified and costed. Cost figures were established as differences to a Case 1 baseline except for POCC operations which were identified as total support requirements. By ground rule, cost savings were not derived for POCC and onboard hardware not utilized to support the various cases. Cost results are summarized in Figure I-1.

		POCC			ONBOARD			TOTAL COST* ($)
		HARDWARE (Δ$)	SOFTWARE (Δ$)	OPERATIONS (HR)	HARDWARE (Δ$)	SOFTWARE (Δ$)	OPERATIONS (ΔHR)	
	CASE 1	0	0	10,880	0	0	0	$326,000
SL-1	CASE 2	0	($78,000) SAVINGS	5,420	0	$563,000	4,590	$786,000
	CASE 3	0	($24,000) SAVINGS	6,570	0	$33,000	1,860	$262,000
	CASE 1	0	0	11,900	0	0	0	$357,000
SL-2	CASE 2	0	($36,000) SAVINGS	7,320	$294,000	$32,000	1,910	$567,000
	CASE 3	0	($14,000) SAVINGS	9,700	0	$32,000	870	$332,000

*OPERATIONS HOURS CONVERTED TO DOLLARS USING $30/HR

Figure I-1. Onboard vs Ground Operations Cost Summary

The quantitative results of this study indicate that use of a POCC, with data processing capability, to support real-time mission operations would be the most cost effective case. Specifically, the added cost in crew training and onboard software or hardware needed to make Case 2 feasible more than offset the additional POCC operations costs for Cases 1 or 3. Case 2 costs approximately $500,000 more for Spacelab 1 and $200,000 more for Spacelab 2.

In addition, several qualitative factors should be considered in comparing the three cases. These factors are:

A. Scientific Return
B. Operational Flexibility
C. Onboard Equipment Resources
D. Flight Crew Utilization

SCIENTIFIC RETURN

It is not possible to get the same experiment scientific return in Case 2 as it is in Case 1 or Case 3. The very nature of scientific experimentation requires frequent evaluation of experiment outputs with readjustments of inputs to obtain the desired results. Evaluation of outputs often requires years of education, training, and experience available only through the dedicated scientist. Experimentation time availability coupled with the inherent problems of verbal communication required in Case 2 preclude the ground-based scientist of providing the most effective interface with his experiment.

The required scientific knowledge can partially be translated to onboard operations by increasing crew size (allowing more time per experiment), providing extensive crew training, and providing complex automated scientific data processing and evaluation programs. These approaches increase the cost yet still fail to give the same degree of scientific return as available through the well-informed ground-based scientist of Case 1 and Case 3.

OPERATIONAL FLEXIBILITY

The ability to monitor and control payloads from the ground (Cases 1 and 3) provides a significant degree of flexibility not available in Case 2. Should onboard problems (e.g., crew sickness or diversion of attention from one payload to problem investigation of another payload or STS support system) preclude accomplishment of scheduled payload activities, ground control could be assumed with a potential of salvaging significant payload operations.

The requirements for increased crew training and the increased complexity of onboard hardware and/or software required by Case 2 would minimize the flexibility for changing payloads late in the prelaunch preparation phases.

ONBOARD EQUIPMENT RESOURCES

The increased demand for added hardware, software, and crew to support Case 2 may significantly deplete STS-provided resources for payload support. Case 2 would tend to increase weight, power consumption, data processing resources, and habitation support resources. The result of these demands may necessitate a decrease in payload-carrying capability. The introduction of the more sophisticated payloads beyond those studied for Spacelabs 1 and 2 would accentuate this problem.

FLIGHT CREW UTILIZATION

There are certain payloads where an increase in crew utilization can result in a reduction of ground support requirements and still produce the same scientific return. Recognizing these situations and planning accordingly should result in an overall reduction of real-time operational costs. This increased crew utilization is reflected in Case 3 of this study. The crew activity required to support Case 2 was determined to be an extremely heavy work load, particularly for the Spacelab 1 type payloads.

In conclusion, it appears that a Case 3 configuration, which includes real-time ground-based scientific data-processing capabilities, would result in the most cost-effective approach to real-time payload mission operations support.

Section 1

INTRODUCTION

The Space Transportation System (STS) currently under development by NASA will begin a new era of space activity that will involve a significant increase in the number and type of space payloads and missions. To satisfy the needs of the various payload users and in order to utilize the STS in the most effective way, additional emphasis is being given by NASA to the unique planning and program integration activities necessary to fully exploit STS capabilities. This planning and integration process becomes extremely important when considering the high rate of projected STS traffic, the frequent requirement for payload sharing of STS flights, the varied states of payload development, and the different operational aspects of each payload. These activities include studies of cost-effective approaches to payload integration and mission operations. Real-time mission support of the Spacelab payload operations is a significant component of the overall payload integration cost.

This report documents the results of an analytical study performed to examine the cost relationships of providing payload real-time mission operation support from onboard vs the ground-based Payload Operations Control Center (POCC).

1.1 PURPOSE

The purpose of this task was to perform a trade study which examined the cost relationship of three assumed cases of onboard vs ground capability. The three cases are (1) full data-and-command centralized POCC with minimum onboard control, display, and data processing; (2) voice-only centralized POCC with maximum (within STS accommodations capability) onboard control, display, and data processing; and (3) data and command systems added to a voice-only centralized POCC to permit mission feasibility or significantly reduce overall costs. Complementary onboard equipment will be used as required.

1.2 SCOPE

This task was conducted during the period from November 1976 through 31 March 1977. The study was limited to an evaluation of the experiments from the Spacelab Missions 1 and 2 as defined by the MSFC Strawman Summary documents.[1] Refer to Figure I-1-1 for a listing of experiments. During the conduct of the study, such realities as the Tracking and Data Relay Satellite System (TDRSS) blackout periods, data downlink constraints, and the value of man-on-the-scene were considered for the minimum onboard operations of Case 1. Man-in-the-loop vs automation comparisons were emphasized for the onboard operations of Cases 2 and 3.

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SPACELAB-1
(7 DAYS - 196 EXP HRS)

NASA PAYLOADS

1.	AP-09-S	ELECTRON ACCELERATOR
2.	AP-13-S	LOW LIGHT LEVEL TV
3.	ST-31-S	DROP DYNAMICS
4.	EO-01-S	ZERO-G CLOUD PHYSICS
5.	LS-13-S	MINILAB
-	VFI	VERIFICATION FLT INSTR

ESA PAYLOADS

1.	APE-01	LIDAR
2.	SPE-80-85	SPACE PROCESSING
3.	SPE-01	FREE-FLOW ELECTROPHORESIS
4.	EOE-01	METRIC CAMERA
5.	APE-07	INFRARED RADIOMETER
6.	STE-10	HEAT PIPE
7.	ASE-01	WIDE-FIELD GALACTIC CAMERA

IPS - ESA INSTRUMENT POINTING SUBSYSTEM
MPM - MINIATURIZED POINTING MOUNT

SPACELAB-2
(12 DAYS - 1091 EXP HRS)

NASA PAYLOADS

1. 65-CM PHOTOHELIOGRAPH (IPS)
2. SOLAR MONITOR PACKAGE (IPS)
3. SOFT X-RAY TELESCOPE (IPS)
4. LYMAN-ALPHA WHITE-LIGHT CORONOGRAPH (IPS)
5. HIGH-SENSITIVITY X-RAY BURST DETECTOR (IPS)
6. SKYLARK COSMIC X-RAY TELESCOPE (MPM)
7. LOW LIGHT LEVEL TV (MPM)
8. FAR UV SCHMIDT CAMERA/ SPECTROGRAPH (MPM)
9. TRANSITION RADIATION SPECTROMETER
10. EUV IMAGING TELESCOPE

- VFI (VERIFICATION FLIGHT INSTRUMENTATION)

Figure I-1-1. Spacelab Experiments (Strawman)

1. Spacelab 1 Strawman, MSFC, SE-012-020-2H, October 1976; and Spacelab 2 Strawman, MSFC, SE-012-022-2S, December 1976.

1.3 GROUND RULES AND ASSUMPTIONS

A. Case 1 (maximum POCC/minimum onboard)

- Experiment will be monitored and controlled at the POCC; onboard control will be minimized.
- Must consider TDRSS blackout periods, data downlink constraints, and value of man-on-the-scene.

B. Case 2 (voice-only POCC/maximum onboard)

- All experiment operational data transmission and commands shall be voice-only to and from a centralized POCC.
- Man-in-the-loop vs automation comparisons will be made.

C. Case 3 (minimum systems data POCC/maximum onboard)

- The minimum amount of command control, display, and data processing equipment will be added to a voice-only centralized POCC that will permit mission feasibility or significantly reduce overall costs.
- Man-in-the-loop vs automation comparisons will be made.

D. Spacelab Missions 1 and 2 are to be used for this study.

E. All data transmission to and from the ground will be via the TDRSS.

F. One centralized POCC at Johnson Space Center (JSC) will be assumed as the baseline for all cases.

G. Assume the crew size is variable for each case.

H. For all cases, the onboard control and display shall be as defined by the Payload Specialist Study[1] for the aft flight deck (AFD) and by the Spacelab Accommodations Handbook[2] for the Spacelab module.

I. Accommodations for onboard data processing requirements exceeding the capability of the Spacelab Command and Data Management System (CDMS) shall be assumed as part of each instrument design for all cases.

J. Assume Caution and Warning (C&W) is constant for all cases.

K. Verification Flight Instrumentation (VFI) and related operations are to be considered as a high-priority experiment, however, it is not to be the prime design driver.

L. All costs are Rough Order of Magnitude (ROM), normalized to FY '77 dollars.

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1. Payload Specialist Station Study, Martin Marietta Corp., Report MCR-76-403, November 1976.
2. Spacelab Accommodations Handbook, Review Issue, PDR-B, 1976.

M. Costs will be determined as increments to a baseline system. The baseline system is considered to be the current system design and POCC/NASCOM facilities presently planned for early Spacelab missions.

N. POCC facility deletions that are possible for Case 2 (minimum POCC) and Case 3 (minimum systems POCC) will not be costed.

O. Onboard equipment reductions will not be considered for any of the three cases.

P. Utilization or operating costs will be expressed in man-hours. Man-loading will include both Government and Contractor services.

Q. The basic operations and maintenance of POCC facilities, communications, and ground data systems are assumed to be constant for all cases and are provided wholly by JSC as the POCC host.

R. Real-time software used in POCC computers will be developed, maintained, and funded by JSC. Software for offline analysis and software for user-provided equipment will be user-provided, maintained, and funded.

S. Computation support for payload activity replanning will be performed on an MSFC computer using terminals located in the POCC and the software system used for premission planning.

T. Continuous POCC manning is required throughout the mission for all cases, but manning levels are dependent upon specific payload activity requirements.

Section 2
APPROACH

The general approach followed for this study is summarized in Figure I-2-1.

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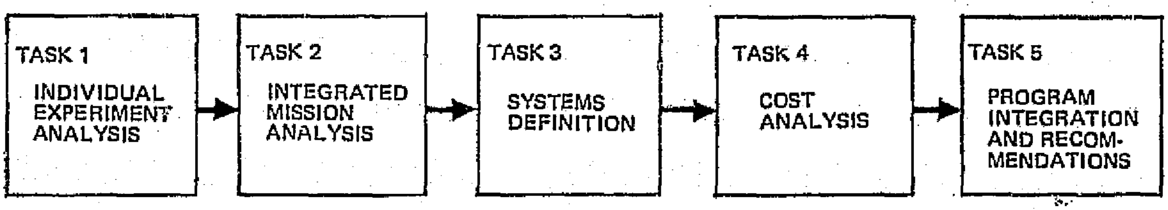

Figure I-2-1. Study Flow

2.1 TASK 1 — INDIVIDUAL EXPERIMENT ANALYSIS

An analysis of each experiment was conducted to develop an operating plan for each of the three cases. Individual experiment and CDMS interfaces were defined for each experiment using existing documentation and consultation with cognizant investigators and payload engineers. The onboard and ground personnel and hardware/software support requirements were identified. Potential instrument design and Spacelab support system impacts were also identified.

2.2 TASK 2 — INTEGRATED MISSION ANALYSIS

Based on NASA/MSFC-supplied mission experiment timelines, each of the individual operating plans for each of the three study cases developed in Task 1 were integrated to identify mission and/or support system total demands. Crew demands including VFI were assessed along the entire timeline. Total demands were assessed by reviewing the entire timeline to select certain critical high-activity periods for more detailed assessment. System impacts were identified and integrated mission support requirements were established for each study case (e.g., crew size, POCC manning, downlink data rates, uplink command rates, TV transmission, etc.).

2.3 TASK 3 — SYSTEMS DEFINITION

Based on the results of the integrated mission analysis (Task 2), impacts on baseline hardware and software design were described for both the onboard systems and the POCC.

2.4 TASK 4 — COST ANALYSIS

A cost work breakdown structure was prepared with associated costing ground rules and assumptions. Using the system definition results of Task 3, a cost analysis was performed in accordance with the cost work breakdown structure.

2.5 TASK 5 — PROGRAM INTEGRATION AND RECOMMENDATIONS

All findings were summarized, both quantitative and qualitative, for each study case.

Section 3
STUDY RESULTS

3.1 INDIVIDUAL EXPERIMENT ANALYSIS

Each individual experiment on Spacelab 1 and Spacelab 2 was separately analyzed to (1) identify currently defined characteristics and planned operations; (2) define an experiment control, display, and data management baseline (Case 1) including CDMS interface and operations; (3) define variations to this baseline for Case 2 and Case 3; and (4) assess the individual experiment impacts, by case, on the flight crew, POCC staffing, and planned hardware and software. The sources for data on the experiments included (1) the mission Strawman documents, (2) SSPD documents, (3) mission Announcements of Opportunity (AOs); (4) various studies on specific payloads or disciplines involved, and (5) telecons with specific investigators or lead engineers involved in the conceptual design of planned experiments or instruments. In addition, MDAC experience with Skylab experiment operations and data management, tempered by the STS and Spacelab operation guidelines and policies, were used as appropriate. Where no clear or common definition of an item was available, estimates or assumptions were made consistent with the best or most recent descriptions. This was also the approach used, where necessary, in adapting the definitions to off-nominal cases.

3.1.1 Spacelab 1 Individual Experiment Analysis

The twelve Spacelab 1 experiments analyzed are presented in Table I-3-1 along with the basic location of their hardware components, general pointing requirements, and basic objectives. As indicated, Spacelab 1 contains both NASA and ESA experiments located in the (long) module and on the pallet. Pallet-mounted instruments generally have a control and display panel located in a rack in the module. Half the experiments are rack only, one experiment is mounted (when operated) at the module viewport, and one is deployed (when operated) from the module airlock. The experiment set is

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Table I-3-1

SPACELAB 1 EXPERIMENTS

	Experiments	Locations		Pointing		Basic Objective
		Module	Pallet	STS	Other	
1.	AP-09 Electron Accelerator	Rack (C&D)	Inst	X		Active sounder of magnetosphere and atmosphere.
2.	AP-13 LLL TV	Rack (C&D)	Inst	X	±45° Z-Cone	AP-09 sensor plus extended objects viewing.
3.	ST-31 Drop Dynamics	Rack	—	—	—	Drop dynamics.
4.	EO-01 Cloud Physics Lab	Rack	—	—	—	Cloud microphysics.
5.	LS-13 Minilab	Rack	—	—	—	Cell, tissue/blood, and urine/frog otolith.
6.	APE-01 LIDAR	Rack (C&D)	Inst	X	Align	Active atmosphere sounding.
7.	SPE-80/85 Space Processing	Rack	—	—	—	Alloys, fiber/crystals/pure metals/superconductors.
8.	SPE-01 Electrophoresis	Rack	—	—	—	Pure chemical and biological specimens.
9.	EOE-01 Metric Camera	Viewport	—	X	Z-Steer	Earth mapping (targets).
10.	APE-07 IR Radiometer	Rack (C&D)	Inst	X	±60° Y Z-Scan	Passive atmospheric sounding.
11.	STE-10 Heat Pipe	Rack	—	—	—	Heat pipe technology.
12.	ASE-01 Wide Field Galactic Camera	Airlock	—	X	—	Extended objects mapping.

multidiscipline; four (33%) are atmospheric and space physics sounders or sensors, one other (EO-01) is highly oriented to atmospheric physics, and a sixth (ST-31) is also physics oriented. Two experiments are in space processing, one is in life science/biomed, and one each is in earth mapping, astronomy mapping, and space technology (heat pipe). Six (50%) of the experiments require some degree of STS pointing and orientation, and three of these require some degree of additional pointing control (pointing, steering, and/or scanning).

Table I-3-2 briefly summarizes some operating characteristics of these experiments, including their primary control source and crew functions for the baseline case (Case 1). Typical run times are presented for each experiment. The run times include calibration as well as actual data gathering time, but does not include any set-up or refurbish time; rather, each is representative of the time which requires continuous or near continuous monitoring and control. Some run times (e. g., APE-01) actually consist of a series of rapid data runs (i. e., 4/second) scanned over the period indicated. Others, such as ST-31, EO-01, SPE-80/85, and SPE-01, consist of a precisely controlled experiment process and procedure performed (largely automated) over the period indicated. Some are tied to certain flight conditions (night side viewing by AP-09, AP-13, and APE-01) or targets (EOE-01) which are firmly committed to schedule, once orbited.

As indicated, data rates are all moderate to low except for the numerous TV requirements. Most of these can be met by short selected viewing at the beginning and/or end of experiments and are primarily operating aids to the Principal Investigator (PI) at the POCC in assessing experiment progress and contingencies (this is not available for Case 2, by definition). Several prime data records of experiments are on film with little or no real-time monitor interface except as provided by sampled TV viewing. For all cases, the data stream to ground, except for operational TV, is essentially the same and provides the capability to perform postflight analysis. For Case 2, no real-time data processing or display is available from this data stream.

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Table I-3-2

SPACELAB 1 EXPERIMENT OPERATIONS CHARACTERISTICS

	Experiments	Duration (h) Typical Run	Data (kBPS) Scientific	HK	Baseline Case Control	Crew OPS
1.	AP-09 Electron Accelerator (1) (2)	0.3	16.2	1.2	POCC	Activate
2	AP-13 LLL TV (1) (2)	0.3	TV	0.2	POCC	Activate
3.	ST-31 Drop Dynamics (3)	0.5	Film/TV	1.3	Program Seq	Support
4.	EO-01 Cloud Physics	2.0	1.6/Film	0.6	CDMS Program	Activate
5.	LS-13 Minilab	0.7	7/TV	1.0	CREW/CDMS	Operate
6.	APE-01 LIDAR (1) (2)	0.5	54.4	4.0	POCC	Activate
7.	SPE-80/85 Space Processing (3)	2.0	Film/TV	1.2	Program Seq	Support
8.	SPE-01 Electrophoresis	0.5	3/Film	1.0	Program Seq	Support
9.	EOE-01 Metric Camera (2)	0.1	Film	0.2	CREW/CDMS	Operate
10.	APE-07 IR Radiometer (2)	0.5	69.0	1.0	POCC/CDMS	Activate
11.	STE-10 Heat Pipe	4.0	0.3	0.2	POCC/CDMS	Activate
12.	ASE-01 Wide-Field Galactic Camera (2) (3)	0.2	Film/TV	0 3	CREW/CDMS	Operate
	VFI I and II	(Assumed Constant)	60.4		MCC/CREW	Support
		(Assumed as Avail)	TV		(No POCC IF)	Operate

(1) These experiments are operated on night side only

(2) These experiments require STS pointing

(3) TV coverage limited to selected samples only (primarily operations assess aid)

For the baseline case, primary experiment control and monitoring are centered in the POCC except where special factors require or favor onboard control (POCC monitoring is used in all Case 1 experiments). In three cases, onboard control is exercised by preprogrammed sequencers contained in the experiment itself; for Case 1 these are subject to program update command link from POCC, prior to each run activation. While these could perhaps be more easily effected by the crew (via POCC voice and text uplink) directly on the experiment panel, it was elected to apply Case 1 guidelines for maximum POCC control/minimum onboard operations. However, in all cases, experiment activation (initial set up and turn-on) was considered primarily an onboard crew function.

For one experiment (EO-01), because of the complexity of operation (including control feedback and use of the CDMS) and run duration, it was elected to maintain primary control onboard, even for Case 1. In addition, the minilab and cameras require significant crew manual operations and support and are baselined for onboard control, although the POCC contributes by monitoring data and TV and advising.

In addition to the 12 experiments shown here, there are some eight different groups of verification flight test (VFT) instruments including module and pallet instruments. Most of these are passive or require little crew support. They were not individually analyzed; however, their impacts on the data link and on the crew work load were taken into account in the integrated analysis.

3.1.1.1 AP-09 Electron Accelerator

This experiment consists of a high-voltage electron beam discharged into space to evaluate interaction with the ambient and perturbed plasma, length of magnetic field lines, magnetospheric electric fields, and induced atmospheric emissions. A variety of sensors (assumed fixed in the payload bay for Spacelab 1) are used, including a vector magnetometer, low-light-level TV (LLL TV), and electrostatic potential analyzers. Also included are high-pressure nitrogen supplies which vent a plume of gas in the path of the electron beam for viewing by the LLL TV (AP-13). Figure I-3.1 shows the arrangement of the AP-09 main elements interfaced to the CDMS. Data

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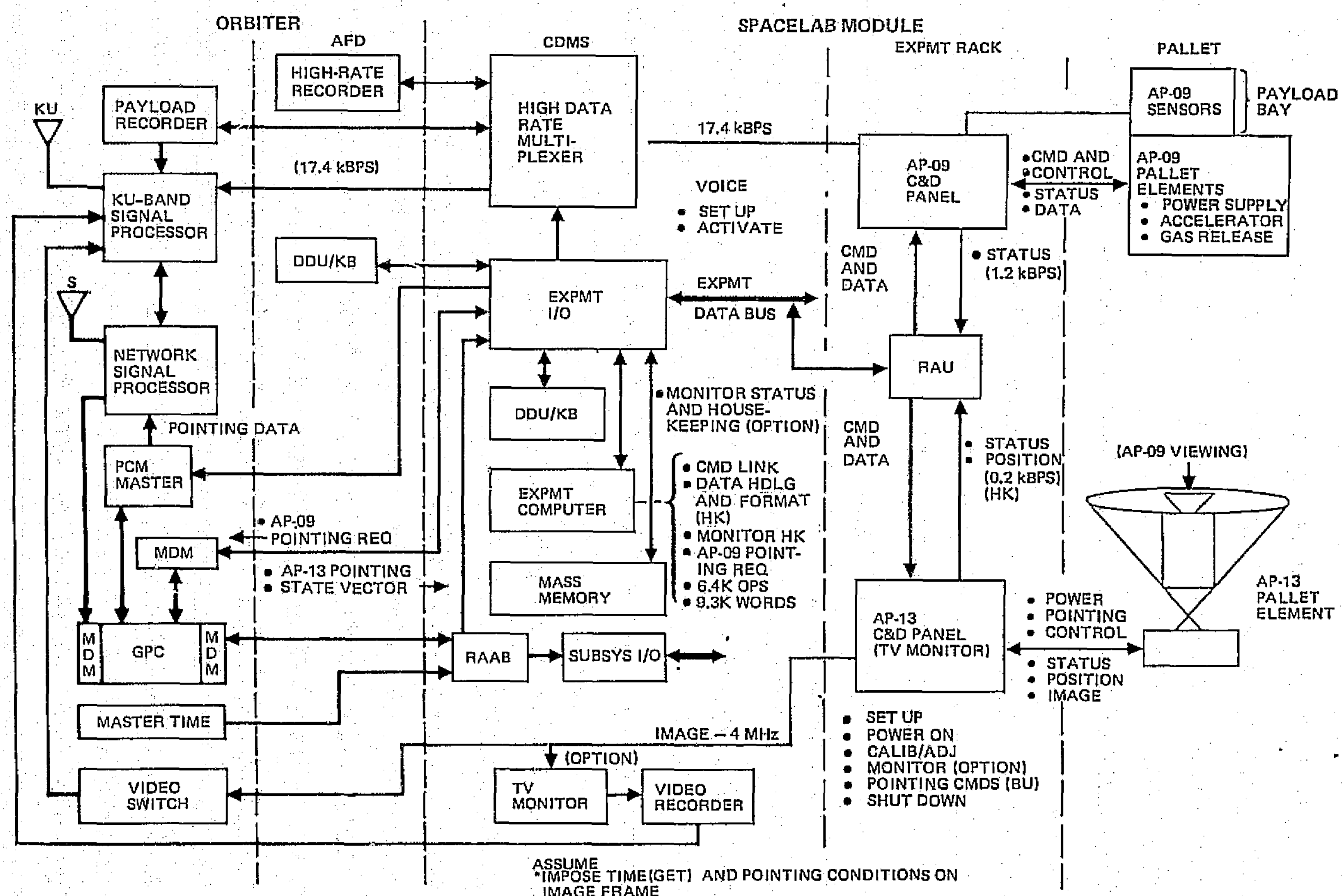

Figure I-3-1. Spacelab 1 AP-09 Electron Accelerator and AP-13 Low Light Level TV, Case 1 Control and Display/Data Processing

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functions and control operations are also indicated for Case 1. Experiment AP-13 (LLL TV), which works closely with AP-09, is also shown.

Operation of the AP-09 experiment requires night side conditions and orientation by STS with respect to the magnetic field and velocity vector. Alignment with the magnetic field is monitored by the Spacelab experiment computer through the magnetometer signals and controlled by forwarding pointing requests to the STS general purpose computer (GPC). Closed-loop pointing control is maintained onboard, even for Case 1, as the most practical approach to maintaining alignment during discharge. It is assumed that onboard override (manual or general purpose computer) or ground command (from MCC) is available if needed. Activation of AP-09 is initiated onboard by a payload specialist at the AP-09 C&D panel (set up and turn-on).

For Case 1, POCC uplinks commands (through MCC) to the experiment computer to load in the AP-09 programs out of mass memory. POCC then initiates the AP-09 programs on coordination and verification by the onboard crew. AP-09 operations and housekeeping are monitored at the POCC by the AP-09 systems engineer; onboard display and monitoring is available to the crew as an option or backup only. Experiment control and beam discharge is assumed to be commanded from the POCC (involves coordination with onboard crew, STS, and AP-13). Sensor scientific data is downlinked directly through the high-rate multiplexer (along with the housekeeping data) to the POCC. Magnetometer data required for STS alignment is also supplied through this data bus to the experiment computer. The downlinked scientific data is monitored by the AP-09 PI and the system scientist to assess operations acceptability. Experiment computer functions are indicated along with estimates of the computer operations per second and memory requirements (AP-09 and AP-13 combined). These estimates were based on the required computer functions and the number of parameters, sample rates, and/or data rates required. With this approach, onboard crew work load, primarily activation, was minimal (0.2 man) when averaged over the run time.

For Case 2, the major changes are (1) deletion of POCC command uplink (operations are centered onboard at the data display unit/keyboard [DDU/KB] and AP-09 panel); (2) data bus access of AP-09 science data (all sensors) for onboard automated monitoring by the experiment computer (data is still directly downlinked through the high-rate multiplexer [HRM] for postflight analysis, but onboard monitoring is limited to a gross assessment as to sensor output); and (3) in conjunction with AP-13, TV display of AP-09 plume discharge onboard to the payload specialist for comment and assessment to the POCC PI (voice-link only). This TV image is still downlinked for ground record as vital to postflight analysis of AP-09 (or AP-13) experiments; however, by definition, it is not available at the POCC in Case 2. POCC and PI control can still be exercised to a limited degree through voice uplink, or preferably by text if complicated, to the onboard payload specialist for input at the DDU/KB or AP-09 panel. The scientific monitor function imposed on the experiment computer increases its load significantly but still within capacity. The load (42K OPS, 30K word) is total (all programs and subroutines) for AP-09 and AP-13; actual load at any instant may be significantly less. The automated monitor function was provided to minimize the monitoring work load imposed on the crew since crew work load, even with added crewmen, appears critical for Case 2. Even with this approach, AP-09 was estimated to require almost a full-time crew (0.9 man) due to activation, TV monitoring, voice link, and control operations.

Case 3 is similar to Case 1, again, but with (1) AP-09 command and control operations onboard and (2) housekeeping and scientific data, including AP-13 TV image, available at the POCC for real-time monitoring and assessment. The required onboard operating programs add only a moderate load on the experiment computer (estimated total is 13K words, 12K OPS maximum). Onboard crew monitoring is minimized, as in Case 1, by effective use of the POCC. However, the increased onboard control function increases crew work load to 0.8 man (almost as high as Case 2, although at a higher level of confidence in a successful operation).

There is no significant onboard hardware differences between cases, and no additions are required to the baselined POCC configuration. Significant software differences occur, however, primarily for Case 2 onboard and for Case 1 at the POCC.

Estimated POCC staffing requirements are shown in Table I-3-3.

Table I-3-3
AP-09 POCC STAFF

Function	Case 1	Case 2	Case 3
Overall assessment/command	1	1/2*	--
Monitor scientific data	1/2	--	1/2
Monitor AP-09/AP-13 TV	1/2	1/2*	1/2
Monitor housekeeping data	1	1*	1
Total	3	2	2

*Per voice link comments only

POCC hardware utilization is maximum for Case 1 (3 CRTs, 1 TV, 1 command panel) and can be met by the planned configuration.

3.1.1.2 AP-13 LLL TV

This experiment is used in combination with the AP-09 electron accelerator and serves as an aspect camera for that experiment. It is also used to detect faint and extended objects in the atmosphere (aurora and airglow). It may also be used as a target search for the wide field galactic camera (ASE-01). LLL TV experiment characteristics and operations applicable to this study are:

- Mounted on a small pointing mount (±45°Z) on pallet. General STS orientations earth, stellar, and magnetic field required during operation.
- Data is analog video (4.2 MHz).
- Housekeeping measurements (<1 kBPS) are monitored during operation.
- Experiment is shut down between runs.
- No set up required after initial activation (unlock, checkout).
- Requires pointing mount operations in conjunction with AP-09 beam viewing, support to ASE-01 target search, and AP-13 unique (atmospheric phenomena).

- Crew involvement is required during data gathering (monitoring and pointing) (Cases 2 and 3).
- POCC involvement is required during data gathering (monitoring for Cases 1 and 3, and pointing for Case 1.
- Real-time visual analysis is required on intermittent basis.
- Deactivation requires lock up and securing mount prior to deorbit.

In Case 1, this experiment will be controlled by ground commands, the pointing mount will be slewed, and the TV camera activated. The interfaces with the CDMS are shown in Figure I-3-1. The ground commands will be processed by the onboard computer and routed through appropriate remote acquisition units (RAUs) to the end items. Housekeeping data will be monitored by the AP-13 system engineer The video signal will be monitored by the PI. Pointing will be controlled from the POCC by the appropriate PI (AP-09, AP-13, or ASE-01). The housekeeping data and the video signal will be monitored intermittently by the flight crew, especially during TDRS data gaps.

In Case 2, the pointing mount and experiment will be controlled and the housekeeping data and the video will be monitored by the flight crew. The video will be downlinked for postflight analysis. The control and monitoring will be accomplished at the DDU/KB or at the dedicated experiment panel. Voice link with the appropriate PI at the POCC will be used to assess and direct the video viewed by the crew.

In Case 3, it is recommended that pointing mount and experiment control be accomplished by the flight crew and that the housekeeping data and video be transmitted to the ground for monitoring and analysis by the AP-13 system engineer and the appropriate PI. The flight crew also monitors video in support of control and pointing operations, rapid response to AP-09 operations, and response to PI direction.

The activities of all three cases can be accomplished with no hardware additions (assumes miniaturized pointing mount analog pointing panel can be used for AP-13 pointing by POCC). The only software changes will require additions to POCC software capabilities, in Case 1, to control the pointing mount and experiment.

Flight crew utilization is low (estimated at 0.2 over the run time) in Case 1. For Cases 2 or 3, because of the increased onboard monitoring and control, crew utilization is almost full-time during runs. POCC personnel supporting the experiment are indicated in Table I-3-4.

Experiment computer functions are indicated in Figure I-3-1 along with estimates of the computer operations per second and memory requirements (combined AP-09 and AP-13). These estimates were based on the required computer functions and the number of parameters, sample rates, and/or data rates required. With this approach, onboard crew work load (primarily activation) was minimal (0.2 man) when averaged over the run time.

3.1.1.3 ST-31 Drop Dynamics

This experiment consists of single rack-mounted equipment to generate drop specimens, inject these specimens into a test chamber, and excite and position them acoustically (three drivers with variable frequencies, power levels, and phasing) while monitoring their physical dynamic properties (oscillations, shape, fission, etc.). Each experiment run is primarily controlled by a preprogrammed sequencer in the experiment hardware (magnetic tape being considered) and data are recorded on three orthogonally positioned film cameras. This includes film edge record, via light-emitting diodes (LEDs), of run number, time, and test conditions. Manual operations include drop

Table I-3-4

AP-13 POCC STAFF

Function	Case 1	Case 2	Case 3
Overall assessment and command*	1	1	1
AP-13 unique experiment video**	1	-	1
Monitor housekeeping data	1	-	-
Total	3	1	2

*Has video display also in Cases 1 and 3 (Case 2 voice-only)

**Not required with AP-09 operations (monitor function met by AP-09 PI).

fluid changes and servicing, film loading, test chamber cleaning, and control panel and TV camera set ups. Limited direct viewing or TV coverage of the test chamber is provided to assist in real-time assessment and subsequent run reprogramming.

Current design goals call for a self-sufficient experiment package with minimum functional interfaces with Spacelab (i. e., no data nor CDMS, no controls, and only power, thermal, acceleration, and timing inputs). All controls and displays are onboard with voice support from ground; experiment data is returned on film.

Figure I-3-2 presents the ST-31 and CDMS interface for Case 1. To operate from the ground, additional flight hardware features would be required, i. e.,

A. Design changes to allow remote panel controls/displays.
B. Basic CDMS components and interfaces (RAU, software).
C. Optics to permit simultaneous TV and film camera.
D. TV camera mount and connection.

Also for Case 1, flight crew support would still be required to change film, clean chamber, etc. Film would still be primary data source. POCC software, data, and TV systems would also be required.

For Case 2, the data bus link is still required to minimize the crew monitoring requirements The TV may be eliminated in favor of direct viewing, if possible, for the voice link comment and assessment to the PI (no TV at POCC). In addition, program changes need to be directly entered by the onboard crew (via DDU/KB or, preferably, the ST-31 C&D panel) since command uplink is not available from the POCC. It is possible that ST-31 CDMS interface may be eliminated for Case 2 if crew monitoring at the rack is permitted; however, adding simultaneous panel monitoring to chamber viewing plus the manual operations, may present an excessive demand on crew time line.

Data downlink via HRM for postflight analysis is not required in Case 2 since the same data is available on the ST-31 film record.

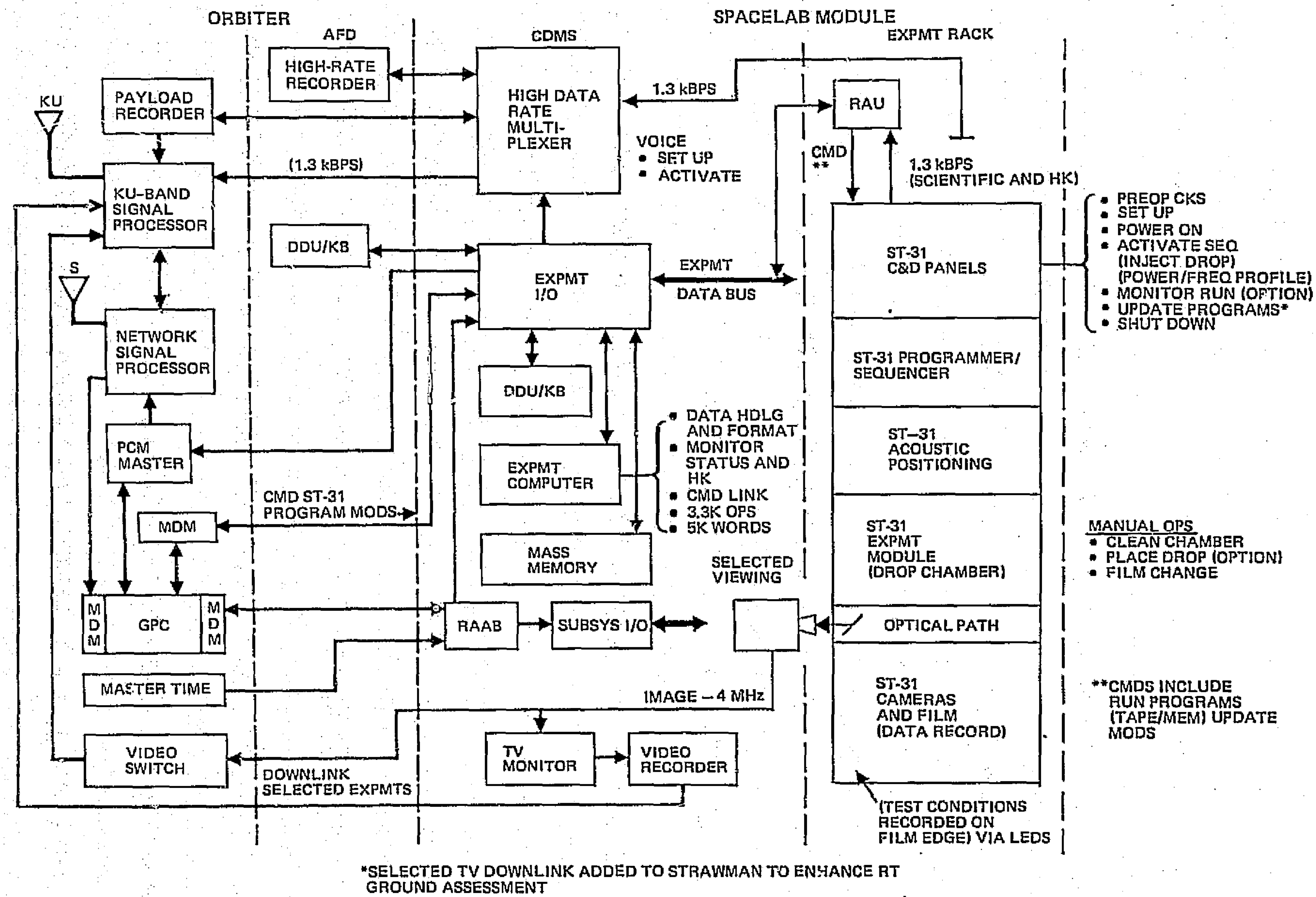

Figure I-3-2. Spacelab 1 ST-31 Drop Dynamics, Case 1 Control and Display/Data Processing

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Figure I-3-3 presents the ST-31 and CDMS configuration for Case 3. This is near the nominal configuration (currently planned) with no direct interface to the CDMS although some method of providing flight timing is required. This might be provided by a minimal input from another experiment RAU. TV viewing and downlink to the POCC PI is provided, however, as a means of enhancing experiment operations and success by allowing real-time assessment and potential program updating (via voice and text uplink-directed crew manual input to the ST-31 C&D panel). The only real-time monitor available to POCC is the selected video viewing. Prime experiment record, for post-flight analysis, is the returned film record. The flight crew may provide occasional ST-31 panel monitoring and comments (voice) to POCC as requested.

Flight crew utilization is estimated (over the run time) at 0.4 men for Case 1, full time for Case 2, and 0.6 men for Case 3. POCC personnel estimates are similar to that presented for AP-09 at three, two, and two for Cases 1, 2, and 3, respectively.

No new hardware procurements are required in any case as the added RAU and connectors for Cases 1 and 2 are assumed available from currently authorized inventory. The minor experiment equipment features such as RAU interface, TV mount, etc., are assumed within the currently conceived equipment scope. POCC requirements can be met by the baseline.

Onboard software requirements are maximized for Case 2 (assuming CDMS monitoring), and POCC software requirements are maximized for Case 1. Case 3 requires no CDMS or POCC software.

3.1.1.4 EO-01 Atmospheric Cloud Physics

This experiment examines the zero-g behavior of gases and aerosols injected into an environmentally controlled test chamber to determine the atmospheric microphysics of cloud formations, dispersion, condensation, thermal transfers, etc. Operation consists of both manual and automated functions interspersed over relatively long run times (2 hours). Data are collected on film and via an electronic data train. Primary control is

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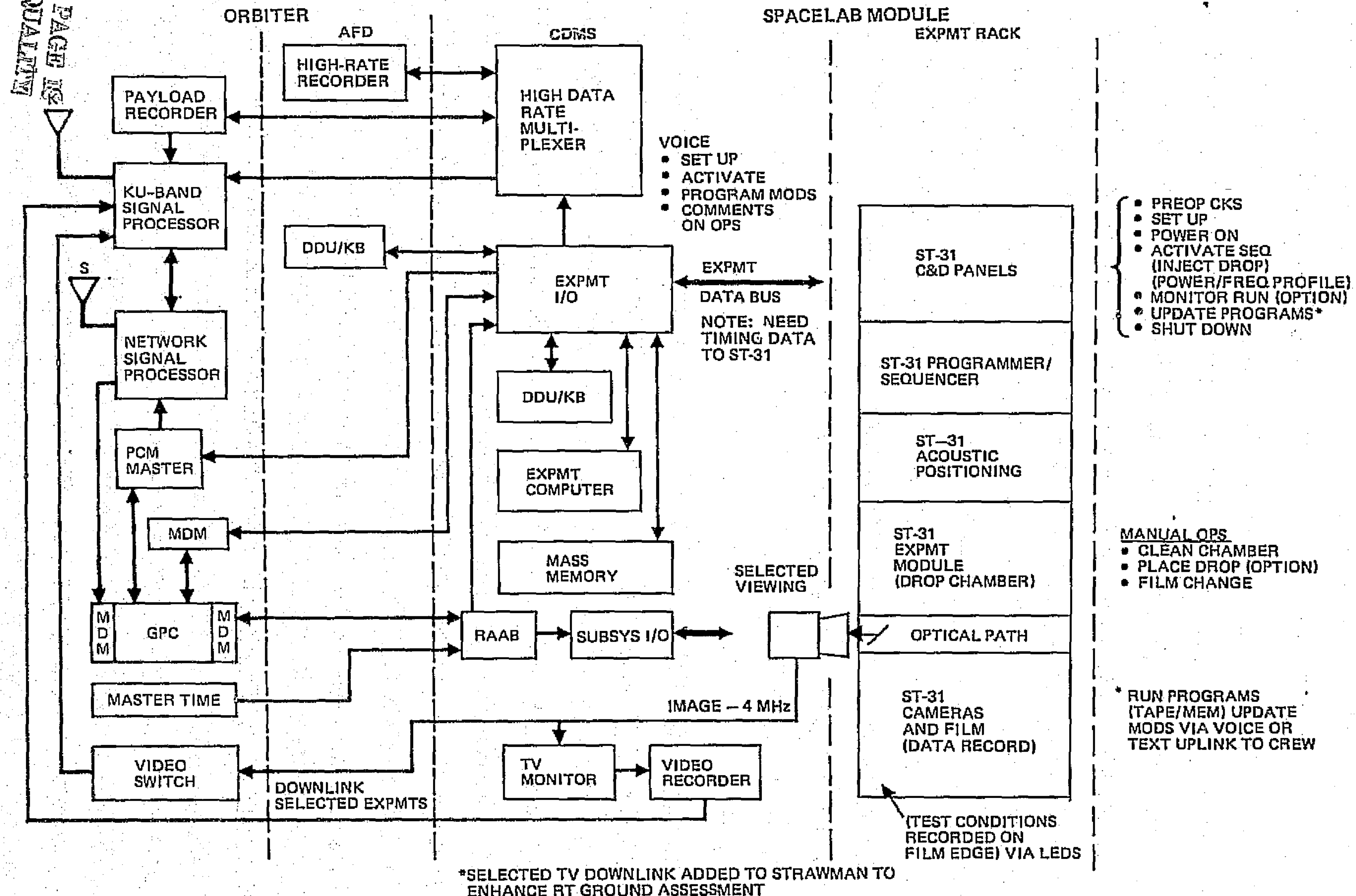

Figure I-3-3. Spacelab 1 ST-31 Drop Dynamics, Case 3 Control and Display/Data Processing

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currently centered onboard in the CDMS and requires closely coupled feedback control loops. The flight hardware configuration is the same for all cases (Figure I-3-4); however, POCC control is impractical due to the Tracking and Data Relay Satellite (TDRS) loss-of-signal (LOS), experiment run time, and close feedback control incompatibilities. For this reason, Case 1 is defined with CDMS onboard control of EO-01. The POCC can monitor and evaluate the EO-01 scientific and housekeeping data stream, and can assess experiment or equipment problems, uplink advice, and program changes (for subsequent runs).

For Case 2, program modifications and updates must be voice and/or text uplinked to the onboard crew for manual entry at the DDU/KB (or EO-01 panel, aerosol manifold, etc., as appropriate); however, POCC PI ability to assess and manage the experiments will be severely limited due to lack of data, except by voice comments or readouts. Onboard crew time to monitor EO-01 could prove excessive. EO-01 is already monitored by the CDMS computer for housekeeping and program operations, and extending this function with additional programs to monitor some of the scientific data for gross correlation and limits, will require additional memory and computer operations. Otherwise, Case 2 is operated basically the same as selected for Case 1. Case 3 is even closer to Case 1 in operation, the only difference being that no command uplink is available since POCC management or changes are via voice and/or text to the crew. The EO-01 data stream is available at the POCC as in Case 1.

Flight crew utilization is lowest for Case 1 (0.4 man) and about the same for cases 2 and 3 (0.7 man) because of the similar control mode and the use of the CDMS for automated monitoring in Case 2.

POCC personnel requirements are estimated as a PI, an experiment scientific monitor, and a system engineer (three) for Case 1, and a PI and system engineer (two) for Cases 2 or 3.

No new hardware is required in any case. Onboard software needs are maximum for Case 2, estimated at up to 47K words memory and 30K OPS computing), and are a minimum for Case 1 (Figure I-3-4).

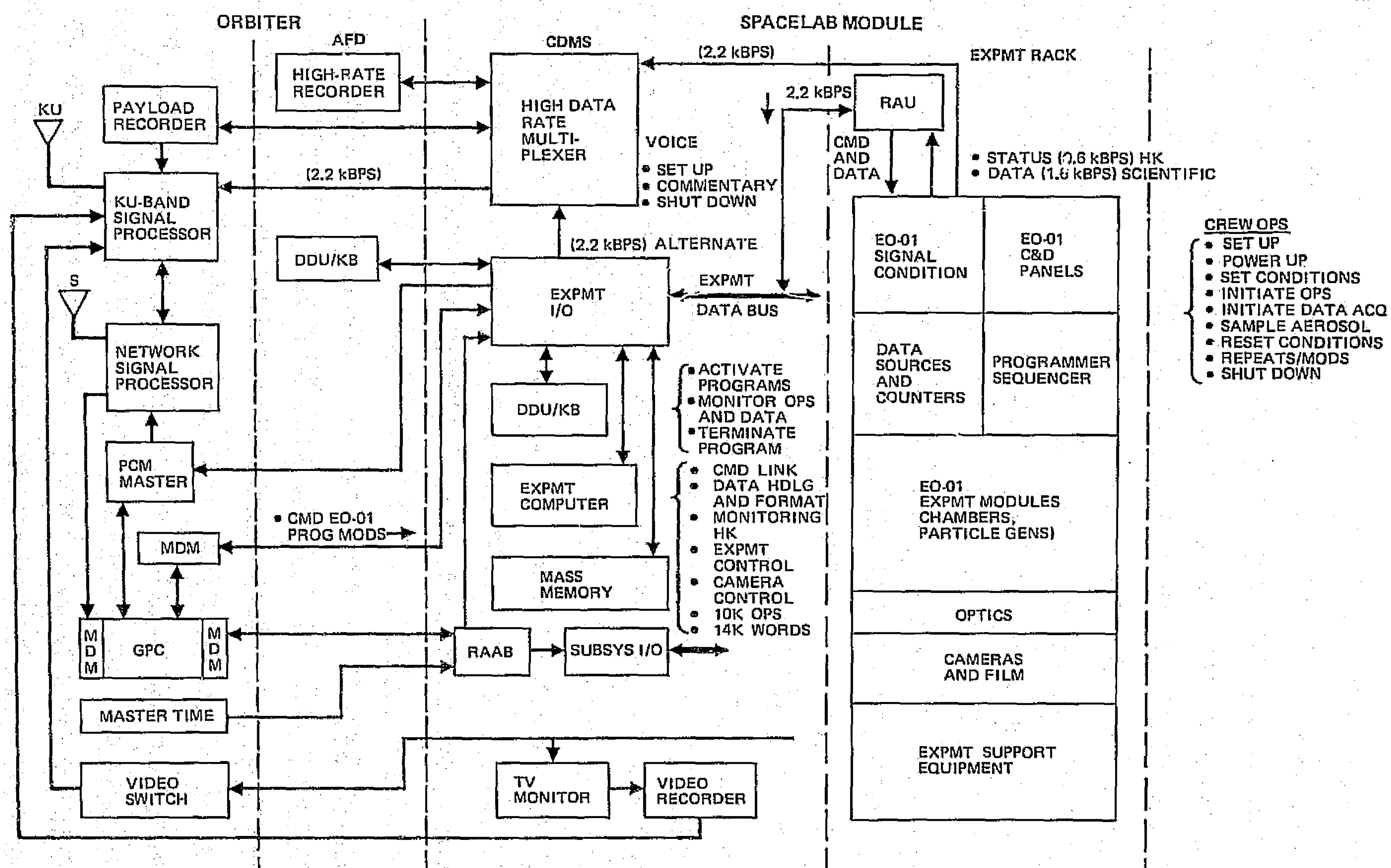

Figure I-3-4. Spacelab 1 EO-01 Cloud Physics, Case 1 Control and Display/Data Processing

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3.1.1.5 LS-13 Minilab

This is a double rack of life science experiments to investigate body fluid redistribution; vestibular function; and cell and tissue growth, development and organization, and to develop accurate urine volume measurement systems. The operation consists of taking biomedical measurements such as blood pressure; collecting, processing, and preserving specimens; and stimulating vestibular function (this is assumed to consist primarily of the frog otoligth experiment). Some of the preceding are mostly manual operations performed by skilled specialists and could not be readily mechanized for remote ground control. Others, such as the cell and tissue growth and vestibular stimulation, while subject to ground control, could also be easily implemented onboard manually or via CDMS programs.

Figure I-3-5 shows the LS-13 and CDMS interface and functions for Case 1. One feature, suggested here, is voice tag with the downlinked data, primarily for postflight analysis convenience since real-time operations will be linked by one of the operational voice channels. In addition, it may be feasible to downlink LS-13 data available to experiment computer by program or direct command via the input/output (I/O) unit output to the HRM. Because of the need for continuous monitoring of certain LS-13 functions, especially housekeeping, it was elected to perform these basic functions onboard with the CDMS to avoid the problem of TDRS data gaps. In addition, this provides a closer control, including automated alert and corrective action, over basic LS-13 functions. Housekeeping data is also available to the POCC (Cases 1 and 3) for more sophisticated assessment and evaluation as necessary. In addition, scientific data is provided in the form of a 7 kBPS data stream (more recent data indicates this may peak at values up to 100 kBPS) as well as selected TV viewing (the 6 MHz request shown may be downgraded to the nominal 4 MHz available in the Spacelab system). In any event, film record is available on return for postflight analysis.

For Case 2, the data stream downlink is the same except for no TV (POCC is limited to voice only and data stream is for postflight analysis). Computer software estimate is increased to 24K words to provide increased automated monitoring of data to minimize crew monitoring requirements.

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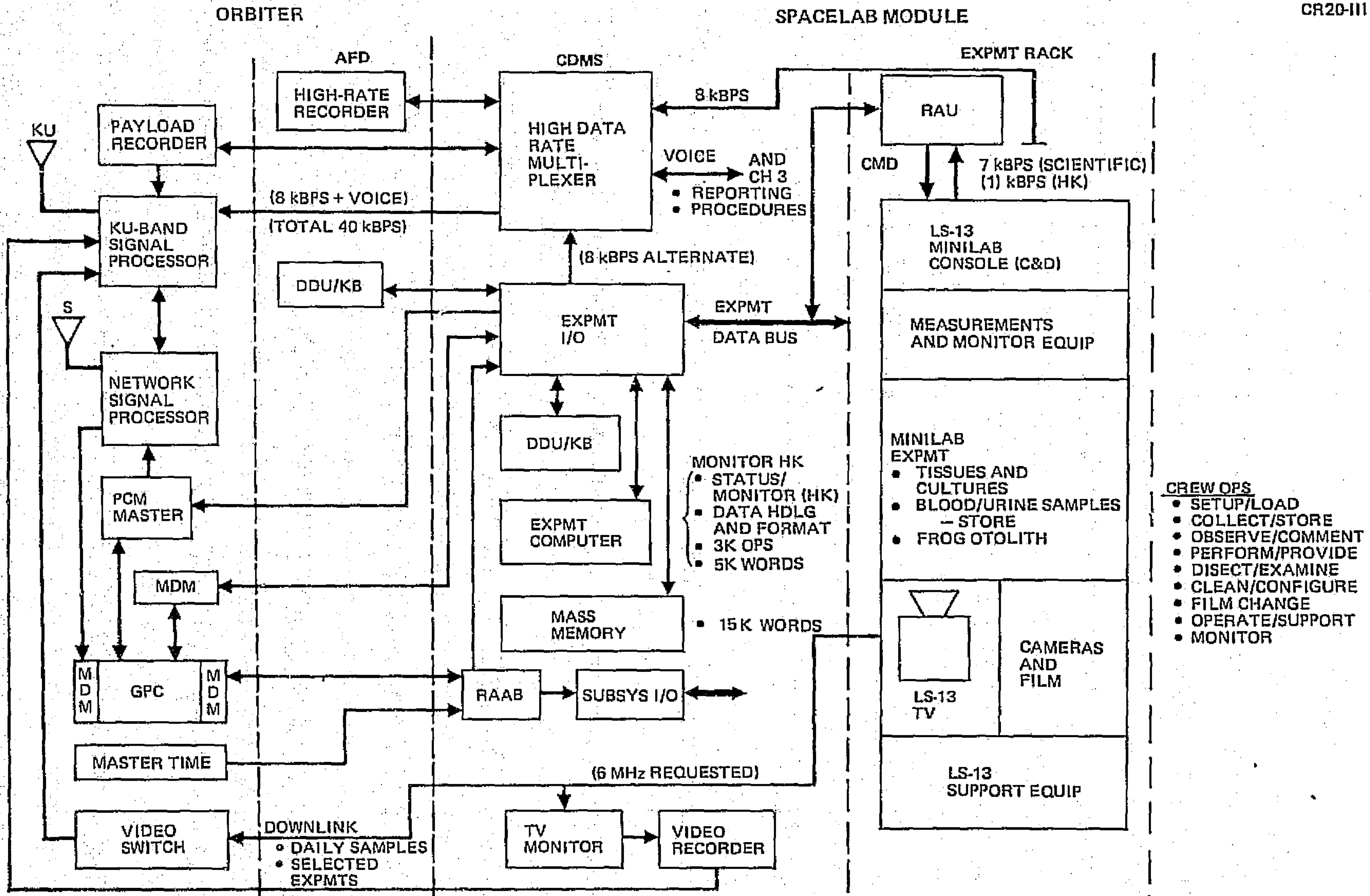

Figure I-3-5. Spacelab 1 LS-13 Minilab, Case 1 Control and Display/Data Processing

Case 3 is the same as Case 1. Flight crew requirements (1.3 men during LS-13 operations) are estimated as the same in all cases since computer monitoring in Case 2 is assumed to supplant POCC monitoring functions.

POCC personnel requirements are similar to that estimated for EO-01 (i.e., three, two, and two for Cases 1, 2, and 3, respectively).

Hardware is the same in all cases. Software is maximum for Case 2 onboard and for Cases 1 or 3 on the ground.

3.1.1.6 APE-01 LIDAR

This experiment uses equipment for sounding the atmosphere in the optical band by laser backscatter techniques in order to define mean structure, temperatures, winds, and distribution of aerosols, atoms, ions, and gases.

The low-power (1-Joule pulse) laser limits operation to night side passes; repetition is four soundings per second once the instrument is aligned and calculated. Possible misalignment requires adjusting the laser optics relative to the receiver. Calibration is achieved by adjusting dye flow to the tunable dye laser and to a reference opacity and density (reference sources assumed provided in experiment). Once initiated, this calibration can be largely automated, as can the operation (STS pointing, laser operation, dye-flow calibration); however, man monitoring and support appears warranted, at least on early missions. Housekeeping functions involve power supply and conditioning and cooling; these are also largely automated in the experiment, but should be monitored by the CDMS with man as occasional monitor, backup, and contingency. Scientific data is produced in rapid bursts (typically 50 msec). Figure I-3-6 presents the APE-01 and CDMS configuration and functions for Case 1.

Primary control and monitoring is executed from the POCC. The flight crew activates the AP-09 panel and performs any required preoperation checks. POCC commands the necessary programs into the onboard computer as well as directs commands to AP-09. The onboard computer monitors status and housekeeping as well as forwards uplink commands and formats housekeeping

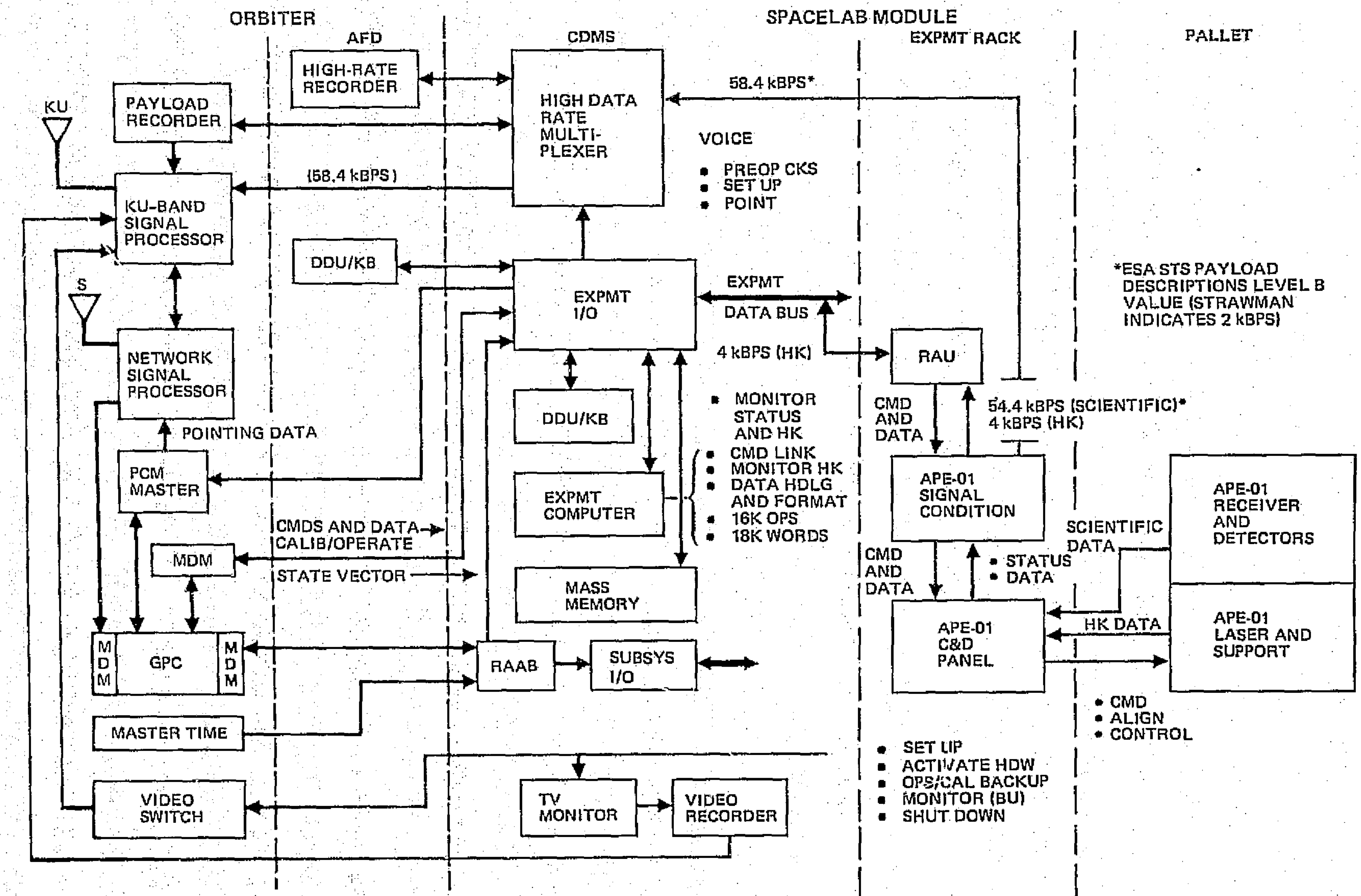

Figure I-3-6. Spacelab 1 APE-01 LIDAR, Case 1 Control and Display/Data Processing

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data for onboard display (for activation and preoperation checks, occasional operations are displayed on demand). APE-09 scientific data and housekeeping data is downlinked directly through the HRM to the POCC for monitoring and assessment.

For Case 2, APE-01 control and monitoring is centered in the CDMS experiment computer. APE-01 pointing requirements are determined from the GPC for execution. Onboard work load is increased for calibration and APE-01 operating assessments; this is partly offset by providing a gross scientific data assessment (sensor limits, output, and logic) to the experiment computer functions. These added functions increase the estimated total onboard computer load to 84K OPS and 50K words (not all required simultaneously).

Onboard crew utilization is increased from 0.4 man (Case 1) to full-time (1.0). This is due to the increased onboard calibration and control, control and monitoring of pointing requirements, and monitoring and assessment of the APE-01 and CDMS operations. Total data stream is still directly downlink, via HRM, for postflight analysis.

Case 3 maintains onboard calibration and control, including determination of pointing requirements, but scientific data monitoring and assessment decreases to about 0.6 man - with minimum onboard monitoring or involvement, once a run is fully initiated. Onboard computer operations decrease to an estimated total APE-01 load of 16K OPS and 23K words.

Onboard hardware and configuration is the same in all cases and maximum POCC requirements (Case 1) of one scientific display and one housekeeping display are within the baseline. POCC software is maximum for Case 1. POCC personnel estimates are two, one, and one for Cases 1, 2, and 3, respectively.

3.1.1.7 SPE-80/85 Space Processing

This experiment provides three furnace facilities for research on processing alloys, particle and fiber reinforced materials, and dispersed superconductors, and purification of metals in a controlled zero-g environment. Specimens are positioned and melted in a closely controlled environment of inert gas. In some cases, the melted specimen is mixed or positioned by acoustics. Specimen selection; specimen insertion, mounting extraction, and stowage; and panel set ups require the flight crew, but other operations are automated by a programmable experiment sequencer. The preprogrammed experiment sequencer would control the furnaces heating, gas composition and pressures, cooling flow, time line, acoustic or mechanical positioning and mixing devices, and data collection. These would include nominal value housekeeping programs and specific experiment programs. This would be subject to reprogramming (program update) onboard via command uplink (Case 1) or direct crew entry (Cases 2 or 3) at either the CDMS or SPE-80/85 C&D panel. Reprogramming would nominally be limited to setting of certain key program parameter values (temperature profile, run time, pressures, etc.) in an existing program.

Scientific data are collected on film and in specimens, with supporting engineering data on equipment performance and test conditions (temperatures, time, pressures, accelerations, and acoustics) supplied via CDMS data train. Individual experiment runs vary from as low as 1 hour to as long as 24 hours, with a typical run time of 4 hours. Up to three runs may proceed simultaneously by using all three furnaces, however, nominal operation would have only one or two runs at a time.

Figure I-3-7 shows the SPE-80/85 elements and their interface and functions with the CDMS for Case 1. As indicated, a TV interface is shown for downlinking news of the specimens to the POCC for experiment assessment and update. Current ESA design does not appear to provide direct viewing into a furnace during operation, in which case, TV downlink would be limited to the selection and installation process and the postrun extraction and examination. This would still be highly useful to the POCC PI in assessing experiment results and subsequent operations.

SPE-80/85 is currently a semiautonomous design with limited operations, status monitor and data acquisition, imposed on the CDMS. For Case 1, this includes a POCC command uplink capability, including updates of the

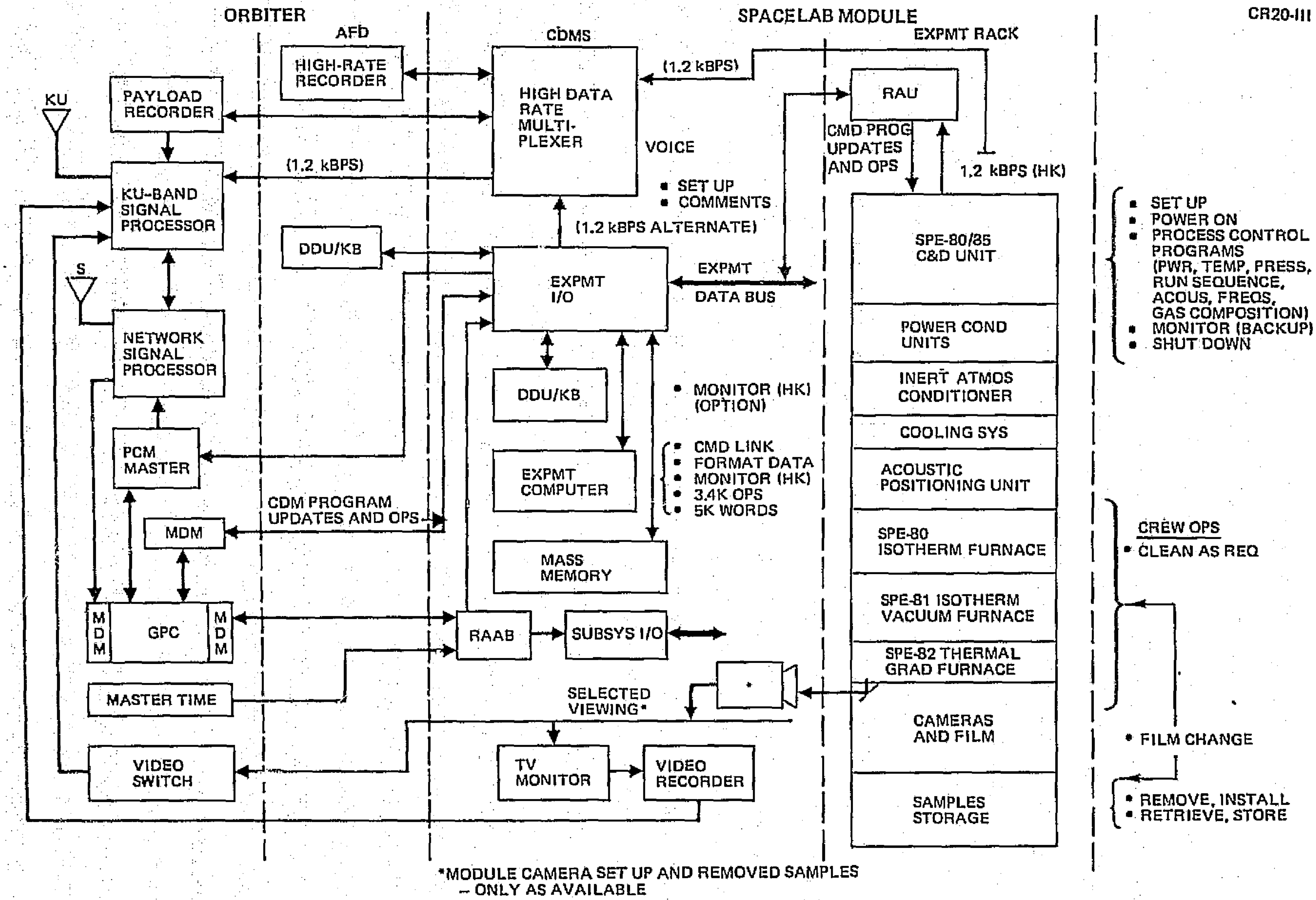

Figure I-3-7. Spacelab 1 SPE-80/85 Space Processing, Case 1 Control and Display/Data Processing

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SPE-80/85 programmer. For Case 2, the TV downlink is not available to the POCC. Experiment observation is limited to the onboard crew (verbal link to POCC) prerun and postrun descriptions of specimens. Real-time viewing of specimen runs depends upon furnace viewports accessible to the crew or to closed-circuit television (CCTV). These would be of more limited value since onboard crew work load would not permit more than occasional monitoring. Program updates from POCC voice, or text, uplink would be entered by the crew at the DDU/KB or SPE-80/85 C&D panel. SPE-80/85 data stream is monitored by CDMS computer to assure proper operation of equipment and runs (this is largely redundant to the experiment-contained control, but is provided for operations assurance to minimize crew monitor requirements in Case 2). This increases CDMS work load estimate to 6K OPS, 16K words.

Case 3 is the same as Case 1 except that control is executed onboard via voice or text uplink.

Crew utilization is estimated at 0.3 man for Case 1 (primarily the necessary manual operations), 0.7 for Case 2 (visual monitoring and conveying to POCC by voice), and 0.4 for Case 3 (Case 1 plus control function).

POCC personnel requirements during runs is estimated similar to that for AP-09, i.e., three, two, and two for Cases 1, 2, and 3, respectively. No added hardware requirements were identified.

3.1.1.8 SPE-01 Free-Flow Electrophoresis

The free-flow electrophoresis facility includes all equipment to perform automatic electrophoretic separations for analytical and preparative purposes. The dimensions of the separation chamber are in the order of 180 by 30 by 4 mm (fluid cross section). A buffer solution is pumped through the separation chamber by means of a rate-controlled peristaltic pump. Biological samples are injected near the upstream end of the chamber at a predetermined rate. An electrical field is applied perpendicular to the buffer flow which deflects the samples at different angles depending on their electrophoretic mobility. At the downstream end of the separation chamber, the fraction obtained is collected by a series of small tubes into a compartmented storage rack. The results may be observed visually by an optical window. Data recording is possible either photographically or via a special optoelectronic data acquisition device which generates an electrical signal derived from the concentration of light-absorbing material (fractions) along a cross section of the separation chamber.

In addition to the basic equipment described, some auxiliary equipment is necessary to support the main function.

A. In order to remove gas bubbles generated by electrolysis, a separate purge fluid loop is provided. To prevent gas from penetrating into the buffer flow, both electrodes are separated from the active volume by an ion exchange membrane.

B. As live biological samples are used, special provisions must be made for temperature control. The separation chamber is cooled by a liquid cooling loop to withdraw the heat generated by electrolysis processes. As chamber low temperatures (+5°C) are required, active cooling is provided.

C. In order to keep the samples alive for the mission duration, the sample fraction storage volume is cooled to an average temperature of ±2°C. As continuous cooling, even during ascent and descent, is required, a dedicated battery module has to be used.

Figure I-3-8 shows the SPE-01 and CDMS elements and functions. Crew operations include set up and reduction of buffer fluids and flow rates; set up and installation of fraction collection; activation of buffer flow which is automatically controlled; selection and injection of samples into the flows; monitoring of separation through density scan readouts or direct visual, if feasible; isolation, removal, and storage of collected fraction rack; clean up and purge; and film change.

During the actual flow run, the process (flow rate, purge loops, voltage level, temperature, etc.) is controlled by the selected experiment program (DDU/KB or SPE-01 C&D panel) in the experiment sequencer. Experiment data is provided to the CDMS for monitoring housekeeping and for format and display at the DDU; it is also directly downlinked through the HRM.

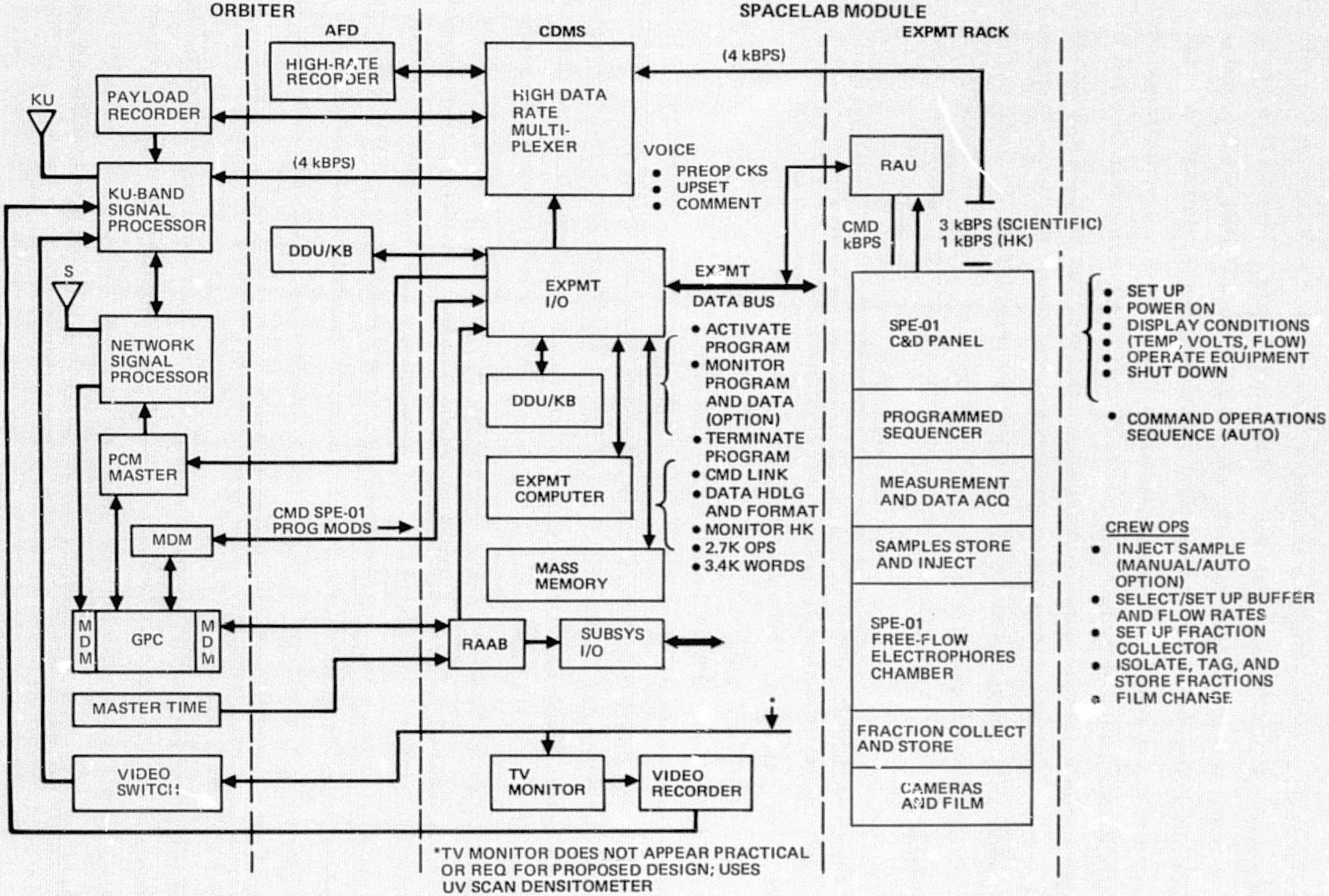

Figure I-3-8. Spacelab 1 SPE-01 Free-Flow Electrophoresis, Case 1 Control and Display/Data Processing

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For Case 1, command uplink to SPE-01 is provided to adjust and modify the run per the POCC PI assessment of downlinked data. For Case 2, program modifications are entered directly via DDU/KB or SPE-01 C&D panel per POCC PI voice and/or text direction. The experiment demands a large degree of crew support despite automated run control. To minimize crew demands for onboard monitoring (Case 2) the CDMS computer is used to monitor the scientific output (density counts, etc.) as well as key housekeeping parameters. This increases computer work load to an estimated 6K OPS, 13K words. Case 3 is like Case 1 except POCC PI does not have direct control access (crew entry onboard through CDMS or SPE-01 C&D panel).

Crew utilization is estimated at 0.5 man or Case 1, and 0.8 for Cases 2 and 3. POCC personnel is estimated at three, two, and two for Cases 1, 2, and 3, respectively. No hardware additions are required in any case.

3.1.1.9 EOE-01 Metric Camera

This experiment utilizes a high-resolution, geometrically accurate camera (visible and near) for earth mapping and for calibration reference for the more experimental earth-imaging sensors. The camera is gimbal-mounted at the optical viewing window during operation and is removed and stowed when not in use. Interval timing and slew control is by CDMS computer which requires Orbiter state vector data. Destowing, installation, film loading, panel set ups, calibration, removal, and restowing are manual. Actual operation for data-taking can be manual but will normally be automatically timed with target acquisition and pointing by the CDMS computer update from the STS state vector. The flight hardware configuration (Figure I-3-9) remains the same for all cases, with software and manpower emphasis being the primary differences.

Data consist primarily of housekeeping and status (temperatures, film number, power levels, time, optics settings, and gimbal angles). It is suggested that some of these key parameters be recorded, via LEDs, on the film edge if feasible to facilitate correlation. At any rate, this data is monitored and operated (primarily targeting, steering, and operation) by the CDMS. The

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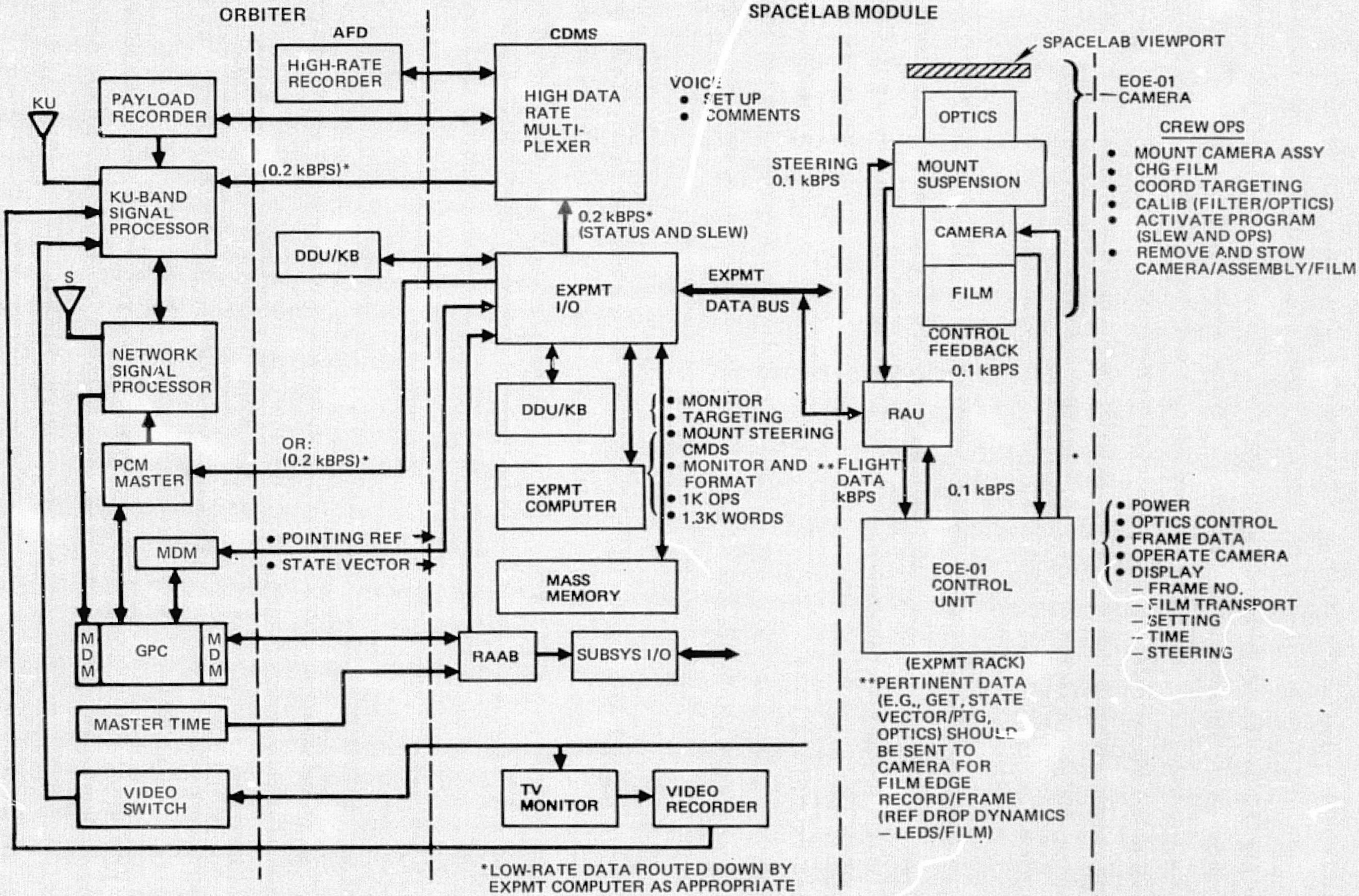

Figure I-3-9. Spacelab 1 EOE-01 Metric Camera, Case 1 Control and Display/Data Processing data is also downlinked through the experiment computer I/O unit via the experiment I/O unit line to the HRM or down the 64 kBPS operational line to the PCM, if available (data is very low rate). The mode may be preprogrammed or selectable by command. An alternative would be onboard record, however, downlinking would be needed to comply with Case 1 ground rules and allow a degree of camera operation real-time evaluation and assessment at the POCC. This mode of data retrieval, which is necessary for postflight analysis of the film record, appears suited to the Cases 2 and 3 also.

For Case 1, pointing requirements could be determined at the POCC from STS state vector projections and provided to the CDMS for execution; however, it would seem more practical to center this function onboard, as in Cases 2 and 3, and supply the pertinent pointing information to the POCC for monitor and record. Primarily, EOE-01 lends itself to onboard control and operation and differences between cases is primarily limited to providing for some increases to automated monitoring (2K OPS, 4K words) of camera operation and conditions for Case 2 to minimize crew work load.

Crew utilization is estimated as full-time during manual operations, but dropping to 0.1 man (Case 1) and 0.5 man (Cases 2 or 3) when averaged over the run period. Case 1, which depends upon a high degree of POCC control as well as monitoring, may be impractical. POCC staffing is estimated at one man (PI) over the run period in every case. No hardware differences were identified.

3.1.1.10 APE-07 IR Radiometer

This experiment consists of six identical radiometers used to measure atmospheric temperatures and distribution of constituent gases as a function of altitude, space, and time. Five of the radiometers share a single limb-scanning system, while a reference measurement channel is directed at the reference altitude. Each radiometer has two channels except for a CO_2 reference detector. A black body calibration reference can be imposed on each radiometer. Housekeeping and scientific data (70 kBPS) acquired by the pallet-mounted instrument is provided to the APE-07 control panel mounted in a module rack (Figure I-3-10). This is then downlinked through the HRM

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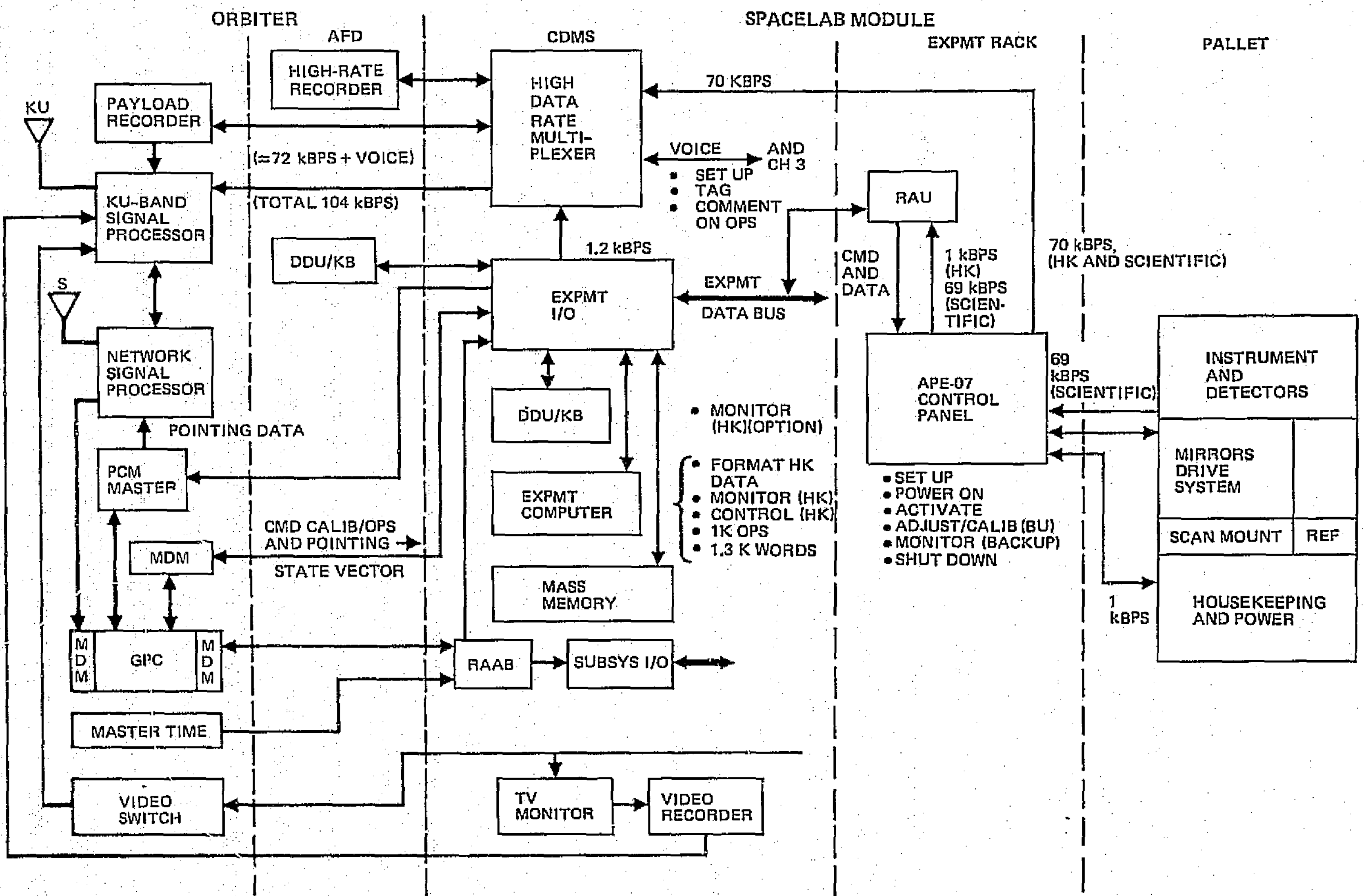

Figure I-3-10. Spacelab 1 APE-07 IR Radiometer, Case 1 Control and Display/Data Processing

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to the ground for postflight analysis (all cases) and for real-time experiment operation monitoring at the POCC (Cases 1 and 3 only). For Cases 1 and 3 only, housekeeping and operations data (1 kBPS) is routed through an RAU, from the APE-07 panel, to the CDMS for onboard monitor and control operations. For Case 1, primary control is from the POCC. For Cases 2 and 3, primary control is onboard from the CDMS which provides an operating and scanning program based on experiment pointing requirements and STS state vector updates (basic viewing orientation is provided by the Orbiter). Calibration is primarily provided onboard through the provided instrument references and appropriate CDMS program.

For Case 1, once activated by the crew, APE-07 will be operated from the POCC through call-up and monitoring of the CDMS and APE-07 programs and the APE-07 downlinked scientific data stream. For Case 3, these programs will be called up and initiated by the crew with POCC primarily involved in monitoring and assessing APE-09 scientific data. For Case 2, scientific data is also provided to the CDMS for onboard monitoring and verification of sensor operations and data limit checks. This will significantly increase the experiment computer work load (estimated at 20K OPS, 27K words for Case 2).

Crew utilization over APE-01 run time is estimated at 0.2 man for Case 1 and 0.4 for Cases 2 and 3 (increased onboard control). POCC personnel include a PI and an APE-07 system engineer for all cases, and an additional APE-07 experiment data monitor for Case 1 (PI performs this function for Case 3). No new hardware requirements were identified. Some APE-07 onboard software is required in all cases, but is maximum for Case 2.

3.1.1.11 STE-10 Heat Pipe

The purpose of this experiment is to evaluate the heat transfer capabilities of heat pipes in zero-g. Heat is transferred from a source (an electronic control box) by heat pipes to a thermal capacitor and then through a one-way heat pipe to a heat rejection point (Spacelab water loop). Operation requires turning on and off the heat source, via a manual or a preprogrammed automation mode, and monitoring temperature distribution through the system, using approximately 10 monitoring points. Figure I-3-11 shows the system components and the interfaces with the CDMS. Data functions and control operations for Case 1 are also shown.

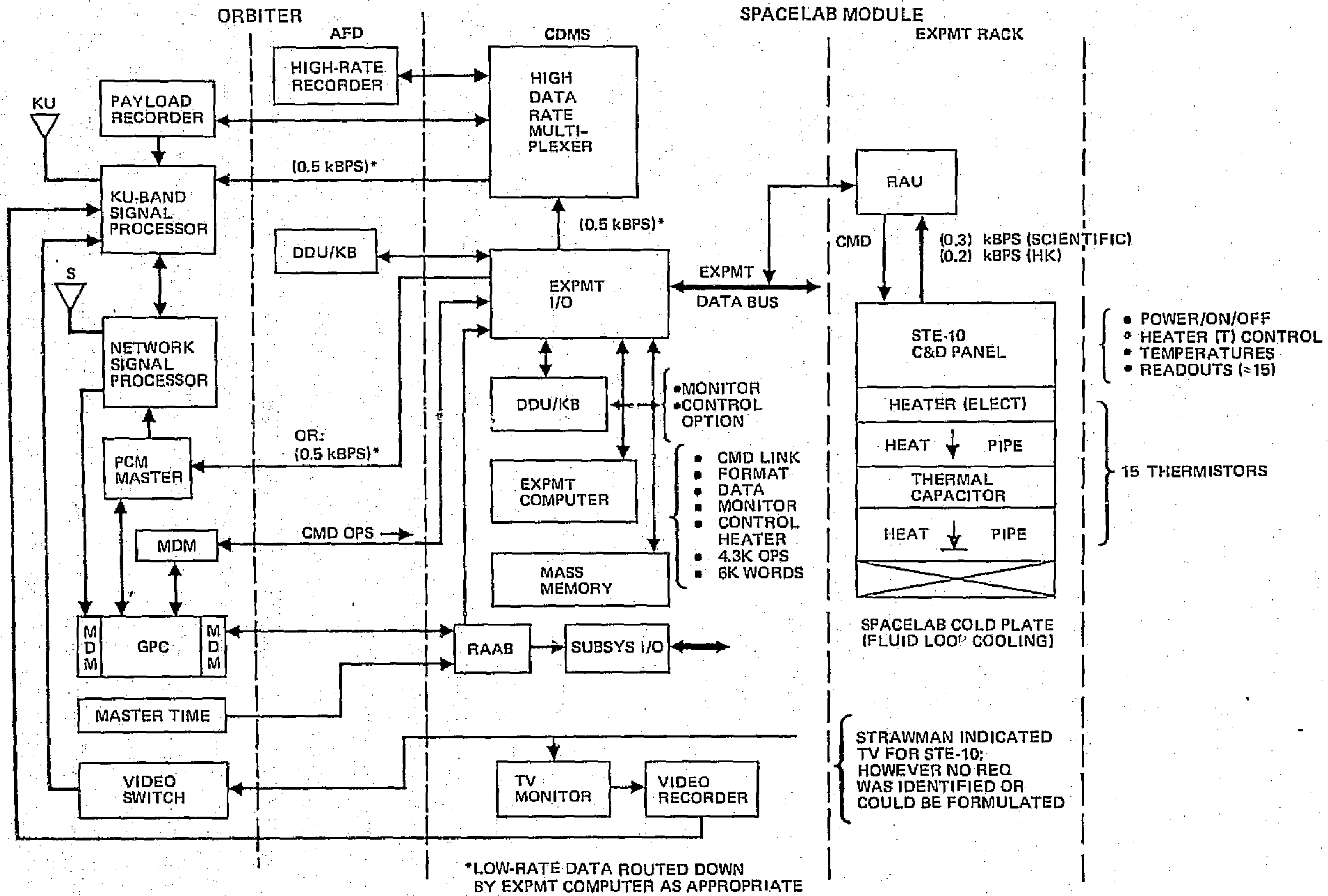

Figure I-3-11. Spacelab 1 STE-10 Heat Pipe, Case 1 Control and Display/Data Processing

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In Case 1, the control of the experiment and the monitoring of the system temperatures is accomplished by the ground through the experiment computer and appropriate RAU. Data analysis accomplished by the PI in the POCC will identify changes to the test or will determine the requirements for subsequent tests. The flight crew will support the ground personnel by monitoring experiment operation, especially during TDRS data gaps.

In Case 2, the control of the experiment and monitoring of the data will be the responsibility of the flight crew. This will be accomplished at the DDU/KB or the experiment C&D panel. Information downlinked to the POCC via the voice link will permit the PI to evaluate the operations and assist the flight crew in evaluating the data.

In Case 3, the control of the experiment will be performed by the flight crew and monitoring and evaluation of the data will be accomplished in the POCC. The flight crew will also monitor the data and, in conjunction with the PI, evaluate the operation and determine changes.

Crew utilization is estimated as 0.1, 0.5, and 0.5 man for Cases 1, 2, and 3, respectively (increased monitoring and control in Cases 2 and 3). POCC requirements are estimated as two, a PI and an STE-10 engineer, for Cases 1 and 3, and one PI for Case 2.

There is no onboard hardware differences and no additions are required to the baseline POCC configuration.

3.1.1.12. ASE-01 Wide-Field Galactic Camera

This experiment uses a wide-field (120° by 60°) camera to map extended objects, i.e., galactic equator, zodiacallight, sky background, etc. Exchangeable filter modules, automated or possibly manual, with four ranges (from 1500 Å to 9000 Å) are used to gather photographic data. (TV as a targeting aid is optional.) The camera is launched in the Spacelab airlock and is deployed outside the airlock before film exposure. The airlock inner door is opened only for camera servicing, film and filter changes. Camera access and servicing is, of course, manual; data-taking operations can be manual or automatic. Camera changeout (various film types) is a planned capability. AP-13 may be suitable to provide targeting search. The flight hardware configuration (Figure I-3-12) is the same for all cases. With minor software and manpower differences, most control and display is onboard with POCC displays and capability to initiate or sequence data taking for Case 1.

As with EOE-01, camera operation and status is available on a low-rate data stream routed to or through the CDMS computer and downlinked, to the POCC in Cases 1 and 3, via the HRM (Experiment I/O unit input) or 64-kBPS operational line as preprogrammed or selected. For Case 2, this data stream is available only for postflight analysis, and the TV target search option is not available to the POCC. Onboard crew may use the CCTV, possibly with AP-13, to perform this function in coordination with the POCC PI via voice link.

Crew utilization is estimated as full-time (1.0 to 1.5 men) during deployment or changeout, and at 0.3 man (Case 1) or 0.5 (Cases 2 or 3) over a typical run time. Airlock operations imply contingency provisions for EVA.

POCC requirements are estimated as one man, PI, over the run period in every case. No hardware differences were identified.

3.1.2 Spacelab 2 Individual Experiment Analysis

A Spacelab 2 experiment complement, consisting of the ten experiments listed in Table I-3-5, was assessed to determine impacts on ground and flight mission operations and resultant program costs. These experiments, selected from the astronomy, solar physics, and high-energy astrophysics disciplines, are installed on two 6-meter ESA pallet trains with controls, indicators, and support equipment installed on the Orbiter AFD or in the ESA Igloo. No pressurized Spacelab module is assigned to this mission.

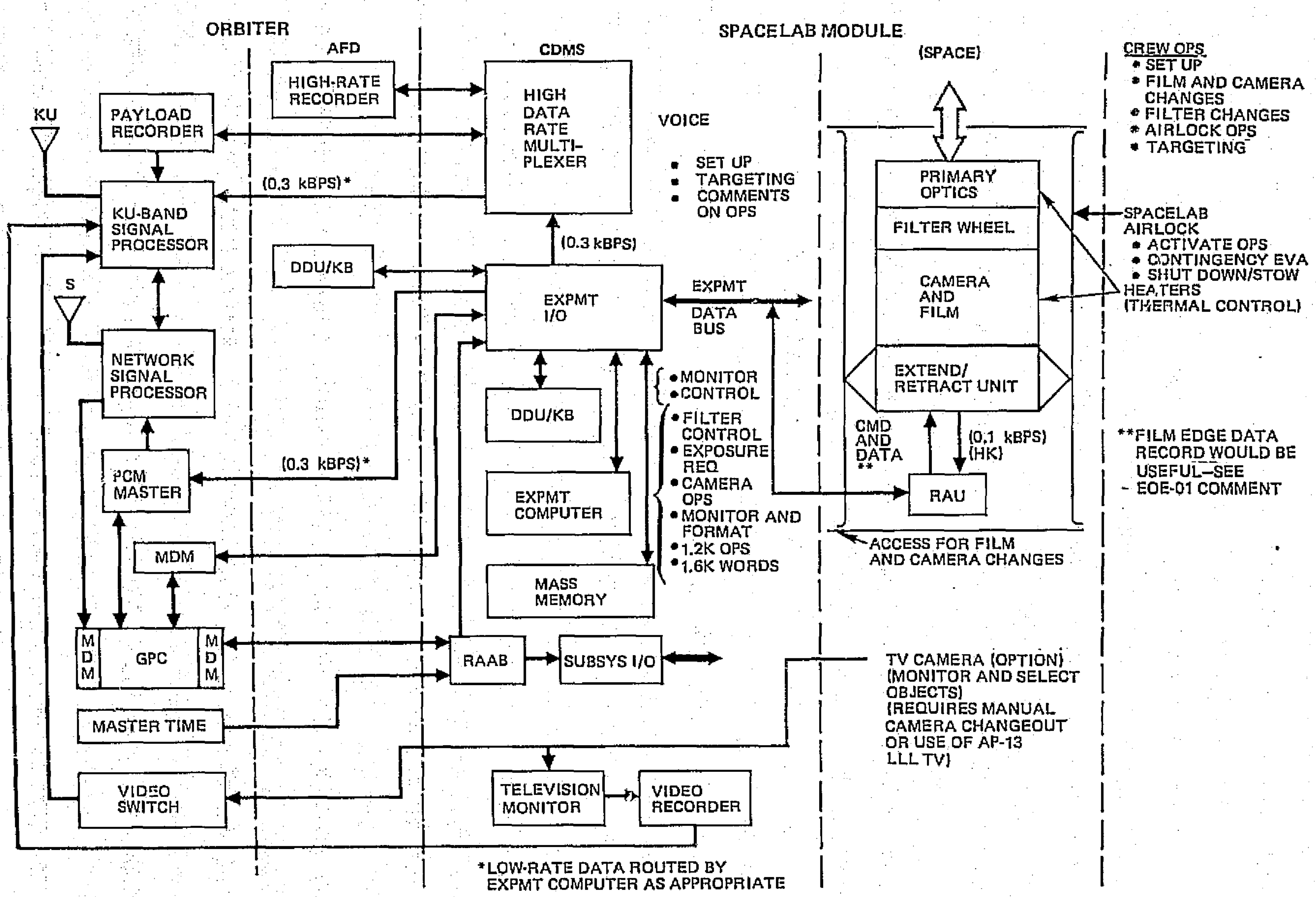

Figure I-3-12. Spacelab 1 ASE-01 Wide-Field Galactic Camera, Case 1 Control and Display/Data Processing

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The solar experiments, numbers 1 through 5 in Table I-3-5, are mounted on an Instrument Pointing System (IPS). The far ultra-violet (UV) Schmidt camera/spectrograph, low-light-level television (LLL TV), and Skylark cosmic x-ray telescope are mounted on a miniaturized pointing mount (MPM), while the remaining two experiments are hard-mounted on the pallet.

Table I-3-5
SPACELAB 2 EXPERIMENTS

1.	65-cm photoheliograph
2.	Solar monitor package
3.	Soft x-ray telescope
4.	Lyman-Alpha white-light coronagraph
5.	High-sensitivity x-ray burst detector
6.	Skylark cosmic x-ray telescope
7.	LLL TV
8.	Far UV Schmidt camera/spectrometer
9.	Transition radiation spectrometer
10.	Extreme UV imaging telescope

Each experiment was analyzed for each of three cases of onboard versus ground capability (see Subsection 1.1), and the impact on experiment operations was determined. The interfaces of each experiment with the Orbiter and Spacelab CDMS was defined. The Spacelab 2 Strawman was used as a guide for mission analysis and planning, and a preliminary timeline was used to determine experiment activities.

The following subsections contain the individual analyses performed for each experiment and its operation with the onboard versus ground capability necessary to support the experiment.

3.1.2.1 65-cm Photoheliograph

This experiment is used to obtain high-resolution photographs of solar features. It is used in combination with other solar experiments and also in combination with the extreme UV imaging telescope to obtain stellar photographs. Sixty-five-cm photoheliograph experiment characteristics and operations applicable to this study are:

- Mounted on IPS.
- Data is gathered on film.
- TV camera is part of unit and is used to provide identification of what is being observed.
- Housekeeping measurements (≈12) are monitored during operation.
- Experiment is not shut down between runs.
- Setup includes programming of filters, etc. Experiment runs through program automatically.
- Crew involvement is small during data run (intermittent viewing of TV).
- No real-time data analysis.

The operation of the 65-cm photoheliograph in Case 1, where maximum POCC operations are employed, requires that ground control be used to slew the IPS to the sun or stellar object, set up the proper filter sequences, and then initiate the data-taking cycle. The interfaces with the CDMS is shown on Figure I-3-13. These ground commands will be processed by the appropriate Spacelab computer through a subsystem or experiment RAU to the end item. The television camera in the experiment will provide real-time presentation of the target being observed. All scientific data gathered by the photoheliograph is recorded on film contained within the experiment. Housekeeping data, indicating experiment health and program run conditions, will be telemetered to the ground for evaluation in the POCC by the PI. The TV and housekeeping data are also available for the onboard flight crew to monitor experiment activities in support of ground personnel, espeically during TDRS data gaps.

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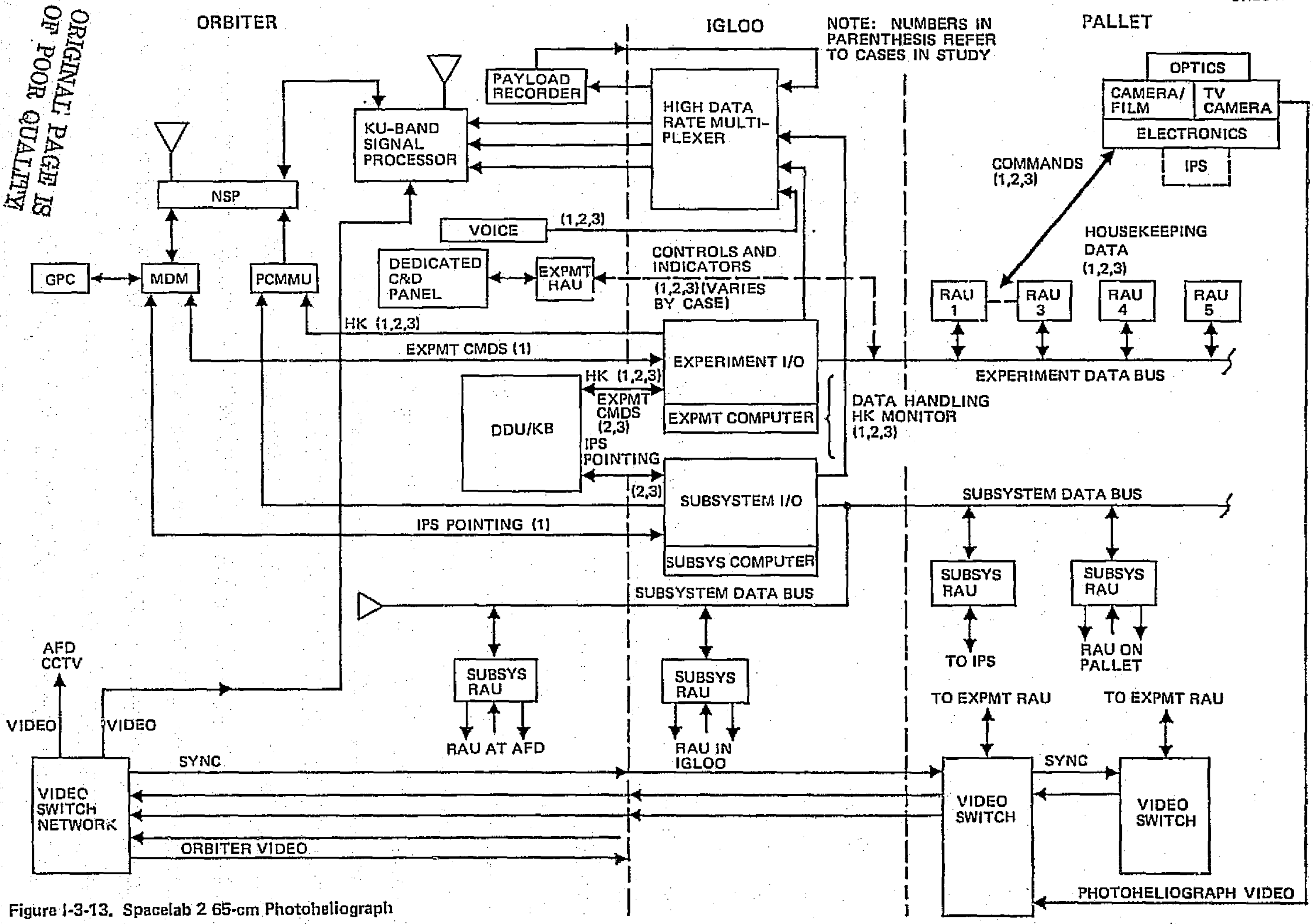

Figure I-3-13. Spacelab 2 65-cm Photoheliograph

Case 2 requires that the command and monitoring activities be accomplished by the flight crew. In this case, the uplink IPS pointing commands and experiment commands will be eliminated, and the downlink TV and housekeeping data will not be available in the POCC. Only voice communication will be provided between the flight crew and the POCC. The commands and monitoring will be accomplished at the DDU/KB or at the dedicated experiment C&D panel, both located in the Orbiter AFD. Interface with the IPS and experiment will be as in Case 1, through the appropriate computer and RAU. The housekeeping data will be monitored by the flight crew to check the health and operation of the experiment while the TV will be monitored intermittently to verify the target being observed.

In Case 3, it is recommended that the control of the IPS and experiment be performed by the on-orbit flight crew while the major monitoring of experiment operation and health be accomplished by the PI at the POCC. Flight crew support can be provided to the PI, as required, and monitoring will be provided during TDRS data gaps.

The activities of all three cases can be accomplished with no hardware additions to the POCC or to onboard systems. Control of the IPS or experiment will require no new addition to software onboard; however, additional software must be provided at the POCC to provide control of the IPS.

Flight crew utilization is slightly less for Case 1 than for the other cases because more functions are being performed on the ground; however, in all cases, the utilization is low because set-up time is small (1 to 2 minutes) and monitoring is only intermittent. Ground personnel supporting the experiment would be the same for the three cases except that no pointing engineer is required for Case 2.

3.1.2.2 Solar Monitor Package

This experiment is used to obtain high-resolution solar images and to measure solar magnetic fields. During this mission it is used in combination with other solar experiments. Solar monitor package experiment characteristics and operations applicable to this study are:

- Mounted on IPS.
- Data rate of 50 kBPS.
- TV camera is part of unit and is used to provide identification of what is being observed.
- Housekeeping measurements (≈ 30) are monitored during operation.
- Experiment is not shut down between runs.
- Set up includes programming of experiment filters, etc. Experiment runs through program automatically.
- Crew involvement is small during data run (intermittent viewing of TV).
- Some real-time data analysis is required to identify presence of unique magnetic fields.

This experiment consists of three sensors (Hydrogen Alpha [Hα] camera, an x-ray ultraviolet [XUV] monitor, and a magnetoheliograph) which are operated simultaneously.

In Case 1, the solar monitor package will be controlled by ground commands. The IPS will be slewed to the sun, the experiment program filters and sequences will be set up and the data-taking initiated. The interfaces with the CDMS to accomplish these operations is shown in Figure I-3-14. The ground-originated commands will be processed by the Spacelab computers and routed through appropriate RAUs to the end item. TV cameras in the experiment will provide real-time presentation of the target being observed. Scientific data will be downlinked to the POCC and will be evaluated by the PI to determine the presence of unique magnetic fields. The TV and housekeeping data will be monitored by the PI to determine proper operation of the experiment. The TV and housekeeping data is also available onboard for monitoring by the flight crew to support the ground operations, especially during times of TDRS data gaps.

The flight crew activities accomplished in Case 2 are similar to those performed by the ground in Case 1. The IPS and experiment are controlled by crew direction and the TV and housekeeping data are intermittently monitored to verify operation. However, the data output of the experiment, a 50 kBPS digital stream cannot be continuously processed and analyzed by the onboard

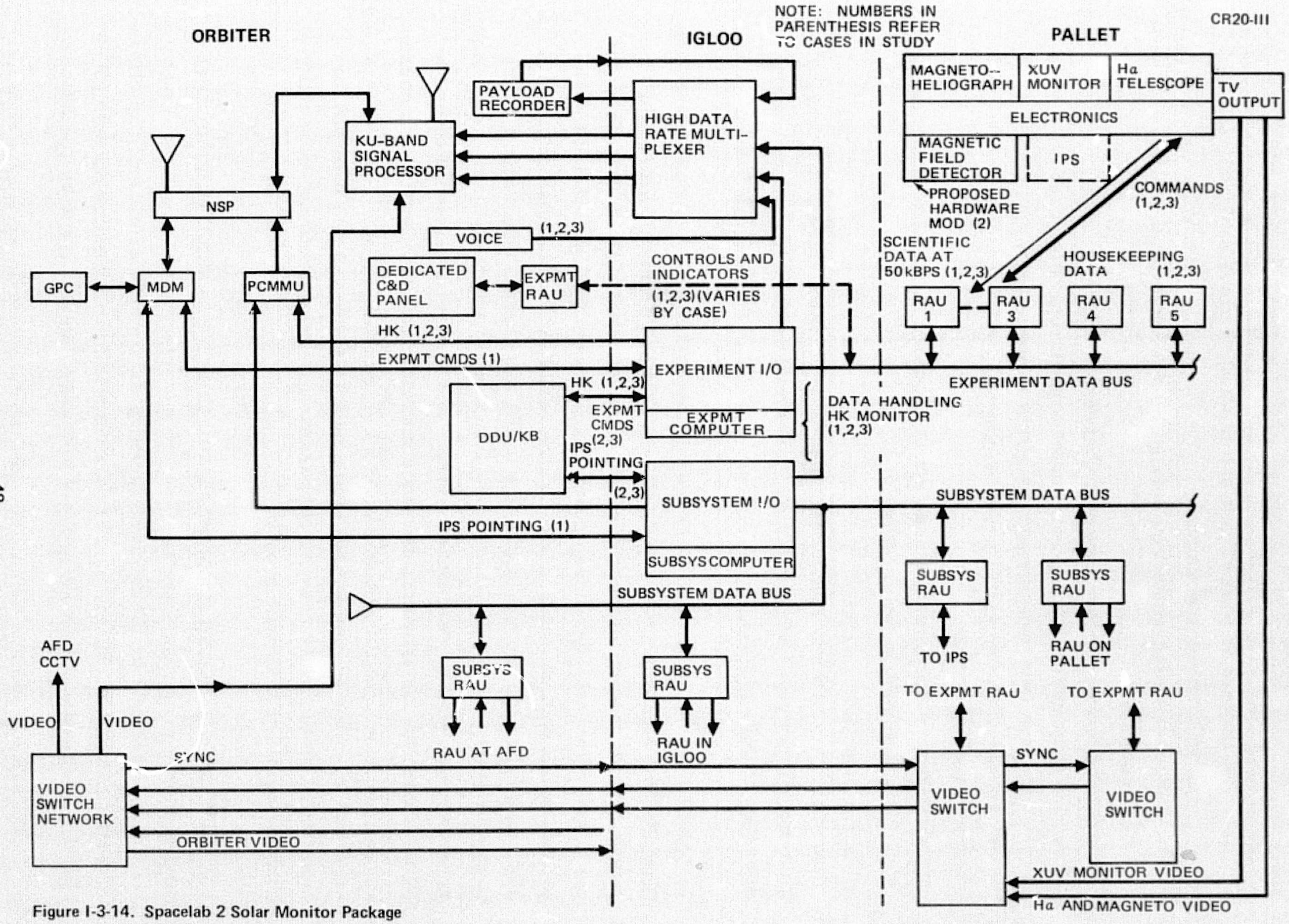

Figure I-3-14. Spacelab 2 Solar Monitor Package computer. This information, in Case 1, can be handled by the ground computing facility and magnetic fields can be identified. In order to increase the experimental scientific return of Case 2 identification of unique magnetic fields which might require additional data acquisition, it is recommended that a detector be developed as an integral part of the experiment. This detector will alert the flight crew of the presence and location of unique magnetic fields, and, with the use of the voice link to the PI, permit the crew to determine if additional data runs are required.

In Case 3, it is recommended that the flight crew control the IPS and the experiment. The TV, housekeeping data, and scientific data should be downlinked to the POCC for PI evaluation as in Case 1. In this case, as in Case 1, the addition of the magnetic field detector will not be required. During data acquisition, the flight crew will be required to monitor the TV and housekeeping data on an intermittent basis, mainly during times when there are TDRS data gaps.

The activities of all three cases can be accomplished with no hardware additions to the POCC and only the addition of the magnetic field detector identified for Case 2. Control of the IPS or experiment will require no new additions to software onboard; however, additional software must be provided at the POCC for Case 1 for control of the IPS.

Utilization of the flight crew is slightly less for Case 1 operations because the ground personnel are controlling the IPS and experiment. However, flight crew activities are not large in any of the cases, because set up time is minimal and monitoring is required only intermittently.

Ground personnel required to support the experiment are the same for all cases except that no pointing engineer is required for Case 2.

3.1.2.3 Soft X-Ray Telescope

This experiment is used to study solar phenomena and physical properties. It is used in combination with other solar experiments and contains two sensors, an x-ray telescope, and proportional counters. Soft x-ray telescope experiment characteristics and operations applicable to this study are:

- Mounted on IPS.
- Data is gathered on film.
- Housekeeping measurements (≈9) are monitored during operation.
- Set up consists of a mode selection. Experiment runs through program automatically.
- Experiment is shut down between runs.
- Crew involvement is small during data run (monitoring).
- No real-time data analysis.

In Case 1, the telescope operations will be controlled by ground commands; the IPS will be slewed to the sun, the experiment mode will be selected, and the data run will be initiated. The interfaces with the CDMS are shown on Figure I-3-15. Ground commands will be processed by an onboard computer and routed to the IPS or experiment through the appropriate RAU. Scientific data is gathered on film however, housekeeping data will be downlinked to the POCC so that the PI can monitor the operation and health of the experiment. This housekeeping data is also available for intermittent monitoring by the flight crew, especially during TDRS data gaps.

In Case 2, the command and monitoring activities are accomplished entirely by the flight crew and the limited voice interface with the ground will be utilized to assist the crew with the operations. The commands and the monitoring will be accomplished at the DDU/KB or at the dedicated experiment C&D panel, both located in the Orbiter AFD. Interface with the CDMS equipment will be, as in Case 1, through the appropriate computer and RAU. Housekeeping data will be monitored by the flight crew to check the health and operation of the experiment.

In Case 3, the control of the IPS and experiment should be maintained by the flight crew while monitoring of the housekeeping data should be performed by POCC personnel. Intermittent monitoring will be provided by the flight crew to cover operations during TDRS data gaps.

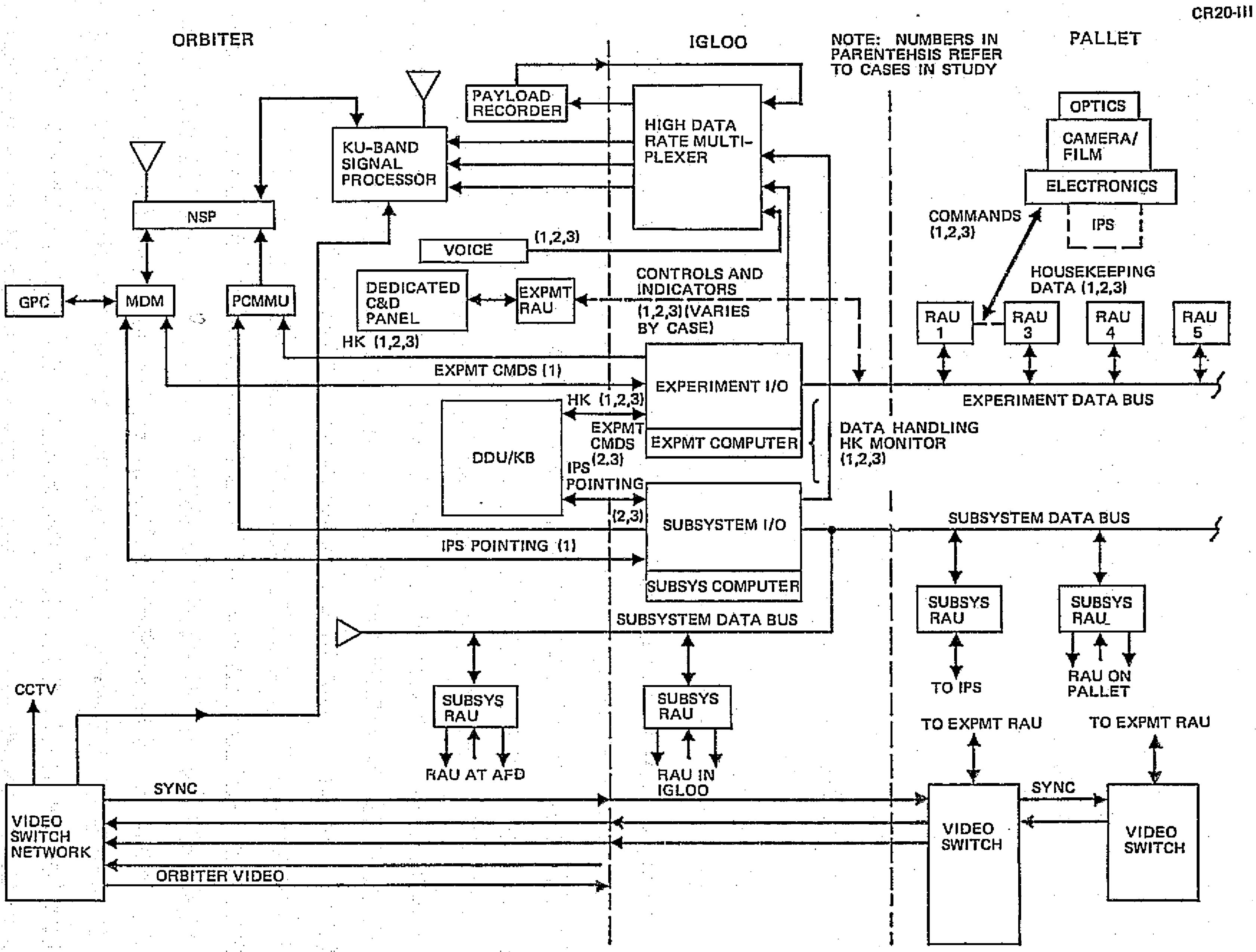

Figure I-3-15. Spacelab 2 Soft X-Ray Telescope

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No additional POCC or flight hardware is required for this experiment in any of the cases. However, additional software would be required for the POCC only to provide for control of the IPS.

Utilization of the flight crew is nearly the same for all cases, being only slightly less in Case 1, because all functions are accomplished by ground control. However, because set up time is only a few minutes and monitoring of housekeeping data is only intermittent, the overall utilization in each case is low.

Ground personnel required to support the experiment are the same, except in Case 2 where no pointing engineer is required.

3.1.2.4 Lyman-Alpha White-Light Coronagraph

The purpose of this experiment is to obtain high-resolution images of the sun and to study the solar corona. It is used in combination with other solar experiments and consists of two sensors, one which analyzes the sun in the Lyman-Alpha (Lα) wavelength (1216 Å) and the other which photographs the sun (the white-light coronagraph [WLC]). Lyman-alpha WLC experiment characteristics and operations applicable to this study are:

- Mounted on IPS.
- Data is gathered on film (WLC) and a 200 kBPS data train (Lα).
- Housekeeping measurements (≈40) are monitored during operation.
- Experiment is shut down between runs.
- No set up is required. After initiation, experiment runs through program automatically.
- Crew involvement is small during data run (monitoring).
- Some real-time data analysis is required on the Lα output.

The operation of this experiment requires, in Case 1, that ground control slew the IPS to the sun and activate the sensors. The experiment will run through the program automatically without additional commands. The interfaces with the CDMS are shown in Figure I-3-16 with the ground commands being processed by the appropriate flight computer and routed to the end items through a subsystem or experiment RAU. The scientific data from the WLC is recorded on film while the data from the Lα is downlinked on a

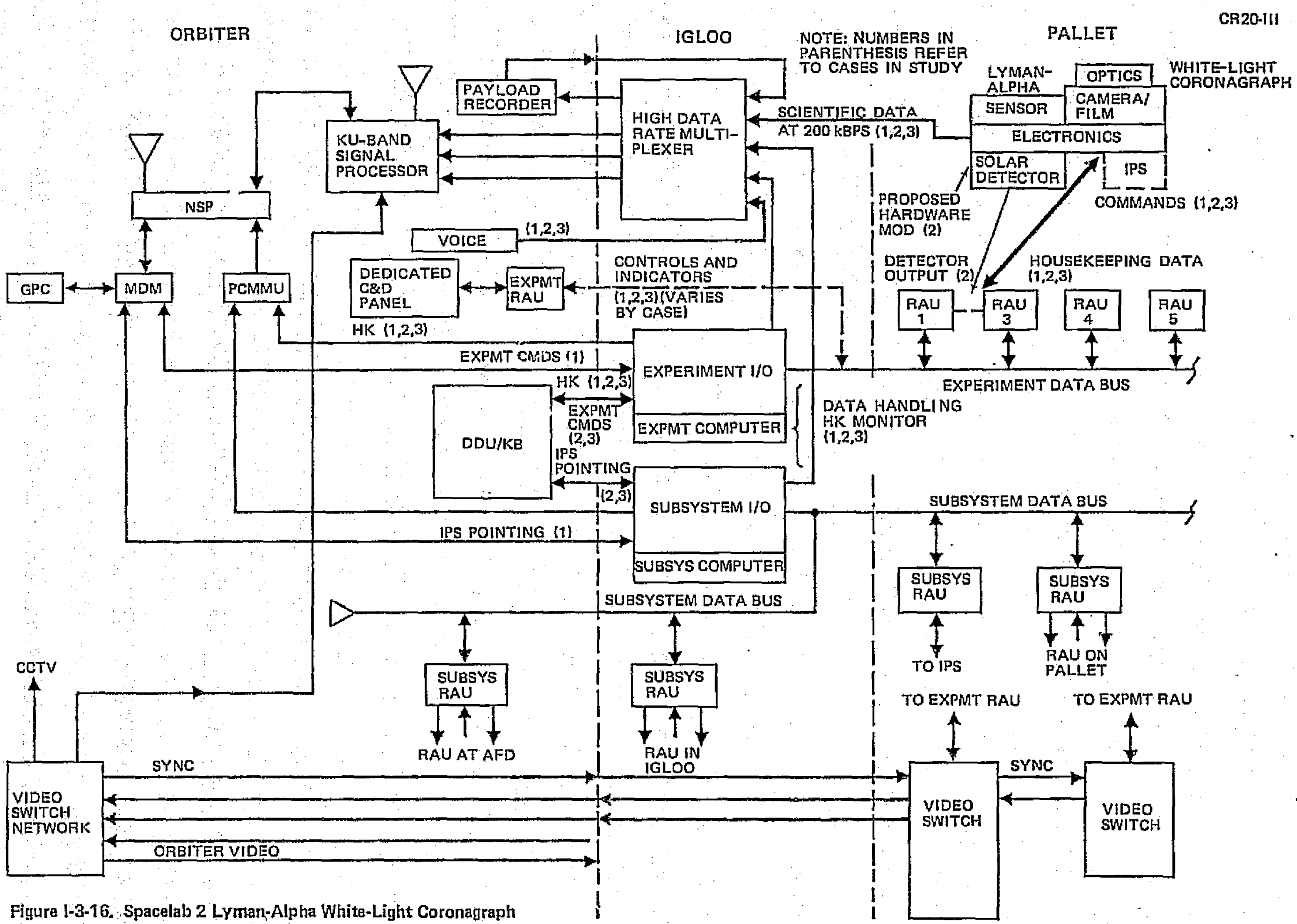

Figure I-3-16. Spacelab 2 Lyman-Alpha White-Light Coronagraph

200 kBPS data train for monitoring and analysis by the PI. Housekeeping measurements for both sensors will be telemetered for evaluation by the ground personnel. The housekeeping data will also be available for the flight crew, in support of ground personnel, to monitor the health and operation of the experiment, especially during the TDRS gaps.

For Case 2, the command and monitoring of the experiment will be accomplished by the flight crew. This will be performed in the AFD at the DDU/KB or at the dedicated experiment C&D panel. Interface with the end items will be through appropriate computers and RAUs. The flight crew will monitor the health and operation of the experiment using the housekeeping data. However, it is necessary to monitor the output of the Lα sensor to determine the occurrence of solar phenomena which might require additional data runs. The continual analysis of the output data, at 200 kBPS, would require a large computer capability. This can be accomplished in Case 1 by the ground-based computer but would not be within the capability of the flight computer. Consequently, it is recommended that a detector be developed and incorporated into the Lα equipment to detect solar phenomena and alert the flight crew of the presence and location of them. The flight crew, in conjunction with ground personnel via the voice link, can then determine if additional data runs should be conducted.

In Case 3, it is recommended that the control of the IPS and the experiment be maintained by the flight crew and that, as in Case 1, the monitoring and evaluation of scientific and housekeeping data be accomplished by the PI in the POCC. The addition of the solar detectors will not be required for this case. During data acquisition, the flight crew will be required to monitor housekeeping data on an intermittent basis especially during TDRS gaps.

No additional POCC hardware additions are required for any of the three cases, and only the addition of the solar detector was identified for Case 2. Control of the IPS or experiment will require no new additions to software onboard; however, additional software must be provided at the POCC for Case 1, for control of the IPS.

Flight crew utilization is less for Case 1 than Cases 2 or 3 because ground personnel are controlling the experiment. However, since set-up time is small and only intermittent monitoring is required, the flight crew activities are not large in any of the cases.

Ground support for the experiment is the same for all cases except that no pointing engineer is required for Case 2.

3.1.2.5 High-Sensitivity X-Ray Burst Detector

This experiment is used to investigate x-ray emissions of the sun. It is used in combination with other solar experiments. High-sensitivity x-ray burst detector experiment characteristics and operations applicable to this study are:

- Mounted on IPS.
- Data rate of 60 kBPS.
- Housekeeping measurements (≈10) are monitored during operation.
- Experiment is shut down between runs.
- No set up required. After activation, experiment runs through program automatically.
- Crew involvement is small during data gathering (monitoring).
- No real-time data analysis.

In Case 1, the burst detector will be controlled by ground commands, which will slew the IPS to the sun and initiate data-taking. The interfaces with the CDMS are shown in Figure I-3-17. The commands will be processed by the Spacelab computers and routed to the IPS and experiment through appropriate RAUs. Scientific and housekeeping data will be downlinked to the POCC for monitoring by the PI to determine proper operation of the experiment. The housekeeping data is also available for onboard monitoring by the flight crew, especially during TDRS data gaps.

Flight crew activities, in Case 2, include the control of the IPS and activation of the burst detector. The scientific data will be downlinked to the ground for analysis later in the mission or after mission completion. No onboard analysis is required. During Case 2 operations, the crew will monitor the housekeeping measurements to verify experiment operation. Onboard control and monitoring will be accomplished at the AFD DDU/KB or the

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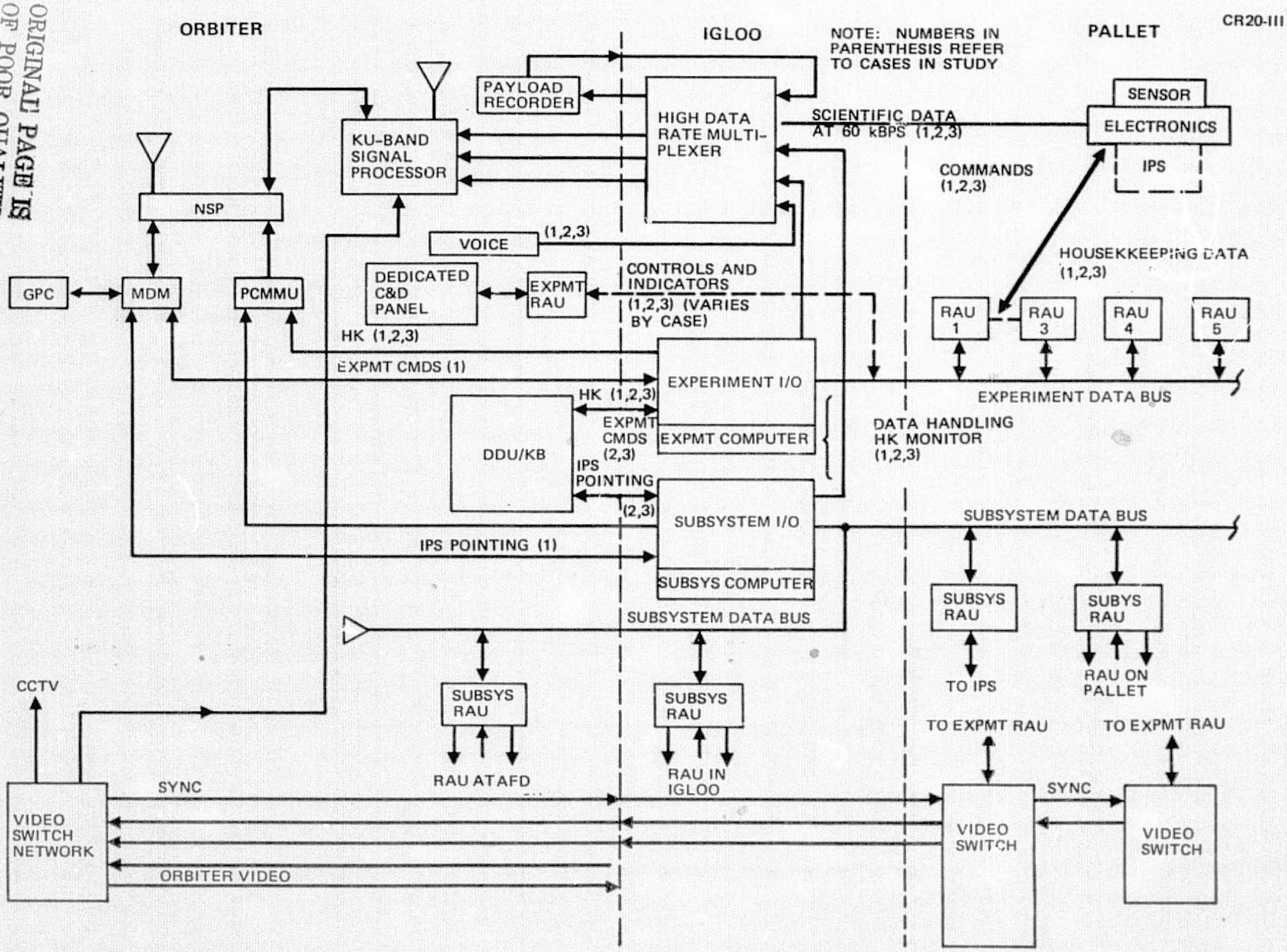

Figure I-3-17. Spacelab 2 High-Sensitivity X-Ray Burst Detector dedicated experiment C&D panel. Interface with the CDMS, the IPS, and experiment will be through the appropriate computer and RAU.

In Case 3, the control of the IPS and experiment should be maintained by the flight crew while monitoring of the scientific and housekeeping data should be performed by the PI at the POCC. Intermittent monitoring of the house-keeping data will be accomplished by the flight crew, especially during times of TDRS data gaps.

No additional hardware is required at the POCC or onboard to support this experiment. However, additional software is required for the POCC only to provide for control of the IPS.

Flight crew utilization is essentially the same for all cases, with only slightly less support required in Case 1. Because there is no set up required and since monitoring of housekeeping data is intermittent, overall utilization in each case is low. Ground personnel support is the same for all cases except that no pointing engineer is required for Case 2.

3.1.2.6 Skylark Cosmic X-Ray Telescope

This experiment is used to map x-ray sources in space. It is used in combination with the LLL TV. Skylark cosmic x-ray telescope experiment characteristics and operations applicable to this study are:

- Mounted on MPM.
- Data rate is 4 kBPS.
- Housekeeping measurements ($\approx$5) are monitored during operation.
- Experiment is shut down between runs.
- No set up required. After activation, experiment runs through program automatically.
- Crew involvement is small during data gathering (monitoring).
- No real-time data analysis.

The operation of this experiment, in Case 1, will be by ground commands; the MPM will be slewed to the spatial target, and the data run will be initiated. The interfaces with the CDMS are shown on Figure I-3-18. The ground commands will be processed by an onboard computer and routed to

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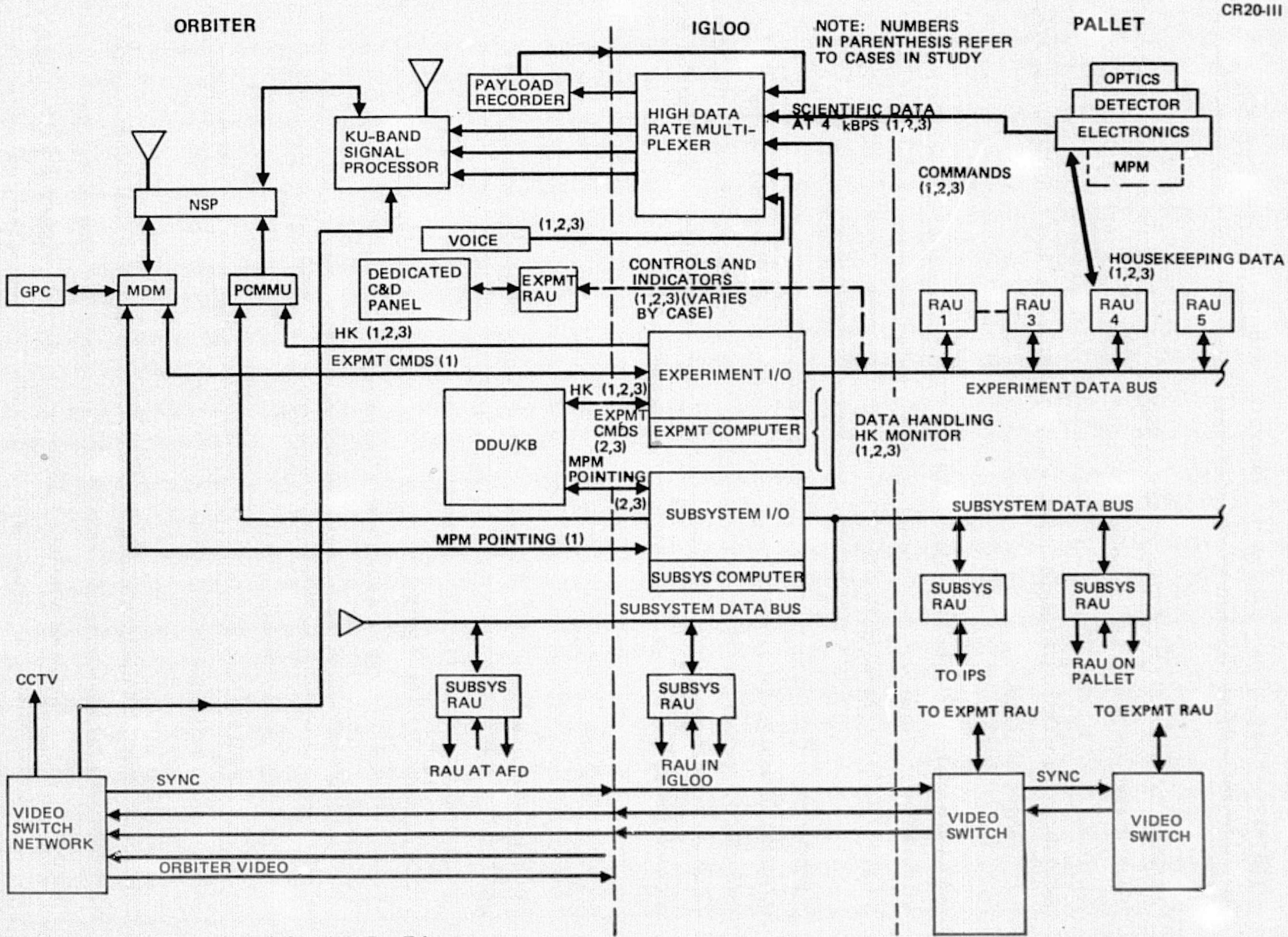

Figure I-3-18. Spacelab 2 Skylark Cosmic X-Ray Telescope the MPM or experiment through the appropriate RAU. Scientific and housekeeping data are transmitted to the ground to be analyzed by the PI at the POCC. The housekeeping data is also available for intermittent monitoring by the flight crew, especially during TDRS data gaps.

The operation of the MPM and experiment, in Case 2, will be controlled by the flight crew. The MPM will be slewed and data-taking initiated. Housekeeping measurements are monitored by the flight crew to verify experiment operation. The control and monitoring will be conducted at the DDU/KB or at the dedicated experiment C&D panel, both located in the Orbiter AFD. In this case, the scientific data will not be monitored onboard because no real-time analysis is required. However, it will be downlinked for subsequent analysis.

In Case 3, the MPM and experiment will be operated by the flight crew, but, as in Case 1, the housekeeping and scientific data will be monitored by the PI. Flight crew support of the PI can be provided by intermittent monitoring of the housekeeping data, especially during times of TDRS data gaps.

Activities in all cases can be accomplished with no additional hardware. No new additional software is required onboard but, additional software is required in the POCC for control of the MPM in Case 1.

Flight crew utilization is low in all cases because activation time is small and monitoring is only required intermittently. Flight crew utilization is slightly less in Case 1 because the control is maintained in the POCC.

Ground personnel supporting the experiment would be the same for all three cases except that no pointing engineer is required in Case 2.

3.1.2.7 LLL TV

This experiment is used in combination with the Skylark cosmic x-ray telescope and serves as an aspect camera for that experiment. It is also used to detect faint objects in the presence of bright stars. LLL TV experiment characteristics and operations applicable to this study are:

- Mounted on MPM.
- Data is video.

- Housekeeping measurements (≈ 1) are monitored during operation.
- Experiment is shut down between runs.
- No set up required. Experiment operated automatically after activation.
- Crew involvement is small during data gathering (monitoring).
- Real-time visual analysis is required on intermittent basis.

In Case 1, this experiment will be controlled by ground commands, the MPM will be slewed, and the TV camera activated. The interfaces with the CDMS are shown in Figure I-3-19. The ground commands will be processed by the onboard computers and routed through appropriate RAUs to the end items Housekeeping data will be monitored by the PI. The video signal will be monitored also by the PI and will be analyzed by ground computers to identify any faint objects. The housekeeping data and the video signal will be monitored intermittently by the flight crew, especially during TDRS data gaps.

In Case 2, the MPM and experiment will be controlled and the housekeeping data and video will be monitored by the flight crew. The video will be downlinked for subsequent analysis. The control and monitoring will be accomplished at the DDU/KB or at the dedicated experiment C&D panel, both located in the Orbiter AFD.

In Case 3, it is recommended that MPM and experiment control be accomplished by the flight crew and that the housekeeping data and video be transmitted to the ground for monitoring and analysis by the PI. The flight crew can provide monitoring support during times of TDRS data gaps.

The activities of all three cases can be accomplished with no hardware changes. The only software changes will require additions to POCC software capabilities, in Case 1, to control the MPM.

Flight crew utilization is slightly less in Case 1 than in Cases 2 or 3, because there is little set-up time and monitoring is only intermittent.

Ground personnel supporting the experiment would be the same in all cases, except that no pointing engineer is required for Case 2.

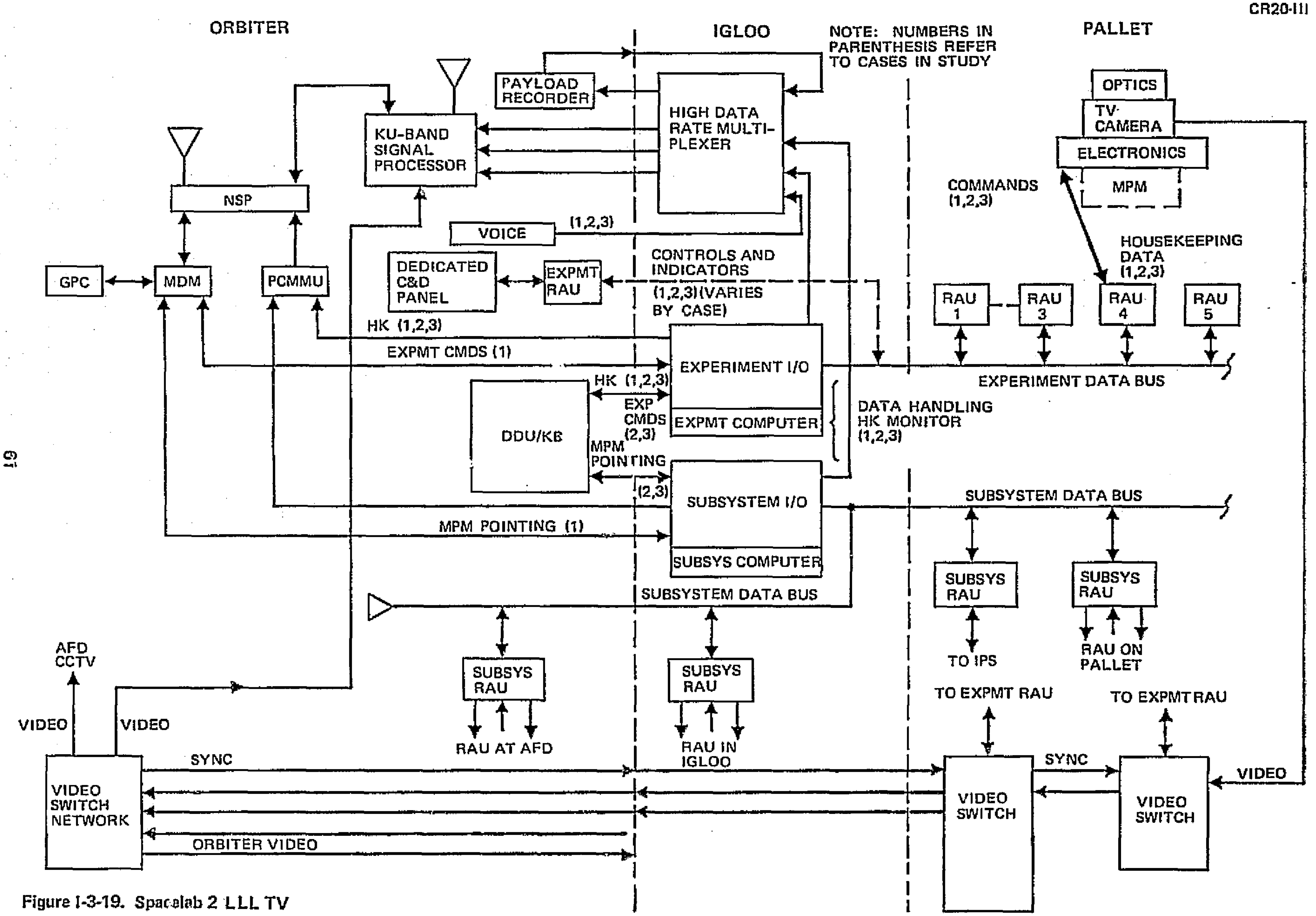

Figure I-3-19. Spacelab 2 LLL TV

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3.1.2.8 Far UV Schmidt Camera/Spectrograph

This experiment is used to perform spectrometry and photometry of spatial objects. Far UV Schmidt camera/spectrograph experiment characteristics and operations applicable to this study are:

- Mounted on MPM.
- Data is gathered on film.
- TV camera is part of unit and is used to provide identification of what is being observed.
- Housekeeping measurements (≈ 4) are monitored during operation.
- Experiment is shut down between runs.
- Setup includes programming corrector plates and mirror gratings. Experiment runs through program automatically.
- Crew involvement is required intermittently during data runs to monitor experiment and record time and targets.
- No real-time data analysis.

In Case 1, the MPM and experiments will be controlled by ground commands. In operation, the MPM will be slewed to the target, the experiment corrector plates and gratings will be programmed and data-taking will be initiated. The interfaces with the CDMS is shown in Figure I-3-20. The ground commands will be processed by the appropriate Spacelab computer through the RAUs and then to the end item. The TV camera in the experiment will provide real-time presentation of the target being observed. All scientific data is recorded on film contained within the experiment. Housekeeping data will be monitored by the PI in the POCC. The flight crew will support experiment operations by monitoring the video and housekeeping data on an intermittent basis, especially during times of TDRS data gaps.

In Case 2, the command and monitoring activities will be performed by the flight crew. A voice link will provide PI support for the flight crew activities. The control will be accomplished at the DDU/KB or at the dedicated experiment C&D panel, both located at the Orbiter AFD. Interface with the IPS and experiment will be through the appropriate computer and RAU.

Housekeeping data and TV will be intermittently monitored by the flight crew to verify the health of the experiment and the target being observed.

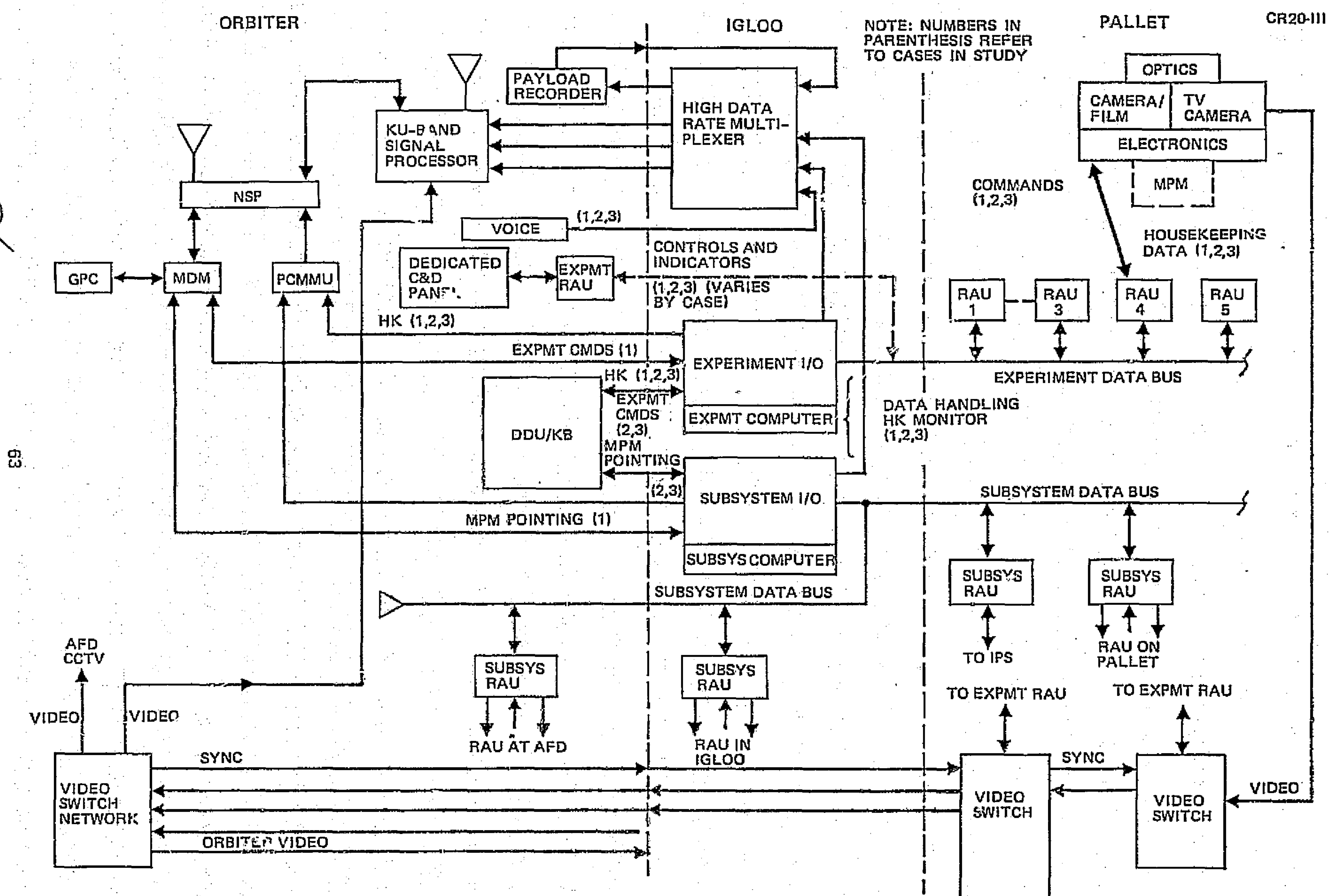

Figure I-3-20. Spacelab 2 Far UV Schmidt Camera/Spectograph

In Case 3, it is recommended that the control of the MPM and experiment be performed by the flight crew while the monitoring of experiment operation and TV be accomplished in the POCC by the PI. The flight crew will support the ground personnel by monitoring these outputs during TDRS data gaps.

The activities of all three cases can be accomplished with no hardware additions to the POCC or to onboard systems. Control of the MPM will require additional software only for the POCC.

Flight crew utilization is slightly less for Case 1 than the other cases because more functions are being performed on the ground; however, in all cases the utilization is low because set-up time is small, a couple of minutes, and monitoring is required only intermittently.

Ground personnel supporting the experiment would be the same for all three cases except that no pointing engineer is required for Case 2.

3.1.2.9 Transition Radiation Spectrometer

This experiment is used to determine flux and energy spectra of cosmic protons and electrons. Transition radiation spectrometer experiment characteristics and operations applicable to this study are:

- Hardmounted on pallet.
- Data rate is 50 kBPS.
- No housekeeping data.
- Unit is operated continuously throughout mission.
- No set up required; once activated, experiment operates automatically.
- No crew involvement during data gathering except in Case 2.
- No real-time data analysis, but identification and location of energy sources are desirable.

The operation of this experiment requires, in Case 1, that the unit be activated as early as possible in the launch sequence to commence data-taking. The experiment will operate continuously during the mission until deorbit when it will be shut down. The interfaces with the CDMS are shown in Figure I-3-21 with ground commands being processed by the experiment computer and distributed through the appropriate RAU. Scientific data is transmitted at a rate

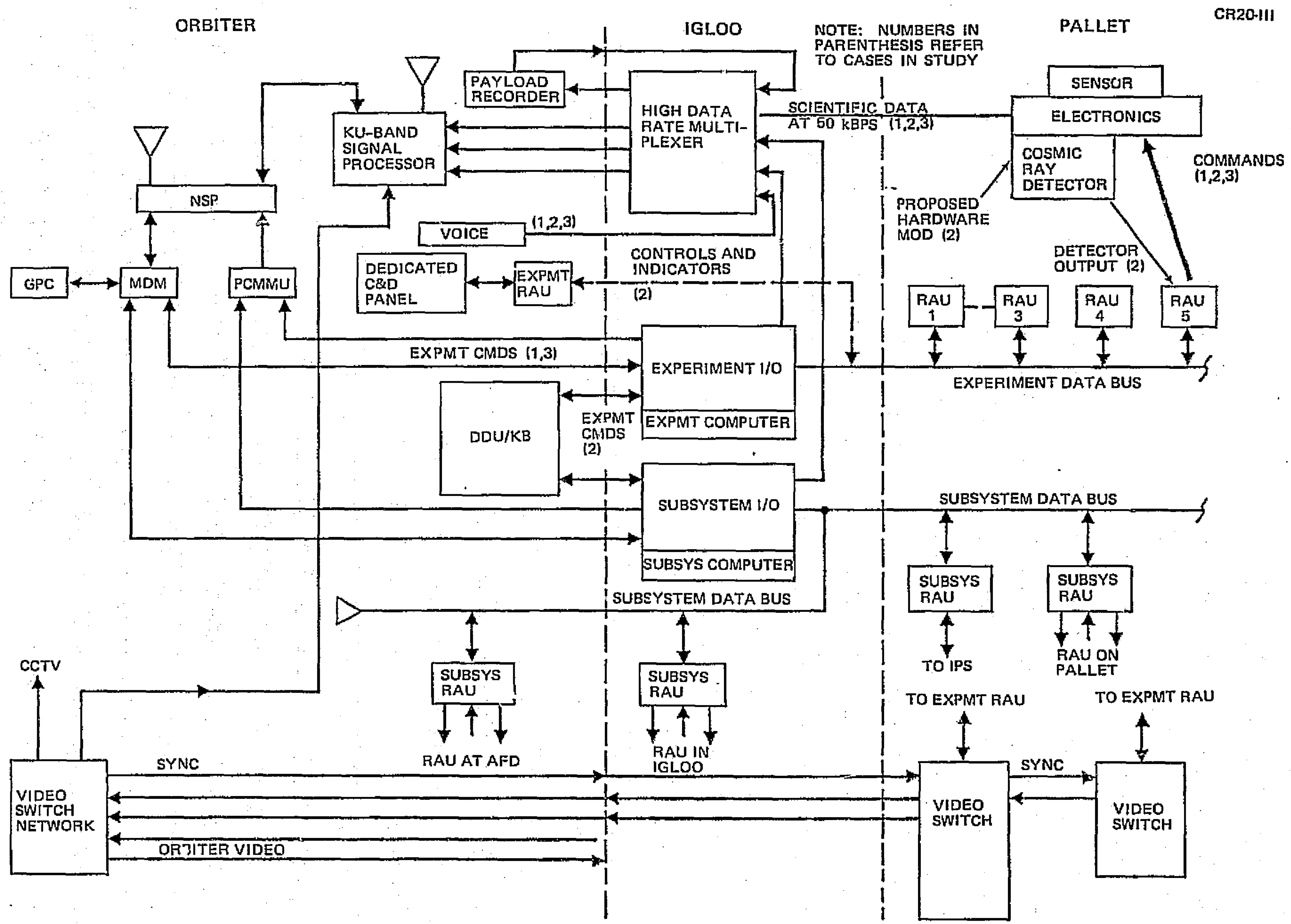

Figure I-3-21. Spacelab 2 Transition Radiation Spectrometer of 50 kBPS and will be monitored by the PI. Subsequent analysis will be performed to evaluate the data. The experiment has no housekeeping data to be monitored. No flight crew support will be required for this experiment.

For Case 2, the experiment will be activated by the flight crew, either by commands generated at the DDU/KB or at the dedicated experiment C&D panel, both located in the Orbiter AFD. This activation will be accomplished as early as possible during the launch or orbital phases. The data output of the experiment, a 50-kBPS digital stream, cannot be continuously processed and analyzed by the onboard computer. In order to increase the scientific return of the identification of specific energy sources which might require additional data acquisition (Case 2, in particular), it is recommended that a detector be developed as an integral part of the experiment. This detector will alert the flight crew of the presence and location of unique energy sources, and, with the use of the voice link to the PI, permit the crew to determine if additional data acquisition is required.

In Case 3, it is recommended that the control and monitoring of the experiment be performed, as in Case 1, by ground personnel. No flight crew support will be required.

The activities of all three cases can be accomplished with no hardware additions to the POCC and only the addition of the detector identified for Case 2. Control of the experiment will require no new additions to onboard or POCC software.

No utilization of the flight crew is required for Cases 1 and 3. Since there is no set-up required and because monitoring is required only intermittently, flight crew activities are small for Case 2. Ground support for the experiment is the same for all cases.

3.1.2.10 Extreme UV Imaging Telescope

This experiment is used to obtain extreme UV images of stellar objects. It is used in combination with the 65-cm photoheliograph. Extreme UV imaging telescope experiment characteristics and operations applicable to this study are:

- Hardmounted on pallet.
- Data rate of 200 kBPS.

- Housekeeping measurements (≈ 4) are monitored during operation.
- Experiment is shut down between runs.
- Set up requires monitoring of housekeeping measurements for approximately one minute after activation. Experiment runs automatically.
- Crew involvement during data acquisition includes recording of Shuttle aspect angles.
- Some real-time, or near real-time, data analysis is required.

In Case 1, the extreme UV imaging telescope will be controlled by ground commands. The experiment will be activated and housekeeping measurements will be monitored. After this initial activity, the experiment will operate automatically. The interfaces with the CDMS for this experiment are shown in Figure I-3-22. The ground commands will be processed by the Spacelab computers and routed through appropriate RAUs to the unit. Scientific data will be downlinked to the POCC and will be evaluated by the PI to determine unique sources of extreme UV. Housekeeping measurements will be monitored to determine proper operation of the experiment. The flight crew will support ground operations by recording Shuttle aspect angles and by monitoring the housekeeping data on an intermittent basis especially during times of TDRS data gaps.

Flight crew activities in Case 2 will be similar to those performed by the ground personnel in Case 1. The experiment will be activated and housekeeping measurements will be monitored for approximately one minute prior to the start of data acquisition. The control of the experiment will be accomplished through the DDU/KB or the dedicated experiment C&D panel located in the Orbiter AFD. Housekeeping measurements will be monitored intermittently and Shuttle aspect angles will be recorded. The scientific data, a 200 kBPS digital stream, cannot be continually processed and analyzed by the onboard computer. In order to increase the scientific return of the experiment for Case 2, it is recommended that a detector be developed as an integral part of the experiment. This detector will alert the flight crew of the presence and location of unique extreme UV sources and, with the use of the voice link to the PI, permit the crew to determine if additional data runs are required.

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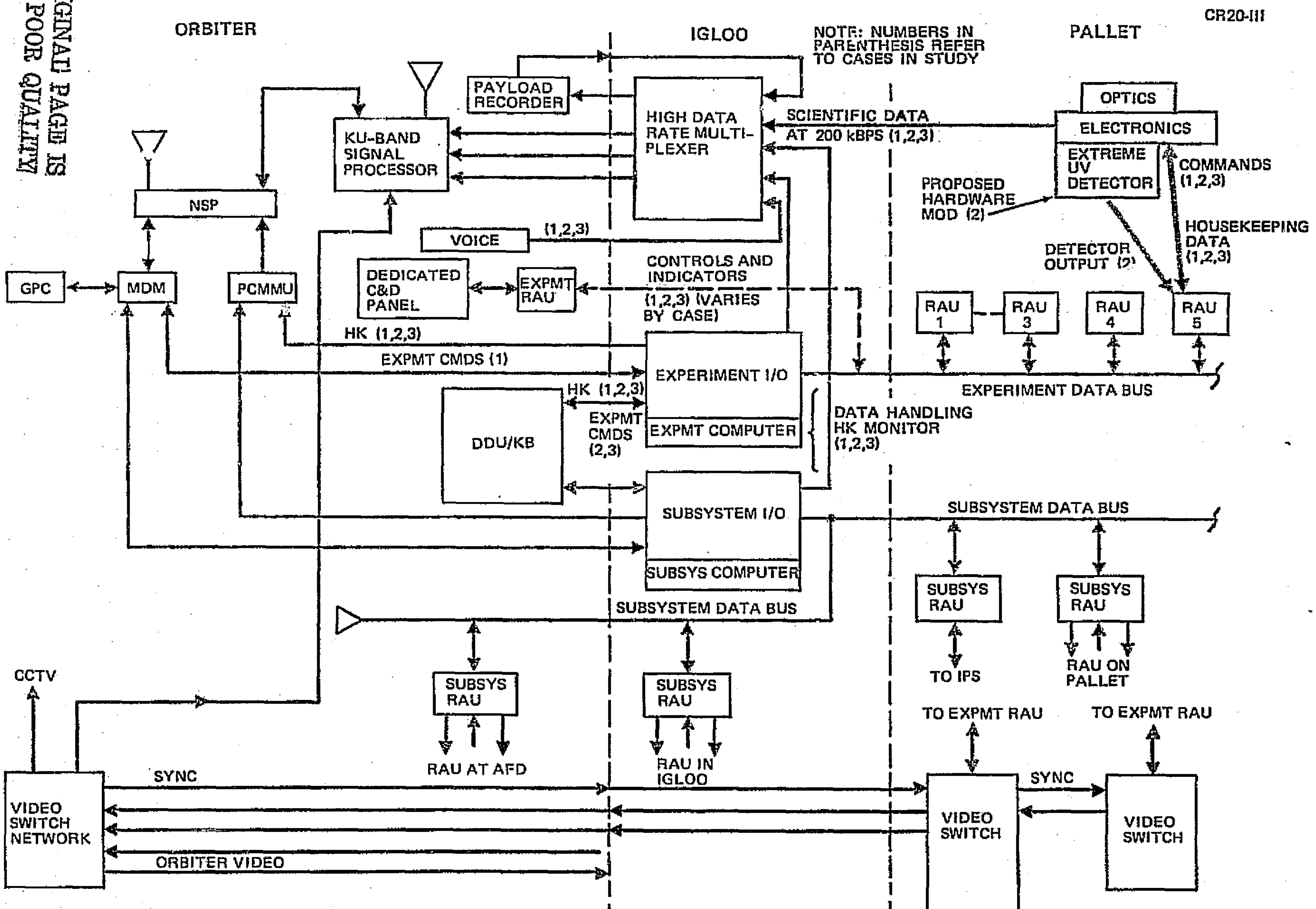

Figure I-3-22. Spacelab 2 Extreme UV Imaging Telescope

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In Case 3, it is recommended that the flight crew control experiment activation and the initiation of data acquisition. The scientific and housekeeping data should be downlinked to the POCC for PI evaluation, as in Case 1. In this case, the addition of the extreme UV detector will not be required. During data acquisition, the flight crew will be required to monitor the housekeeping data on an intermittent basis, especially during times when there are TDRS data gaps.

The activities of all three cases can be accomplished with no hardware additions to the POCC and only the addition of the extreme UV detector identified for Case 2. Control of the experiment will require no new additions to software onboard or at the POCC.

Utilization of the flight crew is slightly less for Case 1 operations because the ground personnel control and monitor the experiment. The flight crew is required to periodically record Shuttle aspect angles and to monitor the housekeeping data, especially during TDRS data gaps.

Ground support for the experiment is the same for all cases.

3.2 INTEGRATED EXPERIMENT ANALYSIS

Based on NASA MSFC-supplied mission experiment time lines, each of the individual experiment operating plans for each of the three study cases developed in Task 1 were integrated to identify mission and/or support system total demands. Crew demands, including VFI, were assessed along the entire time line. Total demands were assessed by reviewing the entire time line to select certain critical high-activity periods for more detailed assessment. System impacts were identified and integrated mission support requirements were established for each study case (e.g., crew size, POCC manning, downlink data rates, uplink command rates, TV transmission, etc.).

3.2.1 Spacelab 1 Integrated Experiment Analysis

The operation of the Spacelab 1 experiments in an integrated mode was analyzed using a NASA MSFC-supplied detailed mission time line. A summary of that time line, indicating experiment operations only, is shown in Figure I-3-23. While certain Spacelab 1 experiments tend to operate in groups (e.g., night side viewing AP-09, AP-13, and APE-01), in general, operations are independent of each other insofar as resource utilization

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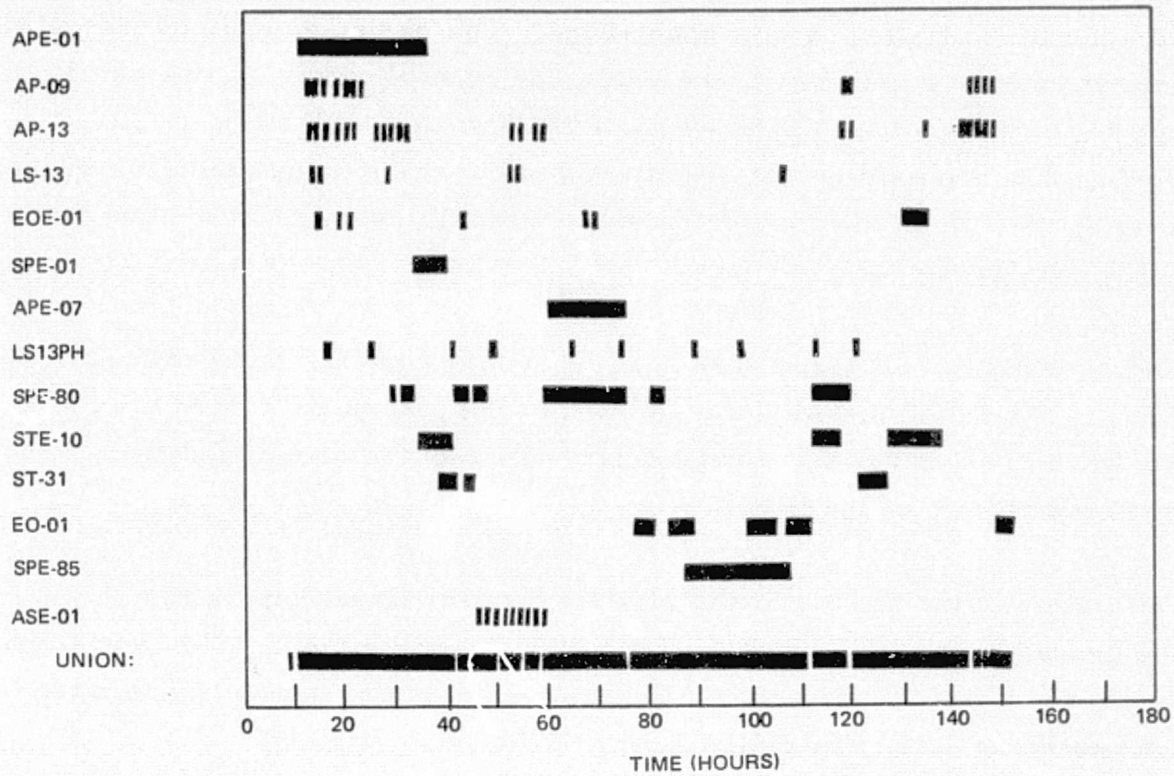

Figure I-3-23. Spacelab 1 Experiment Time Line (MSFC Spacelab 1 Strawman, SE-012-020-2H, October 1976)

permits. Most external-viewing experiments require earth orientation and tend to operate in groups, while most internal laboratory-type experiments are generally distributed to preclude excessive resource demands. As indicated in Figure I-3-23, experiment operations are not initiated until T+12 hours and terminated around T+154 hours. The summary time line indicates periods of experiment activity; however, these are not necessarily continuous. APE-01 LIDAR is operating only during night side passes, typically for 30 minutes per orbit, followed by a quiescent housekeeping period and then recalibration for the next run. Only a few experiments, such as SPE-80/85, EO-01, or STE-10, may run nearly continuously for several hours or more. Even with these experiments, operating demands and data production peaks are generally limited to only parts of the cycle. As Figure I-3-23 indicates, seldom are more than two or three experiments operating during any one period. One of these periods, which appears to be one of the highest activity periods is the first shift (T+12 to T+20) when AP-09/13, APE-01, and LS-13 operate.

Table I-3-6 identifies four time periods identified as high-demand periods for deeper analysis of support requirements. The detailed time line was used to sum the combined demands from each of the individual experiments over these periods.

In the process, these periods cover all experiments except for the two camera experiments, EOE-01 and ASE-01. The camera experiments do not impose high demands on the CDMS, although they can impose loads on the crew during their activation or deactivation.

As Table I-3-6 indicates, Spacelab 1 experiment operations place significant demands on crew support, even for Case 1 where primary experiment monitoring and control is from the POCC. Crew demand is rounded up to integral values and does have greater margin for Case 1. Case 2 support is based on a degree of increased data monitoring by the CDMS to relieve the crew of excessive monitoring demands. Demands on CDMS and POCC are all within their capability except for CDMS operating memory demands for Case 2. POCC channel demands are the minimum acceptable level required simultaneously to support the experiments indicated. In practice, an additional channel may be desired for monitoring other experiments status and housekeeping.

To support the development of the integrated demands analysis summarized in Table I-3-6, the highest activity period indicated (GET 12-19) was analyzed in some detail and is presented in Figures I-3-24 through I-3-29. For each case, there is an onboard integrated time line and a corresponding POCC integrated time line. The experiment profile presented at the top of the Figures is the same in each case for convenient reference. As discussed earlier, experiment operating periods are generally comprised of a series of operating runs, preceded by adjustment or calibration operations and intervening shutdown or standby modes. VFI activities are also indicated during this period since it makes similar demands on the payload crew and/or mission specialist as well as the data link. It is assumed to place minimum demand on the CDMS (except for CDM-03 which exercises the system) and none on the POCC (VFI is handled on the ground by the MCC). It was not clear if the VFI ground operations at JSC would consume one of the four

Table I-3-6

SPACELAB 1 INTEGRATED TIME LINE MAXIMUM DEMAND PERIODS

GET	12-19			36-41			60-66			100-105		
Experiments	AP-09/AP-13 APE-01 LS-13			ST-31 SPE-01 STE-10			SPE-80/85 APE-07 LS-13			SPE-80/85 EO-01		
Cases	1	2	3	1	2	3	1	2	3	1	2	3
Onboard												
Crew (PS and MS)*	2	3	3	2	3	2	2	3	2	2	3	2
CDMS												
Data Bus (kBPS)	25	80	30	10 →	→	→	14	84	14	8 →	→	→
HRM (kBPS)*	330 →	→	→	140 →	→	→	290 →	→	→	130 →	→	→
Experiment Computer (K OPS)	30	140	50	10	20	8	12	44	14	13	36	13
Experiment Computer (K Words)	38	80**	41	12	24	12	14	67**	16	24	67**	24
DDU/KB Quantity	2	2	2	2	2	2	2	2	2	2	2	2
TDRS (kBPS)*	330 →	→	→	140 →	→	→	290 →	→	→	130 →	→	→
TV*	√	√	√	√		√	√		√	√		√
POCC												
Crew (Basic + Experiment)	20	14	16	18	13	15	19	14	15	16	12	13
Channels	3	0	3	2	0	2	2	0	2	2	0	2
Experiment CRTs	8	0	8	5	0	5	6	0	6	4	0	4

*Includes VFI - also superimposes playback
**Not all active simultaneously

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output channels available to the POCC; however, since it appeared possible to accommodate POCC needs with only three channels (Cases 1 or 3), this was not pursued further.

Figure I-3-24 presents the onboard time line for Case 1. As indicated, crew operations are primarily limited to activation, operation of some VFI, and LS-13 experiments. Some monitoring support is also provided, especially during TDRS data link gaps with the POCC. Experiment payloads generally control their internal housekeeping functions (and provide display) and some also control and display their experiment operations to at least some degree of autonomy. The CDMS provides for AP-09 pointing support and LS-13 operations control (AP-09/13 and APE-01 calibration and operations control are uplinked from the POCC).

Onboard crew support is within the provided time line up to T+16 hours when only one crewman is on duty - support of APE-01 operations at the same time as LS-13 and VFI operations should require more than the single crewman indicated, possibly PS-2 duty shift should be extended.

As discussed earlier, CDMS utilization is moderate for Case 1. Although operating memory may approach its limit if all programs for an experiment are assumed active whenever the experiment is active, in practice, only some or parts of these programs may be required at any given time.

Multiplexer capacity assumes seven channels active during this period, including programmed or commanded data provided from the experiment computer link. Experiment information rates (including VFI and record dumps) are indicated, although actual data rates on the line will be determined by the selected multiplexer clock rate. Data downlink is provided for Mode 2 operation by the TDRS to accommodate the high-TV demands characteristic of Spacelab 1. The channel capacities are more than adequate to handle even the maximum rate encountered (328 kBPS) which includes playback by the payload recorder and provisions for digital voice tag of LS-13 operations data.

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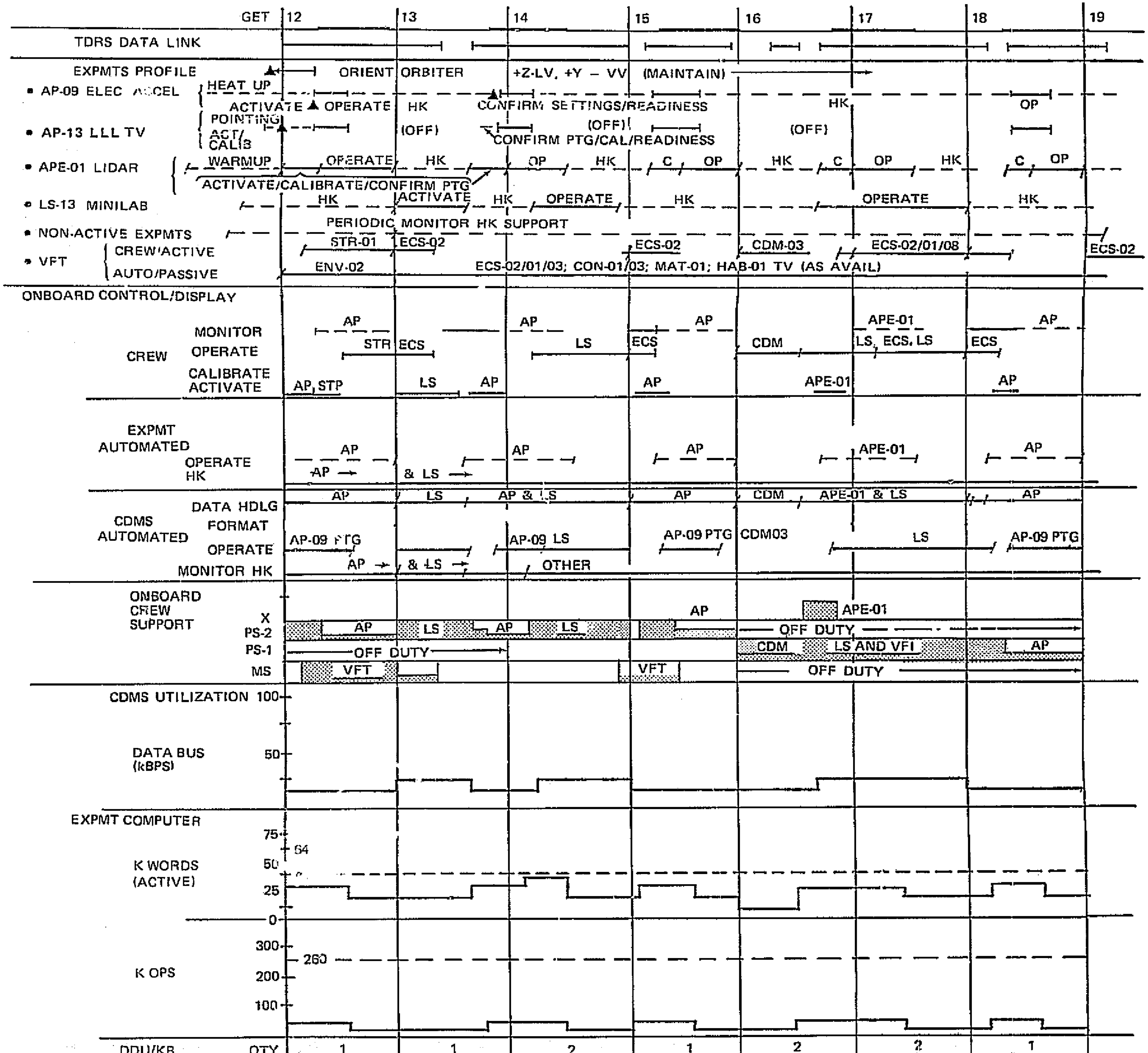

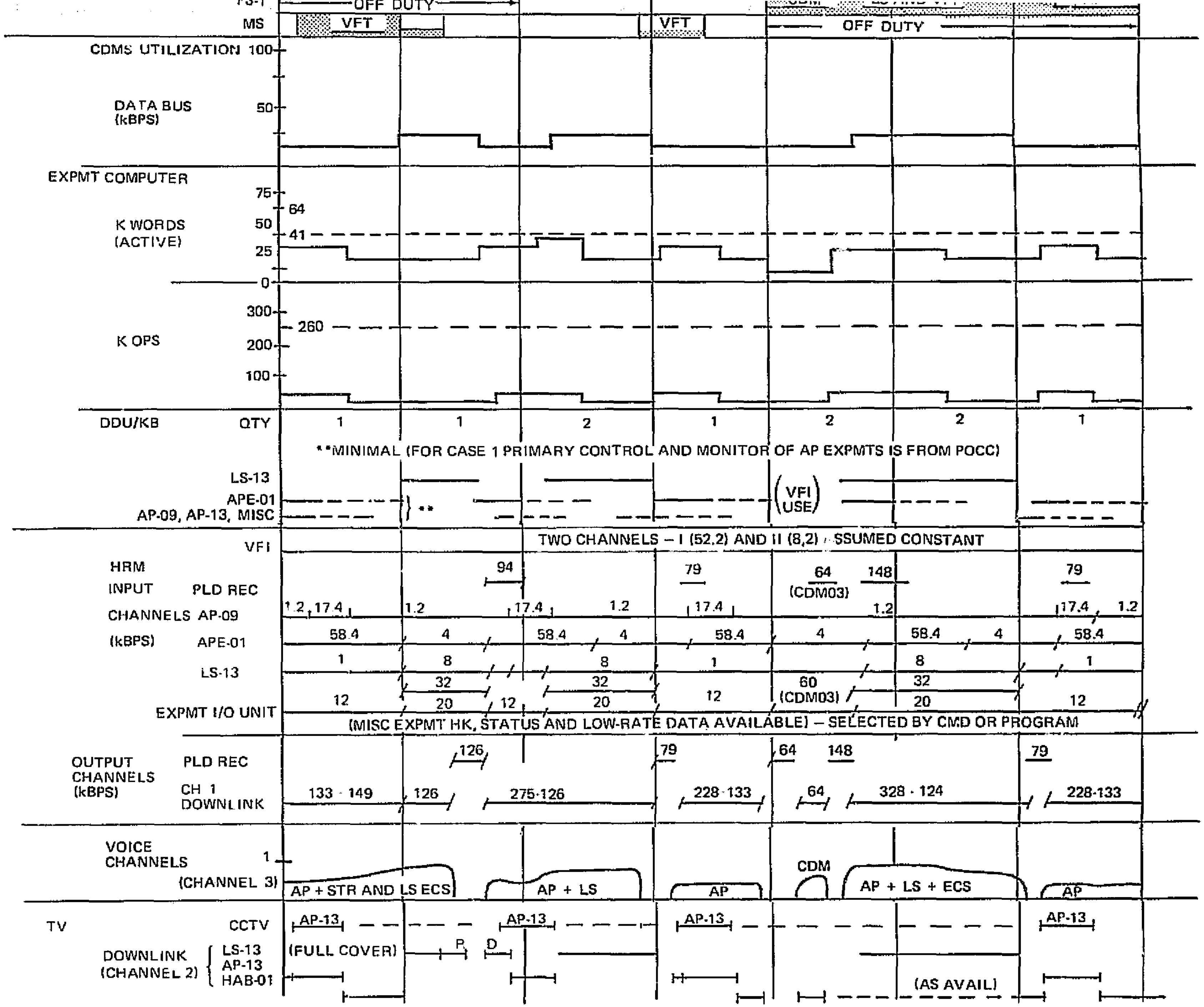

Figure I-3-24. Spacelab 1 Onboard Integrated Time Line - - Case 1

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Case 1 POCC time line over this period is shown in Figure I-3-25. This indicates a high degree of POCC activity involved in operating and monitoring these experiments and is assessed as probably the most active Case 1 period for POCC for Spacelab 1. POCC personnel requirements are summed at 20 active positions (including a Case 1 basic core of 10) up to T+16. This also requires up to eight experiment-dedicated CRTs (above the basic core and STS displays) as well as use of the two command panels and a pointing command panel for the POCC control of LLL TV (AP-13) operations in conjunction with AP-09. POCC computing support requirements are indicated only by general functions in this section. They are quantified (in terms of additional programs and instructions to the basic host-provided capability) in Subsection 3.4.2.

Figure I-3-26 presents the onboard time line for Case 2 over the same time period. Additional onboard demands on operations (AP-09/13 and APE-13) and monitoring raise crew support needs (including VFI) up to three during the first hour and require maintaining a two-man shift requirement into the next shift. This assumes only minimal monitoring demands on the crew, using automated CDMS programs to monitor data. The resultant work load on the experiment computer may exceed its current memory capacity. However, the data available and the level of analysis could not verify this. Estimates of program sizes, based on parameters or bits operated on for each function, at this point are debatable and closer editing may reduce the scaling factors used. In addition, programs may be segmented and pulled out from mass memory only during immediate use, reducing the storage demands on the operating memory. At any rate, the overload (factor of 2) was not sufficient at this time to assess that additional computer capacity was required for Case 2, automated monitoring. Case 2 requires increased use of DDU/KB units (still within capacity). Multiplexer use is essentially the same in all cases, the difference is how the downlink is used on the ground. However, TV downlink is limited to those portions of AP-13/AP-09 vital to postflight analysis. No LS-13 TV is provided since POCC has no TV display, by definition. VFI TV downlink (HAB-01) is assumed available to the MCC.

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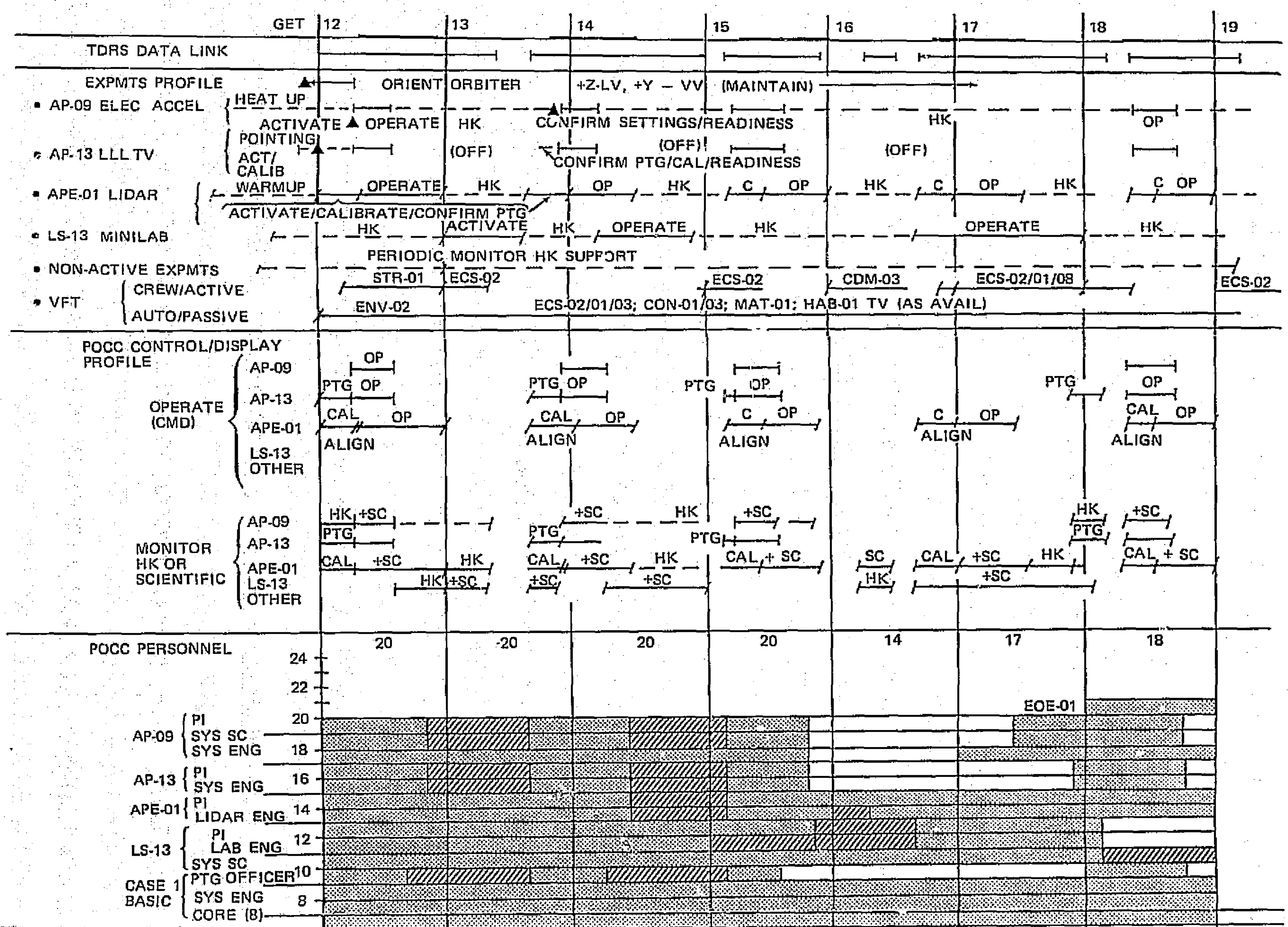

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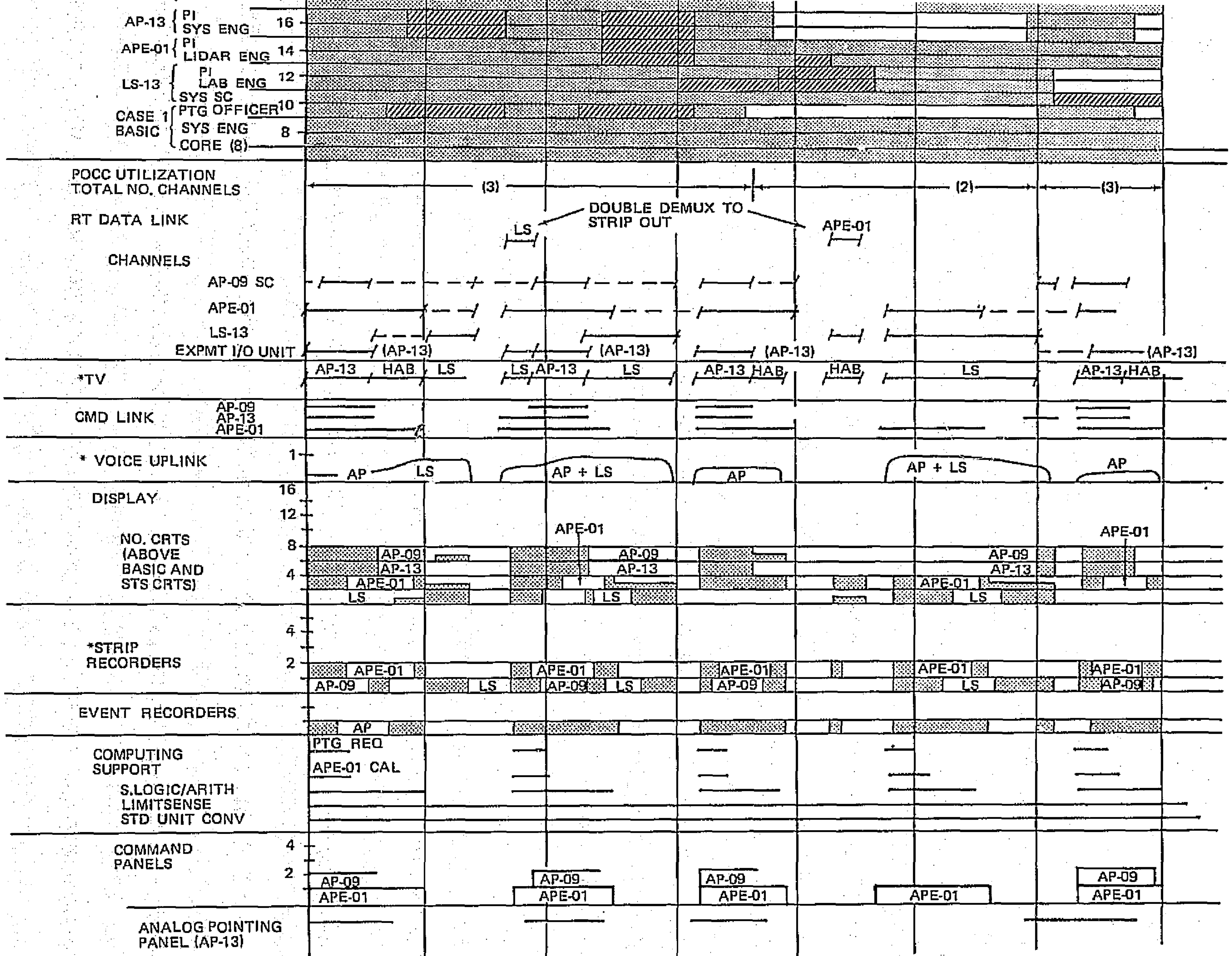

*TV AND VOICE CHANNEL RECORD ASSUMED AVAILABLE FOR IMMEDIATE RECALL AND DISPLAY (OH-TV OR FREE CRT)

Figure I-3-25. Spacelab 1 Ground POCC Integrated Time Line — Case 1

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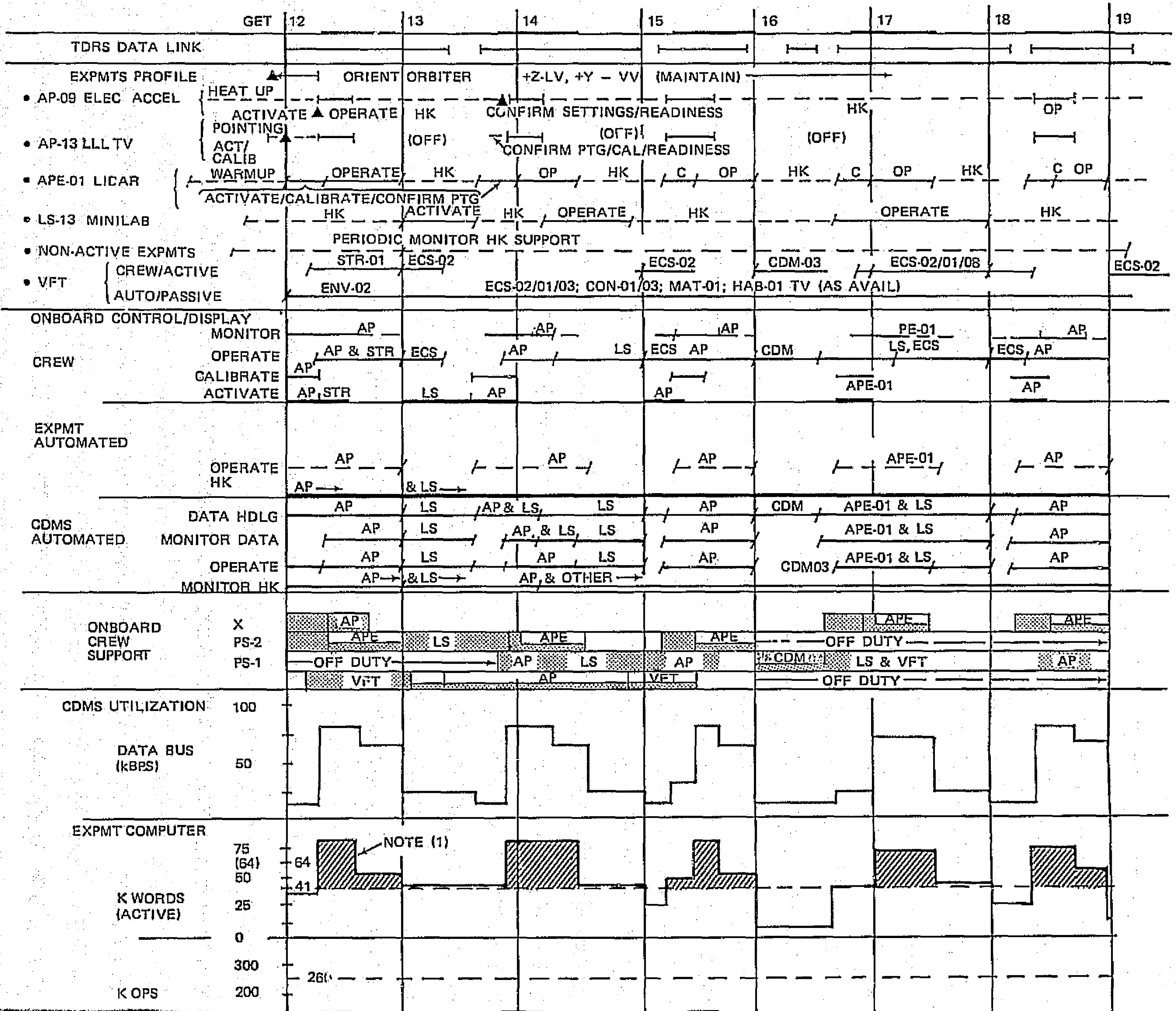

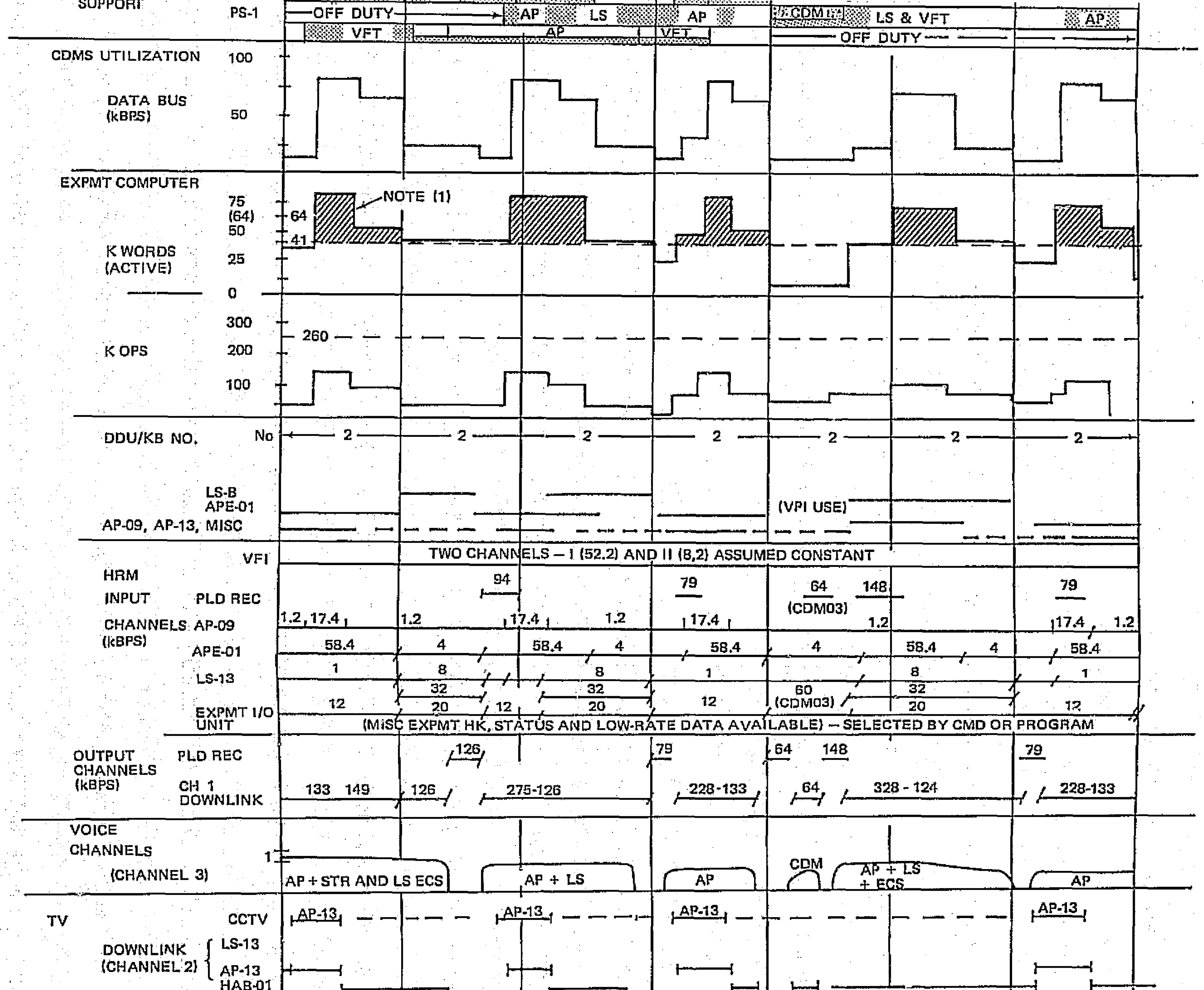

NOTE (1): LOADING IN ALL ACTIVE EXPMT PROGRAMS (INCLUDING DATA MONITOR ASSESSMENT) SIMULTANEOUSLY COULD EXCEED CAPACITY; HOWEVER SEGMENTATION AND TIME SHARING SHOULD ALLOW ACCOMODATION WITHIN CAPACITY.

Figure I-3-26. Spacelab 1 Onboard Integrated Time Line — Case 2

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Case 2 POCC requirements are minimal over any time period. Figure I-3-27 indicates four to six additional specific experiment personnel are required over a basic POCC core of eight. No equipment, except voice link, is required.

Case 3 onboard time line CDMS utilization is very similar to Case 1 (Figure I-3-28). Crew support requirements are closer to Case 2, three men initially and a two-man crew on the next shift. If need be, this might be reduced to nearer the Case 1 level by restoring AP-13 operations and control to the POCC. (This reflects the flexibility in use of resources available to Case 3 compared to Cases 1 or 2.) For this study, it was decided to retain onboard control so long as crew size could be reasonably accommodated and no extensive software and CDMS requirements were generated (as in Case 2). Again, the multiplexer time line is the same. TV downlink is the same as for Case 1.

POCC requirements for Case 3 (Figure I-3-29) are closer to Case 1. Personnel requirements are less (16 versus 20 up to T+16 hours); however, display needs are essentially the same (eight experiment-dedicated CRTs), but still well within the baseline POCC configuration. No command functions or panels are indicated, but backup or selected use to minimize crew peak work loads might be considered in later planning.

In the assessment of the Spacelab 1 experiments, a concern for the acquisition of the highest quality of scientific data identified the need for additional monitoring capability for Case 2. In Cases 1 and 3, the scientific data is available in the POCC for computer and PI analysis. However, during Case 2, this data link is not available. In addition, even with maximum payload crew (five including mission specialist), only limited monitoring time was available compared to that provided by a ground facility and team. The approach used for Spacelab 1 was to sample the experiment scientific data for preprogrammed logic and limit checks by the experiment computer. This approach was selected because most of the experiments already interfaced with the CDMS to some degree, and many of the experiments were subject to a variety of test conditions including changes during the mission. This would allow changing and updating the value of monitor program parameters depending on the specific experiment test conditions. Except

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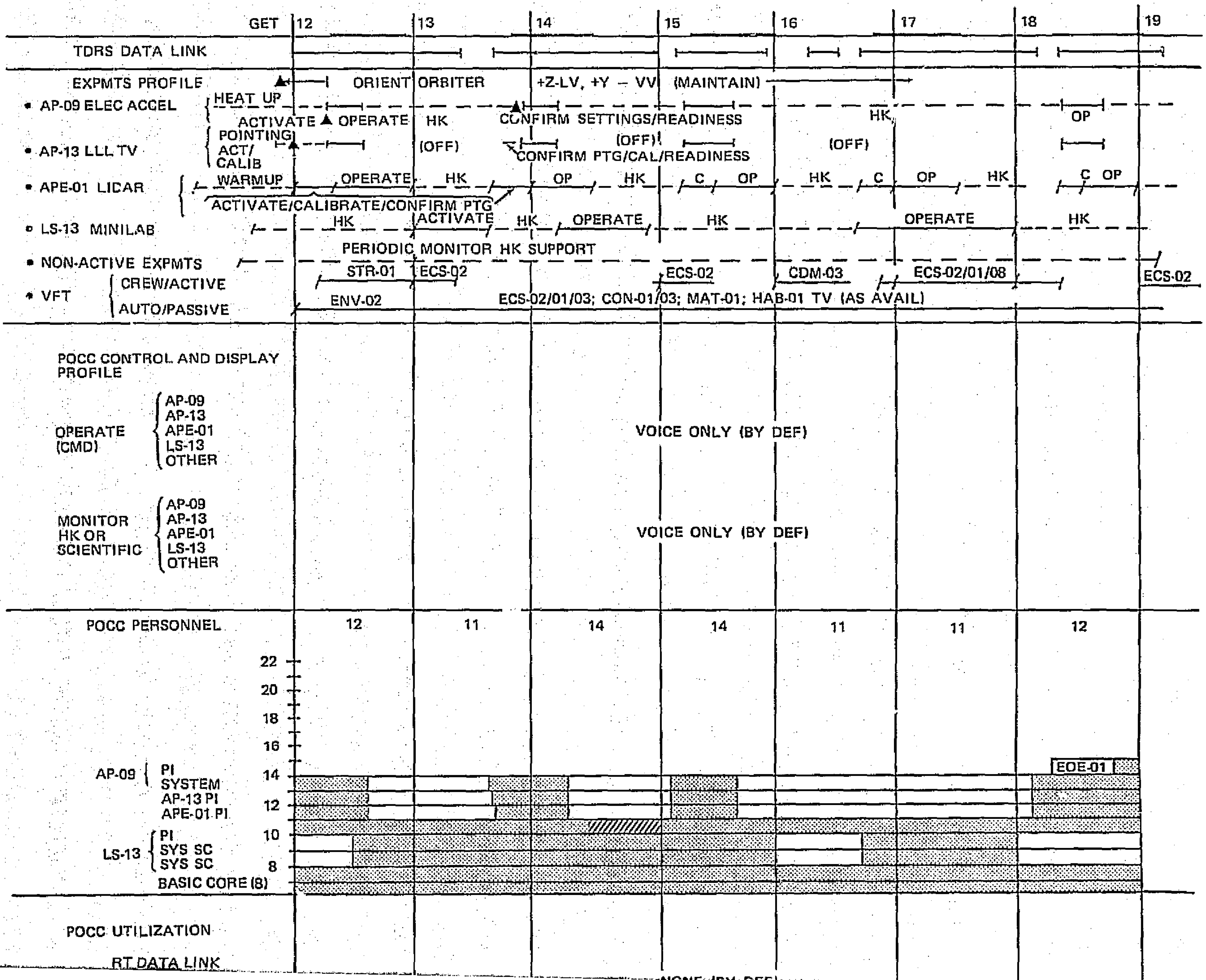

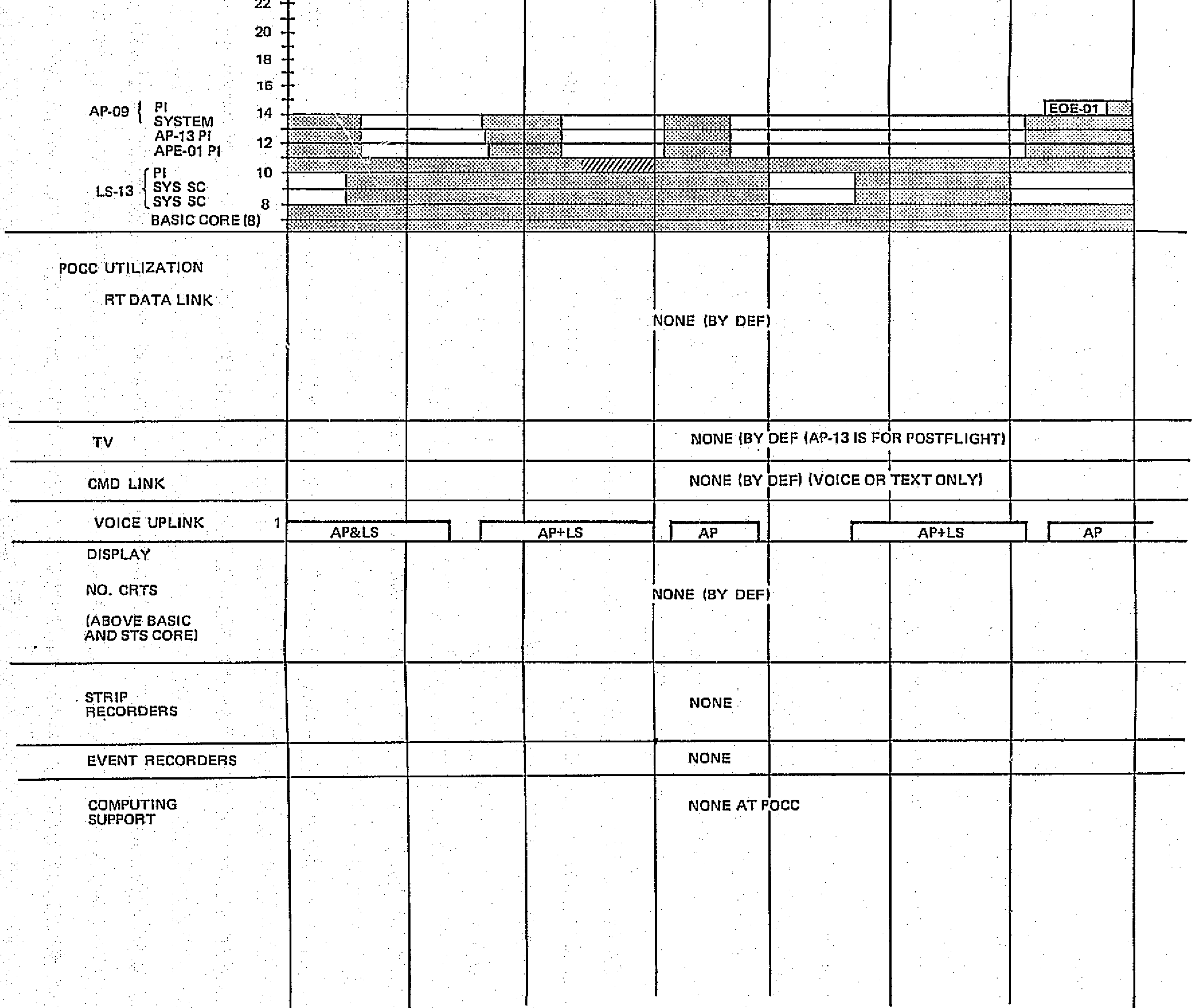

Figure I-3-27. Spacelab 1 Ground POCC Integrated Time Line — Case 2

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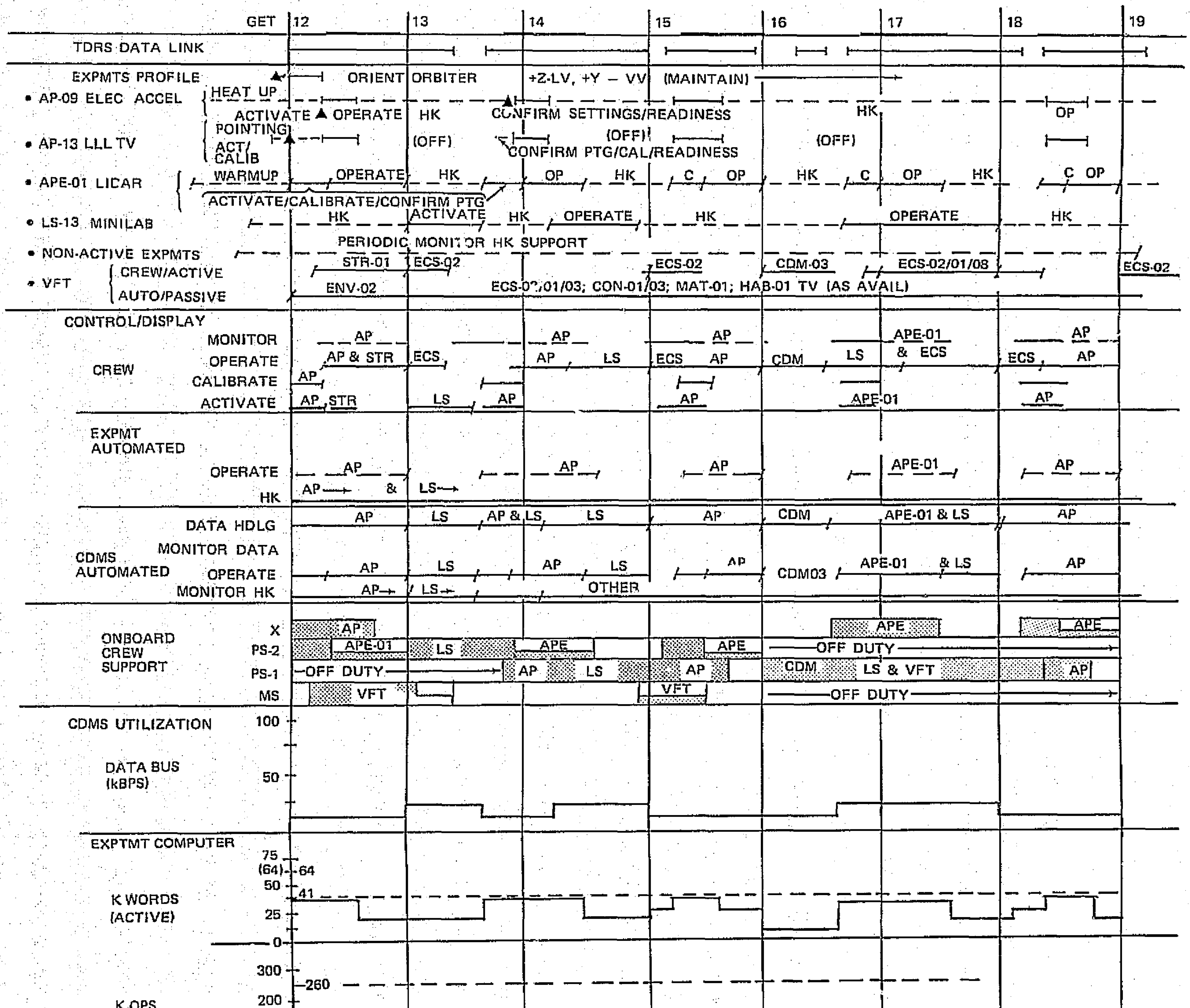

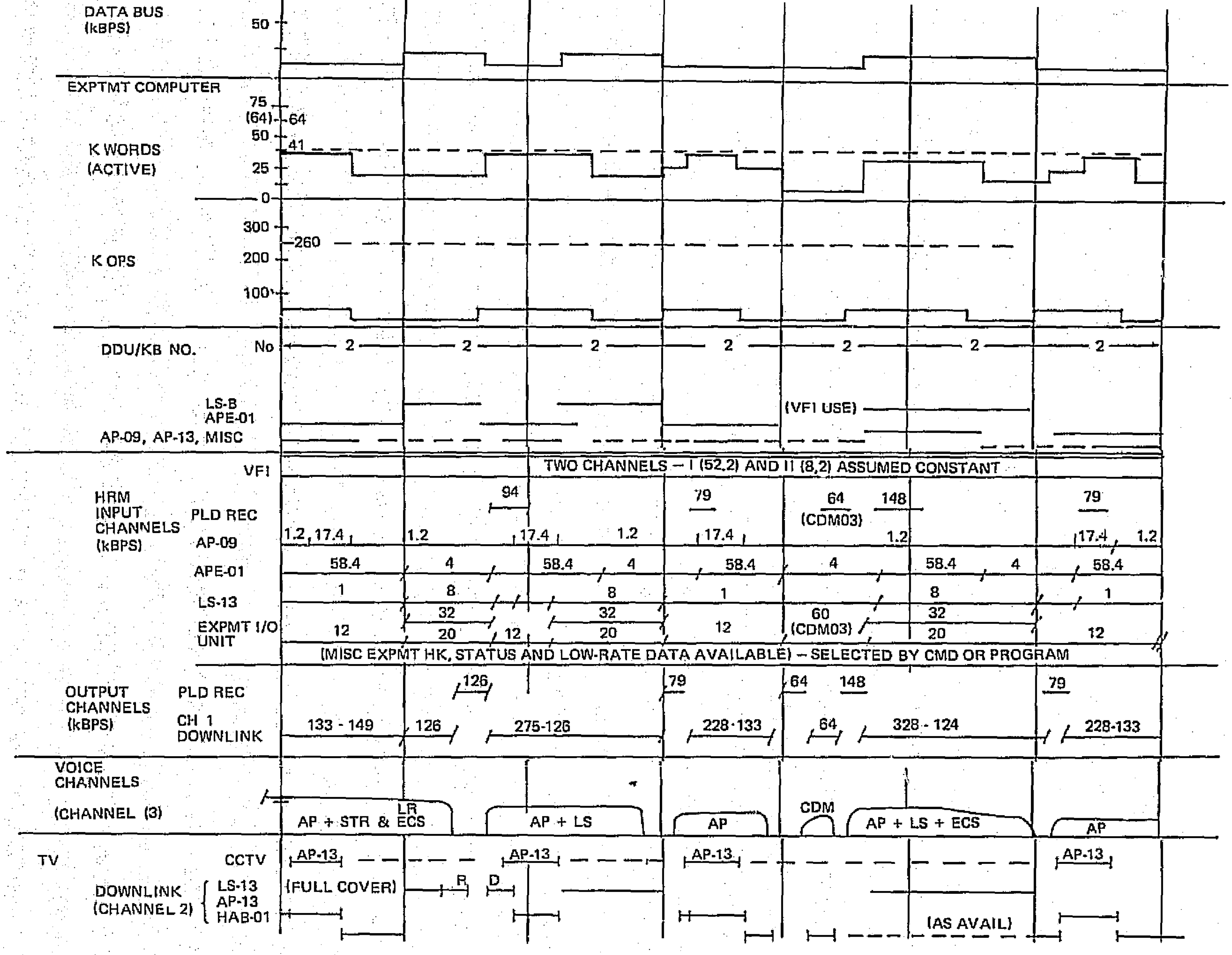

Figure I-3-28. Spacelab 1 Onboard Integrated Time Line – Case 3

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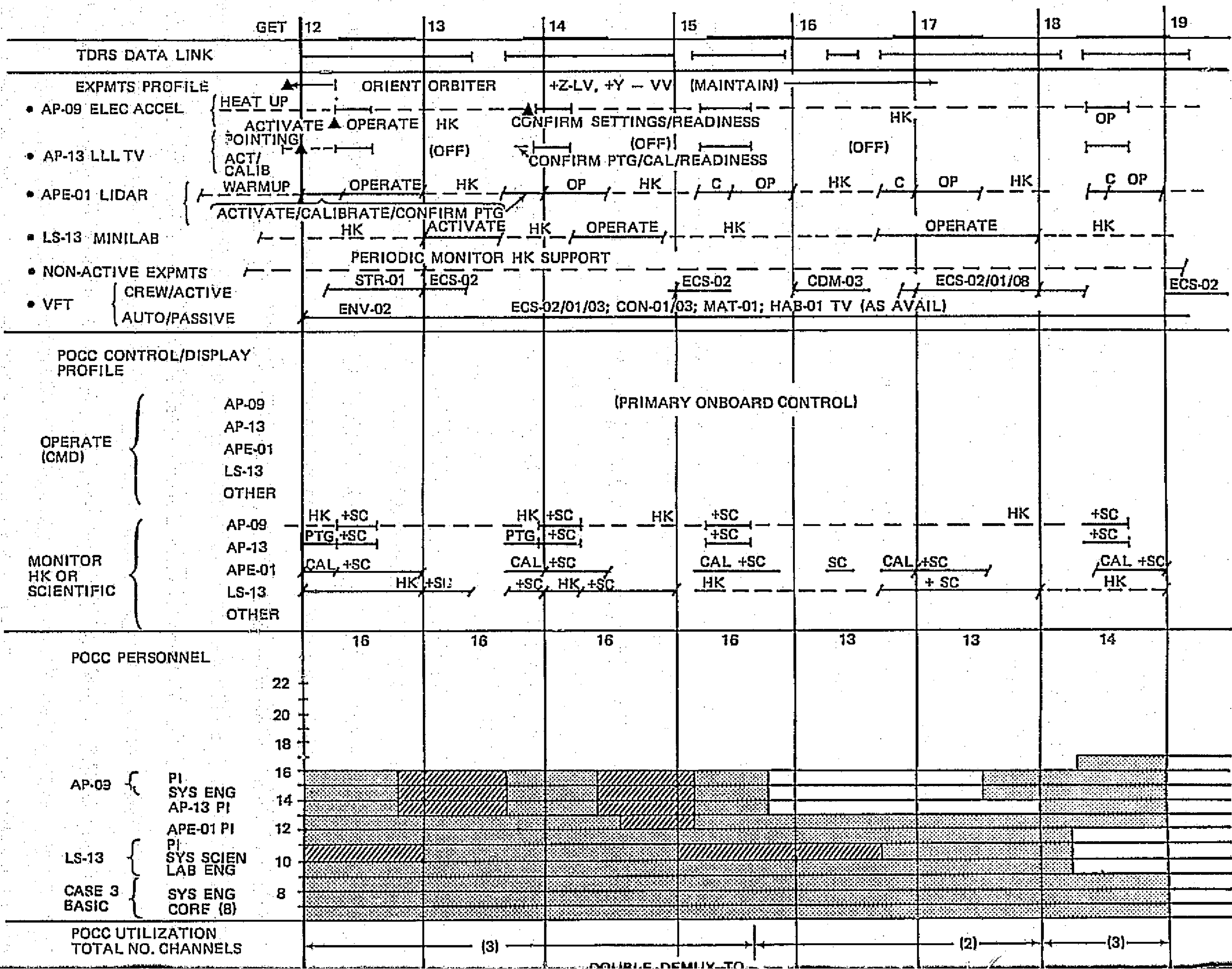
SPACELAB 1 GROUND-PUCC INTEGRATED TIMELINE — CASE 3



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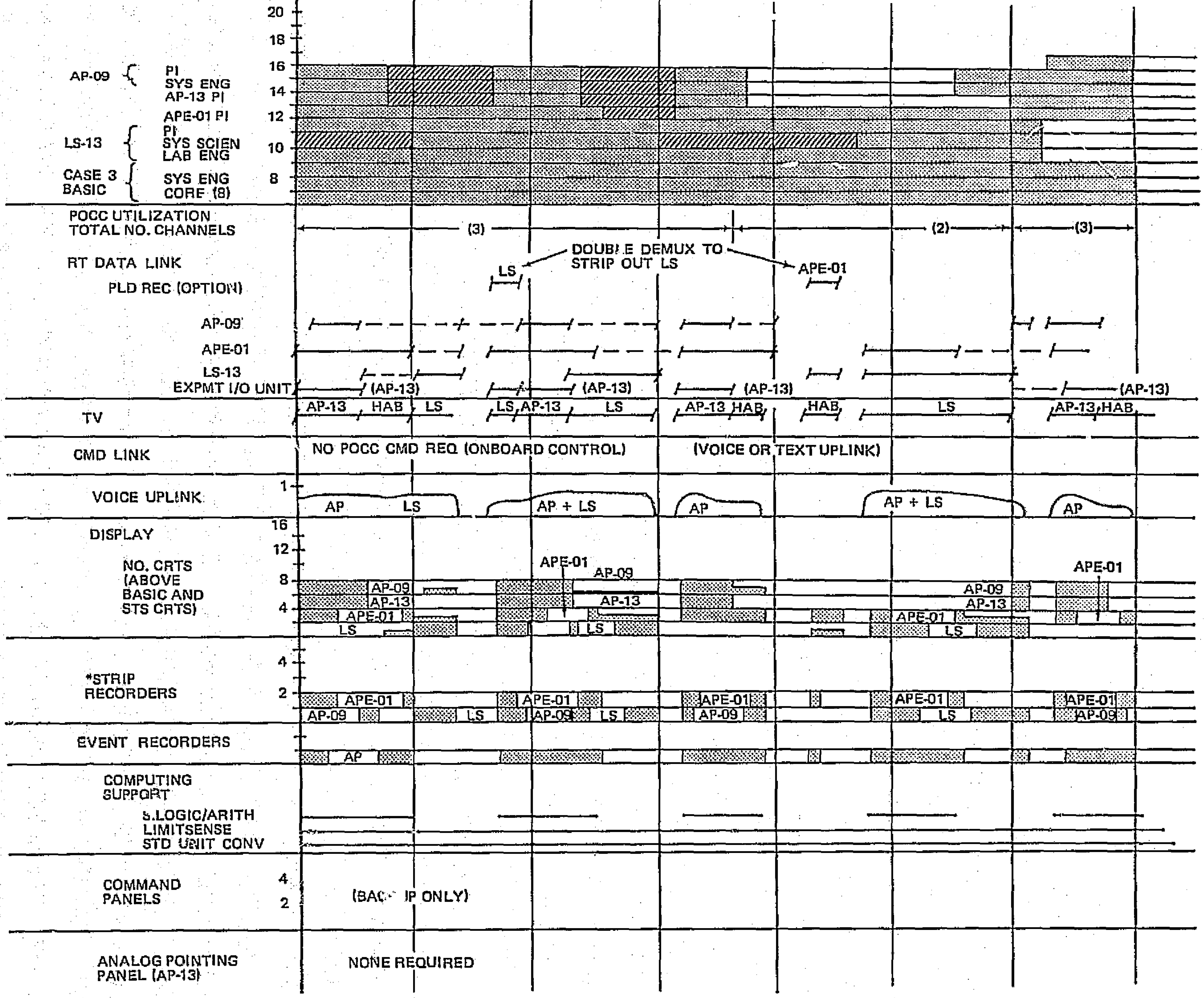

Figure I-3-29. Spacelab 1 Ground POCC Integrated Time Line — Case 3

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for AP-09, AP-13, or ST-31, no image data is involved (hard-copy film data is restricted to postflight analysis in all cases). For these three experiments, onboard crew monitoring of image data, coupled with voice link to the appropriate POCC PI, is used. For other experiments and non-image data from AP-09, and ST-31, software programs are provided to assess whether data is being produced or acquired when expected and if it falls within expected ranges of values. Variations or excursions are called to the attention of the crew for assessment. The quality of this assessment, from the limitation of the automated check, and the limitation of crew skills and work load, would often tend to be less than provided in Cases 1 or 3 where a dozen or more qualified specialists can monitor the data at the POCC. Table I-3-7 presents an assessment of relative scientific data quality which might be expected in each case, using Case 1 as the nominal reference case. Depending upon their operating and data characteristics, some experiment's quality are more subject to degradation than others. For example, for AP-09 and AP-13, understanding of complex and subtle visual data which cannot be easily verbalized to the ground (POCC PI) would tend to limit these experiments to the onboard crew's skill and understanding. On the other hand, SPE-01 data can largely be easily described and quantified by the crew over the voice loop, allowing better interpretation of results and uplink of advice by the POCC PI. An average value is shown as a general indicator; however, since not all experiments produce data of equal value, the average value should not be assessed as a measure of the relative scientific value in each case. Similarly, the assessment inherently assumes a relative crew skill and PI skill and an experiment adaptation potential (capability and requirement) to mission updating.

The following general findings were derived in the Spacelab 1 payload evaluations with the degree of applications varying with payload.

3.2.1.1 Case 1

A. Control functions and operations management are centralized in POCC. POCC controls onboard automation.

Table I-3-7

SPACELAB 1 - RELATIVE SCIENCE QUALITY ASSESSMENT

			Case 1 (Reference)	Case 2	Case 3
1.	AP-09	Electron Accelerator	1.0	0.5	1.0
2.	AP-13	LLL TV	1.0	0.5	1.0
3.	ST-31	Drop Dynamics	1.0	0.7	0.9
4.	EO-01	Cloud Physics Lab	1.0	0.7	1.0
5.	LS-13	Minilab	1.0	0.8	1.0
6.	APE-01	LIDAR	1.0	0.6	0.9
7.	SPE 80/85	Space Processing	1.0	0.6	1.0
8.	SPE-01	Electrophoresis	1.0	0.8	1.0
9.	EOE-01	Metric Camera	1.0	1.0	1.0
10.	APE-07	IR Radiometer	1.0	0.7	1.0
11.	STE-10	Heat Pipe	1.0	1.0	1.0
12.	ASE-01	Wide-Field Galactic Camera	1.0	0.9	1.0
		Average	1.0	0.73	0.98

B. Flight crew plays role of support technician (activates manual tasks).

C. Flight crew work loads are at minimum (of three cases).

D. POCC equipment and manpower is at maximum.

E. Case 1 requires that rigid design criteria be imposed early in payload development to provide suitable instrumentation and remote control.

F. Certain kinds of payloads and functions cannot fit Case 1 in a practical way (e.g., life sciences biomedical specimen extraction and processing; manual set ups or servicing).

G. POCC evaluates malfunctions and problems and develops contingency plans with Mission Operations Control Room (MOCR).

H. Minimum demand is placed on onboard automatic system since POCC computation and data monitoring capability is used.

I. LOS constraint on POCC control must be accommodated in flight planning. This is difficult for certain experiments requiring close control and having typical run times over 1.3 hours.

3.2.1.2 Case 2

A. Control functions, monitoring, and operations management are centralized onboard.

B. Flight crew performs technician role plus a more active scientific role (highest skill level).

C. Flight crew work loads are at maximum.

D. POCC acts as scientific and engineering advisor, based on verbal data received from crew.

E. POCC assists in evaluating malfunctions and problems and in developing contingency plans.

F. Maximum demand is placed on onboard data management systems (experiment computer).

G. Case 2 requires design for equipment and flight crew self-sufficiency.

H. Less sensitive to LOS.

3.2.1.3 Case 3

A. Control functions and operations are concentrated onboard. Monitoring, assessment, planning, and advisory functions are provided by POCC.

B. Tradeoffs are possible to optimize planned operations as hardware and operations mature.

C. Flexibility exists to react to contingency requirements.

D. Intermediate demand is placed on onboard automatic system and on flight crew (intermediate skill level).

E. Most payloads which are automated through the CDMS are readily adaptable, via software changes, to control from either onboard or POCC.

3.2.1.4 General

A. Except for some real-time TV used only in Cases 1 and 3 and some ST-31 data in Case 1, essentially the same data stream is downlinked in all three cases. The difference is only that for Cases 1 and 3, it is processed for real-time display and use. It is downlinked for postflight analysis in all cases.

B. Crew work load is extensive and demanding (multiskill, etc.) in all cases.

3.2.2 Integrated Experiment Analysis - Spacelab 2

The operation of the Spacelab 2 experiments in an integrated mode was analyzed using a NASA MSFC-supplied mission time line. The costs related to onboard versus ground real-time mission operations required that the following details be identified for each of the three study cases:

A. Flight crew activities and man-loading.
B. Onboard hardware modifications.
C. Onboard software modifications.
D. Ground support activities and man-loading.
E. Ground hardware modifications.
F. Ground software modifications.

This subsection presents the information assessed and the results used in analyzing the cost differentials between the three study cases for Spacelab Mission 2.

3.2.2.1 Integrated Mission Activities

The Spacelab 2 experiments operate in groups depending on the discipline from which they were selected. Solar monitoring experiments are active concurrently in joint operating programs during daylight portions of the orbit while stellar experiments are scheduled during the night portion. This results in a mission time line that exhibits a repetitious nature with experiment groups being active as the Orbiter revolves through day and night portions of the orbit.

The NASA MSFC-supplied mission time line was reviewed to determine times of maximum experiment activity or unique experiment combinations. Two representative time spans, Figures I-3-30 and I-3-31 were selected to be used in the study analysis. In these figures and in subsequent subsections, the experiments and combinations of experiment are identified by abbreviations. A listing of these abbreviations is provided in Table I-3-8.

3.2.2.2 Flight Crew and Ground Crew Activities and Man-Loading

The experiment operations (See Subsection 3.1) do not require full flight crew attention except during that portion of the time line when experiments

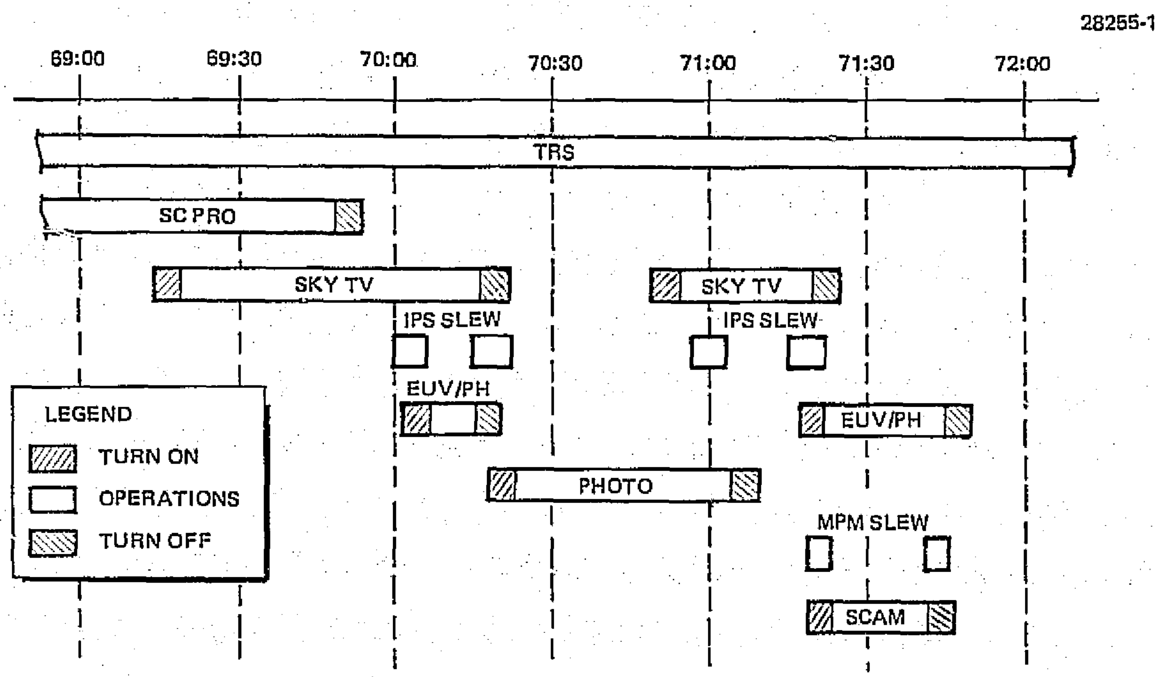

Figure I-3-30. Spacelab 2 Experiment Operations (GET 69:00 Hr to 72:00 Hr)

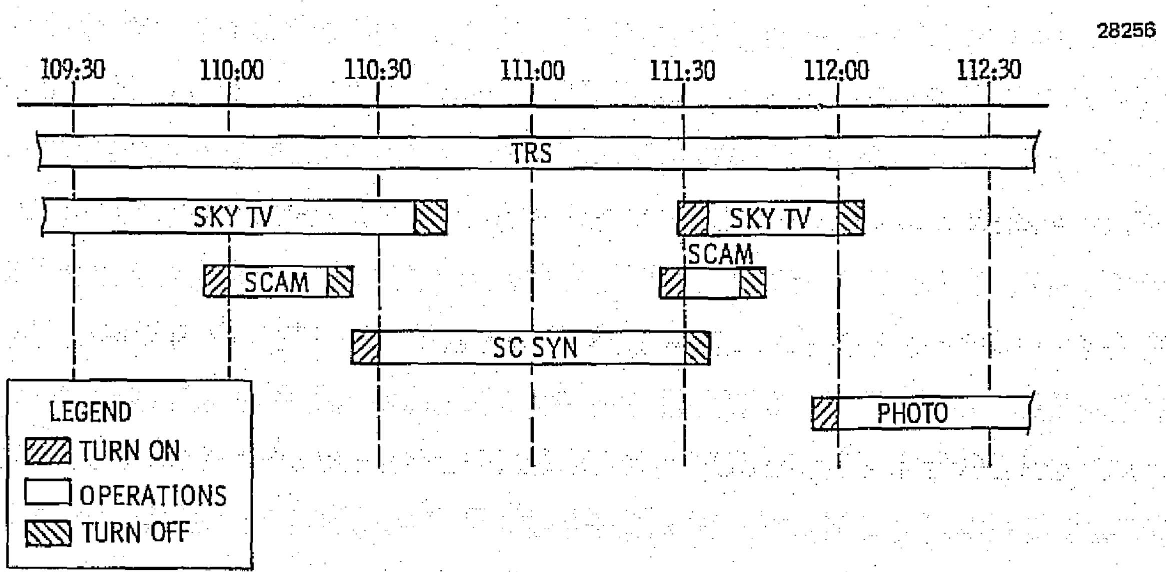

Figure I-3-31. Spacelab 2 Experiment Operations (GET 109:30 Hr to 112:30 Hr)

Table I-3-8

SPACELAB 2 EXPERIMENT IDENTIFICATION

Abbreviation	Experiments
TRS	Transition Radiation Spectrometer
SC PRO (Sun-Centered Synoptic Program)	65-cm photoheliograph Solar monitor package Soft x-ray telescope Lyman-Alpha white-light coronagraph High-sensitivity x-ray burst detector
SKY TV	Skylark cosmic x-ray telescope LLL TV
IPS SLEW	Slewing of instrument pointing system
EUV/PH	Extreme UV imaging telescope 65-cm photoheliograph
Photo (Photoheliograph Program)	65-cm photoheliograph Solar monitor package Soft x-ray telescope High-sensitivity x-ray burst detector
MPM SLEW	Slewing of MPM
SCAM	Far UV Schmidt camera/spectrograph
SC SYN (Sun-Centered Synoptic Program)	65-cm photoheliograph Solar monitor package Soft x-ray telescope Lyman-Alpha white-light coronagraph High-sensitivity x-ray burst detector

are being turned on or off. Monitoring of the experiment at other times is required only intermittently. Consequently, the overall flight crew utilization for each experiment is low.

In Case 1, with the control and monitoring of all experiments being accomplished by ground personnel, the flight crew is responsible primarily for advising, via the voice link, the ground of the status of the experiment and monitoring housekeeping data during TDRS data gaps. In Case 2, the flight crew activities are a maximum because they are required to turn on and off each experiment prior to and after each data run. Even this activity can be minimized by controlling each experiment through the computer DDU/KB. Experiments can be set up for a run while the required pointing maneuvers (Orbiter, IPS, or MPM) are being accomplished and can be activated, as required, through the computer interface. Monitoring of the experiments will require slightly more crew time than in Case 1, but, here again, the computer can be used to automatically perform limit checks on the housekeeping data and the crew can concentrate on the monitoring of scientific data.

Case 3 presents a crew activity between Cases 1 and 2 because the responsibility for monitoring data is shifted to the ground except during periods of TDRS data gaps which average 15 percent of the orbit.

The combining of individual experiments into the mission time line does not require serial addition of crew activities. Set ups and activations can be accomplished in parallel and more than one experiment can be monitored simultaneously.

The requirements for the ground crew are inverse to those of the flight crew. Little ground support can be provided in Case 2 because only a voice link is provided to the POCC. Here, it was determined that only a PI or his assigned representative need to be assigned to support experiment activities.

In Cases 1 and 3, where monitoring of scientific and housekeeping data can be accomplished in the POCC, the ground support necessary was determined by evaluating the type and quantity of data downlinked and the complexity of the experiment. Relatively simple experiments with little data such as the soft x-ray telescope which records data on film, would not require additional personnel for this case. Also considered in ground crew man-loading for Case 1, was the complexity of set up and activation of each experiment. More complex experiments, such as the solar monitor package with three active sensors, were assigned additional support.

The man-loading of the flight crew and ground personnel for each of the cases is assessed in Subsection 3.3.

3.2.2.3 Onboard Hardware and Software

The control and display of the experiments is accomplished through the CDMS with commands generated by the ground or on-orbit through the DDU/KB or the individual experiment C&D panels.

The small quantity of commands necessary to set up each experiment (i.e., filters and gratings) and initiate data acquisition is well within the capability of the CDMS. Control of the experiment sequences is accomplished within the experiment. Data produced by the experiments is transmitted through the computer or the HRM and does not, for Spacelab 2, exceed the capabilities of the onboard system. Data profiles for the two representative time spans are shown in Figure I-3-32 and I-3-33. On Spacelab 2, the VFI hardware generates continuous data at a 60 kBPS rate. Since this data is routed to the HRM for transmission to the ground, it is included in these figures so as to identify the total data profile.

In the assessment of the Spacelab 2 experiments, a concern for the acquisition of the highest quality of scientific data identified the need for additional experiment hardware for Case 2. In Cases 1 and 3, the scientific data is available in the POCC for computer and PI analysis. However, during Case 2, this data link is not available. Although the onboard computer could probably be utilized to continusously monitor and process the scientific data of an individual experiment, it would seriously limit the system from performing other functions. Consequently, the inability to monitor this data and identify unique sources of solar or stellar phenomena would degrade the scientific data of selected experiments. An assessment of relative scientific data of Spacelab 2 experiments for each experiment is shown in Table I-3-9.

In order to increase the scientific quality of Case 2, it is proposed that selected experiments incorporate detectors that will alert the flight crew to the existence of specific phenomena. This can be analyzed by the flight crew, and, by coordination with the PI via the voice link, the scheduling of additional data runs can be proposed to conduct additional investigation of the phenomena.

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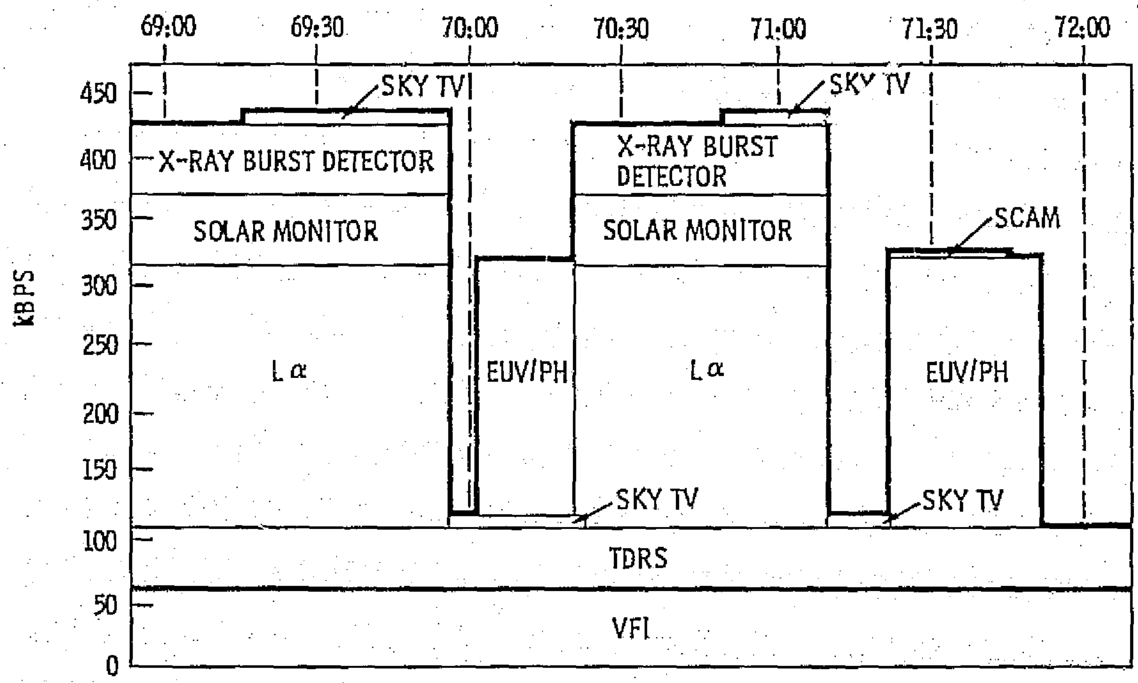

Figure I-3-32. Spacelab 2 Data Profile (GET 69:00 Hr to 72:00 Hr)

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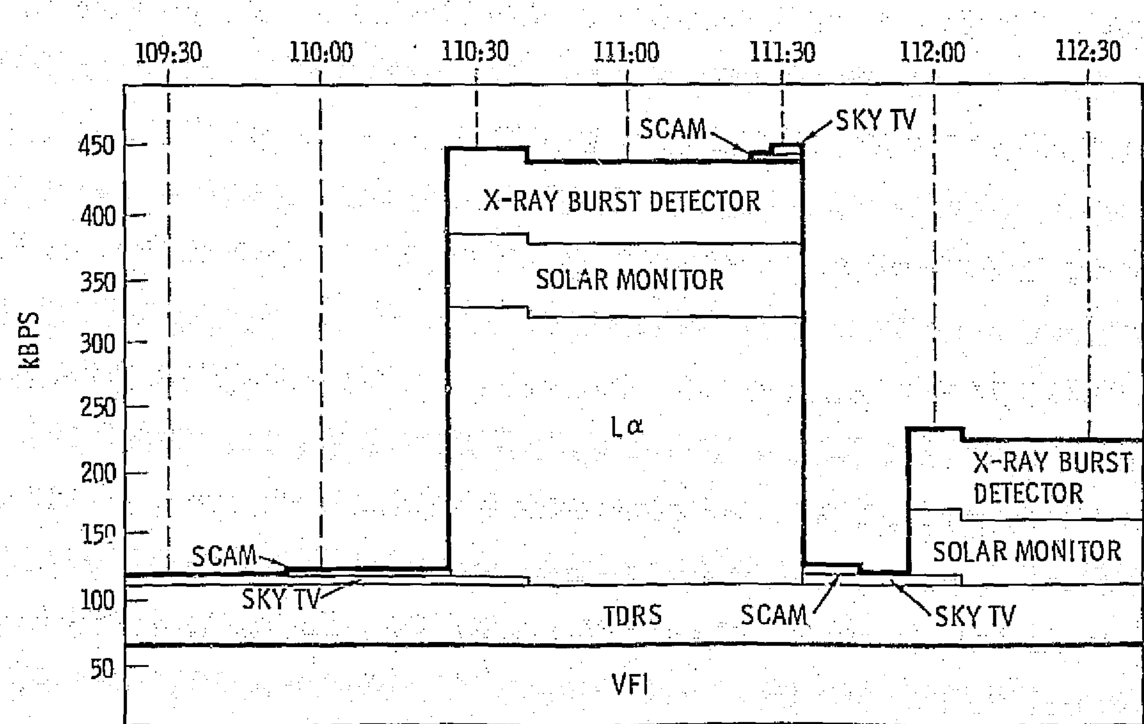

Figure I-3-33. Spacelab 2 Data Profile (GET 109:30 Hr to 112:30 Hr)

Table I-3-9

RELATIVE SCIENTIFIC QUALITY ASSESSMENT

	Cases		
	1 (Reference)	2	3
65-cm Photoheliograph	1.0	1.0	1.0
Solar Monitor Package	1.0	0.8	1.0
Soft X-Ray Telescope	1.0	1.0	1.0
Lyman-Alpha White-Light Coronagraph	1.0	0.7	1.0
High-Sensitivity X-Ray Burst Detector	1.0	0.9	1.0
Skylark Cosmic X-Ray Telescope	1.0	0.8	1.0
Low-Light-Level TV	1.0	0.7	1.0
Far UV Schmidt Camer/Spectrograph	1.0	1.0	1.0
Transition Radiation Spectrometer	1.0	0.6	1.0
Extreme UV Imaging Telescope	1.0	0.8	1.0

The analysis performed for each experiment, to determine if that experiment is a candidate for the incorporation of an additional detector, is provided in Subsection 3.4.1.

3.2.2.4 Ground Hardware and Software

The requirements for POCC control consoles, displays, and computing facilities were compared to the baseline POCC definition. The Spacelab 2 data profile does not exceed the computing capabilities in the POCC and will require no additional computer facilities. The use of control consoles can be assigned to PIs when individual experiments are scheduled in the time line. The quantity shown in the baseline is sufficient to support the activities of Spacelab 2.

It was assumed that the control of the pointing systems (IPS and MPM) is not within the baseline software design. Therefore, for Case 1, additional software must be developed to provide the necessary commands. This analysis is provided in Subsection 3.4.2.

3.2.2.5 Conclusions

The assessments of the impacts of Spacelab 2 on ground and flight personnel, equipment, and software for the three study cases is developed in Subsections 3.3 and 3.4. It is shown that Case 1, providing for ground control and display, requires that ground costs escalate to support this effort and the flight crew performs minimum activities. In Case 2, the flight crew is responsible for controlling and monitoring the experiment operations and the ground personnel serve only a support role using the voice link. In this case, costly experiment modifications are required to provide for detection of solar or stellar phenomena that, in Case 1, could be detected by POCC equipment and personnel.

In Case 3, optimum utilization of both the flight crew and ground support is obtained. The flight crew provides control and activation of the experiments and the ground monitors and analyzes experiment data. The voice link is used in coordinating operational information and for optimizing experiment activities.

3.3 MISSION OPERATIONS

3.3.1 POCC Operations

3.3.1.1 POCC Summary

Spacelab 1 and Spacelab 2 POCC Man-Hours

The POCC related costs are expressed in man-hours for each of the three cases for both the Spacelab 1 and Spacelab 2 missions. These costs include both experiment and integration personnel required to develop requirements and procedures for the POCC as well as the training and staffing of the POCC for real-time support of the mission. These hours are shown in Table I-3-10. Additional discussion of this table for case comparisons are in subsequent paragraphs under Spacelab 1 and Spacelab 2.

The bottom line of Table I-3-10 indicates that the grand total POCC-related effort is greater for Spacelab 2 than for Spacelab 1. This condition is caused by the longer duration of the Spacelab 2 mission (12 days versus 7 days) and also by the longer operation durations of the experiments (1,091 hours versus

Table I-3-10

POCC RELATED OPERATIONS - TOTAL MAN-HOURS

	Spacelab 1			Spacelab 2		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Experiment OPS (PIs)						
Requirements	745	267	382	693	334	536
Procedures	3,975	1,416	2,035	2,770	1,284	2,096
Training	1,245	387	579	1,111	408	798
POCC Staffing (No. of Personnel)	933 (38)	572 (23)	637 (26)	2,620 (32)	1,707 (20)	2,180 (26)
Total	6,898	2,642	3,633	7,194	3,733	5,610
Payload Integration (MSFC)						
Requirements	265	185	200	221	144	182
Procedures	1,594	1,114	1,198	1,326	872	1,094
Training	575	345	380	477	264	325
POCC Staffing (No. of Personnel)	1,552 (20)	1,162 (14)	1,162 (14)	2,680 (20)	2,304 (14)	2,392 (16)
Total	3,986	2,776	2,940	4,704	3,584	3,993
Grand Total	10,884	5,418	6,573	11,898	7,317	9,603

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196 hours). The experiment durations for Spacelab 2 cause every experiment to require two-shift operations, thus, considerably increasing the total man-hours. Other factors which influence the man-hour requirements are shown in Figure I-3-34.

The experiment portion of the Spacelab 1 total man-hours is similar to that of Spacelab 2; however, the POCC staffing man-hours are considerably greater for Spacelab 2 due to the greater total length of mission and to the longer durations of experiments even though the average crew size is smaller. Generally, the effort required for development of requirements and procedures are greater for Spacelab 1 because of the higher complexity and less repetition during the mission.

The integration portion of the total effort follows essentially the same pattern with the length of mission causing the greatest difference between Spacelab 1 and Spacelab 2. Staffing is generally over 1,000 man-hours greater for Spacelab 2 in each of the three cases.

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	MISSION DATA		INCREASE (↗) IN PARAMETER CAUSES				
						STAFFING	
PARAMETER	SPACELAB 1	SPACELAB 2	REQ	PROCEDURES	TRAINING	FLIGHT	GROUND
MISSION DURATION	166 HR	288 HR	↗	↗	↗	↗	↗
TOTAL DURATION OF ALL EXPERIMENTS	196 HR	1,091 HR	↗	↗	↗	↗	↗
NO. OF EXPERIMENTS	12	10	↗	↗	↗	↗	↗
NO. OF EXPERIMENTS REQUIRING TWO SHIFTS	3	10			↗		↗
VFT CREW INVOLVEMENT	CONSIDERABLY MORE	LESS				↗	
EXPERIMENT CREW INVOLVEMENT	CONSIDERABLY MORE	LESS				↗	↗
COMPLEXITY OF EXPERIMENTS	CONSIDERABLY MORE	LESS	↗	↗	↗	↗	↗
REPETITION OF EXPERIMENTS	CONSIDERABLY MORE	MORE	↘	↘	↘	↘	↘

Figure I-3-34. Manpower Influence Factors

POCC Integration Functions

Management — Two persons are required for each of the three cases for management, one person manages the POCC personnel activities and the second has overall experiment responsibility. These functions are required full time for all three cases.

The first function is performed by someone who repeatedly is in charge of the POCC and crew activities during mission activities and does not necessarily follow the payload development cycles. The second function is performed by the payload manager, and his assistant on second shift, who have historical knowledge of the development of all the experiments and their four levels of integration. He is the only POCC member that has overall knowledge of all experiments and the Spacelab systems.

Payload Operations — Personnel are required for payload operations functions to perform coordination between the experiment members of the POCC and between them and outside functional areas such as MCC, NASCOM, and MSFC. Outside coordination includes coordination between the experiment operators in the POCC with the STS and Spacelab systems engineers for evaluation and operation of the payload support systems and with the GSFC network for data flow. These activities do not change in degree from one case to another. Personnel required in this group are a Spacelab systems engineer and a pointing systems engineer. The pointing system engineer is only required during mission activities that utilize IPS or payload-provided pointing systems. Data management coordination is required to determine the payload data requirements on the STS and TDRSS/STDN. Due to the reduced POCC data requirements in Case 2, the data management function is reduced for that case and somewhat for Case 3.

Planning — The payload activity planning function is required for (1) replanning the remaining activities when changes are necessary, (2) coordination of activity planning in the POCC and with MCC, (3) formatting uplink text for the MS data file, (4) keeping a history of the flight, and (5) responding to planning support data requests. These functions are required on each shift for all three cases.

POCC Integration Man-Loading

The quantity of personnel that are required for each job function as described in the previous paragraph is shown in Table I-3-11. Two equal shifts are required throughout the mission duration. These crew sizes were used to define the detailed integration man-hours which are described in subsequent paragraphs under Spacelab 1 and Spacelab 2.

The man-loading was developed assuming that the training, procedure development, and the learning curves for the Spacelab activities were in an operational mode. The level of ground crew activity in the POCC for Spacelab 1 and Spacelab 2 is not necessarily representative of future flights. The POCC experiment activity does not include the effort required for the verification flight test activities. The verification flight test activity does, however, impose accommodation requirements on the STS, Spacelab systems, and crew, detracting from experiment operations.

After performing this analysis, it became obvious that the POCC integration effort is nearly the same for all three cases. The effort associated with these job functions is not appreciably affected by the data that are being displayed in the POCC. Since the integration job functions are primarily required for coordination between the payload community and other organizational areas, they are required for all three cases. Also, since Spacelab systems data is being displayed in the MCC Spacelab support room and the experiment data interfaces are essentially the same for all three cases, the coordination activity tends to remain constant across the cases.

POCC Experiment Team Functions

A POCC experiment team is required for each experiment that will be operated during the mission. The team will be required to be on-station at all times that their experiment is in operation. The size of the team varies from one to three in accordance to the complexity of the operation and to the technical complexity of the experiment. The team consists of the PI with one or two other experiment specialists who monitor and evaluate real-time experiment housekeeping and scientific data. Two shifts are required if the timing causes personnel to be on-station more than 14 hours (maximum) at one time. For most experiments, the team is the largest for Case 1 and the smallest for Case 2.

Table I-3-11
POCC INTEGRATION MAN-LOADING

	Case 1	Case 2	Case 3
Management	2	2	2
Payload Operations	3	2	2
Planning	4	3	3
Subtotal	9	7	7
Pointing Support (Optional)	1	1	1
Total (Including Option)	10	8	8

The POCC experiment team is responsible to check the real-time data against the predicted data to (1) verify that conditions in the Spacelab are not adversely affecting the scientific data quality; (2) verify that the experiment instrumentation is remaining in calibration and that it is working within limits; and (3) constantly evaluate the data to verify that the data is real (distinguish between actual and similar data), verify that the data is within predicted boundaries, identify phenomenon and/or targets that were not anticipated, and identify data that would necessitate changes in the remainder of the flight.

Detailed experiment team man-loading is presented in subsequent subsections under Spacelab 1 and Spacelab 2.

POCC Operations Analysis Methodology

Experiments — The number of man-hours estimated to be required for preparation of procedures are based on the number of pages that are required for the experiment which is a function of the total duration (D) of the experiment, its relative technical complexity (C), the repetition (R) of subtasks during the mission, and the number of personnel involved.

The number of man-hours required for preparation of requirements is closely related to the number of procedures pages that are necessary to fulfill those requirements. Requirement development is also influenced by the preceding factors (D, C, and R).

Training man-hours are a function of the total number of persons involved (both shifts) plus the class preparation time and the instructor's teaching time, all of which are affected by relative complexity, repetiveness, and duration of the experiment. The complexity factors were determined for the experiments relative to the various other experiments on Spacelab 1 for POCC Case 1. The complexity was then estimated for each experiment for the POCC for Cases 2 and 3, relative to Case 1. The higher the complexity, the higher the C factor. The same techniques were repeated for Spacelab 2 experiments and the complexities were determined relative to the complexities of Spacelab 1 to provide continuity of analyses for the two missions.

The repetition (R) factors were determined for experiments relative to the other experiments on Spacelab 1. These factors are a function of how much of the experiment activity repeats itself during the mission. Since the R factor is a multiplier, the more the repetition, the lower the factor. For example, if only one procedure is required and it is repeated 10 times during the mission, then the repetition factor would be considerably smaller than R of an experiment which has no repetition during the mission. The repetition factors for Spacelab 2 experiments were determined relative to those of Spacelab 1 for purposes of continuity of analysis for the two missions.

<ins>Integration</ins> — The methodology for performing operations man-power analysis for the integration effort is essentially the same as for the experiments. However, lower factors prevail for technical complexity and repetition, as compared to the experiments, because the integration activities are closely associated with the Spacelab systems, data systems, and the flight crew activities which tend to be similar from one mission to another. Higher levels of experience and higher learning curves also reduce the relative effort of the integration activity.

3.3.1.2 Spacelab 1 Mission

Spacelab 1 POCC Comparison of Cases

Experiment — The total Spacelab 1 man-hours required for each case were shown in Table I-3-10, Subsection 3.3.1.1. Table I-3-10 specifies the effort required for requirements, procedures, training, and POCC staffing. The total POCC effort was the greatest for Case 1, less for Case 3, and least for Case 2. The larger number of POCC personnel involved in Case 1 is the prime driver that causes all of the activities to be higher. The man-loading for the Spacelab 1 POCC experiment team is shown in Table I-3-12. The table depicts 8 of the 12 experiment teams as requiring 3 persons for Case 1 (an average of 2.5 persons). Case 2 has seven crews of 2 persons and five crews of 1 for an average of 1.6 persons per team. Case 3 has nine crews of 2 persons and three crews of 1 for an average of 1.8 persons per crew.

Summation of personnel listed in Table I-3-12 adds up to 30 for Case 1, 19 for Case 2, and 21 for Case 3. Since two shifts per day are required for three experiments (AP-13, APE-01, and SPE-80/85), the total number of persons required at JSC are 38 for Case 1, 23 for Case 2, and 26 for Case 3. Additional personnel are required in Cases 1 and 3 to monitor real-time data and to perform evaluation of the data providing maximum experiment data quality.

Integration — The effort shown earlier on Table I-3-10 for POCC payload integration indicates that Case 1 is the greatest. Case 3 is less, and Case 2 is the least. All three cases are closer to each other than those for the experiments. As explained in an earlier subsection, the integration effort tends to remain relatively constant across the cases since it is a function of Spacelab systems and NASCOM data systems which require relatively the same effort for all three cases. The basis for this effort for integration was the man-loading shown earlier in Table I-3-11.

Table I-3-12

SPACELAB 1 POCC EXPERIMENT MAN-LOADING

	Case 1	Case 2	Case 3
1. AP-09	3	2	2
2. AP-13 (1)	3 (2)	1 (2)	2 (2)
3. ST-31	3	2	2
4. EO-01	3	2	2
5. LS-13	3	2	2
6. APE-01 (1)	2	1	1
7. SPE-80/85 (1)	3	2	2
8. SPE-01	3	2	2
9. EOE-01	1	1	1
10. APE-07	3	2	2
11. STE-10	2	1	2
12. ASE-01	1	1	1

(1) Two shifts required.

(2) 2, 1, and 1 when run with AP-09.

Spacelab 1 POCC Substantiating Data

Table I-3-13 displays the next lower level of data that were used to prepare Table I-3-10. It shows the effort required for each experiment for preparation of procedures and requirements and for fulfilling the necessary training requirements of Spacelab 1. These quantities were derived from factors based on experiment duration (D), complexity (C), repetition (R), and quantity of personnel involved.

Man-hours for staffing was based on quantity of personnel and duration of the experiments. Preparation time prior to operation and evaluation time during postoperation was added to the experiment duration for a more accurate estimate of staffing for the experiments. This technique was not utilized for the integration crew since that crew maintains stations around the clock on a two-shift basis and the nature of the work is more routine.

Table I-3-13

SPACELAB 1 POCC RELATED MAN-HOURS FOR EXPERIMENTS

Experiment	Crew Size			Experiment Duration	Procedures ~Man-Hours			Requirements ~ Man-Hours			Training ~Man-Hours		
Case	1	2	3	Hour	1	2	3	1	2	3	1	2	3
1. AP-09	3	2	2	6.6	201	59	119	37	11	22	54	15	30
2. AP-13	3/3	1/1	2/2	16.7	261	51	153	48	10	29	108	15	56
3. ST-31	3	2	2	8.8	310	121	152	57	23	29	90	30	40
4. EO-01	3	2	2	19.3	587	231	231	108	43	43	162	55	55
5. LS-13	3	2	2	12.2	296	145	204	55	28	39	84	35	50
6. APE-01	2/2	1/1	1/1	24.8	345	101	101	63	19	19	112	35	35
7. SPE-80/85	3/3	2/2	2/2	56.4	785	308	540	144	58	101	324	105	182
8. SPE-01	3	2	2	6.2	243	120	120	45	23	23	72	30	30
9. EOE-01	1	1	1	5.2	113	33	33	21	6	6	24	8	8
10. APE-07	3	2	2	15.0	456	135	270	84	25	25	126	35	65
11. STE-10	2	1	2	20.3	265	79	79	49	15	15	65	16	20
12. ASE-01	1	1	1	4.3	113	33	33	21	6	6	24	8	8
Experiment Total	38	23	26		3,975	1,416	2,035	745	267	382	1,245	387	579
Integration Total	10/10	7/7	7/7	166.0	1,594	1,114	1,198	265	185	200	575	345	380

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3.3.1.3 Spacelab 2 Mission

Spacelab 2 POCC Comparison of Cases

Experiment – The POCC comparison of cases for Spacelab 2 is very similar to Spacelab 1. Again, the total POCC effort was the greatest for Case 1, less for Case 3, and least for Case 2. These results were primarily influenced by the number of personnel involved in each case. The three cases were relatively closer together on a percentage basis than for Spacelab 1. The man-loading for the Spacelab 2 POCC experiment team is shown in Table I-3-14. The average POCC team for each experiment is 1.6 for Case 1, 1.0 for Case 2, and 1.3 for Case 3. These man-loading levels were lower for Spacelab 2 than Spacelab 1 because Spacelab 2 experiments are generally less complex and tend to be more self-contained.

Summation of personnel listed in Table I-3-14 adds up to 16, 10, and 13 for Cases 1, 2, and 3, respectively. Since all experiments require two shifts per day, the total number of POCC experiment personnel that are required at JSC are 32, 20, and 26 for Cases 1, 2, and 3, respectively.

Again, the additional personnel are required for Cases 1 and 3 to monitor control and evaluate real-time data so that the quality of scientific data is at an acceptable level.

Integration – The case-by-case relationship for Spacelab 2 POCC payload integration is similar to that of Spacelab 1. Again all three cases are closer together than those for the experiments due to consistency of job functions in integration. The basis for the integration effort was the man-loading shown earlier in Table I-3-11.

Spacelab 2 POCC Substantiating Data

Table I-3-15 displays the next lower level of data that were used to prepare Table I-3-10. It shows the effort required for each experiment to prepare procedures and requirements and to fulfill the necessary training requirements for Spacelab 2. These quantities were derived from factors based on experiment duration (D), complexity (C), repetition (R), and quantity of personnel involved.

Table I-3-14

SPACELAB 2 POCC EXPERIMENTS MAN-LOADING ①②

		Case 1	Case 2	Case 3
1.	Transition Radiation Spectrometer	1	1	1
2.	Far UV Schmidt Camera/Spectrograph	1	1	1
3.	Extreme UV Imaging Telescope	2	1	1
4.	Skylark Cosmic X-Ray Telescope	2	1	1
5.	LLL TV	2	1	2
6.	65-cm Photoheliograph	1	1	1
7.	Solar Monitor Package	2	1	2
8.	Soft X-Ray Telescope	1	1	1
9.	Lyman-Alpha White-Light Coronagraph	2	1	2
10.	High-Sensitivity X-Ray Burst Detector	2	1	1

① Pointing required (POCC support is required only for Cases 1 and 3

② Two shifts required for all experiments on SL-2.

Man-hours for staffing was based on quantity of personnel and duration of the experiments. Preparation time prior to operation and evaluation time during postoperation was added to the experiment duration for a more accurate estimate of staffing for the experiments. This technique was not utilized for the integration crew since that crew maintains stations around the clock on a two-shift basis and the nature of the work is more routine.

3.3.2 Flight Operations

3.3.2.1 Onboard Summary

Delta Man-Hours

The onboard related costs are expressed in delta man-hours. Case 1 is defined as the reference base (zero), and the delta man-hours of Cases 2 and 3 are relative to Case 1. The man-hours shown in Table I-3-16 are for

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Table I-3-15

SPACELAB 2 POCC MAN-HOURS FOR EXPERIMENTS

Experiment	Crew Size			Experiment Duration	Procedures ~Man-Hours			Requirements ~Man-Hours			Training ~Man-Hours		
Case	1	2	3	Hr	1	2	3	1	2	3	1	2	3
1. Transition Radiation Spectrometer	1/1	1/1	1/1	279.0	89	89	89	22	22	22	28	28	28
2. Far UV Schmidt Camera/Spectrograph	1/1	1/1	1/1	12.5	48	24	48	12	6	12	21	10	21
3. Extreme UV Imaging Telescope	2/2	1/1	1/1	12.4	60	20	20	15	5	5	26	9	9
4. Skylark Cosmic X-Ray Telescope	2/2	1/1	1/1	110.0	211	70	141	53	18	35	92	22	44
5. LLL TV	2/2	1/1	2/2	110.0	211	70	178	53	18	44	92	22	77
6. 65-cm Photo-heliograph	1/1	1/1	1/1	136.0	392	131	392	98	33	98	122	41	122
7. Solar Monitor Package	2/2	1/1	2/2	123.6	791	396	593	198	99	149	346	124	260
8. Soft X-Ray Telescope	1/1	1/1	1/1	123.6	316	158	158	79	40	40	99	50	50
9. Lyman-Alpha White-Light Coronagraph	2/2	1/1	2/2	47.2	302	151	302	76	38	76	132	47	132
10. High-Sensitivity X-Ray Burst Detector	2/2	1/1	1/1	136.6	350	175	175	87	55	55	153	55	55
Experiment Total	16/16	10/10	13/13	1,090.9	2,770	1,284	2,096	693	334	536	1,111	408	798
Integration Total	10/10	7/7	8/8	288.0	1,326	872	1,094	221	144	182	477	264	325

Table I-3-16

ONBOARD RELATED OPERATIONS — DELTA MAN-HOURS

	Spacelab 1			Spacelab 2		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Operations Requirements Definitions	0	160	60	0	160	60
Crew Activity	0	4,431	1,791	0	1,753	809
Total	0	4,591	1,851	0	1,913	869
Flight Crew Required for Experiment Operations	3	5	5	3	3	3

(1) the crew activity which is required to develop requirements and procedures for the payload crew and to provide training and for (2) the preplanning activity by MSFC for the definition of requirements for equipment, software, and operations support.

The related onboard delta man-hours for integration of additional onboard hardware and software for Cases 2 and 3 have been folded into the respective hardware and software costs which are presented in Subsection 3.4 of this report.

The crew activity includes the effort required to develop requirements and procedures, to train the crew, and to staff the crew. The delta man-hours for Spacelab 1 was considerably higher than for Spacelab 2 as a result of additional crewmen being required for Spacelab 1 due to higher technical complexity and less repetition of the Spacelab 1 experiments. Spacelab 1 required three, five, and five crewmen for Cases 1, 2, and 3, respectively, while Spacelab 2 required only three crewmen for all three cases. Even with additional crewmen on Spacelab 1, the utilization is at a higher level than for Spacelab 2. The bulk of the delta man-hours for crew activity is for training.

The crew activity does not include all of the costs associated with the crewmen. In particular, the impact from raising the payload crew from three to five was not assessed for the flight crew support. This support includes (1) medical (doctors, nurses, technicians, medical equipment, and facilities), (2) training equipment (flight simulators, classrooms, training materials, on-the-job type training, etc.), and (3) flight support equipment supply and control and maintenance (personnel hygiene, waste management, food and beverages, wearing apparel, stowage, atmospheric control, etc.).

The effect of these considerations may range from essentially no effect to considerable effect. For example, if the planned medical facility can provide support for two additional crewmen without expanding, then the effect is minimal. On the other hand, if expansion of the medical facility is necessary, then the effect is significant.

The net effect of these costs, which were not considered, would increase Cases 2 and 3 delta costs making them relatively more expensive than Case 1.

The delta integration effort for definition of equipment, software, and support requirements is relatively small as compared to the crew related effort. A delta of 160 man-hours are estimated for Case 2 and 60 man-hours for Case 3. Since the chosen case will be defined well in advance of the preplanning effort, all of the effort is initial effort and not replanning effort. The total number of man-hours for this definition is not significantly influenced by a small percentage increase in either onboard hardware or software. The only significant increase is for crew support requirements definition.

Payload Crew Functions

For Case 1, the majority of the crew functions are concerned with housekeeping, setups, calibration, pointing, data control, and handling, satisfying physical requirements during operation (e.g., changing film magazines, taking blood samples, adjusting equipment, etc.), deactivating and securing, and/or storing equipment and samples.

In addition to these duties, for Case 2 the crewmen are also responsible for performing all experiment operations. This activity includes monitoring and controlling experiment data. These data are checked against the predicted data to (1) verify that conditions in the Spacelab are not adversely affecting the scientific data quality; (2) verify that the experiment instrumentation is remaining in calibration and that it is working within limits; and (3) constantly evaluate the data to verify that the data is real (distinguish between actual and similar data), verify that the data is within predicted boundaries, identify phenomenon and/or targets that were not anticipated, and identify data that would necessitate changes in the remainder of the flight.

In Case 2, items (1) and (2) preceding may be either automated or provided by the flight crew to the same level of quality as in Case 1. On the other hand, item (3) cannot be automated except to a small degree. Item (3) cannot adequately be provided for by the flight crew due to insufficient flight crew personnel or due to insufficient knowledge of the experiment.

Case 2 is not acceptable for a number of experiments of high technical complexity. For example, Spacelab 1 has several experiments that are judged to return scientific results for Case 2 of only about one-half the quality of Case 1.

Crew activities for Case 3 fall between those of Case 1 and Case 2. For those experiments that either do not require real-time evaluation or have a low technical complexity, they may be either automated or operated by the crew (if personnel are available). On the other hand, the remaining experiments are monitored on the ground to attain the necessary level of experiment quality.

Payload Crew Utilization

For the purpose of this study, the payload crew is defined as the PSs and the MS. The commander and pilot involvement was held to a minimum, using them only where absolutely necessary. The MS has the primary responsibility for control and monitor of the VFT and for instrument pointing. The

PSs have the primary responsibility for the experiment functions. On shifts which do not have a MS available, the PS also assumes his duties.

Crew real-time effort was estimated for each experiment and for each operation required for VFT. The individual experiment man-loading levels were analyzed on an integrated basis to determine the quantity of man-hours required for every hour of the mission for Spacelab 1 and Spacelab 2. Assuming 100% utilization of the crewmen while they are on-station, the quantities of crewmen were determined as listed previously on Table I-3-16.

The flight payload crew level-of-effort is considered the norm for Case 1 for which the delta man-hours are zero. Cases 2 and 3 flight man-hour deltas are determined in relationship to Case 1.

Cases 2 and 3 payload activities should be reshaped in accordance to their ground rules to increase the effective utilization of the crew for those cases.

For analysis purposes, the flight crews were assumed to never be sick during the mission. Also, a backup crew was not considered for determining man-hours.

Onboard Operations Analysis Methodology

The methodology utilized for onboard-related man-hour estimates was very similar to that used for POCC-related estimates (reference Subsection 3.3.1.1 POCC Operations Analysis Methodology) for the experiments. Similar techniques were used to determine the man-hours needed for preparation of crew requirements and procedures as well as for crew training.

Factors for duration (D), technical complexity (C), and repetition (R) were also used. The complexity factors were first estimated for the flight crew activities for each experiment in Case 2 since that is the most complex case for the flight crew. These were the same complexity factors as those used for the POCC, Case 1. Complexities of the flight crew activities for Cases 1 and 3 were determined relative to Case 2 (flight).

The repetition factors utilized for flight operations analyses were identical to those used in the POCC operations analyses since repetition of the experiments is not dependent upon relative flight or ground activities.

3.3.2.2 Spacelab 1 Mission

Spacelab 1 Onboard Comparison of Cases

The crew activity delta man-hours for each case was shown in Table I-3-16. The most significant components of crew activity are development of crew requirements and procedures and especially crew training. The case relationships are exemplified by ratios of these efforts of Cases 2 and 3 to Case 1. The ratios to Case 1 for requirements development are 1.9 for Case 2 and 1.5 for Case 3. The ratios are the same for procedures development. The ratios to Case 1 for training are 4.5 for Case 2 and 2.2 for Case 3. The greater crew involvement (larger number of crewmen) in Cases 2 and 3 is the prime driver that causes the ratio to be higher (greatest in Case 2 and least for Case 1).

The ability to monitor and control payloads from the ground (Case 1) provides a significant degree of flexibility not available in Case 2. Should onboard problems (e.g., crew sickness or diversion of attention from one payload to problem investigation of another payload or STS support system) preclude accomplishment of scheduled payload activities, ground control could be assumed with a potential of salvaging significant payload data.

Table I-3-17 shows the man-loading required for the twelve experiments aboard Spacelab 1. This table was used in conjunction with the Strawman time line to integrate the real-time man-loading requirements throughout the flight. Each hour was assessed to determine the total quantity of crewmen required to perform all crew functions. The results indicate that three, five, and five crewmen are required for Cases 1, 2, and 3, respectively.

The Case 1 crew activity requirement for three men was in agreement with the Strawman document[1]. However, the schedule and the quantity of experiments cause the utilization of only three crewmen to be very high.

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[1] Spacelab 1, Strawman, MSFC, SE-012-020-2S, October 1976.

Table I-3-17
SPACELAB 1 FLIGHT PAYLOAD CREWMEN UTILIZATION (1)

		Case		
		1	2	3
1.	AP-09	0.2	0.9	0.8
2.	AP-13	0.2	0.9	0.8
3.	ST-31	0.4	1.0	0.6
4.	EO-01	0.4	0.7	0.7
5.	LS-13	1.3	1.3	1.3
6.	APE-01	0.4	1.2	1.2
7.	SPE-80/85	0.3	0.7	0.4
8.	SPE-01	0.5	0.8	0.8
9.	EOE-01	0.1	0.5	0.5
10.	APE-07	0.2	0.4	0.4
11.	STE-10	0.1	0.5	0.5
12.	ASE-01	0.3	0.5	0.5

(1) Values are crewmen required (1.0 equals one man) during operation (higher during activation, deactivation, etc.).

Consideration should be given to reducing the number of experiments on Spacelab 1 to help alleviate that problem.

Case 2 showed an increase of crewmen to five due to the greater involvement of the crew with the experiments. Even with five crewmen aboard (two on one shift and three on the other), the utilization was unreasonably high to the point that scientific requirement fulfillment was questionable.

It is not possible to get the same experiment scientific return in Case 2 as it is in Case 1 or Case 3. The very nature of scientific experimentation requires frequent evaluation of experiment outputs with readjustments of inputs to obtain the desired results. Evaluation of outputs often requires years of education, training, and experience available only through the dedicated scientist. Experimentation time availability coupled with the inherent problems of verbal communication required in Case 2 does not allow the crewmen to provide an acceptable quality of return for the experiments.

The required scientific knowledge can partially be translated to onboard operations by increasing crew size (allowing more time per experiment), providing extensive crew training, and providing complex automated scientific data processing and evaluation programs. These approaches increase the cost yet still fail to give the same degree of scientific return as available through the well-informed ground-based scientist of Case 1 and Case 3.

Case 3 also requires five crewmen, however, utilization is much lower. With more in-depth analyses, one crewman may be eliminated for this case, leaving two crewmen on each shift. Having unbalanced shifts may create problems in scheduling experiment activity. This could become a real constraint in real-time replanning of flight experiment operation activities (e.g. a target-of-opportunity surfaces during a shift that has only one payload crewman on-station).

For Cases 2 and 3, a very strong relationship exists between crew training, onboard software, and quality of scientific data return. It is physically impossible for 2 additional crewmen to perform the same level of effort that 12 to 15 extra POCC personnel perform in Case 1. It is also unreasonable to expect that all of the scientific knowledge of those 12 to 15 persons could be transferred to the flight crew. Some of the difference may be made up by additional onboard software to handle the routine tasks during experiment operations. Increased training will also increase the quality of experiment returns.

Several iterations were made that increased both software and training; however, many experiments still had unacceptable levels of quality for Case 2. In Case 3, those experiments that were unacceptable in Case 2 where changed to utilize the POCC as in Case 1. The requirements for increased crew training and the increased complexity of onboard hardware and/or software required by Case 2 would minimize the flexibility for changing payloads late in the prelaunch preparation phases.

The increased demand for added hardware, software, and crew to support Case 2 may significantly deplete STS-provided resources for payload support.

Case 2 would tend to increase weight, power consumption, data processing, and habitation support usage. The result of these demands may necessitate a decrease in payload-carrying capability. The introduction of the more sophisticated payloads beyond those studied for Spacelabs 1 and 2 would accentuate this problem.

Spacelab 1 Onboard Substantiating Data

Table I-3-18 depicts the next lower level of data that went into preparation of Table I-3-16. It shows the man-hours of effort which are needed to prepare crew requirements and procedures and to complete the necessary crew training for the payload flight crew of Spacelab 1. The quantities were derived from factors based on experiment duration (D), complexity (C), and repetition (R) along with the quantity of crewmen involved.

Man-hours for staffing was based on the quantity of crewmen and duration of the experiments. This technique of staff estimating is in accordance with the ground rules; however, it does not account for the real costs of having astronauts on the payroll. Accounting for these costs will drive Cases 2 and 3 higher and make them less viable.

3.3.2.3 Spacelab 2 Mission

Spacelab 2 Onboard Comparison of Cases

The crew activity delta man-hours for each case was shown in Table I-3-16. The most significant components of crew activity are development of crew requirements and procedures and especially crew training. The case relationships are exemplified by ratios of these efforts for Cases 2 and 3 to Case 1. The ratios to Case 1 for requirements development are 2.2 for Case 2 and 1.5 for Case 3. The ratios are the same for procedures development. The ratios to Case 1 for training are 2.8 for Case 2 and 1.8 for Case 3. The prime driver that causes the training ratio to be higher is the greater crew involvement (greatest in Case 2 and least for Case 1).

Table I-3-19 shows the man-loading required for the nine experiment groupings aboard Spacelab 2. This table was used in conjunction with the Strawman time line to integrate the real-time man-loading requirements through out

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Table I-3-18

SPACELAB 1 ONBOARD-RELATED MAN-HOURS FOR EXPERIMENTS

Experiment	Crew Size Case			Experiment Duration Hour	Procedures ~ Man-Hours			Requirements ~ Man-Hours			Training ~ Man-Hours		
	1	2	3		1	2	3	1	2	3	1	2	3
1. AP-09	3	5	5	6.6	105	73	53	20	14	10	18	240	112
2. AP-13	3	5	5	16.7	48	96	80	9	18	15	36	288	160
3. ST-31	3	5	5	8.8	64	115	89	12	22	17	48	360	176
4. EO-01	3	5	5	19.3	129	216	216	24	41	41	102	648	432
5. LS-13	3	5	5	12.2	68	109	151	13	21	28	54	336	192
6. APE-01	3	5	5	24.8	48	127	127	9	24	24	174	384	256
7. SPE-80/85	3	5	5	56.4	72	289	108	14	54	20	156	864	168
8. SPE-01	3	5	5	6.2	51	91	91	10	17	17	252	288	192
9. EOE-01	3	5	5	5.2	26	43	43	5	8	8	24	144	96
10. APE-07	3	5	5	15.0	120	168	120	23	32	23	90	504	240
11. STE-10	3	5	5	20.3	65	163	129	12	31	24	30	312	160
12. ASE-10	3	5	5	4.3	28	41	28	5	8	5	24	144	64
Experiment Total					824	1,531	1,235	156	290	232	1,008	4,512	2,248

Table I-3-19

SPACELAB 2 FLIGHT PAYLOAD CREWMEN UTILIZATION (1)(3)

Groupings	Case 1	Case 2	Case 3
1. SC SYN	0.1	0.2	0.2
2. SC PRO	0.1	0.2	0.2
3. PHOTO	0.2	0.2	0.2
4. EUV/PH	0.1	0.1	0.1
5. SKY TV	0.4	0.4	0.4
6. S CAM	0.3	0.3	0.3
7. TRS	0	0	0
8. M Slew (2)	1.0	1.0	1.0
9. I Slew (2)	1.0	1.0	1.0

(1) Pointing required for all cases.

(2) Support utilization is only 0.1 man (after reslewing).

(3) During experiment operations (higher duration activation, deactivation, etc.).

the flight. Each hour was assessed to determine the total quantity of crewmen required to perform all crew functions. The results indicate that three crewmen are required for all three cases.

The Case 1 crew activity requirement for three men was in agreement with the Strawman document[1]. Unlike Spacelab 1, the schedule and the quantity of experiments allow a reasonable utilization of the three crewmen.

Case 2 also showed a requirement for three crewmen; however, a much higher utilization is required. That high-utilization rate approaches the limit, but by minor changes and/or minor Orbiter crew utilization, the three crewmen can fulfill the crewmen requirements.

Case 3 also utilized three crewmen, but at a more relaxed utilization rate. Use of the Orbiter crew is not required for this case.

[1]Spacelab 2, Strawman, MSFC, SE-012-022-28, December 1976.

Spacelab 2 Onboard Substantiating Data

Table I-3-20 depicts the next lower level of data that went into preparation of Table I-3-16. It shows the man-hours of effort which are needed to prepare crew requirements and procedures and to complete the necessary crew training for the flight payload crew of Spacelab 2. The quantities were derived from factors utilizing experiment duration (D), complexity (C), and repetition (R) along with the quantity of crewmen involved.

Man-hours for staffing were based on the quantity of crewmen and duration of the experiments. As stated earlier, it does not account for the real costs of flying personnel which would drive Cases 2 and 3 higher and make them less viable.

3.4 SYSTEM MODIFICATIONS

3.4.1 Hardware Modifications

3.4.1.1 Spacelab 1

This study identified no hardware modification requirements for Spacelab 1. The POCC baseline plan is adequate for ground support (control, monitoring, and analysis) of the experiment operations in all three study cases. Flight systems and experiment hardware design requirements are adequate to support mission activities for each of the study cases. However, in Case 2, increased use of the Spacelab experiment computer resulted in near saturation of the computer's capacity. Added experiment or operational complexity of later missions may result in a requirement for additional computer capacity.

3.4.1.2 Spacelab 2

The POCC baseline plan, as for Spacelab 1, is adequate to support ground operations for Spacelab 2. Ground computers will be used to analyze experiment scientific data to identify unique solar or spatial phenomena (i.e., solar magnetic fields or stellar extreme UV sources). The consoles identified in the POCC will be adequate if experiment support personnel (PIs, etc.) are assigned to specific consoles only at those times that their individual experiment is scheduled on the flight time line.

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Table I-3-20

SPACELAB 2 ONBOARD-RELATED MAN-HOURS FOR EXPERIMENTS

Experiment	Crew Size Case 1	2	3	Experiment Duration Hour	Procedures ~ Man-Hours 1	2	3	Requirements ~ Man-Hours 1	2	3	Training ~ Man-Hours 1	2	3
1. Transition Radiometer Spectrometer	3	3	3	279.0	44	44	44	8	8	8	33	43	40
2. Far UV Schmidt Camera Spectrograph	3	3	3	12.5	12	24	12	3	5	3	9	23	11
3. Extreme UV Imaging Telescope	3	3	3	12.4	9	29	29	2	6	6	7	29	26
4. Skylark Cosmic X-Ray Telescope	3	3	3	110.0	35	104	70	7	21	13	26	103	62
5. LLL TV	3	3	3	110.0	35	104	52	7	21	10	26	103	48
6. 65-cm Photoheliograph	3	3	3	136.0	65	196	65	12	37	12	49	191	60
7. Solar Monitor Package	3	3	3	123.6	197	396	297	37	74	56	148	380	266
8. Soft X-Ray Telescope	3	3	3	123.6	79	159	159	15	30	30	59	155	143
9. Lyman-Alpha White-Light Coronagraph	3	3	3	47.2	76	151	76	14	28	14	57	147	68
10. High-Sensitivity X-Ray Burst Detector	3	3	3	136.6	88	176	176	16	32	32	66	170	157
Experiment Total					640	1,383	980	121	262	184	480	1,344	881

There is no requirement for additional onboard hardware to support study Cases 1 and 3. This is because scientific data can be analyzed and monitored by ground computers and personnel. However, in Case 2, it is recommended that additional hardware be incorporated into specific experiments. This hardware is necessary to increase the scientific return of these experiments and to ensure that any unique phenomena occurring during the mission will be observed. To determine which of the Spacelab 2 experiments would be candidates for additional hardware to increase the scientific return, the data output of each was analyzed to identify those which can be monitored on-orbit. Four experiments (65-cm photoheliograph, soft x-ray telescope, white-light coronagraph portion of the Lα/WLC experiment, and far UV Schmidt camera/ spectrograph) record the scientific data on film which will be processed and analyzed after the mission. Three experiments (high-sensitivity X-ray burst detector, Skylark cosmic X-ray telescope, and LLL TV) transmit data which is not processed in real time but is analyzed by more rigorous methods.

Four experiments, solar monitor package, Lyman-Alpha portion of the Lα/WLC experiment, transition radiation spectrometer, and extreme UV imaging telescope, should be considered for the addition of special hardware for increasing the scientific return for Case 2.

The solar monitor package, along with other data acquisition, measures the solar magnetic field. It is desirable to monitor the output of the magnetograph for detection of unique magnetic fields which might require further investigation during a data run. After this signal is digitized and routed out of the experiment, the data cannot be continuously monitored by onboard computers to detect magnetic fields. It is proposed for Case 2 that a detector be designed and incorporated into the experiment. This detector will monitor the sensor output, and, by synchronization with the sensor, will locate sources of unique magnetic fields. The detector will provide a signal to the Orbiter AFD to alert the flight crew of the occurrence and location of the magnetic field.

The Lα sensor monitors the sun in the 1216 Å wavelength. During experiment operations, this sensor will detect solar phenomena which could require further investigation. In Cases 1 and 3, the data will be transmitted to the ground for computer analysis in the POCC. However, in Case 2, where there is no link to the POCC, all data must be monitored onboard. Continuous monitoring and analysis of the output of the Lα sensor would not be compatible with flight computer usage. It is recommended that the output of the Lα sensor be monitored by a specially designed detector which would indicate to the flight crew the presence and location of any unique events of the sun. Then, using the voice link with the PI, the crew could determine if additional data-taking should be planned.

The transition radiation spectrometer is an experiment which operates continuously throughout the mission and is used to determine flux and energy spectra of cosmic protons and electrons. Ground monitoring computers in the POCC can be used to analyze the continuous stream of data to identify spatial locations where the concentration of these phenomena might require additional data acquisition. In Case 2, this continuous data link to the POCC is not available, consequently, the detection of these radiation sources must be accomplished onboard. Monitoring of this data would limit flight computer support of other experiments. Therefore, it is recommended for Case 2 that an energy detection system be incorporated into the experiment to monitor the spectrometer output and alert the flight crew of the presence of unique radiation sources.

The output of the extreme UV imaging telescope, used to obtain extreme UV images of stellar objects, is transmitted to the POCC for analysis in Cases 1 and 3. The analysis will identify the existence of extreme UV sources which could require additional data acquisition. In Case 2, where data monitoring is accomplished entirely onboard, it would impact the operation of other experiments to use the experiment computer to continuously monitor the output of this experiment. Consequently, for Case 2 it is recommended that a detector be developed and incorporated into the experiment which would monitor the telescope output and alert the flight crew of the location of any unique extreme UV sources. With the assistance of the PI, through the voice link, it can be determined if additional runs should be scheduled to acquire data on the extreme UV sources.

3.4.2 Software Modifications

Software cost deltas for both the onboard and the POCC functions were determined for each of the three cases. In addition, a Case 2 onboard option involving automating some of the operator functions was also estimated.

Experiment computer capacity was assessed for adequacy in each of the trade cases. The requirements were determined from estimates of the total number of program instructions, sizing a worst-case second, and the computer operations per second.

Experiment data management functions were estimated in seven functional categories for Spacelab 1 and Spacelab 2 for each case and converted to software program instructions and computer operations per second. These estimates were based on experiment and instrument descriptions and on discussions with investigators experienced with each experiment. The categories were:

A. Limit check and alert operator of anomalies (parameter per second).
B. Gather and format data for telemetry (TM) - (kBPS) this did not include TM data sent directly to the HRM.
C. Gather data and convert for display or CRTs (parameters) - update once per second maximum.
D. Send commands to experiment - either preprogrammed, uplinked, or operator initiated - (CMDS).
E. Communications with the Orbiter computer - uplink commands, data transfer, etc. (words per second).
F. Data reduction and evaluation - (functional definition).
G. Special computations - (functional definition).

A summary of the data after conversion to program instructions and operations per second is shown in Tables I-3-21 and I-3-22.

For the automation on Case 2, scientific data was monitored by the experiment computer to determine if the experiment was operational and data of some quality was being transmitted on the downlink. It reflects an attempt to reduce the crew work load required to accomplish the mission. It was not intended to evaluate the scientific data as a PI on the ground would be expected to do.

The standard programs available (limit check, I/O, DDU/KB message program, data conversion to engineering units, telemetry data formating, and other utilities) will handle most of the experiment housekeeping functions.

Table I-3-21

PROGRAM INSTRUCTIONS

	Type	Case 1	Case 2	Case 3
Spacelab 1 Basic	ENG	14,974	15,000	15,003
Pointing Data	SYS ANA	-	500	500
Heat Rate	SYS ANA	-	100	100
Automated	ENG	-	15,343	-
	SYS ANA	-	5,183	-
POCC Spacelab 1	ENG	17,152	-	13,293
Pointing Data		500		
Heat Rate		100		
Spacelab 2 Basic	ENG	4,041	5,981	5,981
POCC Spacelab 2	ENG	7,386	-	5,376
IPS and MPM Pointing	SYS ANA	400	-	-

Table I-3-22

EXPERIMENT COMPUTER OPERATIONS PER SECOND

	Case 1	Case 2	Case 3
Spacelab 1 (All Experiments) Basic	60.64K	(1) 168.85K	(1) 165.65K
Automated (All Experiments)	-	139.4K	-
Worst Case 4 Experiments, (2) Basic	-	137.75K	-
Automated Worst Case 4 Experiments (2) (3)	-	86.4K	-
Spacelab 2 (All Experiments) Basic	85.92K	100.56K	100.56K

Note: 260k OPS/sec available.

(1) Includes some high-rate scientific data on the experiment computer TM downlink.

(2) Experiments AP-09, EO-01, LS-13, and APE-01.

(3) No more than two of these experiments are ever on together.

It is assumed the experimenter will provide the data (parameters, limits, etc.) required for these programs to operate. Any closed-loop control program would have to be entirely supplied by the experimenter. For ease of development, it would seem that most closed-loop control would be self-contained within the experiment. One experiment (EO-01, Spacelab 1) used the experiment computer for closed-loop control.

Similarity between Cases 1, 2, and 3 is created by:

A. The downlink TM being required for ground recording for offline analysis (Cases 1, 2, and 3) in addition to its use at POCC (Cases 1 and 3).

B. The monitoring and limit test of housekeeping parameters are required during TM blackout periods. This results in programming for onboard monitoring and limit testing for Cases 1 and 3 in addition to ground monitoring and limit testing.

C. It is felt that if the onboard displays (CRTs) are utilized for any phase of experiment operations, any parameter available to the experiment computer will be available to the CRT display. The CRT is used in some phase, in all cases. From a programming standpoint, the amount of information entered for display use is dependent on the experiment and not on the trade case.

Certain functions were not included in the onboard software for any case.

A. Resource Planning. The resource analysis of any online rescheduling of experiment operations was ground ruled as being done on the ground. The onboard computer capacity is not adequate for this type of number-crunching program.

B. Pattern Recognition of Scientific Data to Identify Events. This type of program would exceed the capability of the onboard computer and be very expensive to prepare.

With the present definition level of the experiments and the indication that the experiments seem to be mostly self-contained, the CDMS computer system appears capable of handling the computing load for all experiments. For the basic operations for both Spacelab missions, the margin (OPS/sec) is adequate when all experiments are operated simultaneously. For Case 2, when the automation is added to the basic operation, the available OPS/sec are exceeded. As shown in Table I-3-22, the worst case four experiments, basic and automated, were estimated and their sum is within the available (OPS/sec). A large margin is established because a review of the Spacelab 1 time line revealed no more than two of these experiments are ever operated together.

Memory (K words) for the experiment computer were estimated, based on the instructions and functions for each experiment. The results are summarized in Table I-3-23. It was assumed any problem with rapid access memory could be solved by segmenting the operational program and bringing in segments from mass memory as required. If this is required, it will impact the I/O and reduce the available OPS/sec in the central processing unit (CPU). As the experiment computer has direct memory access (DMA), I/O should not be a problem unless too many memory access cycles are stolen from the CPU during DMA utilization.

Table I-3-23

EXPERIMENT COMPUTER ACTIVE MEMORY ESTIMATE (K WORDS)

Spacelab 1	Case 1	Case 2 (Automated)	Case 3
All Experiments	71	229	89
Worst 4 Experiments (1)	32	104 (2)	41

Note: Capacity (at 64%) = 41K Words

(1) Experiments AP-09 and AP-13, APE-01, and LS-13 (EO-01 operates alone or with SPE-85 only).

(2) Assumed accommodated by accessing program segments from mass memory, only as required.

Standard Spacelab programs are assumed to exist for limit checking, CRT display, uplink commands, and TM formatting. The engineering type of programmer enters information into an existing program using formats defined by the existing programs. The system analyst works from basic requirements and designs programs to accomplish specified functions. For the POCC software, the same number of instructions were used for similar functions accomplished on the ground and onboard.

The instruction conversion factors were as shown in Table I-3-24.

Table I-3-24

INSTRUCTION CONVERSION FACTORS (HOURS/INSTRUCTION)

	Onboard Computer	POCC Computer
System Analyst	2.7	0.68
Engineering Data	0.54	0.14

The conversion factors are for checked-out instructions written in a higher order language. They also reflect an additional complexity factor of four for the onboard programs which is primarily involved with the test and integration with the onboard system.

The total software hours were derived from the estimated programming instructions and conversion factors. These are shown in Table I-3-25 for each mission and case.

Special programs for evaluating and monitoring data (heat-rate calculations) or aiding operator decisions (experiment pointing) must be written for the onboard experiment computer for Case 2 and for the POCC (computers) for Case 1. In either case, the basic programs would be the same. The cost deltas would occur primarily in the development and integration process. This could be heavily influenced by the availability of compatible computer systems at the experimenter's facility. For the studied missions, very few special programs were identified.

3.5 COST ANALYSIS

3.5.1 Cost Approach

A rough-order-of-magnitude (ROM) cost estimate was made of all hardware and software modifications required to support real-time mission operations for each of the three assumed cases of onboard versus ground real-time mission operations (see Subsection 3.4 for definition of hardware and software modifications).

For cost estimating, the baseline system was assumed to be the current system design and POCC and NASCOM facilities presently planned for early Spacelab missions. All costs were estimated as differences to this baseline.

Table I-3-25

SOFTWARE HOURS

	Type	Case 1	Case 2	Case 3
Onboard Software Spacelab 1				
Basic (No Special Automation)	ENG	8,138	8,152	8,153
Pointing Data	SYS ANA	-	1,351	1,351
Heat Rate	SYS ANA	-	270	270
Automated (22,347-Hr Total)	ENG	-	8,339	-
	SYS ANA	-	14,008	
POCC Software Spacelab 1 Basic	ENG	2,334	-	1,809
Pointing Data	SYS ANA	340	-	-
Heat Rate	SYS ANA	68	-	-
Onboard Software Spacelab 2				
Basic	ENG	2,196	3,251 Automated scientific data monitoring is met by added experiment hardware	3,251
POCC Software Spacelab 2	ENG	1,005	-	731
IPS and MPM Pointing	SYS ANA	272	Should be part of Spacelab subsystem	

Operations support costs were estimated in total man-hours for POCC operations and in delta (Δ) man-hours to a Case 1 baseline for onboard operations.

A cost work breakdown structure was established as shown in Figures I-3-35 and I-3-36.

The costing exercise was governed by the following ground rules:

A. Accommodations for onboard data processing requirements exceeding the capability of the Spacelab CDMS were assumed as part of each instrument design for all cases.

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- **POCC RELATED COSTS**
  - **HARDWARE (DESIGN, MOD, TEST)** — Δ$
    - POCC (OSF/JSC)
      - DATA PROCESSING
      - DATA DISPLAY
      - COMMAND AND CONTROL
      - SPECIAL COMPUTATIONS
      - OPERATION AND MAINTENANCE OF ADDED EQUIPMENT
    - NASCOM (OTDA/GSFC)
      - DATA TRANSMISSION EQUIPMENT
      - OPERATION AND MAINTENANCE OF ADDED EQUIPMENT
  - **SOFTWARE** — Δ$ (ΔHR AND SKILLS)
    - OPERATIONS SUPPORT (OSF/JSC)
      - DATA PROCESSING
      - COMMAND PROCESSING
      - SPECIAL COMPUTATIONS
  - **OPERATIONS** — TOTAL MAN-HOURS
    - EXPERIMENT OPERATIONS (OSS/PIs)
      - REQUIREMENTS DEVELOPMENT
      - OPERATING PROCEDURES
      - TRAINING
      - POCC STAFFING
    - PAYLOAD INTEGRATION (OSS/MSFC)
      - REQUIREMENTS DEVELOPMENT
        - EQUIPMENT REQUIREMENTS
        - DATA ACQUISITION SUPPORT REQUIREMENTS
        - SOFTWARE REQUIREMENTS
        - OPS SUPPORT REQUIREMENTS
        - PROCEDURE REQUIREMENTS
      - PROCEDURE INTEGRATION
      - TRAINING
      - POCC STAFFING

Figure I-3-35. Cost Work Breakdown Structure, POCC Related Costs

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- **ONBOARD RELATED COSTS**
  - **HARDWARE (DESIGN, MOD, TEST)** — Δ $
    - EXPERIMENT MODIFICATIONS (OSS/PI)
      - AIRBORNE EQUIPMENT
        - INSTRUMENTATION
        - DATA PROCESSING
        - DATA DISPLAY
        - CONTROL
        - SUPPORT SYSTEMS (POWER, ETC.)
        - CHECKOUT REQUIREMENTS
      - GROUND SUPPORT EQUIPMENT
        - SIMULATION AND CHECKOUT
        - SPECIAL TEST
        - HANDLING
    - SPACELAB/ORBITER MODS (OSF/MSFC/JSC)
      - AFT FLIGHT DECK PSS ADDITIONS
      - SPACELAB SUPPORT SYSTEMS
      - GROUND SUPPORT EQUIPMENT
        - SIMULATION AND CHECKOUT EQUIPMENT MODS
  - **SOFTWARE** — Δ $ (Δ HR AND SKILLS)
    - EXPERIMENT (OSS/PI)
      - AIRBORNE SOFTWARE
        - DATA REDUCTION AND DISPLAY
        - DATA ANALYSIS
        - OPERATIONAL PROCEDURES
        - DATA STORAGE AND RECALL
      - GROUND SOFTWARE
        - SIMULATION, CHECKOUT, DIAGNOSTIC
    - SPACELAB/ORBITER (OSF/MSFC/JSC)
      - AIRBORNE SOFTWARE
        - INTEGRATED PAYLOAD DATA REDUCTION AND DISPLAY
        - REPLANNING/RESOURCES EVALUATION
        - OPERATIONAL PROCEDURES
        - DATA STORAGE AND RECALL
      - GROUND SOFTWARE
        - SIMULATION, CHECKOUT, DIAGNOSTIC
  - **OPERATIONS** — Δ MAN-HOURS
    - MISSION OPERATIONS
      - OPERATIONS REQUIREMENTS DEVELOPMENT (OSS/MSFC)
        - EQUIPMENT REQUIREMENTS DEFINITION
        - SOFTWARE REQUIREMENTS DEFINITION
        - OPERATIONS SUPPORT REQUIREMENTS DEFINITION
      - CREW ACTIVITY (OSS/MSFC/JSC)
        - OPERATIONS DEFINITION
        - PROCEDURES DEVELOPMENT
        - TRAINING
        - REAL-TIME OPEARTIONS
    - GROUND OPERATIONS (OSS/PI/MSFC/KSC) (PROCEDURE CHANGES AND Δ TASK EFFORT)
      - LEVEL IV SUPPORT
      - LEVEL III, II, I SUPPORT

Figure I-3-36. Cost Work Breakdown Structure, Onboard Related Costs

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B. All costs were ROM normalized to FY '77 dollars.

C. Costs were determined as increments to a baseline system. The baseline system was considered to be the current system design and POCC and NASCOM facilities presently planned for early Spacelab missions.

D. POCC facility deletions that are possible for Case 2 (minimum POCC) and Case 3 (minimum systems POCC) were not costed.

E. Onboard equipment reductions were not considered for any of the three cases.

F. Utilization or operating costs were expressed in man-hours. Man-loading will include both Government and contractor services.

G. The basic operations and maintenance of POCC facilities, communications, and ground data systems were assumed to be constant for all cases, and were provided wholly by JSC as the POCC host.

H. Real-time software used in POCC computers were to be developed, maintained, and funded by JSC. Software for offline analysis and software for user-provided equipment were to be user provided, maintained, and funded.

I. Computations support for payload activity replanning were to be performed by MSFC computer using terminals located in the POCC and the software system used for premission planning.

J. Continuous POCC manning was required throughout the mission for all cases, but manning levels were dependent upon specific payload activity requirements.

3.5.2 Hardware Costs

The only hardware modifications required were in support of Case 2 of the Spacelab 2 mission. The solar monitor package, Lyman-Alpha portion of the Lα/WLC experiment, transition radiation spectrometer, and the extreme UV imaging telescope were modified to add detection systems to enable onboard monitoring of their output. See Subsection 3.4.1 for the description of these modifications. The ROM costs for these modifications were arrived at by estimating the modification as a percentage of total instrument design. Design complexity, verification requirements, etc., were considered in arriving at this percentage factor. The final cost (see Table I-3-26) was arrived at by multiplying this factor times the total cost of a similar instrument as actual instrument costs were unavailable.

Table I-3-26

SPACELAB 2 HARDWARE MODIFICATION COSTS

Solar Monitor Package	\$ 54,000
Transition Radiation Spectrometer	\$ 54,000
Lyman Alpha	\$ 93,000
Extreme UV Imaging Telescope	\$ 93,000
Total	\$294,000

3.5.3 Software Costs

Software modifications were required to support both onboard and POCC operations. These modifications included limited onboard monitoring of scientific data, onboard automation of certain functions to reduce crew workload, and limited ground analysis of scientific data for Cases 1 and 3. See Subsection 3.4.2 for a definition of the software modifications and a breakdown of the software man-hour costs.

Man-hours were arrived at by determining the number of instructions required for each modification and converting this to man-hours. Man-hours were then converted to dollars using a factor of \$30 per hour for engineering and \$20 per hour for the system analyst efforts. See Table I-3-27 for software cost summary.

Table I-3-27

SOFTWARE MODIFICATION COSTS

	POCC Software (Δ\$)	Onboard Software (Δ\$)
Spacelab 1		
Case 1	\$78,000	0
Case 2	0	\$563,000
Case 3	\$54,000	\$ 33,000
Spacelab 2		
Case 1	\$36,000	0
Case 2	0	\$ 32,000
Case 3	\$22,000	\$ 32,000

3.5.4 Operations Costs

Mission operations support was estimated in total man-hours for POCC operations and in delta man-hours to Case 1 for onboard operations. See Subsection 3.3 for a detailed description of the mission operations support tasks and man-hour estimates. See Figure I-3-37 for a summary of operations costs.

The prelaunch operations cost for integration verification of the airborne hardware and software modification are included as part of the total hardware and software cost figures.

3.5.5 Cost Summary

The final results for hardware, software, and operations costs are summarized on Figure I-3-38. It should be noted that due to the relative simplicity of the payloads studied, the currently planned hardware systems for the POCC and Spacelab were adequate (except for onboard Spacelab 2, Case 2) to support the operations without modification for the three assumed operating modes studied.

Since Case 1, a full data and command centralized POCC was used as a costing baseline and requires the most software for POCC operations, the software costs for Cases 2 and 3 were presented as a cost savings over Case 1. Note that the operations support is presented as total hours for the ground POCC support and in delta hours to a Case 1 baseline for onboard operations.

The quantitative results of this study indicate that use of the POCC (with data processing capability) to support real-time operations would be most cost effective. Converting operations hours to dollars (at $30 per hour), the total cost differences between Cases 1 and 3 were about $100,000 for either mission. Case 2 costs were higher ($200,000 to 500,000). An evaluation of the more complex downstream Spacelab payloads, which were not studied in this analysis due to a lack of definition, may provide more significant cost differences.

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	STAFFING PERSONNEL		TOTAL OPERATIONS SUPPORT***	
	POCC* MSFC/PIs	FLIGHT** CREW	POCC (TOTAL HOURS)	ONBOARD (Δ HOURS)
SPACELAB 1 (7 DAYS)				
CASE 1	20/38	3	10,884	0
CASE 2	14/23	5	5,418	4,591
CASE 3	14/26	5	6,573	1,851
SPACELAB 2 (12 DAYS)				
CASE 1	20/32	3	11,898	0
CASE 2	14/20	3	7,317	1,913
CASE 3	16/26	3	9,603	869

* TWO-SHIFT TOTAL
** FOR EXPERIMENT OPERATIONS
*** STAFFING PLUS REQUIREMENTS DEVELOPMENT, OPERATING PROCEDURES, AND TRAINING

Figure 1-3-37. Operations Results

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		POCC			ONBOARD			TOTAL COST* ($)
		HARDWARE (Δ$)	SOFTWARE (Δ$)	OPERATIONS (HR)	HARDWARE (Δ$)	SOFTWARE (Δ$)	OPERATIONS (ΔHR)	
SL-1	CASE 1	0	0	10,880	0	0	0	$326,000
SL-1	CASE 2	0	($78,000) SAVINGS	5,420	0	$563,000	4,590	$786,000
SL-1	CASE 3	0	($24,000) SAVINGS	6,570	0	$33,000	1,850	$262,000
SL-2	CASE 1	0	0	11,900	0	0	0	$357,000
SL-2	CASE 2	0	($36,000) SAVINGS	7,320	$294,000	$32,000	1,910	$567,000
SL-2	CASE 3	0	($14,000) SAVINGS	9,700	0	$32,000	870	$332,000

*OPERATIONS HOURS CONVERTED TO DOLLARS USING $30/HR

Figure 1-3-38. Onboard vs Ground Operations Cost Summary

3.6 QUALITATIVE ANALYSIS

Qualitative evaluation of several additional factors should also be considered in arriving at a decision as to the degree of onboard versus ground-based operations. A listing of these factors follows.

A. Scientific Return
B. Operational Flexibility
C. Onboard Equipment Resources
D. Flight Crew Utilization
E. Growth Potential
F. Reliability
G. Safety
H. Marketability

These factors are very difficult to quantify to allow for cost comparisons. However, a qualitative analysis was conducted for several of the more significant factors.

3.6.1 <u>Scientific Return</u>

It is not possible to get the same experiment scientific return in Case 2 as it is in Case 1 or Case 3. The very nature of scientific experimentation requires frequent evaluation of experiment outputs with readjustments of inputs to obtain the desired results. Evaluation of outputs often requires years of education, training, and experience available only through the dedicated scientist. Experimentation time availability coupled with the inherent problems of verbal communication required in Case 2 preclude the ground-based scientist of providing the most effective interface with his experiment.

The required scientific knowledge can partially be transmitted to onboard operations by (1) increasing crew size (allowing more time per experiment), (2) providing extensive crew training, and (3) providing complex automated scientific data processing and evaluation programs. These approaches increase the cost yet still fail to give the same degree of scientific return as available through the well-informed ground-based scientist of Case 1 and Case 3.

Relative scientific data quality assessments were performed for each of the experiments on the two missions. From these assessments, it can be determined if experiment operations in each of three cases can be performed and evaluated to produce the best scientific return possible. In this effort, Case 1 was used as a reference for evaluating Cases 2 and 3. As an example, experiments which gather scientific data solely on film (e.g., metric camera and soft x-ray telescope) would not have a reduced scientific return because the data is not real-time analyzed. Other experiments which do not record data on film provide, in one form or another, the capability for real-time analysis which could identify changes in experiment operation as the mission progresses to increase the scientific return of the experiment. This scientific quality indicates (1) the ability of the flight crew, in Case 2, to perform this real-time data analysis with the equipment provided onboard or (2) the ability of the flight crew and the ground personnel, in Case 3, to perform real-time data analysis within the constraints of this case. These assessments are presented in Tables I-3-28 and I-3-29. Note that the average numbers of these tables do not consider the relative value of the various experiments and therefore do not necessarily represent the scientific return for the total mission.

3.6.2 Operational Flexibility

The ability to monitor and control payloads from the ground (Cases 1 and 3) provides a significant degree of flexibility not available in Case 2. Should onboard problems (e.g., crew sickness or diversion of attention from one payload to problem investigation of another payload or STS support system) preclude accomplishment of scheduled payload activities, ground control could be assumed with a potential of salvaging significant payload operations.

The requirements for increased crew training and the increased complexity of onboard hardware and/or software required by Case 2 would minimize the flexibility for changing payloads late in the prelaunch preparation phases.

Table I-3-28

SPACELAB 1 — RELATIVE SCIENTIFIC QUALITY ASSESSMENT

			Case 1 (Reference)	Case 2	Case 3
1.	AP-09	Electron Accelerator	1.0	0.5	1.0
2.	AP-13	LLL TV	1.0	0.5	1.0
3.	ST-31	Drop Dynamics	1.0	0.7	0.9
4.	EO-01	Cloud Physics Lab	1.0	0.7	1.0
5.	LS-13	Minilab	1.0	0.8	1.0
6.	APE-01	LIDAR	1.0	0.6	0.9
7.	SPE 80/85	Space Processing	1.0	0.6	1.0
8.	SPE-01	Free-Flow Electrophoresis	1.0	0.8	1.0
9.	EOE-01	Metric Camera	1.0	1.0	1.0
10.	APE-07	IR Radiometer	1.0	0.7	1.0
11.	STE-10	Heat Pipe	1.0	1.0	1.0
12.	ASE-01	Wide-Field Galactic Camera	1.0	0.9	1.0
		Average	1.0	0.73	0.98

Table I-3-29

SPACELAB 2 — RELATIVE SCIENTIFIC QUALITY ASSESSMENT

		Case 1 (Reference)	Case 2	Case 3
1.	65-cm Photoheliograph	1.0	1.0	1.0
2.	Solar Monitor Package	1.0	0.8	1.0
3.	Soft X-Ray Telescope	1.0	1.0	1.0
4.	Lyman-Alpha White-Light Coronagraph	1.0	0.7	1.0
5.	High-Sensitivity X-Ray Burst Detector	1.0	0.9	1.0
6.	Skylark Cosmic X-Ray Telescope	1.0	0.8	1.0
7.	LLL TV	1.0	0.7	1.0
8.	Far UV Schmidt Camera/Spectrograph	1.0	1.0	1.0
9.	Transition Radiation Spectrometer	1.0	0.6	1.0
10.	Extreme UV Imaging Telescope	1.0	0.8	1.0
	Average	1.0	0.83	1.0

3.6.3 Onboard Resources

The increased demand for added hardware, software, and crew to support Case 2 may significantly deplete STS-provided resources for payload support. Case 2 would tend to increase weight, power consumption, data processing resources, and habitation support resources. The result of these demands may necessitate a decrease in payload-carrying capability. The introduction of the more sophisticated payloads beyond those studied for Spacelabs 1 and 2 would accentuate this problem.

3.6.4 Flight Crew Utilization

There are certain payloads where an increase in crew utilization can result in a reduction of ground support requirements and still produce the same scientific return. Recognizing these situations and planning accordingly should result in an overall reduction of real-time operational costs. This increased crew utilization is reflected in Case 3 of this study. The crew activity required to support Case 2 was determined to be an extremely heavy work load, particularly for the Spacelab 1 type payloads.

Section 4
CONCLUSIONS AND RECOMMENDATIONS

Major conclusions including qualitative evaluation for these missions are summarized on Figure I-4-1. As stated previously, the cost analysis favors Case 3. With respect to scientific return, it is not possible to get the same experiment science return in Case 2 as in Cases 1 or 3. Extensive flight crew education, training, and experience would be required to match the knowledge of the well-informed ground-based scientist. In addition, complex onboard science processing equipment would have to be added to aid the flight crew to process data and monitor and control certain experiments. Case 1 with maximum ground support should provide the greatest scientific return with Case 3 being a very close second. With respect to operational flexibility, the ability to monitor and control payloads from the ground and onboard (Case 3) provides more flexibility than Cases 1 and 2. Onboard problems, such as crew diversions or sickness, could preclude accomplishment of scheduled payload activities in Case 2. Furthermore, the requirements for increased crew training and increased complexity of hardware and software would minimize the flexibility in Case 2 for changing payloads late in the prelaunch period. The potential loss of ground control because of communication difficulties would minimize the flexibility of Case 1.

With respect to onboard resources, both Cases 2 and 3 will require increased onboard weight, power, data processing, and habitation support which will reduce STS resources for payload support as well as payload capability. Case 2 would impose the greatest impacts. With respect to flight crew utilization, the flight crew work load for Spacelab 1 type missions is extremely heavy for Case 2. In Case 3, the work load is less and with proper planning there could be a reduction in ground support requirements without a decrease in scientific return. Case 3 is favored over Case 1 because of increased effectiveness during selected payload operations when the value of a hands-on operation is exploited. In conclusion, Case 3 was determined to be the recommended approach.

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	CASE 1 (MAX POCC)	CASE 2 (VOICE POCC)	CASE 3 (PARTIAL POCC)
COST (HARDWARE, SOFTWARE, OPERATIONS)			√
SCIENTIFIC RETURN (TRAINING, INFORMATION PROCESSING)	√		
OPERATION FLEXIBILITY (FLT OPS SCHEDULING, PRELAUNCH CHANGES)			√
ONBOARD RESOURCES (WEIGHT, POWER, DATA PROCESSING, HABITATION SUPPORT)	√		
FLIGHT CREW UTILIZATION (WORKLOAD, HANDS ON ADVANTAGES)			√

OVERALL CONCLUSION — CASE 3 RECOMMENDED

Figure I-4-1. Onboard vs Ground Real-Time Mission Operations Conclusions

Overall recommendations for the onboard versus ground real-time mission operations analyses are shown on Figure I-4-2. It is recommended that a ground crew be used for real-time mission support of selective scientific payloads, particularly those that require special data analysis in order to continue real-time operations during the mission. The flight crew should be used (with backup ground capability) for real-time housekeeping operations of experiments to ensure that they are working properly, and to conduct any special operations that may be required. Flexibility in the mode of operations (onboard versus ground) should be maintained depending upon the mission or experiment. Onboard operations will be better for some missions and experiments, whereas ground operations will be better for others. The outcome is very mission and equipment dependent. Therefore, it is recommended that follow-on studies be conducted to evaluate these modes of operation for downstream Spacelab missions. Additional study may also be advisable to analyze how special payloads groupings could optimize crew utilization.

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DIRECT ACTION:

- USE GROUND CREW FOR REAL-TIME MISSION SUPPORT OF SELECTIVE SCIENTIFIC PAYLOADS (SCIENCE DATA REQUIRED TO CONTINUE REAL-TIME OPERATIONS)
- USE FLIGHT CREW FOR REAL-TIME HOUSEKEEPING OPERATIONS OF EXPERIMENTS (PROVIDE GROUND BACKUP CAPABILITY)
- MAINTAIN FLEXIBILITY IN THE MODE OF OPERATIONS (ONBOARD VS GROUND) DEPENDING UPON MISSION/PAYLOAD TYPE

FOLLOW ON STUDIES:

- EVALUATE THESE APPROACHES FOR DOWNSTREAM MISSIONS
- GROUP PAYLOADS TO OPTIMIZE THE UTILIZATION OF FLIGHT CREW

Figure I-4-2. Onboard vs Ground Real-Time Mission Operations Recommendations

PART II

GROUND DATA MANAGEMENT ANALYSIS

(TASK 2.2B)

PART II - SUMMARY

The high quantity of data expected from the Spacelab payloads will create a significant problem for both the real-time data processing required to support mission operations and the non-time-critical data processing needed for experiment data analysis. The purpose of this study was to better understand the ground data management problem and to recommend potontial solutions.

Initially, an information search was performed to determine what studies had been conducted and what plans established within the payload and Space Transportation System (STS) communities relative to payload ground data management. The results of this search indicated that a significant amount of work had already been accomplished in this area. Appendix A provides a list of study reports and other related documents accumulated during the information search.

One of the most significant findings of the information search was a lack of definitive payload ground data processing requirements. It was recognized that detail requirements could not be produced until late in a payload's development phase; however, general requirements could be predicted and were necessary to allow for the long lead times required for development of the complex ground data processing systems. Therefore, in Phase 2 of this task, efforts were concentrated on the development of the generalized payload ground data requirements, particularly those that tended to drive ground data system design. The reports collected during the information search were reviewed to extract applicable requirement type data. Various personnel within the payload community were surveyed to supplement this information. Effort was concentrated on the payloads and types of instruments anticipated to fly in the mid-1980's as these payloads are more demanding on the ground data processing systems.

The more significant ground data requirements of the future which exceed the data processing capabilities currently planned for the early Spacelab missions are summarized below:

- Imaging instruments will generate digital data rates far in excess (potentially in excess of 1,000 MBPS) of current recording, transmission, and processing capabilities.
- Real-time image processing will be required to allow interactive control of the image producing instruments. (It is anticipated that a 1-MBPS real-time image processing capability will be acceptable.)
- Simultaneous transmission of video and high-rate digital scientific data (much greater than the 2-MPBS capability currently planned) will be required.
- Data quantities (potentially in excess of 1×10^{13} bits/day) will far exceed the current capabilities to record and process data within a reasonable period.

During the final phase of this task, various data processing concepts were evaluated to determine which concepts could most effectively satisfy future requirements. The total data processing system was considered, including onboard processing, air and ground transmission systems, real-time data processing, and the non-time-critical postflight data processing. One of these advanced end-to-end concepts is depicted in Figure II-1.

The major conclusions from this analysis was that high data quantities from a few Spacelab payloads are the most significant parameters that drive ground data system design. Thus, recommendations range from means to reduce these data quantities (e.g., onboard compression and selective processing) to large data processing computing complexes designed with growth potential as a key requirement. It is recommended that integrated payload data requirements be developed and that guidelines related to integrated payload data management capabilities and limitations be prepared for the payload community for both real-time and postflight data processing. NASA should promote the future use of payload microcomputers (plus memories) rather than the use of an onboard centralized computer for scientific data processing. Complete payload data autonomy should be the goal.

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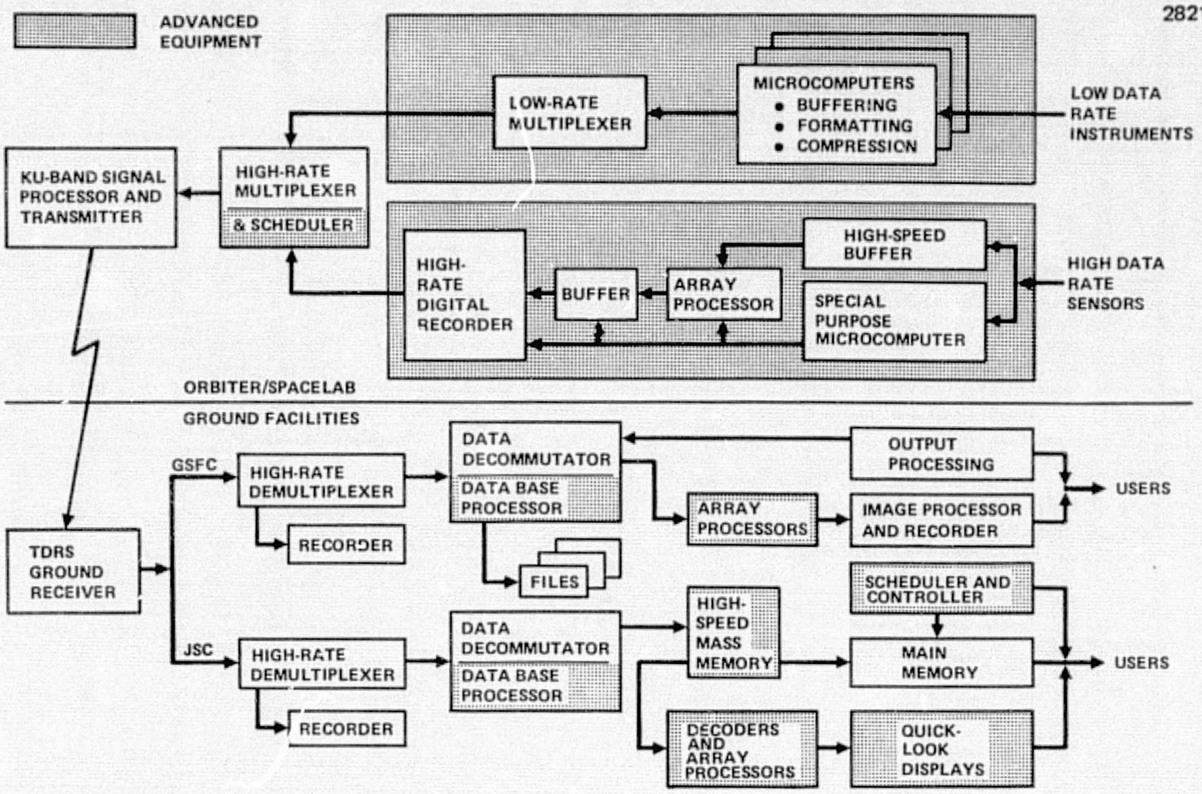

Figure II-1. Advanced Data Handling Concept

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Section 1
INTRODUCTION

Spacelab experiment operations are expected to generate a great deal of data which will be transmitted to the ground via the Tracking and Data Relay Satellite (TDRS). These data will be digital data up to 50 MBPS and will contain real-time data multiplexed with previously recorded data. In addition, analog and video data will also be transmitted to the ground via TDRS. The proper approach to the ground data management problem must be established in order to most cost effectively support real-time operations as well as postflight analyses.

1.1 PURPOSE

The purpose of this task was to conduct an analysis of the Spacelab experiment operations ground data management problem and to establish the most effective approach for ground data processing and distribution to support real-time operations as well as postflight analyses.

1.2 SCOPE

This task was conducted during the period from July 1976 through March 1977. During the early study phase, efforts were concentrated on determining what plans had already been established and what studies had been conducted relative to the ground data handling problem. The subsequent study tasks relied heavily on the data gathered during this initial phase.

It was determined early in the study that the payloads which would tend to drive the ground data processing system design were those with image-producing instruments transmitting their data via the digital data systems. Study efforts were then concentrated on the processing of data from these instruments. An integrated set of payload ground data requirements was developed which was representative of anticipated user needs. These requirements were general in nature and concentrated on those areas which tended to drive ground data systems design.

The final study phase to establish effective approaches to payload ground data management was limited in scope to conceptual definition only. Several existing concepts were evaluated and some new concepts were introduced.

1.3 MAJOR GROUND RULES AND ASSUMPTIONS

Major ground rules and assumptions are as follows:

A. Emphasis will be concentrated on the Spacelab missions and payloads of the mid-1980's and subsequent time frame.

B. Only Spacelab experiment data transmitted via the TDRS will be addressed.

C. No major deviations from currently planned data handling systems will be made during the new concept development (e.g., maintain high rate multiplexer, Ku-band signal processor, TDRSS).

Section 2
APPROACH

The general approach followed for this task is outlined in Figure II-2-1.

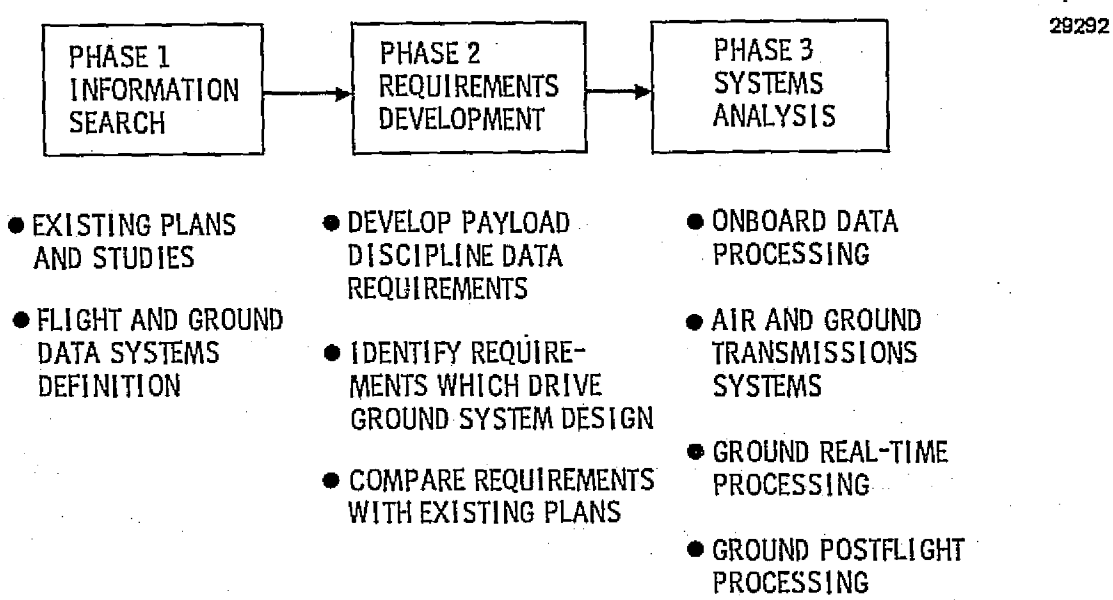

Figure II-2-1. Study Flow

2.1 PHASE 1

An information search was performed to determine what studies had been conducted and what plans established within the STS community relative to real-time and postflight ground data management. These findings were integrated to determine where gaps and potential problems existed and to develop follow-on tasks to concentrate on these areas.

2.2 PHASE 2

One of the most significant findings of the Phase 1 information search was a lack of definitive payload ground data processing requirements. It was recognized that detail requirements could not be produced until late in a payload's development phase. However, general requirements could be predicted and were necessary to allow for the long lead times required for development of the complex ground data processing systems. Phase 2 concentrated on the development of the generalized payload ground data requirements.

A definition of the desired requirements data needed was developed and checklists and tables to aid in the collection of this data were made. The various payload disciplines were evaluated to determine which had the greatest demands for ground data processing. A priority listing was established and the more demanding payload disciplines were given greater attention.

The information collected during Phase 1 was searched and all applicable requirements data were extracted. Where data were not available, personal contacts were made within the payload community to provide the necessary data.

After the generalized ground data requirements from each payload discipline were collected, they were integrated to identify those requirements which would tend to drive ground data system design. These requirements were compared with existing ground data processing plans and the incompatibilities were identified.

2.3 PHASE 3

Using the requirements established in Phase 2, various data processing concepts were evaluated to determine which concepts would most effectively satisfy the requirements. The total data processing system was considered, including onboard processing, air and ground transmission systems, real-time data processing, and the non-time-critical postflight data processing.

Section 3
STUDY RESULTS

3.1 INFORMATION SEARCH

The Spacelab payload ground data management problem has been of concern to the NASA for several years. Significant effort has already been expended among the various NASA centers and their contractors to address specific segments of the problem. The purpose of the information search was to gather the documented reports of the various studies already conducted, integrate and evaluate their findings, and determine where additional efforts were needed to solve the overall ground data management problem.

3.1.1 Data Sources

GSFC, JSC, and MSFC have been the prime NASA centers concerned with ground data management of Spacelab payload data. Each of these centers was visited, key personnel were interviewed, and available reports were collected. This activity was coordinated through the appropriate STS Payload Requirements and Analysis Group (SPRAG) members. The MDC personnel located at JSC provided significant support in the collection of data at that location. In addition, other NASA centers and support contractors were contacted by telephone to request reports related to the ground data management problem.

3.1.2 Information Located

Appendix A provides a listing of all material located either directly related to or significantly contributory to Spacelab payload ground data management.

3.1.3 Data Integration

Documented results of the various studies and NASA planning documents were reviewed and significant data related to Spacelab experiment ground data management were extracted. These data were then integrated with information gathered through discussions with NASA personnel. For ease of display and cross reference, the data were gathered and summarized on a single large work sheet. The work sheet and reference documents reviewed are displayed in Figure II-3-1.

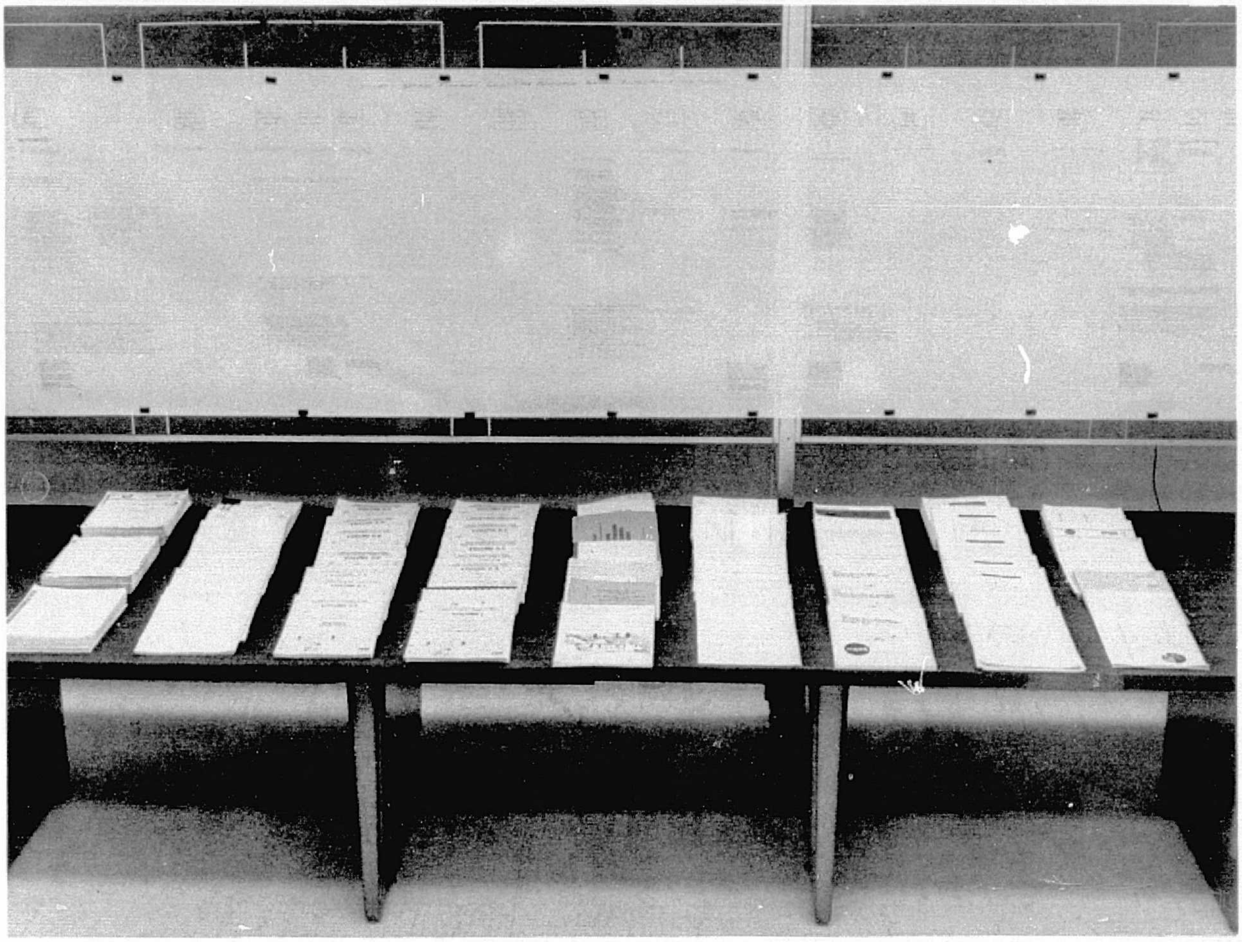

Figure II-3-1. Information Search Documents and Work Sheets

3.1.4 Significant Findings

Many limited-scope studies of payload ground data management have been made; however, no overall assessment work has been conducted and many questions remain unanswered. It became obvious during this review that experiment data generation and data transmission technology are significantly more advanced than ground data processing technology. Consequently, experiment data will be generated and transmitted through the STS and TDRS system (TDRSS) at rates up to 50 MBPS. Ground data management systems will have to be developed to cope with these high rates for support of real-time operations as well as postflight analysis.

Spacelab experiments are lacking a total integrated set of operational requirements. As a result, post flight and real-time ground data processing requirements have not been suffiently defined for ground hardware system definition. Some of the general requirements of significance included a strong desire by the payload community to monitor, and in some cases exercise, ground commands to the payloads from remote facilities where their payload development activities have been concentrated. In addition, some experimenters (e.g., solar physics) have expressed a need for ground monitoring of high-rate image data in real or near real time to allow for reprogramming of payload mission operations.

Several studies resulted in rough order of magnitude (ROM) cost estimates for ground data handling systems (Table II-3-1). Since actual payload user requirements had not been defined, requirements were parameterized in terms of mission use, turnaround time, data volume, and system throughput data rate. A set of design points was selected which spanned the possible system performance requirements explaining the wide range in ROM costs. The ROM costs noted are, therefore, a function of possible user requirements.

Table II-3-1

ROM COST ESTIMATES FOR SELECTED PAYLOAD GROUND DATA HANDLING SYSTEMS

Sensor/Payload	ROM Facility Cost*	ROM Operating Cost* per Year
Interferometer Spectrometer/ Atmospheric and Space Physics (Ref 25)	1.8 to 8.1	2.6
Ultraviolet Spectroheliometer/ Solar Physics (Ref 29)	10.5 to 65.4	1.1 to 17.0
Synthetic Aperture Radar/Earth and Ocean Physics (Ref 6)	24 to 111	3.2 to 34.6
Earth Viewing Remote Sensing Using Multispectral Scanners/Earth Resources (Ref 34)	36.1 to 107.2	N/A

*Cost in millions of dollars (1975 to 1976).

In each case, a sensor was selected from a payload discipline for evaluation which was considered to drive the overall cost. ROM cost numbers were extracted from the referenced documents.

The dominating conclusion from the studies reviewed is that the high data quantities from a few Spacelab payloads is the most significant parameter driving ground data system design. Proposals range from means to reduce data quantities (e. g., onboard compression and selective processing) to large ground data processing complexes with high associated costs designed with growth potential as a key requirement.

3.2 PAYLOAD DATA REQUIREMENTS

One of the more significant findings of the information search was a lack of definition of payload ground data requirements. It was recognized that development of detailed requirements is often impossible until late in the payload development stage when measurement programs are defined and payload operating plans established. However, general requirements can be anticipated and are necessary to allow for conceptual design and long-range planning of the ground data processing facilities. The reports collected during the information search were researched to extract applicable requirement data. Various personnel within the payload community were surveyed to supplement this information. Effort was concentrated on the payloads and types of instruments anticipated to fly in the mid-1980's.

A questionnaire was formulated (see Appendix B) to be used as a guide for data gathering from the existing documents and from the personal interviews. This questionnaire was not distributed to the payload community for them to complete as this approach had been previously attempted by others and was unsuccessful. It was used as a checklist during documentation search and personal interviews. In conjunction with the questionnaire, a table was constructed to organize the requirements data (see Appendix C).

3.2.1 Documentation Search

An automatic search of the NASA Payload Planning Data Bank (PPDB) was performed (a sample computer search is shown in Figure II-3-2) to determine which payloads in particular and which scientific disciplines in general generated the greatest digital data rates and quantities. Figure II-3-3 summarizes the data from this search.

```
do davin2
QUERY NOW PROCESSING
 FILE CONTAINS    6570 RECORDS
QUERY SELECTED      85 RECORDS
ENTER OUTPUT REPORT SITE ID
)print 30
30
ENTER OUTPUT REPORT SITE ID
)PRINT=30

Q,SEARCH-1,SPL P AND S7422 P.
S,S7422 D.
P,FULL,SPACE 1 PL,S7422.

PAYLOAD NBR  MAX DOWN R/T DIG RT (B/S)

  SO18S              .230000+02
  SO19S              .210000+02
  AS50S              .105000+08
  AS31S              .102600+08
  AS32S              .102600+08
  AS54S              .102000+08
  AS04S              .100000+08
  CN18S              .100000+08
  HE23S              .100000+08
  SO15S              .570000+07
  AS07S              .310000+07
```

```
H512S              .300000+07

!!OUTPUT INTERRUPT!!

SO12S              .250000+07
SO14S              .160000+07
SO21S              .160000+07
SO01S              .132000+07
SO11S              .132000+07
AS51S              .126000+07
AS41S              .100000+07
AS48S              .100000+07
CN22S              .100000+07
SO17S              .100000+07
AS10S              .500000+06
AS43S              .500000+06
AS49S              .500000+06
SO13S              .320000+06
OP02S              .266000+06
```

Figure II-3-2. PPDB Sort to Support Payload Selection

28147

SOLAR PHYSICS	PAYLOAD	MAX DOWNLINK DIGITAL RATE (MBPS)	DATA VOLUME (MB/DAY)
SO-18S	SOLAR ATMOSPHERIC WAVE PROPAGATION	23.0	2.0×10^{12}
SO-19S	PHYSICS OF FLARING BRIGHT POINTS	21.0	9.7×10^{11}
SO-15S	SOLAR ACTIVITY EARLY PAYLOAD	5.7	2.6×10^{11}
ASTRONOMY			
AS-50S	COMBINED UV AND IR TELESCOPES	10.5	4.6×10^{10}
AS-31S	COMBINED UV AND IR TELESCOPES	10.3	5.6×10^{9}
AS-32S	COMBINED UV AND IR TELESCOPES	10.3	5.7×10^{9}
AS-54S	COMBINED UV AND IR TELESCOPES	10.2	2.0×10^{10}
AS-04S	UV OPTICAL TELESCOPE	10.0	3.1×10^{9}
HIGH ENERGY ASTROPHYSICS			
HE-23S	GAMMA RAY SURVEY	10.0	8.6×10^{11}
COMMUNICATIONS AND NAVIGATION			
CN-18S	ADAPTIVE DIGITAL VIDEO COMPRESSION SYSTEM	10.0	3.6×10^{10}

OBSERVATION - GROUND DATA PROCESSING SYSTEMS ARE DRIVEN BY PAYLOADS WITH IMAGE PRODUCING INSTRUMENTS (SPECTROMETERS, PHOTOHELIOGRAPHS, INTERFEROMETERS, MULTISPECTRAL SCANNERS, IMAGING RADARS)

Figure II-3-3. High-Data-Rate Payloads from PPDB Search

The documents gathered during the information search were reviewed and data requirements extracted. A summary of estimated scientific data characteristics is presented in Figure II-3-4. Figure II-3-5 lists the primary references used in the search. The housekeeping data characteristics were all very low in data rate and appear compatible with current plans for processing this data.

Appendix C provides the detailed results of the documentation search in table form. The table is organized by subject matter responsive to the requirements questionnaire discussed earlier.

3.2.2 Personal Interviews

Various personnel throughout the payload community were interviewed to determine their ideas and opinions as to what future payload ground data requirements would be. The more significant findings of this survey are summarized below:

- The payload community in general has a strong payload operator concept. In many cases they believe each instrument should have full parallel control from onboard and from the ground. They would prefer to have ground control from their home site for reasons of (1) availability of support equipment and software, (2) availability of support personnel and data, and (3) time and travel budget constraints. This concept results in heavy requirements for real-time ground data transmission and processing systems.
- Historically, much data that has been transmitted to the ground and processed has been useless to the scientist, because of poor quality or lack of scientific value. There are many methods to reduce production and transmission of this data which should be explored. For example, development of a cloud analyzer could be beneficial to several payload disciplines. Dependent of the experiment objectives, there are cases when data should be generated only when clouds are absent or when clouds are present. Development of such a device may be too expensive for the individual payload but may prove cost effective when used for several payloads with the resultant reduced ground data handling and processing costs.

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DISCIPLINE	DATA RATE	DATA VOLUME	SPECIAL CONSIDERATIONS	REF NO.
ASTRONOMY	≤1 MBPS	10^{11} TO 6 X 10^{13} BITS/YEAR (SPECTROGRAPH) 10^{13} TO 10^{14} BITS/YEAR (INTERFEROMETER)	DATA HANDLING REQUIREMENTS DRIVEN BY DATA VOLUME DEMANDS AS OPPOSED TO HIGH DATA RATES	1
HE ASTROPHYSICS	200 BPS TO 800 KBPS	4.7 X 10^{9} BITS/DAY		1
SOLAR PHYSICS	13.2 MBPS (PHOTOHELIOGRAPH)			2
	1.8 KBPS TO 7.3 MBPS (UV SPECTROMETER)	3.7 X 10^{9} TO 4.4 X 10^{12} BITS/5 DAYS	DATA FORMAT COMPATIBLE WITH SHUTTLE STIPULATED TM FORMAT, 8 BIT-BYTES	3
AMPS	7.6 MBPS			4
EARTH OBSERVATIONS	320 BPS TO 120 MBPS	6 X 10^{11} BITS/DAY (THEMATIC MAPPER)	DATA TO BE RETURNED BY SHUTTLE	6
	≤240 MBPS	2.7 X 10^{12} BITS/5 DAYS	NO ON-ORBIT DUMP CONSIDERED	2
EARTH AND OCEAN PHYSICS	150 TO 250 MBPS	1.1 X 10^{13} TO 3.10 X 10^{13} BITS/5 DAYS	ADDITION OF ONBOARD PROCESSING REQUIRED FOR DOWNLINKING DATA	1
	≅197 MBPS	2.8 X 10^{12} TO 20.6 X 10^{12} BITS/5 DAYS	SENSOR USE DURING MISSION VARIES FROM 2.5 TO 26 HOURS	6
SPACE PROCESSING APPLICATIONS	14.5 KBPS	3 X 10^{9} BITS/6 DAYS	DATA DUMP WILL RANGE FROM 23 KBPS TO 1 MBPS	7
ADVANCED TECHNOLOGY	<1 BPS TO 420 MBPS	8.6 X 10^{11} BITS/DAY	DATA FORMAT IS BYTE (8 BITS) OR MULTIBYTE ORIENTED	8

Figure II-3-4. Estimated Scientific Data Characteristics

28178

DISCIPLINE	REFERENCE NO.	REFERENCE
ASTRONOMY	1	IBM, "GROUND SUPPORT REQUIREMENTS FOR SELECTED SHUTTLE PAYLOADS," AUGUST 1975
HIGH ENERGY ASTROPHYSICS	1	- - -
SOLAR PHYSICS	2	IBM, "SPACELAB USER INTERACTION STUDY, PHASE 2 REVIEW," MAY 1975
	3	BALL BROS., "SHUTTLE ERA GROUND DATA PROCESSING PARAMETRIC REQUIREMENTS FOR THE DISCIPLINE OF SOLAR PHYSICS," AUGUST 1975
ATMOSPHERIC, MAGNETOSPHERIC AND PLASMAS IN SPACE (AMPS)	4	MARTIN MARIETTA, "ATMOSPHERIC, MAGNETOSPHERIC AND PLASMAS IN SPACE (AMPS) SPACELAB PAYLOAD DEFINITION STUDY," NOVEMBER 1976
EARTH OBSERVATIONS	5	GENERAL ELECTRIC, "EARTH VIEWING APPLICATIONS LABORATORY (EVAL) CONCEPT DEFINITIONS/PARTIAL SPACELAB PAYLOAD TECHNICAL REPORT," SEPTEMBER 1976
	2	- - -
EARTH AND OCEAN PHYSICS	6	IBM, "SYNTHETIC APERATURE RADAR (SAR) GROUND DATA PROCESSING FACILITY DEFINITION STUDY," JANUARY 1976
	1	- - -
SPACE PROCESSING APPLICATIONS	7	NASA-MSFC, "SPACELAB DESIGN REFERENCE MISSION ANALYSIS, VOL. IV, MISSION C. . .SPACE PROCESSING APPLICATIONS," APRIL 1975
SPACE TECHNOLOGY	8	AERONUTRONIC FORD, "LANGLEY APPLICATION EXPERIMENTS DATA MANAGEMENT SYSTEM STUDY-FINAL REPORT," DECEMBER 1975

Figure II-3-5. Primary References used for Data Requirements Analysis

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- The long-term archiving of unprocessed (raw) data was not believed to be cost effective. Past usage of this data has been extremely low. It was suggested that one to three months should be adequate for archiving of this raw data by NASA.
- It was recommended that all scientific data be available at the Payload Operations Control Center (POCC) for potential real-time or near real-time monitoring in support of mission operations. Image processing will be required at the POCC to allow interactive control of the imaging instruments. It was believed that a 1-MBPS real-time image processing capability would be satisfactory.
- A requirement will exist for simultaneous downlinking of TV and high-rate (greater than 2 MBPS) digital data. The current STS wide-band data transmission systems preclude this simultaneous transmission.
- Up to 10 manually switchable inputs to the Spacelab video network will be required to accommodate 10 pointing instruments which could fly on a five-pallet mission.
- A text and graphics uplink capability of 1 MBPS should be provided for star charts, new observing plans, etc.
- Onboard data storage capable of storing high rate data (much greater than 50 MBPS) for relatively short periods and for subsequent playback via TDRS at slower rates should be provided.
- Central data analysis facilities make sense for the large users with similar image-producing instruments; however, concern was expressed over potential saturation by a few instruments.
- Onboard centralized computer support is not recommended due to complexity and cost of software integration and verification. Use of microcomputers with individual instruments is preferable. Complete data autonomy should be a goal for each payload.
- As instrument design improves and as scientific objectives become more demanding, data rates will increase. Figure II-3-6 depicts a typical example of how a facility class instrument planned for flight in the mid-1980's and a scientist's desire to evaluate solar flare associated shock waves at a velocity of 1,000 km/sec could result in a data rate of 1,800 MBPS.

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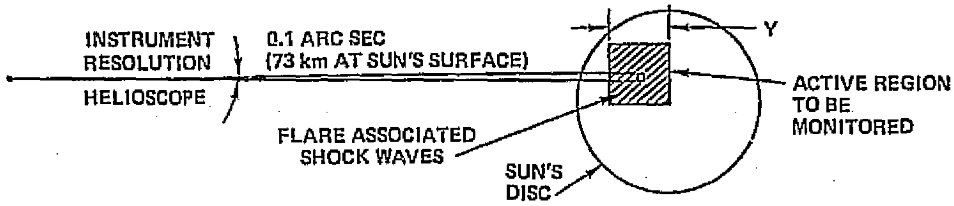

PARAMETERS		DESIRED CAPABILITY	PLANNED CAPABILITY
INSTRUMENT RESOLUTION	X	0.1 ARC SEC	0.1 ARC SEC
SHOCKWAVE VEL (300-1500 km/SEC, 1000 km/SEC TYPICAL)		1000 km/SEC	400 km/SEC
FREQ OF OBSERVATION REQUIRED (FRAME RATE)	A	14 PER SEC	6 PER SEC
ACTIVE REGION TO BE MONITORED (LENGTH OF SIDE)	Y	400 ARC SEC	100 ARC SEC
NUMBER OF IMAGE ELEMENTS (Y^2/X^2)	B	1.6×10^7	1×10^6
BITS PER ELEMENT (256:1 GRAY SCALE)	C	8	8
TOTAL DATA RATE (1) (A X B X C)		1800 MBPS	48 MBPS
REAL-TIME DATA RATE (ONE IMAGE EVERY 10 SEC)		12.8 MBPS	800 kBPS

(1) IF INFORMATION REQUIRING SIMULTANEOUS OBSERVATIONS IN DIFFERENT WAVE LENGTHS AND POLARIZATIONS IS DESIRED, THE NUMBER IS CORRESPONDINGLY HIGHER.

Figure II-3-6. Solar Physics 1-Meter Class Helioscope Data Rate Definition

3.3 SYSTEM CONCEPTS

3.3.1 Current Plans

The Spacelab Payload Data Network is seen to primarily consist of the Orbiter and TDRSS data link, the terrestrial telecommunications system between the TDRSS ground terminal and NASCOM terminal systems at GSFC and JSC, and a return data link via a domestic satellite (DOMSAT) from the TDRSS ground terminal to JSC and GSFC, as shown on Figure II-3-7. In addition, low-rate payload data integrated into the Orbiter's bit stream may be obtained in a backup mode via the Space Flight Tracking and Data Network (STDN) consisting of stations in Fairbanks, Alaska; Goldstone, California; Rosman, North Carolina; Orroral, Australia; Madrid, Spain; and the launch control stations at Bermuda and Merritt Island, Florida. Using the Merritt Island station and pad facilities, it will also be possible to transmit payload data to the network via the TDRS for checkout purposes.

Real and non-real time data will be provided to users at JSC and the tape mailing system is indicated as continuing in use at GSFC. In addition, it has been projected that users may wish to employ their own DOMSAT terminals for direct high-rate data reception although no firm plans have been developed.

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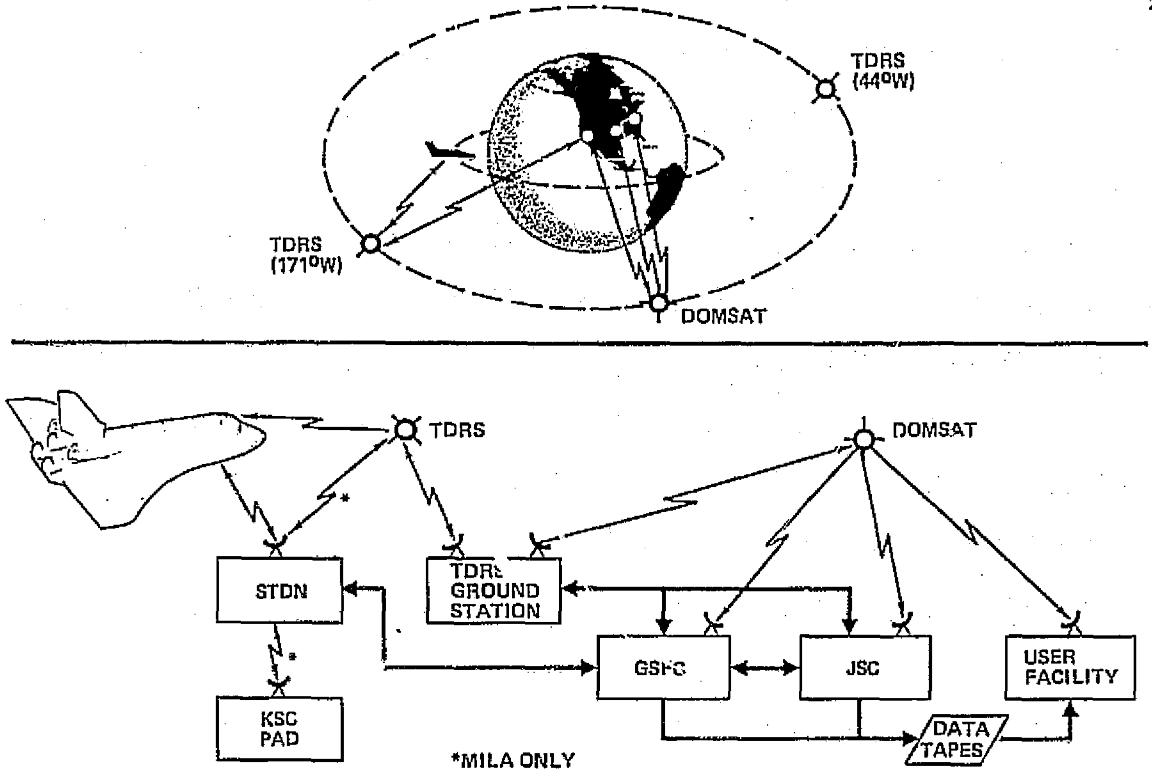

Figure II-3-7. Spacelab Payload Data Network

3.3.1.1 Onboard Systems

Payload data will interface with the Spacelab and Orbiter systems via remote acquisition units (RAUs), the high-rate multiplexer, and an input to the Orbiter's Ku-band signal processor (see Figure II-3-8). The data processing assembly; consisting of the computer, input/output (I/O), main memory unit (not shown), data display units (not shown); and the RAUs perform the functions of command processing and distribution, data acquisition, data processing and transmission, and data display.

The RAUs constitute the low-rate payload data interface. The maximum capability of this interface, as indicated on the right-hand side of Figure II-3-8, is compatible with the data bus average simplex rate of 600 kBPS and maximum transfer rate of 1 MBPS in the burst mode. The figures shown for command and data acquisitions were obtained from the CDMS Specification, Document No. SS-ER-0004, and are believed to be maximum individual rates with programming apportioning the bus capability as necessary for actual operation.

The average output rate of the system to the Orbiter pulse code modulation (PCM) units for experiment ground control is 64 kBPS as indicated by the

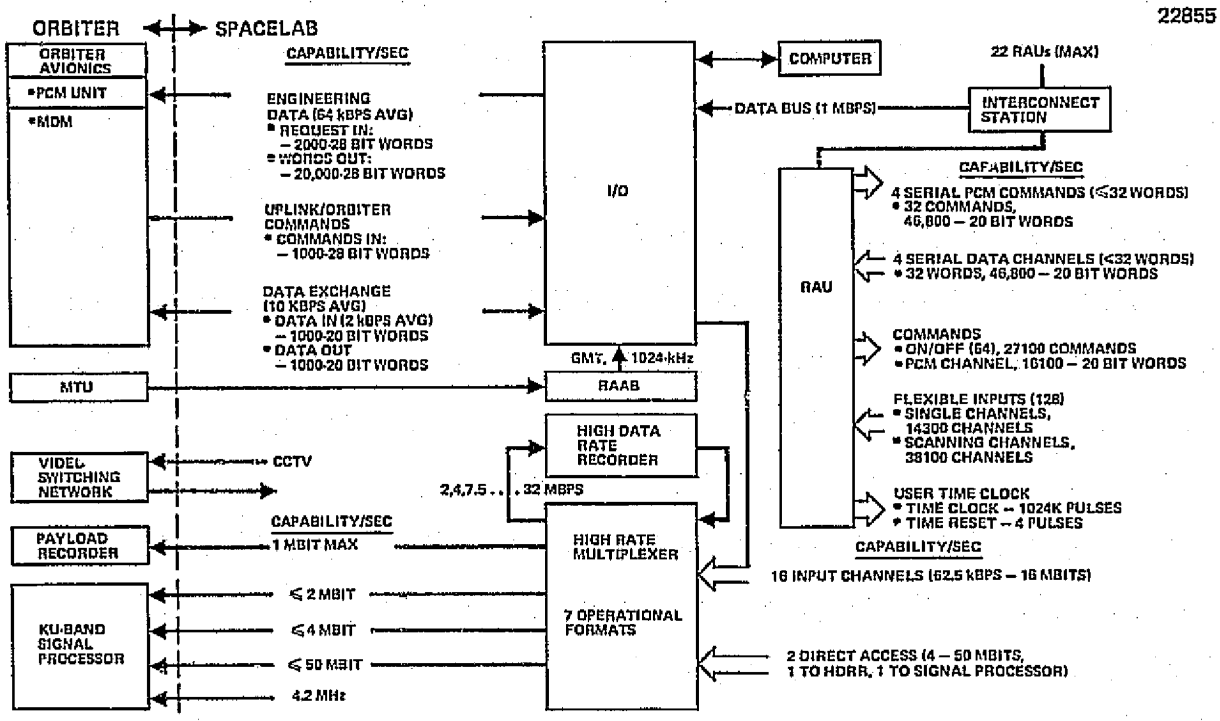

Figure II-3-8. Onboard Systems Spacelab Payload Data Flow

upper left-hand capability data. Actual maximum transfer rate is 1 MBPS in the burst mode. The data is integrated with Orbiter data to comprise a 128-kBPS data stream which may be transmitted via S- or Ku-band systems. In addition, the capability for command uplink and Orbiter state vector update, which would include position and velocity vectors, mission elapsed time (MET), Greenwich Mean Time (GMT), and attitude as well as target update (position, velocity, GMT), via the multiplexer/demultiplexer interface are shown.

The high-rate multiplexer (HRM), shown at the bottom of Figure II-3-8 constitutes the interface for high-rate data. It also includes a data input from the I/O at 1 MBPS which is essentially the data bus rate. Outputs interface with the High Data Rate Recorder (HDRR), payload recorder, and the Orbiter's Ku-band signal processor. Interface information was obtained from The System Concept and the System Requirements for the Spacelab High Data Rate Multiplexer/Demultiplexer, Document No. SLP/2107 dated May 11, 1976 (Reference 37).

Figure II-3-9 shows the detailed functional data flow of the HRM interface between the Spacelab experiments and the Ku-band signal processor. The HRM can operate in seven distinct modes for downlinking the Spacelab data (see Reference 37):

A. Multiplexed data in real-time transmission on one of the three Ku-band signal processor (KUSP) inputs.

B. Multiplexed data recorded on one of the two tape recorders.

C. Combined tape recorder dump and real-time transmission of input data.

D. Recorder direct data dump and multiplexed input data on separate KUSP inputs.

E. Direct access to the 50 MBPS input and the multiplexed input data transmitted on separate KUSP inputs or recorded.

F. Direct access recorded, data and multiplexed input data transmitted on separate KUSP inputs.

G. Multiplexed input data or direct access input data transmitted and recorded (on the high data rate recorder) in parallel.

The characteristics for the two onboard tape recorders are listed in Figure II-3-10. The two key characteristics to make note of are (1) data rate input and (2) data storage capacity which is a maximum for the HDRR, 32 MPBS and 3.6×10^{10} bits, respectively.

The KUSPs functional flow charts are illustrated in Figure II-3-11 which indicates the switching logic available to downlink the Spacelab's experiment data. The KUSP may operate in two different modes as illustrated in the Table II-3-2.

3.3.1.2 TDRSS

It is the intention of the TDRSS to be effectively transparent to the Spacelab's data network. The TDRS acts as a bent-pipe to the Ku-band return link and relays the data to a ground station located at White Sands, New Mexico. The ground station provides the bit synchronization for the return link and decodes the TDRS encoded data. This data is then retransmitted to JSC and GSFC via a NASCOM land line (at 1.544 MBPS) or a proposed DOMSAT (at a data rate comparable to the TDRSS return data link). A TDRS ground station functional flow block diagram is shown in Figure II-3-12.

28179

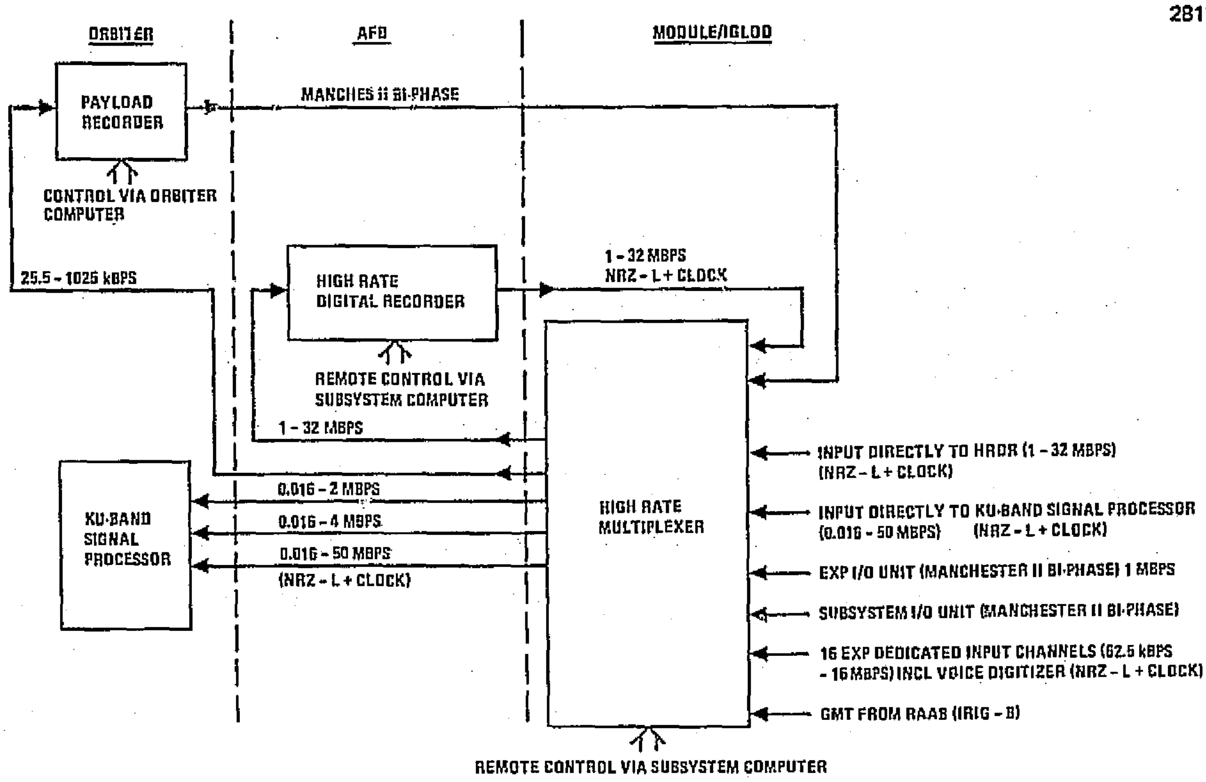

Figure II-3-9. High Data Rate Functional Data Flow

28180

PAYLOAD RECORDER

PARAMETERS	SCS-2000 NASA/SPACE SHUTTLE STR
INPUT DATA RATE	25.5 TO 1024 kBPS (DIGITAL) 1.9 TO 2000 kHz (ANALOG)
INPUT DATA FORMAT	BI-Ø-LEVEL
RECORD TIME	4 TO 80 MINUTES (PER TRACK) 18.6 HOURS TOTAL, MAXIMUM
TOTAL STORAGE	3.4 X 10^9 BITS (DIGITAL) MAXIMUM, 14 [illegible]CKS
RECORD/REPRODUCE RATIO	1 : 20 MAXI[illegible] (DIGITAL) 1 : 1 (ANALOG)
REPRODUCE TIME	4 TO 80 MINUTES (PER TRACK)
REPRODUCE RATE	25.5 TO 1024 kBPS (DIGITAL) 1.9 TO 2000 kHz (ANALOG)
RANDOM ERROR RATE	1 IN 10^6 BITS
JITTER/OUTPUT STABILITY	0.1% MAXIMUM
OPERATING VOLTAGE	±4 VDC
RECORD POWER	42 W, LOOP 65 W, 14 TRACK PARALLEL 48 W, HIGH SPEED SERIAL
REPRODUCE POWER	59 W, LOOP DUMP 65 W, 14 TRACK PARALLEL 63 W, HIGH SPEED SERIAL
SIZE	19.0 X 15.6 X 8 IN.
VOLUME	[illegible] 1 IN.^{3}
WEIGHT	36 LB
TRACK SWITCHING DATA INTERRUPTS	7 SEC MAXIMUM TURN AROUND (AT 120 IPS)
TAPE LENGTH	2400 FEET
TAPE WIDTH	0.5 IN.
TAPE THICKNESS	1 MIL
RECORD SPEED	6 TO 120 IN./SEC IN 14 INCREMENTS (4 SPEEDS ARE PRE-PROGRAMMABLE)

SPACELAB RECORDER

RECORD TECHNIQUE	LONGITUDINAL, 28 TRACKS
DATA TRACKS	26
DATA STORAGE	3.6 X 10^{10} BITS
BIT DENSITY/TRACK	12.5 kBIT/INCH
DATA RATE INPUT	1, 2, 4, 8, 16, 32 MBPS
DATA RATE OUTPUT	1, 2, 4, 8, 16, 32 MBPS
TOTAL RECORD TIME	600, 300, 150, 75, 37.5, 18.75 MIN
DATA TYPE	SERIAL IN, SERIAL OUT, NRZ - L + CLOCK
BIT ERROR RATE	1 X 10^{-6}
PLAYBACK DIRECTION	REVERSE TO RECORD DIRECTION
START TIME	5 S
STOP TIME	2.5 S
TAPE HANDLING	TAPE CARTRIDGE, AUTOMATIC THREADING
TAPE LOADING TIME	0.4 MIN
REWIND TIME	4.6 MIN
TAPE WIDTH/REEL DIAMETER	1"/14"
TAPE REEL WITH TAPE AND CARTRIDGE	4.8 kg

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Figure II-3-10. Characteristics of the Two Onboard Tape Recorders

28181

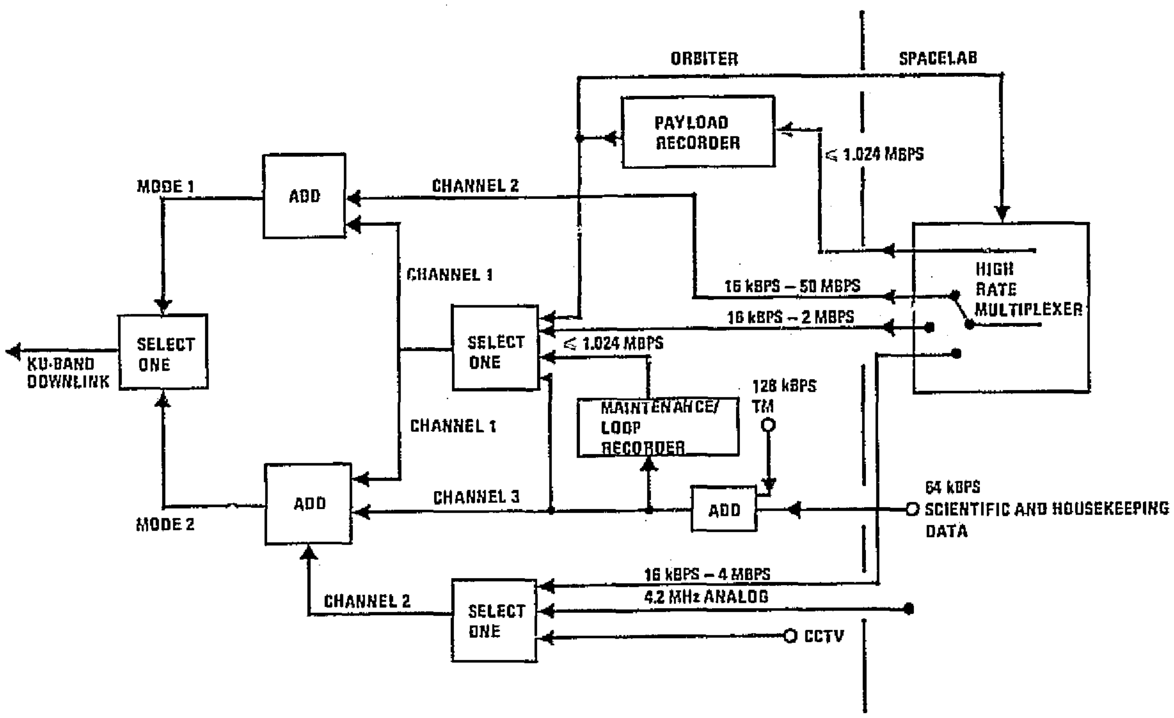

Figure II-3-11. Functional Flow of the Ku-Band Signal Processor

Table II-3-2

KUSP OPERATING MODES

Modes	Channel 1	Channel 2	Channel 3
PM	Digital: 0.016 to 2 MBPS Time Shared: • RT PLD Data • RT OPS Data • Recorder Dumps	Digital: 0.016 to 50 MBPS • Wideband PLD Data	Not available
FM	Digital: 0.016 to 2 MBPS Time Shared: • RT PLD Data • Recorder Data Dumps	Digital: 0.016 to 4 MBPS • PLD Digital Data Or Analog: CCTV or 4.2 MHz • PLD Analog Data • PLD TV • Orbiter TV	Digital: 192 kBPS • RT OPS Data

22854

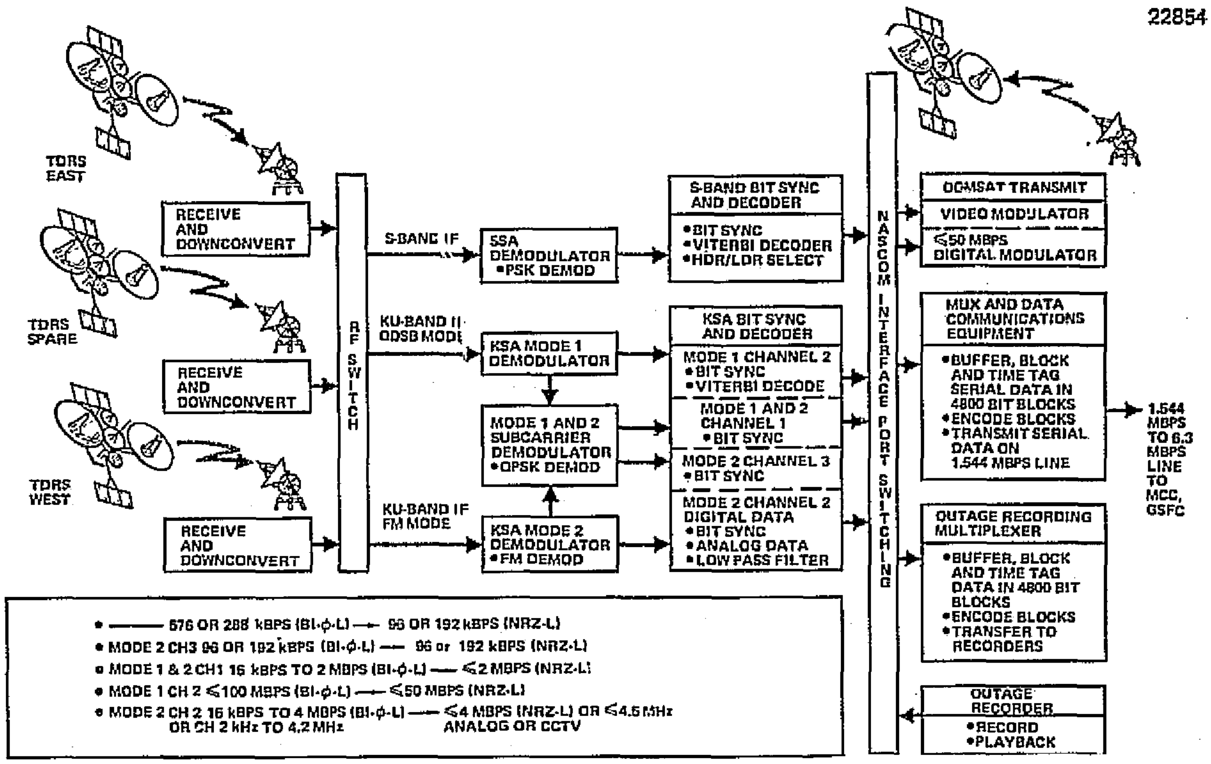

Figure II-3-12. TDRSS Ground Station Functional Flow

3.3.1.3 JSC Ground Systems

Real-time ground support of Spacelab payload operations is currently planned to be supported from a centralized POCC located at JSC.

JSC plans to acquire the wide-band scientific data from the TDRS ground station via a DOMSAT. The operational data stream (and low-rate scientific data) will be received via land line capable of 1.544-MBPS data transmission. The operational data will include the voice loops and will be processed and available to the POCC in real time. It will be possible to display 500 parameters of the operational data on cathode ray tubes (CRTs) and/or strip charts. This data will be available for immediate recall for a 6-hour period.

The wide-band scientific data will be demultiplexed and up to 4 channels of data extracted. Processing data from three of these channels will be limited to 256 kBPS each and the fourth channel limited to 2 MBPS. Five hundred parameters from each of these channels can be displayed (CRT capability will limit total display to 800 parameters at any instant). Data scheduled for display is available for immediate recall for a 6-hour period. Other data on these channels will be recorded and can be made available within 4 hours of any 6-hour period.

MCDONNELL DOUGLAS

Television data which is compatible with the Orbiter system can be displayed. Current plans do not account for processing of payload analog data or for image processing of digital data. Text and graphics uplink capability will be limited to 8 kBPS for the early Shuttle flights and upgraded to 128 kBPS effective with Shuttle flight 17.

The JSC POCC will provide standard unit conversion, limit sensing, and simple logic-arithmetic computations. Special online and offline payload computation support can be provided on a case-by-case basis.

The following information on JSC ground data processing was extracted from Reference 24.

Mission Control Center (MCC) and TDRSS Interface

The MCC and TDRSS interface is comprised of voice, telemetry, video, and command data. The voice interface will include single or dual air-to-ground and ground-to-air duplex voice links between the Orbiter and MCC, and also postpass transmission to MCC of all recorded voice tapes. The telemetry interface will include real-time landline transmission to the MCC of up to 1 MBPS of payload data. Transmission to MCC of multi-megabit scientific data will be provided by a TDRSS/DOMSAT/MCC interface. The video interface at MCC will accommodate both real-time and postpass video data.

The TDRSS/DOMSAT/MCC interface will be identical to the TDRSS and MCC interface and will allow for a throughput (including the multi-megabit data stream) of the entire Orbiter and payload downlink streams, as received by the TDRSS ground station.

MCC and POCC Interface

The exact configuration of the circuits and interface characteristics between the MCC and POCC are not determined at this time. However, the POCC must have nearly unrestricted access to the data at MCC. The interface will be comprised of voice, telemetry, and video data. The voice data will consist of two full-duplex voice channels for payload support. The telemetry data interface will be comprised of housekeeping low-rate sensor data, along with a high-rate scientific data link (currently one channel of 2 MBPS and three channels of 256 kBPS of data). The video interface will consist of a one-way transfer from the MCC to the POCC of Orbiter video data.

3.3.1.4 GSFC Ground Systems

GSFC is responsible for the Spacelab payload non-time-critical data processing. Processing functions currently planned at GSFC for the early Spacelab missions are (1) data capture (record) of all payload data telemetered on the wideband link and (2) verify, format, and forward data to experimenter's facilities for reduction, analysis, and archiving. The full processing system will be sized to process and deliver all data within 30 days. Firm plans for later Spacelab missions have not yet been made. More detailed information on GSFC ground data processing can be found in Reference 24.

3.3.2 Incompatibilities of Current Plans vs Future Ground Data Requirements

It is clear from the data requirements itemized in Subsection 3.2 and the corresponding ground data processing capabilities listed in Subsection 3.3.1, that new data handling techniques will be required to accommodate the Spacelab experiments during the 1985-1990 time frame. Reducing the instrument data rates arbitrarily to match current ground processing capabilities will cause a significant reduction in the instrument's performance. This is illustrated in Figure II-3-13 for the synthetic aperature radar (SAR) sensor. The desired ground resolution for the SAR sensor is equal to or less than 100 meters which relates to approximately 50 MBPS for this example. A further reduction in data rate would produce a disproportionate degradation in resolution.

The range of expected data volumes and data rates for four key image sensors is shown in Figure II-3-14. This plot illustrates the combined data handling requirements for these instruments. Also, the area representing the current ground data handling capabilities was signified by cross-hatching the appropriate values on the same plot. The data volume limitation was determined by a survey of the digital storage technology performed during this study (see Subsection 3.3.3). Again it is clear that more advanced data handling techniques will be required to properly process the data from these instruments.

The more significant ground data requirements of the future which exceed the data processing capabilities currently planned for the early Spacelab mission are summarized below:

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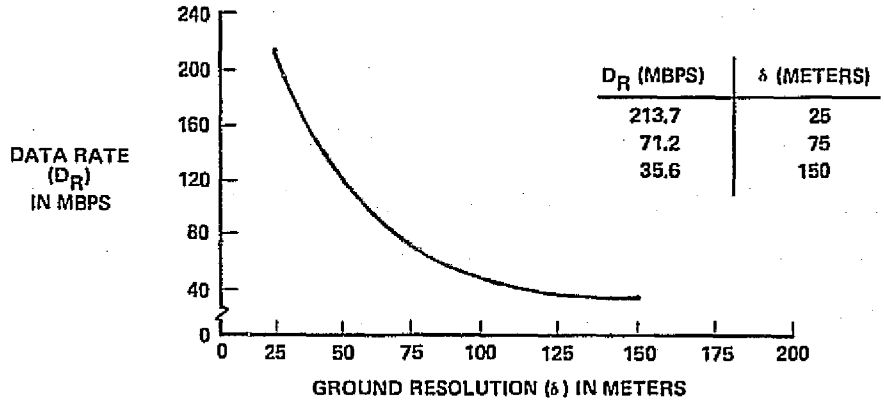
$$\text{DATA RATE} = \frac{\text{SWATH WIDTH (W)}}{\text{RESOLUTION } (\delta)} \times \frac{\text{PULSE REPETITION FREQ (PRF)}}{\text{PRESUMMING FACTOR (n)}}$$
$$\times \text{ NO. OF BITS/WORD (q)} \times \text{ NO. OF RADAR CHANNELS } (N_C)$$

BASELINE DESIGN GUIDE LINES:

$W = 102;\ \text{kM},\quad \delta = 25\ \text{M},\quad \text{PRF} = 2,182\ \text{Hz},\quad n = 1$

$q = 6$ BITS/WORD $N_C = 4$ CHANNELS (TWO WAVELENGTHS AND TWO POLARIZATIONS)

$$\text{THEREFORE, } D_R = \frac{10.2 \times 10^4}{25} \cdot \frac{2.182 \times 10^3}{1} \cdot 6 \cdot 4 \cong 213.7 \text{ MBPS}$$



D_R (MBPS)	δ (METERS)
213.7	25
71.2	75
35.6	150

Figure II-3-13. Synthetic Aperture Radar Data Rate vs Resolution

28159

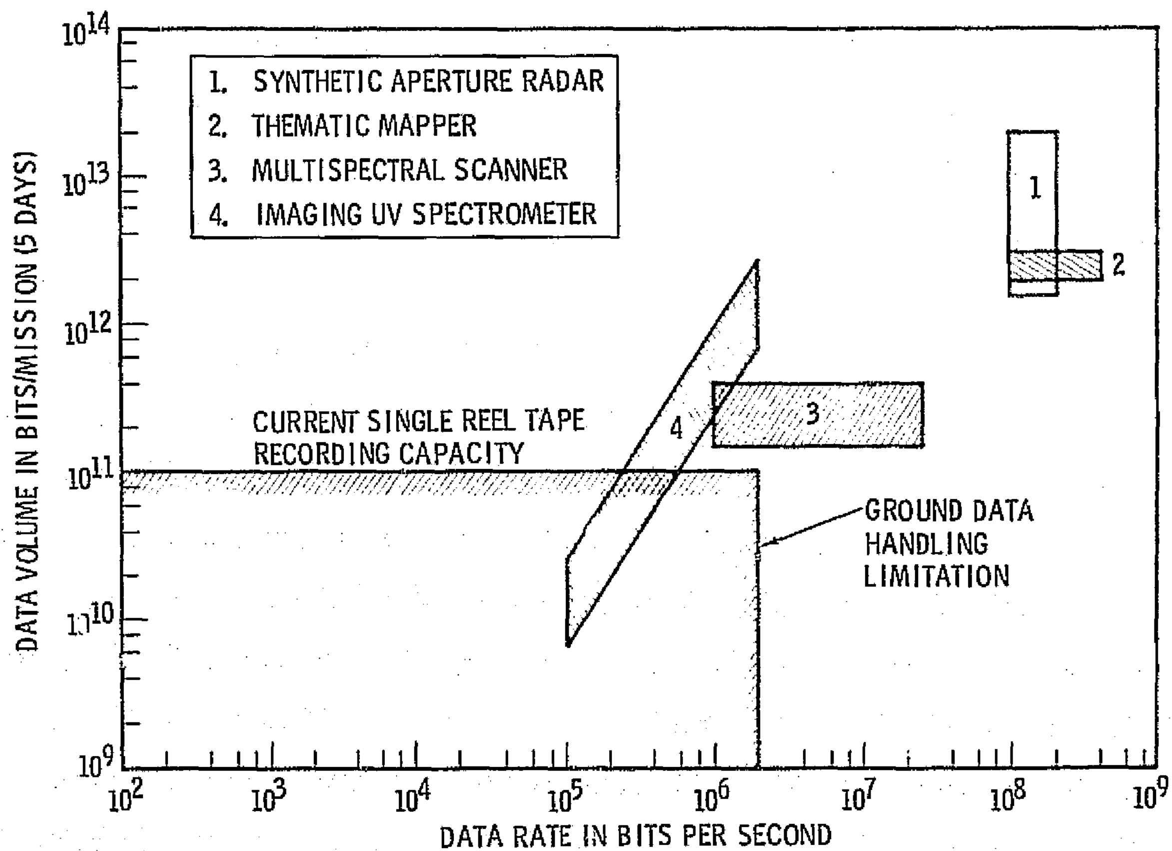


Figure II-3-14. Estimated Sensors Digital Data Output Characteristics

- Imaging instruments will generate digital data rates far in excess (potentially 1,000 MBPS) of current recording, transmission, and processing capabilities.
- Real-time image processing will be required to allow interactive control of the image producing instruments. (It is anticipated that a 1-MBPS real-time image processing capability will be acceptable.)
- Simultaneous transmission of TV and high-rate scientific data (much greater than the 2-MBPS capability currently planned) will be required.
- Data quantities (potentially in excess of 1×10^{13} bits/day) will far exceed the current capabilities to record and process data within a reasonable period of time.

3.3.3 Proposed New Concepts

A perspective flow diagram of a conceptual Spacelab data link is shown in Figure II-3-15. The major elements in the end-to-end data link are (1) the onboard systems (Shuttle), (2) ground systems providing real-time processing (JSC), and (3) ground systems providing data processing that is not time critical (GSFC).

The functions proposed to be performed onboard the Shuttle are data storage, data compression, interactive control and display with both hard and soft-copy capability and data transmission. The functions recommended for the real-time processing site are quick-look analysis, diagnostics, and temporary storage. The non-time-critical processing functions that are recommended are image processing (limited), data base processing, creation of instrument data files, and provision of a complete data interface with the user.

3.3.3.1 Digital State-of-the-Art Storage Survey (References 43 to 56)

Figure II-3-16 presents a table summarizing the results of a brief survey made of available and proposed (1980's) digital storage devices. It will be noted that we have made no distinctions between airborne and ground equipment. An analysis that includes such distinctions would be a useful follow-on effort.

28148-1

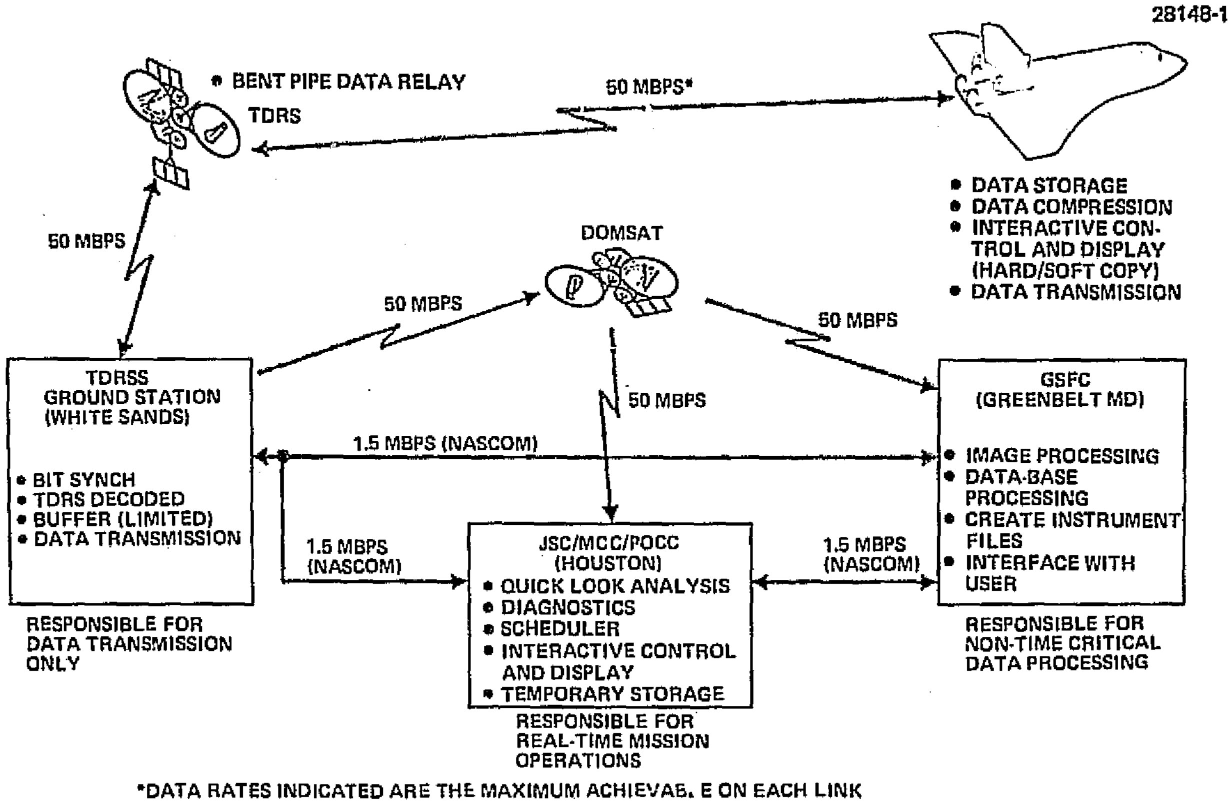


Figure II-3-15. Spacelab Data Downlink Flow Capabilities

28154

DIGITAL DATA STORAGE DEVICES	CURRENT TECHNOLOGY				1980'S		APPLICATION
	CAPACITY (BITS)	BIT RATE (BPS)	ACCESS TIME (MICROSECONDS)	COST PER BIT (CENTS/BIT)	CAPACITY (BITS)	BIT RATE (BPS)	
1. MAGNETIC CORE	7×10^3 TO 8×10^7	< 1 MBPS	0.15 TO 10	~0.50	10^9	1 MBPS	MAINFRAME MEMORIES
2. MAGNETIC TAPE	3×10^9 TO 1.5×10^{11}	6 MBPS	10^4 TO 8×10^5	≤ 0.0001	10^{12}	20 MBPS	PERIPHERAL MEMORIES
3. MAGNETIC DISK	10^8 TO 5×10^{10}	7.5 MBPS	2×10^3 TO 8×10^5	~0.0015	10^{12}	4 TO 10 MBPS	PERIPHERAL MEMORIES
4. METAL OXIDE SEMICONDUCTOR (MOS)	10^4 TO 8×10^7	0.8 MBPS	0.1 TO 8	~0.30	10^9	1 TO 10 MBPS	MAINFRAME MEMORIES BUFFER AND CACHES PERIPHERAL MEMORIES
5. BIPOLAR-SEMICONDUCTOR	10^2 TO 10^6	16.5 MBPS	0.02 TO 0.8	~1.50	10^9	> 10 MBPS	MAINFRAME MEMORIES BUFFER AND CACHES PERIPHERAL MEMORIES
6. MAGNETIC BUBBLE	10^6 TO 10^9	< 1 MBPS	100 TO 6×10^3	~0.05	10^9 TO 10^{10}	10 MBPS	SPACEFLIGHT RECORDER MAIN MEMORY EXTENSION LARGE FILE DATA BASE BUFFERS
7. CHARGE COUPLED DEVICES (CCD)	10^6 TO 10^9	1 TO 5 MBPS	10 TO 500	~0.10	10^9	32 MBPS	SMALL STORAGE BUFFERS AND CACHES CONTROL DATA STORES
8. ELECTRON BEAM	10^7 TO 10^{10}	~1.5 MBPS	0.3 TO 50	~0.05	10^{11} TO 10^{13}	150 MBPS 1,000 (PARALLEL CHANNELS)	IMAGE STORAGE DEVICES
9. LASER BEAM	10^{13}	6 MBPS	5 TO 20	10^{-4}	10^{13}	> 200 MBPS (PARALLEL CHANNELS)	IMAGE STORAGE DEVICES

Figure II-3-16. Table of Digital Storage Technology

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Magnetic-core storage is widely used for the main storage and is directly accessible by the computer's processing unit. The data is stored in a spatial array of elements; in this case, each element can store a single bit and physically consists of a tiny donut-shaped object, which is the magnetic core. Some of the techniques of storage organization used with core storage (e.g., 2D, 3D, and 2-1/2D schemes) are also applicable to other technologies, especially magnetic films. As a rough indication of speed and capacity available in the year 1974, we took the Ampex ECM (Reference 43), as an example, with controller modules of 10^7 bits:

- Read/write cyle - 1 MBPS
- Capacity - 10^9 bits

It is estimated that the magnetic core technology will not advance significantly.

There is much written in the literature on the various types of magnetic tape systems (References 43, 47, and 55) and the values in the tables are reasonable estimates of both airborne and ground devices. Access to these machines takes place in a sequential fashion. Data are recorded as magnetic spots on typically 9 to 28 positions across the width of the tape. Such a set of nine positions may, for example, represent eight information bits and one bit for parity checking. Corresponding to each bit position is a read and write head used for recording or sensing information on the tape. Thus data are retrieved or sent one bit at a time (nine bits in parallel) to the recording heads. When the tape is at rest, recording or reading can start only when the tape is accelerated to, or near, maximum speed. This delay is called start time; it is on the order of 5 msec. An example of a high speed capacity system is the Ampex Terabit memory which has an input and output bit rate of 6 MBPS and a capacity of 3×10^{12} bits/3800-ft reel. Further advances in this technology is also expected to be limited.

Magnetic disk is available in a variety of arrangements. One scheme uses the recording surfaces on rotating disks; all disks rotate together at a fixed speed – they are not stopped or started for access purposes. Read and write heads are mounted in a comb arrangement and each comb has one head for each recording surface. Data are typically stored serially by bit along each of the multiple concentric circles (i.e., tracks) of each disk. Since all heads are positioned together, a single comb position makes a set of tracks available. This set of tracks is referred to as a cylinder. Since head-positioning or seek time requires the longest delay for random access, the capacity of a cylinder is important. In addition to seek time, random access also requires a rotational delay which is approximately in the 10-msec range. For high-speed capacity machines, the input and output bit rates range from 2.7 to 6.5 MBPS and have capacities of approximately 10^9 bits (reference 43). Developmental disk devices have increased capacities of up to 10^{12} bits.

Semiconductors, at the present time, do not serve the mass memory market; however, they do provide a solution for temporary storage (e.g., buffers). Metal oxide semiconductor (MOS) and bipolar transistors are fabricated as monolithic integrated circuits, which is defined as an inseparable assembly of circuit elements in a single structure which cannot be divided without permanently destroying its electronic function.

The MOS transistor is an active semiconductor device in which a conducting channel is induced in the region between two electrodes (source and drain) by a voltage applied to an insulated electrode (gate) on the surface of the semiconducting material (chip). Bipolar devices such as transistor-transister logic (TTL), emitter-coupled logic (ECL), etc., use the conventional p-n junction effect to establish integrated circuit (IC) gates which can act as memory circuits. The junctions are formed by application of alternating steps of various masks and diffusion depths to a semiconductor material. Charge-coupled devices (CCDs) are similar to the MOS shift-register devices but depend on the controlled movement of electrical charges rather than on transistor-like circuits. CCDs are more compact, simpler, and lower in cost than integrated circuit devices. The primary application of CCDs is high-density, low-cost storage.

The values used in this survey for semiconductor memories are the result of surveying published documents (References 43, 46, 47, 50, 51, 52, and 56). The advantage of these devices are their high packing densities. The results indicate that semiconductor memories will be useful as data buffers, low-capacity main memories for microcomputers, and caches for frequently used data.

Magnetic bubbles, with the same logic design as shift registers, are developed in a single-crystal layer of a ferro- or ferrimagnetic material and data can be made to move along paths on the surface. This technique offers low-cost plus high density (i. e., Reference 43 stipulates 10^9 bits/in.^{2} forecast), but is considerably slower in access time than the semiconductor technologies. This device may be a likely candidate for spaceborne recorders because of their high reliability and increased storage density with corresponding decrease in weight and power.

Optical recording and readout memory systems consist of a beam source (laser), beam control device, memory medium, beam deflector, focusing and pivoting medium, focusing and pivoting optics, and a light detector. The high packing density potential of optical memories of more than 10^8 bit/in.^{2} reduces the size of a 10^{12} bit memory to 10,000 in.^{2} of recording surface (Reference 43). However, these capabilities have not been realized because of the following problems.

A. Development of a suitable, nonvolatile, erasable, optical storage medium.

B. Development of high-speed, high-repetition-rate, low-cost digital deflectors which can address a large number of resolution elements.

C. The addressability of a field of 10^8 bits presents a difficult problem due to diffraction, depth of field, depth of focus, etc.

Electron beam devices seem to be far more attractive as a recording device than laser beams (References 54). Electron beam recording utilizes a spot size of the order of 10^2 μm which produces densities of 10^{12} bits/in.^{2}. The electrical signal to be recorded modulates the intensity of an electron beam which is directed at a silver halide recording medium (other mediums are being used, e.g., MOS $Si0_2$/Si interface). In the readout process, the same scanning pattern is used as that used to record. When the beam, acting as a constant current source, strikes the film, a spot of light (equal in size to the cross section of the beam) is generated by a scintillator coating over the emulsion. The intensity of the light, when viewed through the film is modulated as the spot is scanned along the recording. Finally, a photo multiplier collects the photons that have penetrated the film and converts them to an electron flow.

In the 1980's, electron beam memories are considered to be cost competitive with all online random access stored devices (Reference 54), but with far superior performance.

3.3.3.2 Array Processor Survey

Our study included a survey of the technology of high-data-rate image processing in 1974-76. Figure II-3-17 summarizes some of the results of this survey.

The array processor is usually comprised of an array of special purpose microprocessors containing processing elements (PE), viz., algebraic, trigonometric, or exponential operations, which process data in parallel along separate paths on a bit-by-bit basis. The array processor operates in conjunction with a host computer which provides overall program control. Figure II-3-18 illustrates a typical configuration for an array processor (data path flow diagram for the AP-120B Array Transform Processor from Floating Point Systems, Inc).

One of the major applications of array processors is digital image processing. Typical computational functions which can be solved with this processor include image matching, correlation, spatial transformation, image registration, radiometric corrections, change detection, statistical classifications, and various image enhancement techniques. Also, the array processor may be used to control the image display and recording equipment.

3.3.3.3 New Data Handling Concepts in the Literature

Initially, two new data handling concepts were examined that were described in the published literature: (1) GE's Onboard Experiment Data Support Facility (OEDSF) (Reference 9) and (2) the Instrument Telemetry Packet (ITP) Concept, a GSFC report (Reference 10).

The OEDSF concept is shown in Figure II-3-19. This concept uses a matrix-structured pipelined processor that interfaces directly between the sensors and the Spacelab's CDMS, viz., the high-rate multiplexer, high-rate data recorder, and the experiment computer. This processor operates similarly to an array processor; in addition, it handles multiple sensor complements and combinations of low- and high-data rates. The OEDSF would be fabricated with large-scale integration (LSI) circuits (usually defined as > 100 gates per chip) and would dedicate an entire matrix to each sensor. This concept would do most of the data processing onboard the Shuttle.

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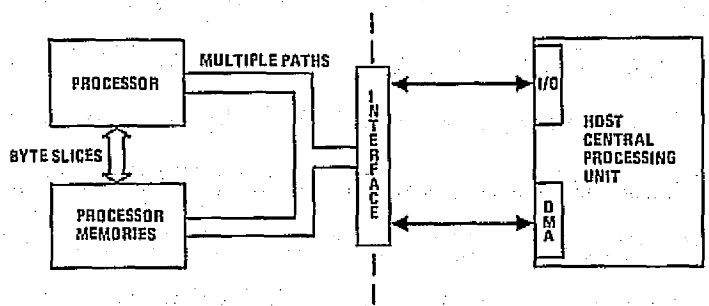
MFG/LOCATION	MODEL NO.	WORD LENGTH (BITS)	MEMORY CAPACITY (WORDS)	INPUT/OUTPUT WORD RATE	MULTIPLY TIME (NSEC)	BENCHMARK CALCULATIONS IN MSECS: FAST FOURIER TRANSFORM	BENCHMARK CALCULATIONS IN MSECS: CONVOLUTION OR CORRELATION	BENCHMARK CALCULATIONS IN MSECS: TWO DIMENSION FFT	WEIGHT (LB)	POWER (WATTS)
1. FLOATING POINT SYSTEMS, PORTLAND, OR	AP-120B	DATA-38 INSTR-04	1M	3 MWPS	500	2.9 (1,024 REAL POINTS)	6.0 (1,024 x 32 POINTS)	1,550 (512 x 512 REAL POINTS)	88	025
2. CONTROL DATA, MPLS, MN	FLEXIBLE PROCESSOR	32	1,024M	2 MWPS	250	–	–	–	–	225
3. ESL INC., SUNNYVALE, CA	ADVANCED SCIENTIFIC ARRAY PROCESSOR	32	05K	1.25 MWPS	<430	5.3 (1,024 REAL POINTS)	25.0 (1,024 x 50 POINTS)	6,300 (256 x 256 REAL POINTS)	–	1,000
4. CSP INC BURLINGTON, MA	MAP 300	32	192K	4 MWPS	210	2.8 (1,024 REAL POINTS)	7.0 (1.024 x 32 POINTS)	–	–	–



EXAMPLE OF ARRAY PROCESSOR BLOCK DIAGRAM

Figure II-3-17. Array Processor Survey (1974-76)

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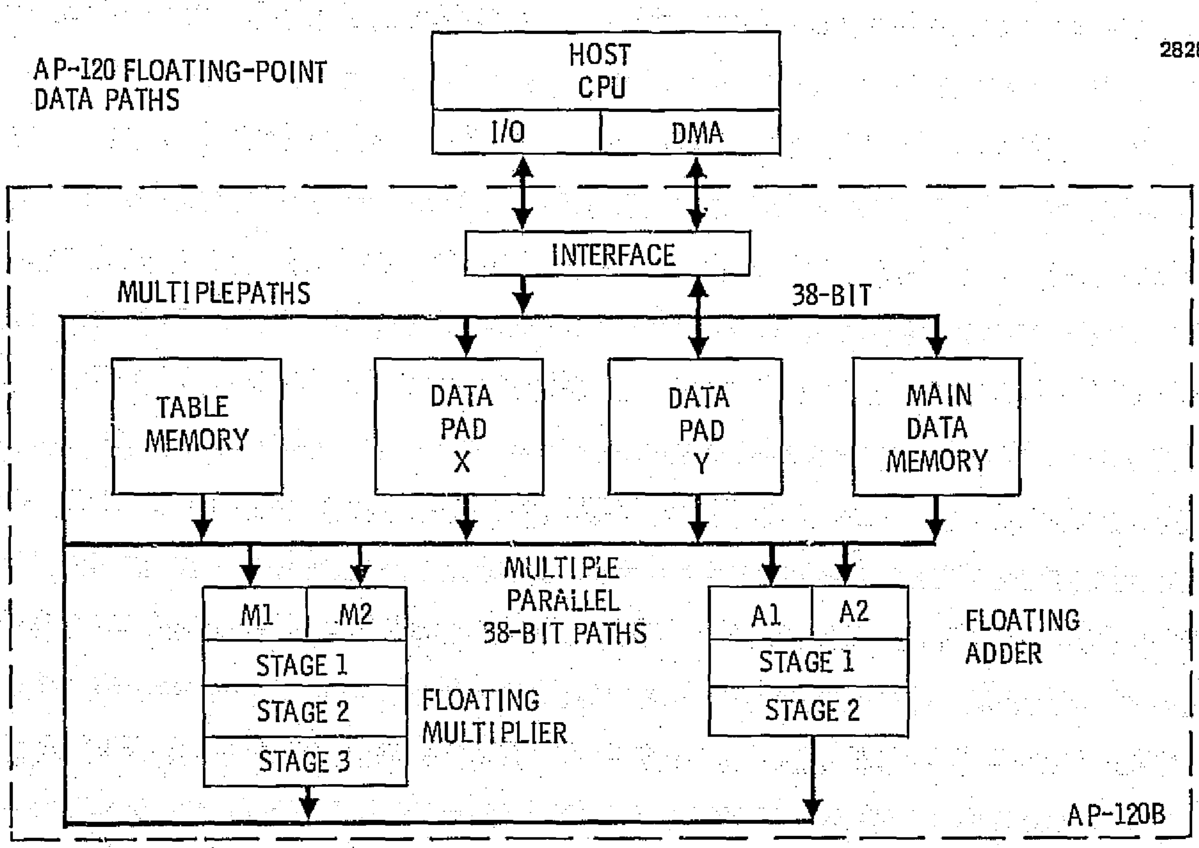


Figure II-3-18. The AP-120B Array Transform Processor

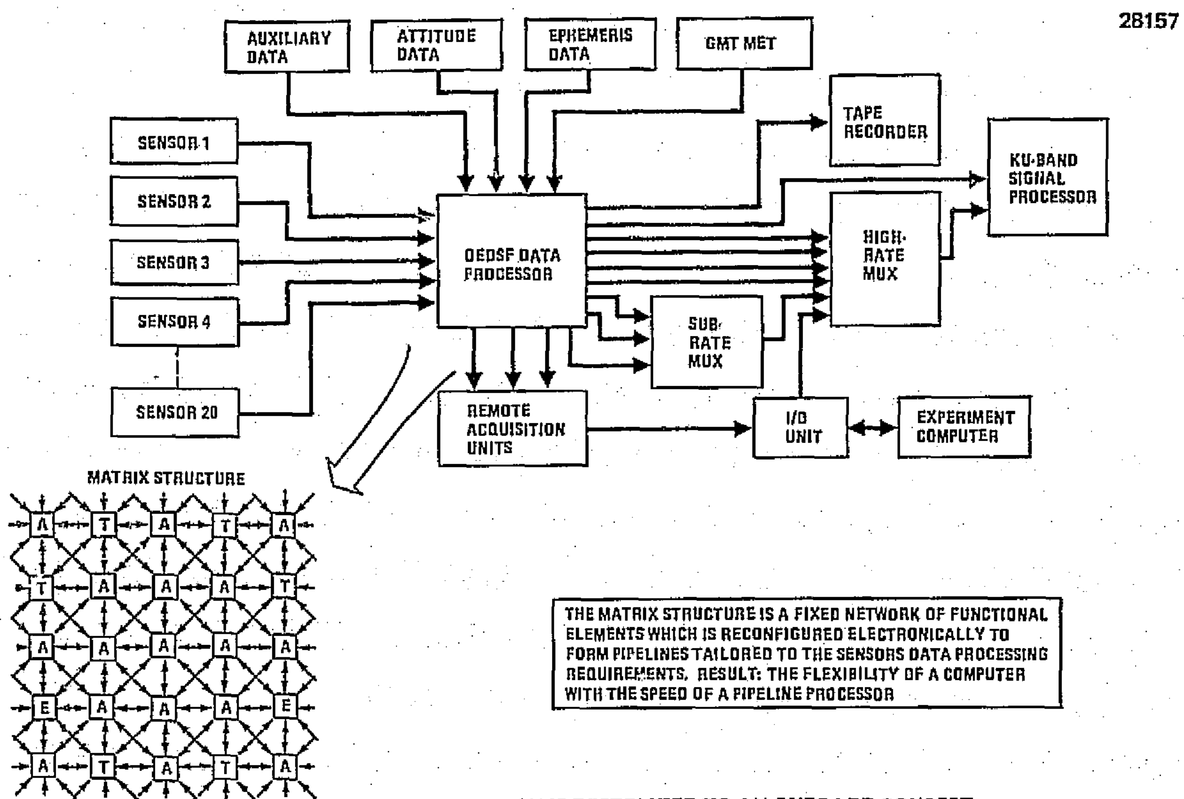


Figure II-3-19. GE's Onboard Experiment Data Support Facility Concept (OEDSF)

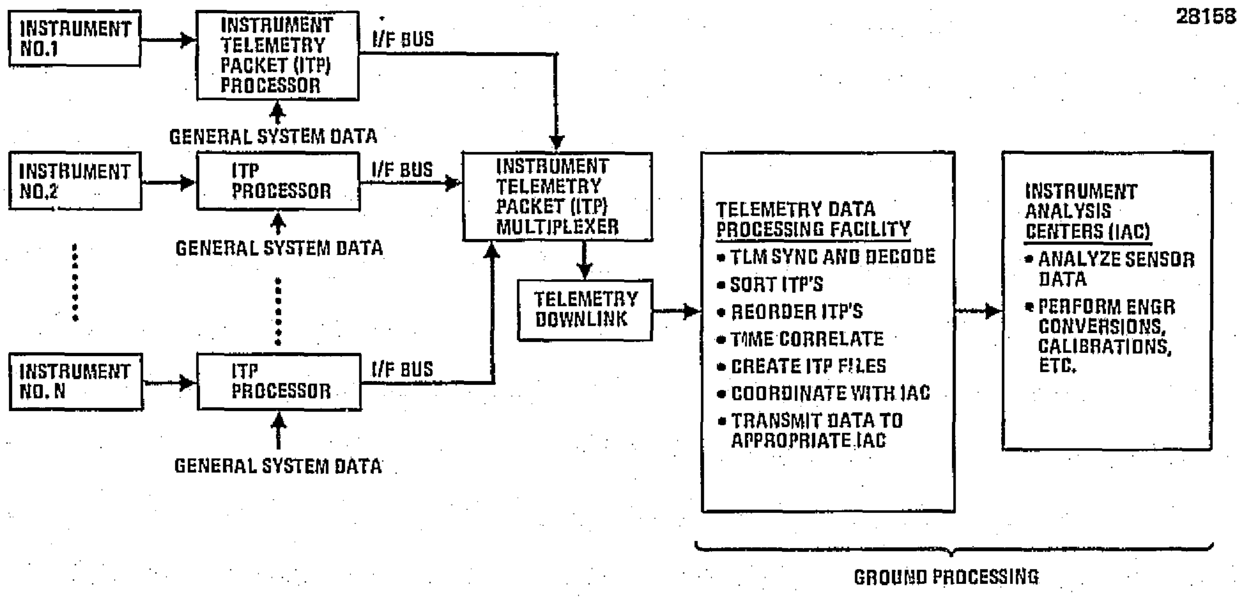
There are some possible disadvantages to this concept and they are:

A. The data throughput of the OEDSF system may be limited to capabilities of the onboard recording devices.

B. There would be a limited capability to select significant (important) portions of the stream of image data for transmission to the ground.

C. The matrix structure must be carefully designed to avoid conflicting mathematical operations being performed on data from different sensors.

The ITP concept was described in a GSFC report and probably was addressed specifically for automated earth-orbiting spacecraft. Figure II-3-20 shows a simplified block diagram of the ITP concept; note that most of the data processing takes place on the ground. The ITP concept is envisioned to handle data from a single sensor. Initially, the ITP would assemble the sensor data along with any required ancillary data and then buffer this combined format for subsequent downlinking or for further processing. Later versions would likely include more sophisticated forms of efficient coding techniques.



NOTE 1: MICROCOMPUTER USED AS ITP PROCESSOR
NOTE 2: MOST OF THE DATA PROCESSING TAKES PLACE ON THE GROUND

Figure II-3-20. Proposed Data Acquisition and Processing Subsystem Concept
(A. Ferris and E. Green, A Proposed Concept for Improved NASA Mission Data Management Options, GSFC, X-533-76-81, October 1976)

The onboard equipment will be comprised of multiple ITP processors and a single multiplexer which is used to route the ITP data to designated output devices (e. g., transmitter or recorders). The ITP processor may be implemented as a microcomputer comprised of a microprocessor; a semiconductor memory, read-only memory for program execution and random access memory (RAM) for buffer storage; and a I/O control unit.

3.3.3.4 New Advanced Concept

A third concept was devised during the last phase of the study and is shown in Figure II-3-21. This concept is proposed to accomplish the onboard data handling task for a high-data rate image sensor. A new equipment complement is required that includes (1) a special-purpose microprocessor used as a pattern recognizer, (2) a high-speed first-in/first-out buffer, (3) a pipelined array processor, (2) a high-speed and capacity recorder, and (5) an interactive quick-look display.

Onboard Processing

Most of the image sensors are observing phenomena (e. g., solar flares) that occur only occasionally for short periods of time, but at extremely high data rates. A pattern recognizer, coupled to a first-in/first-out buffer memory;

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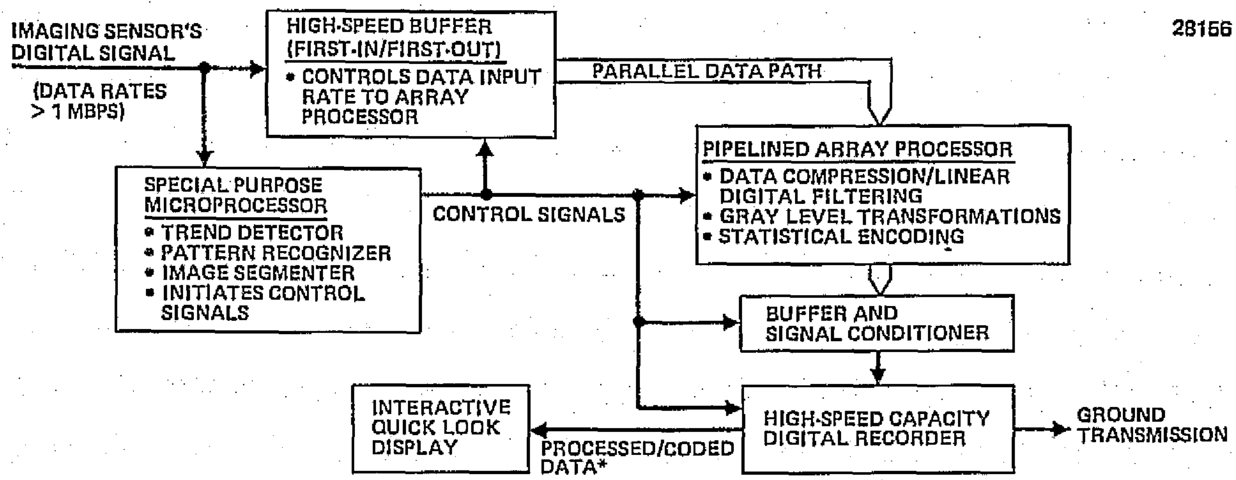

KEY ITEMS

1) DATA COMPRESSION: TYPICAL ACHIEVABLE COMPRESSION RATIOS ARE 4 TO 10:1

2) THE RECORDER MUST BE ABLE TO RECORD SHORT-DURATION HIGH-DATA-RATE SIGNALS AND PLAYBACK AT SLOWER SPEEDS (e.g., BIPOLAR, BUBBLE, AND CCD MEMORY SYSTEMS)

3) PATTERN RECOGNIZER/IMAGE SEGMENTER CAN ISOLATE SIGNIFICANT EVENTS AND DISCARD THE REST

4) A CAPABILITY SHOULD EXIST FOR ONBOARD INTERACTIVE GRAPHICS WHICH CAN ALSO BE TRANSMITTED TO THE GROUND (NOTE: THE DISPLAY WILL ILLUSTRATE PROCESSED/CODED DATA)

5) FOR HIGH RELIABILITY OF THE EXPERIMENTS, SPECIAL SOFTWARE DIAGNOSTIC SCHEMES WILL BE NEEDED

*THE DATA FOR THE QUICK-LOOK DISPLAY IS TIME SHARED WITH THE TRANSMITTED DATA (i.e., DATA STEALING); HENCE, THE HIGH-SPEED RECORDER SERVES A DUAL ROLE

Figure II-3-21. New Onboard Data Handling Concepts

an array processor used to compress the data; and a high-speed digital recorder will permit detecting the appropriate signals and recording for subsequent transmission at a low-data rate. The pattern recognizer will be implemented by a microprocessor which can also be used for trend analyses, image segmentations, and the initiation of control signals to the rest of the image sensor processing equipment. This microprocessor will isolate the significant events and discard unnecessary data. The high-speed buffer simply controls the input rate to the array processor.

The array processor will be used for image data compression. Image compression techniques (References 57 to 67) can achieve a reduction in data rate and volume of 4:1 to 10:1. Examples of such techniques are: (1) low-spatial-frequency notch filtering followed by contrast stretching and (2) Hadamard transformations (Reference 65) combined with removal of high, low-valued, sequency components (also called zonal filtering). The data is then routed to a high-speed capacity recorder.

The recorder must be able to record short-duration high-data-rate signals and playback at slower speeds. Bipolar, CCDs, or magnetic bubble systems may be used for this device. The recorder's output will be routed to the Orbiter transmitter and to an interactive onboard display. The data for the quick-look display will be time shared with the transmitted data which means that the same data will be sent to both locations. It should be noted that the display will have to accommodate compressed and encoded data.

Special uplink commands will be required for interaction with the quick-look display and simultaneous transmission of the display signal to the POCC which will provide a real-time check of the experiment and permit early remedial actions to take place. This establishes a requirement for onboard interactive graphics.

Because of the importance of assuring the correct operation of the experiments, some form of diagnostic software should be placed onboard for detecting a failure and recommending corrective actions.

Ground Data Processing

The following data handling concepts are recommended for the real-time Spacelab processing site (e. g., JSC) which also includes the POCC.

Hadamard (or other transforms, see Reference 42) decoders will be required to decode the quick-look data transmitted from the Spacelab. An array processor will be used to perform the inverse transformation necessary to display the visual image. Image processing at the JSC POCC would be limited to quick-look analysis and evaluating the quality of the downlinked data.

It is also suggested that users who wish to communicate directly with the Spacelab be allocated a coded audio signal (e. g., a voice-print signal match) that the user can enter into a telephone line for facilitating identification and organization of the eligible users. A central switchboard at the POCC will determine the order in which the users will have access to the Spacelab.

The users at the JSC POCC are a subset of the complete set of Spacelab experiment users. These users will want a quick look at their data. Displaying this data to them will require fast decoding, array processing, and interpretation of the users' high-level-language commands. Thus, responding to the users requires a substantial amount of fast digital information processing. The amount of this processing available to the users is limited, thus, the users must compete for the available digital processing. The scheduler/controller will arbitrate among these users' conflicting demands. Depending on each user's commands, the format of the user's data, the information density of the user's data, the relative importance of the data, and the amount of preceding computing time consumed by the user, the scheduler must arrange (1) the sequence and sizes of the data blocks to be stored in the high-speed mass storage (see Figure II-3-23), and (2) the sequence and frequency of the running of each user's display program. The schedule will be implemented as software in the scheduler/controller.

Storing the data blocks in the high-speed mass memory requires a reservation of segments of the mass memory for the elements of these blocks as they arrive from the decommutator. The addresses of the heads of these blocks are conveniently stored in an associative memory (see Reference 68) within the scheduler/controller. The associative nature of this memory facilitates responding to each user's request for various types of data.

Where a user's program, say user A's program, is suddenly interrupted by another user, B, and user B has a higher priority than user A, then user A's intermediate data may be stored at the top of a stack memory (Reference 68) (or, equivalently, a push-down memory). The intermediate data of user A will be retrieved when user B's program is completed. If a still higher-priority user, C, interrupts user B, then user B's intermediate data are stored at the top of the stack (pushing down the data of the other users in the stack) until user C's program is completed. This computer algorithm structure will not only determine priorities but facilitate day-to-day changes in the scheduling of the experiments.

Because of the importance of correcting experiment failures as rapidly as possible and since a full diagnostic and repair capability will not be feasible onboard the Shuttle, it will probably be necessary to have a full failure analyzer on the ground (JSC and MSFC). The analyzer will assist JSC POCC to advise the Spacelab on remedial actions for hardware and software failures that the onboard system cannot cope with.

Suppose a hardware failure occurs in the data processing section of the Spacelab and either (1) this hardware failure cannot be diagnosed onboard or (2) the hardware failure can be diagnosed but a repair procedure cannot be discovered onboard — perhaps because of a lack of an appropriate spare part. Then a full simulator of the onboard data processor, including a capability for simulating hardware failures, may enable the POCC crew to suggest alternate schemes for at least a partial repair.

Suppose a software failure occurs that is too complex to be diagnosed onboard. Then, a full simulation of the system is needed at JSC or MSFC. To enable this simulation to take place, a full memory dump from the onboard computer system to the JSC simulator would provide the JSC programmers the information they need for a diagnosis of the failure, and for finding schemes for at least a partial repair.

The analysis of hardware and software failures is likely to be greatly helped by special software written as a diagnostic aid. We refer to this as diagnostic software.

The following data processing techniques are suggested for non-time-critical processing of Spacelab data at GSFC. Also, array processors will be required to implement the appropriate (e.g., Hadamard) decoding technique needed to restore the images into a visual scene.

At this site, the data is received in the form of a variety of waveforms multiplexed together, nonmultiplexed signals, medium-rate data, and high-data-rate image sensor data. Most of the new data handling concepts presented here are only concerned with image processing since the analysis of non-image sensor data is well within the current state of the art.

Figure II-3-22 is a table that lists standard digital image processing techniques which should be considered for GSFC and examples of their corresponding applications. These techniques are discussed in detail in Reference 42 and will not be elaborated on in this report. It should be noted that some real-time processing algorithms may be included at this site. For example, associative memory designs may be used to facilitate dynamic loading of new programs. Also, data base processing (Reference 41) may be

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FUNCTION	EXAMPLES OF APPLICATIONS
1.) DECODING	INVERSE HADAMARD (OR FOURIER) TRANSFORMATION INTO VISUAL SCENES.
2.) IMAGE SEGMENTATION	SCENE ANALYSIS; E.G., DISCRIMINATION BETWEEN TERRAIN FEATURES LIKE FORESTS, URBAN AREAS, BODIES OF WATER, ROADS, ETC.
3.) NOTCH FILTERING	REMOVE SHADING EFFECTS CAUSED BY NONUNIFORM ILLUMINATION.
4.) GEOMETRIC CORRECTION	CORRECTIONS OF DISTORTIONS IN SCANNER OR TELESCOPE (OPTICS)
5.) INTERFRAME RECONSTRUCTION	ELIMINATE FLICKER IN SLOW MOTION VIEWING OF RAPID EVENTS (E.G., SOLAR FLARES).
6.) DEBLURRING	CORRECTION OF DISTORTIONS DUE TO IMAGE MOTION AND ATMOSPHERIC TURBULENCE.
7.) IMAGE CORRELATION	CONSTRUCTION OF TOPOGRAPHIC MAPS FROM STEREO-PAIRS.
8.) DATA BASE PROCESSING	ANALYSIS AND CORRELATION OF SENSOR DATA FROM SEVERAL (SENSOR) FILES.

NOTE: MOST OF THESE NEW DATA HANDLING TECHNIQUES APPLY TO IMAGE PROCESSING ONLY.

Figure II-3-22. New Data Handling Concepts, Non-Time-Critical (GFSC)

used for correlating data from several sensors and can have applications for both quick-look analyses and visual image processing evaluations (GSFC).

3.3.3.5 End-to-End Concept

This final section will address a complete Spacelab experiment data link which is comprised of (1) onboard systems and (2) ground systems — real-time processing (JSC) and ground systems and non-time-critical processing (GSFC). This end-to-end concept is illustrated in Figure II-3-23.

Onboard Processing

Since the low-rate data will be received at the onboard data handling interface with widely varying speeds and waveform spectra, this data will be processed by LSI-designed microcomputers. The processing will be comprised of buffering, formating plus data correlation, and simple forms of data compression, if desired. The low-rate data streams will be multiplexed into a single bit stream which is in turn combined with the high-data rate signals in the HRM.

Because of the immense data rates produced by some of the image sensors, it is necessary to use parallel processing techniques where possible. This can be implemented by array processors in which the mathematical operations

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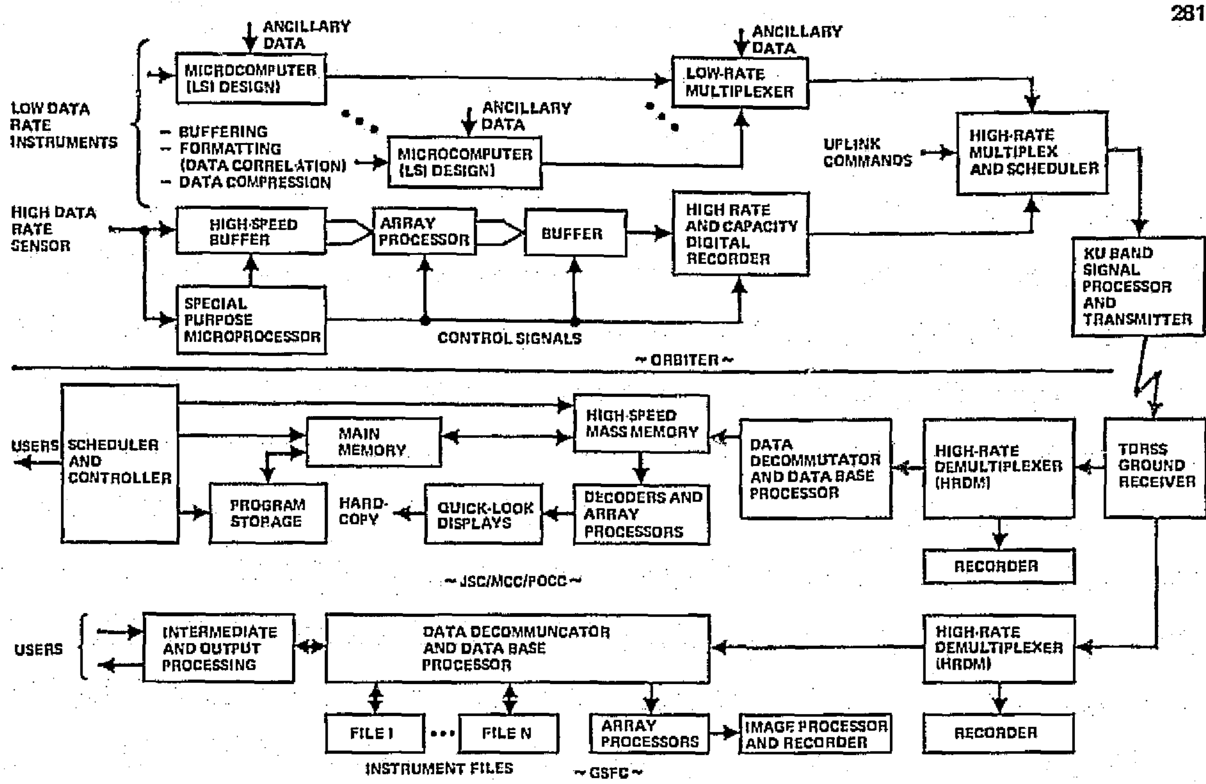

Figure II-3-23. Model of an Advanced End-to-End Data Handling Concept

are distributed throughout an array structure and the data is pipelined (at 1 to 4M words per second data rate) through the processor. Use of high-capacity, fast-access memory devices (e.g., magnetic bubbles) will be used as buffers between the high-rate data processing and the HRM. A scheduler will be included in the HRM to provide remote control of the downlink data.

Ground Data Processing

Since the same or related objects are often observed by two or more imaging sensors, it is desirable to correlate the data from these sensors. For this purpose, a data base processor will provide a method for correlating data with various formats and codes. Use of programmable read-only memories (PROM) or other forms of firmware will expedite the implementation of the data base processors. Ground use of the array processors will provide the inverse transformation of the image data, corresponding to the selected onboard data compression technique. Array processors may be used for both quick-look analysis and data quality evaluations.

Computer-assisted experiment scheduling will make use of stacked and associative memory (software) designs. Much of the scheduling of experiments for data acquisition may be carried out by stack or push-down memories (i.e., last-in/first-out). These memories store the addresses of programs for initiating the acquisition of data. Associative memories are used to facilitate the dynamic loading of new programs. When a change in a program takes place, the new program must be loaded into the main memory from a mass storage unit (e.g., disk). The addresses of the statements in this new program may be allocated with the help of an associative memory which designates the available space.

Database Processing

When data arrives from the decommutator, it is in a variety of formats, depending on the number of bits per sample, the time between samples, the number of samples to be viewed in each frame of a display, the number of samples per word of memory, and the information requested by the user. For example, the user may wish to see the correlation between two sequences of observations immediately following a solar flare: (1) the magnetic field along an earth meridian coplanar with the sun, and (2) the amount of cosmic ray particles in selected energy intervals. These data need to be placed into a data structure to facilitate the retrieval of the desired information and to facilitate correlating simultaneous data.

The database processor facilitates this task by placing all the data into a consistent data structure, in blocks covering a specified time interval. These data are then retrievable for output processing and/or correlation, even though the user requesting the data may not be familiar with the data's format and data structure.

Section 4
CONCLUSIONS AND RECOMMENDATIONS

Major observations related to the Spacelab payload data processing system requirements are shown on Figure II-4-1. The most overriding observation is that the high data rate and volume from a few Spacelab payloads are the most significant parameters driving ground data system design. A high percentage (greater than 90%) of Spacelab digital downlink data is image data. It is expected that image data rates will increase in the future to levels well above the 50 MBPS rate as science and technology activities in orbit are increased. Simultaneous video as well as high-rate science data will be required which will further increase transmission and handling requirements. In addition to these incompatibilities, other program issues are still unresolved, such as the fact that most users prefer real-time mission support from their home sites rather than at a centralized facility. Although many questions remain unanswered, considerable effort is being expended at this time by NASA and the payload community to solve these incompatibilities.

Conclusions from the ground data management analysis are shown on Figure II-4-2. Payload data processing requirements are expected to increase, but firm requirements are not yet available. Most users are very flexible - they claim, "This is what we would like, but tell us what we need to live within." Thus, data requirements are largely conceptual, and firm requirements will have to be evolved with payload hardware and software development. This is the paradox of the problem because integrated payload data requirements, which are not yet developed, are needed now in order to properly plan for the necessary ground data management system.

It has been stipulated by NASA that the Orbiter/TDRSS link will accommodate data rates up to 50 MBPS, and the subsystems to accomplish this rate are well defined. However, the ground processing systems are limited to early mission support requirements (~2 MBPS) and, therefore, these systems are

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- HIGH DATA RATE AND VOLUME REQUIREMENTS DRIVE GROUND DATA SYSTEM DESIGN
- HIGH PERCENTAGE OF DOWNLINK DATA IS IMAGE DATA (GREATER THAN 90 PERCENT)
- IMAGE DATA RATE REQUIREMENTS WILL INCREASE IN FUTURE (> 50 MBPS)
- SIMULTANEOUS VIDEO AS WELL AS HIGH RATE SCIENCE DATA WILL BE REQUIRED FOR INTERACTIVE CONTROL
- MOST PAYLOAD USERS PREFER TO PROVIDE REAL-TIME SUPPORT FROM HOME SITES
- PAYLOAD COMMUNITY AND NASA AWARE OF AND ACTING TO SOLVE PROBLEM

Figure II-4-1. Key Observations

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- USER DATA PROCESSING REQUIREMENTS ARE LOOSELY DEFINED
- PAYLOAD SENSOR OUTPUT AND DATA TRANSMISSION CHARACTERISTICS EXCEED CURRENT PROCESSING CAPABILITIES
- REAL TIME IMAGE PROCESSING IS A VALID REQUIREMENT
- USE OF CURRENT TECHNOLOGY ADVANCEMENTS ARE NECESSARY
- EFFECTIVE DATA PROCESSING REQUIRES END-TO-END SYSTEM PLANNING
- ONBOARD PROCESSING WILL BECOME A NECESSITY
- A STRONG USER/PROCESSOR UNION IS REQUIRED

Figure II-4-2. Ground Data Management Concluisons not as advanced as the TDRSS. The projected data rates greater than 50 MBPS will require improved onboard as well as ground processing systems. The ability to process image data in real time will be required to support interactive payload mission operations. In order to meet the higher data rate payload requirements, several proposals have been made ranging from more sophisticated data processing designs and computing complexes to the use of advanced technology data recording techniques. Data compression and filtering (selective processing) at the source will become necessary using microprocessors that reflect the rapid developments in integrated circuits and other specilized equipment. A strong union of the payload community and the data processing community is required to allow end-to-end system planning for an effective data processing system.

Overall recommendations for the ground data management analysis effort are summarized on Figure II-4-3. It is recommended that direct action be taken to develop a system for the simultaneous downlinking of video and digital data at a rate much greater than the current constraint of 2 MBPS. Methods to further reduce the processing of useless data should be encouraged such as the combination of onboard/ground interactive graphics combined with computer-assisted scheduling. In general, NASA should promote the future use of payload microcomputers (plus memories) rather than the use of an onboard centralized computer. Complete payload autonomy should be the goal of future planning.

A follow-on study is recommended that would develop integrated payload data processing requirements and user guidelines related to payload data management capabilities for use by both the payload and data processing communities. An investigation of new electronic technology advancements needs to be conducted for application within the payload data processing system. Improved computer designs, such as array processors, could be used to implement data compression techniques. In addition, high capacity/speed memory systems could be used as buffers (such as magnetic bubbles, bipolar semiconductors, or charged coupled devices) and as image storage devices (such as laser and electron beam systems).

DIRECT ACTION:

- DEVELOP SYSTEM FOR SIMULTANEOUS DOWNLINKING OF VIDEO AND HIGH RATE DIGITAL DATA
- ENCOURAGE TECHNIQUES TO REDUCE THE PROCESSING OF USELESS DATA
- PROMOTE PAYLOAD DATA AUTONOMY WITH ONBOARD MICRO-COMPUTERS FOR SCIENCE DATA PROCESSING

FOLLOW ON STUDIES:

- DEVELOP INTEGRATED PAYLOAD DATA PROCESSING REQUIREMENTS AND USER GUIDELINES
- INVESTIGATE USE OF NEW TECHNOLOGY
    - IMPROVED COMPUTER DESIGNS FOR DATA COMPRESSION
    - USE OF HIGH CAPACITY/SPEED MEMORY SYSTEMS AS BUFFERS AND IMAGE STORAGE DEVICES

Figure II-4-3. Ground Data Management Recommendations

Appendix A
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Appendix B
SPACELAB PAYLOADS GROUND DATA HANDLING REQUIREMENTS QUESTIONNAIRE

This appendix outlines a questionnaire used during this study as a checklist to gather ground data handling requirements via a documentation search and personal interviews.

I. PRELAUNCH

Are there any prelaunch activities (i. e., Level I, II, or III which require ground data handling operations? If so, is data handling support required in real time or near real time? Do any of the prelaunch tests require command and control from remote locations (e. g., POCC)?

II. LAUNCH, ASCENT, DESCENT, AND LANDING

Are there any data handling requirements needed during these mission phases? Are there any command and control operations required during these phases?

III. MISSION OPERATIONS

A. What method of downlinking the experiment housekeeping data is desired? What format, word size, and data rate is required?

B. Is real-or near-real-time scientific data required by the Spacelab experimenter? What method of downlinking is desirable? What will be the data format, word size, data rates, and repetition rates?

C. Are ground commands and/or two-way voice required for payload operation? What will be the format, word size, and uplink data rates? What is the desired command validation method?

D. Is (offline) temporary storage of scientific, housekeeping, command, and voice required? What is the estimated data volume, duration of storage, and repetition rates required for this storage?

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E. Is real- or near-real-time experiment data desired at a remote site (other than the POCC)? Where? What type of data (e.g., voice transcripts/tapes, scientific, and correlated engineering data) and how prompt is it required?

F. Are there any special computational techniques desired for use on the scientific data, near real-time? How often is the technique required? What is the quantity of data required? Computational speeds and output products?

G. What are the desired outputs from the POCC (e.g., computer-compatible tapes)?

H. What type of engineering or housekeeping data is desired to correlate with the experiment data (e.g., Orbiter trajectory, Spacelab attitude, instrument pointing angles, and mission timing)? Are there any special requirements for this data, viz, data accuracy and method of integrating the data with the scientific data?

I. Is archiving of the scientific data required? Define requirements, e.g., data form (computer compatible tapes, film, etc.), data volume, and duration of storage?

IV. POSTMISSION OPERATIONS

A. After the mission, are there any special processing techniques and data output formats required by the Spacelab experimenter(s), either for downlinked data or data returned via the Orbiter?

B. Are there any constraints on the postmission data volume and the time lines of the data delivered to the experimenters?

C. What type of housekeeping (or engineering) data is desired to correlate with the scientific data and are there any unique requirements for this data (e.g., data accuracy)?

D. Would a centralized data processing and analysis facility be useful to you, if provided?

E. What type of onboard data processing and operations would be useful to make the ground data handling process more cost effective?

Table C-1 (Page 1 of 6)

QUESTIONNAIRE RESULTS FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS
GROUND DATA HANDLING REQUIREMENTS – ON-ORBIT

Spacelab Science Discipline	Payload or Experiment	Information Source or Contact	Method and Form of Downlinking the Scientific Data	Method and Form of Downlinking Housekeeping Data	Method of Performing the Command & Control of Experiments	Temporary Storage Reqmts for the Downlinked Data	Remote Site Data Requirements (other than POCC)	Ap
1. Solar Physics	SO-01-S Dedicated Solar Sortie Mission	IBM "Spacelab User Interaction Study, Phase 2 Review," 1975.	13.2 MBPS digital output (photoheliograph). TV display for crew/ground display. 786 frames/orbit Digital data sent to ground via transmission link or to high-speed recorders.	Preselected engr parameters for failure detection–onboard or ground monitor.	Video display used for proper target selection and accurate instrument pointing. Sample full target images, saving only image changes of a prescribed magnitude. Devise convenient (onboard) sensor calibration techniques to improve the overall scientific data quality.	Wrap-around recording technique storing only current data history to reduce overall data volume–onboard or ground scheme.		Scien from elimi onbo proce Com and p dupli sing. Softw ment e.g., data data Prepl ducti data
2. Solar Physics	Dedicated Solar Physics Payload (e.g. Conventional and Imaging UV Spectrometer	Ball Bros. "Shuttle Era Grnd Data Processing Parametric Reqmts for the Discipline of Solar Physics," 1975.	Data rates range from 1.82 kBPS to 7.28 MBPS. Shuttle stipulated TLM format: 8 bits/word or integer multiple. Frame is an integer multiple of 16 bits. Max frame length: 8,192 bits. Nonbyte oriented data shall be organized into total lengths which are multiples of 8 bits The range of the average data rates for the cases studied are presented in Table 3-4.	Telemetry overhead and housekeeping data assumed to be 10% of the scientific data rate. The telemetry data is integrated with the scientific data.	A video uplink is proposed for processed images to be used by the payload specialist to aid in experiment operations. Data storage and turnaround time requirements may preclude the use of the 50 MBPS data link for control purposes and the 2 MBPS downlink may have to be used instead.	Storing data from 2 to 7 days; for experiments including the imaging UV spectrometer requires data storage capability of $>1x10^{12}$ bits (see Table 4-2).	Data from the TDRS ground station will be relayed to a preprocessor facility, then sent to a control facility and placed on computer-compatible tapes which are sent to an analysis facility. The functions designated for the preprocessing and control facilities can be considered to be included in the POCC (see Sec. 4.2 and 4.3) The analysis facility (which may be included in the POCC) will: (1) archive images with little scientific info and (2) process images of scientific value (see Sec 4.4.1)	Magn A da techr Sec. Refo scien whic raste (see Imag form to co lishe 4.5.3 Engi sion: look conv equa Meas ing: are f Visu sing: data Plot algo Stati

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Table C-1 (Page 1 of 6)

S FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS – MISSION OPERATIONS
GROUND DATA HANDLING REQUIREMENTS – ON-ORBIT

Form nking g Data	Method of Performing the Command & Control of Experiments	Temporary Storage Reqmts for the Downlinked Data	Remote Site Data Requirements (other than POCC)	Application of Special Computational Techniques	POCC Desired Outputs	Method and Type Correlated Housekeeping Data with Scientific Data	Data Storage Requirements at the POCC
er par- ilure board nitor.	Video display used for proper target selection and accurate instrument pointing. Sample full target images, saving only image changes of a prescribed magnitude. Devise convenient (onboard) sensor calibration techniques to improve the overall scientific data quality.	Wrap-around recording technique storing only current data history to reduce overall data volume-- onboard or ground scheme.		Scientific data sampler from high-rate output to eliminate useless data– onboard or ground processing. Comparison of current and past data to avoid duplicate data processing. Software editing of instrument data eliminating, e.g., instrument saturated data and out-of-tolerance data. Preplanned data range reduction due to evolved data system confidence.		Sample instrument line noise vehicle control/stability and hardware gimbal jitter. Sample payload sensor outputs to supplement target selection function.	
rhead ping to be entific data ith data.	A video uplink is proposed for processed images to be used by the payload specialist to aid in experiment operations. Data storage and turnaround time requirements may preclude the use of the 50 MBPS data link for control purposes and the 2 MBPS downlink may have to be used instead.	Storing data from 2 to 7 days; for experiments including the imaging UV spectrometer requires data storage capability of $>1\times10^{12}$ bits (see Table 4-2).	Data from the TDRS ground station will be relayed to a preprocessor facility, then sent to a control facility and placed on computer-compatible tapes which are sent to an analysis facility. The functions designated for the preprocessing and control facilities can be considered to be included in the POCC (see Sec. 4.2 and 4.3) The analysis facility (which may be included in the POCC) will: (1) archive images with little scientific info and (2) process images of scientific value (see Sec 4.4.1)	Magnitude decoding: A data compression technique (see Sec. 4.5.1). Reformatting: separating scientific data into arrays which correspond to a raster or spectral scan (see Sec 4.5.2). Image registrations: transformation of image points to correct for pre-established criteria (see Sec. 4.5.3). Engineering unit conversion: (1) conversion via look-up tables and (2) conversion via math equations. Measurement limit sensing: data outside limits are flagged. Visual display processing: Scale scientific data and drive displays. Plotting and histogram algorithms. Statistical computations.	The outputs from the preprocessing/control facilities will be (see Fig. 4.3 and Table 4-3) • Scientific data – High-quality visual display hard copies – Hard copies of CRT plots, histograms, and data summaries – High-speed printer tabulations – Image and tabular microfilm • Housekeeping data –Hard copies of CRT plots, histograms, and data summaries – High-speed printer tabulations – Tabular microfilm	Initially the integrated housekeeping/scientific data are time correlated and separated into two data records. Housekeeping data are converted to engring units prior to being recombined with the scientific data. The formatter combines the appropriate housekeeping data with the scientific data. There shall be real or near real-time limit checking and trend analyses performed on the housekeeping data for display and hard copy recording.	See Table 4-2.

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Table C-1 (Page 2 of 6)

QUESTIONNAIRE RESULTS FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS
GROUND DATA HANDLING REQUIREMENTS — ON-ORBIT

Spacelab Science Discipline	Payload or Experiment	Information Source or Contact	Method and Form of Downlinking the Scientific Data	Method and Form of Downlinking Housekeeping Data	Method of Performing the Command & Control of Experiments	Temporary Storage Reqmts for the Downlinked Data	Remote Site Data Requirements (other than POCC)	Applic Co T
1. Earth and Ocean Physics	Two key instruments are: imaging radar (synthetic aperature and the multispectral scanner (MSS; – the MSS was evaluated in the EO discipline study.	IBM "Ground Support Requirements for selected Shuttle Payloads," Aug 1975.	The synthetic aperature radar (SAR) is estimated to have an overall (i.e., 4 channels: 2 wavelengths/2 polarizations) data rate ranging from 150 to 250 MBPS (see Fig 4.5.10). The data vol for a 5-day mission (@R = 215 MBPS) is expected to range between 1.11×10^{13} and 3.10×10^{13} bits – for a duty cycle between 13 and 40 hr/mission (see Fig 4.5-10). The addition of onboard data processing is required to provide for downlinking for sensor data for quick-look analysis.	The housekeeping data will be multiplexed with the sensor data. The housekeeping data was estimated to contain 100 parameters. Sample at 5 times per sec – at approx 3 kBPS data rate.	This function will be handled by air/ground voice channel supplemented by sensor housekeeping data – processed real-timed and quick-look sensor data – processed near real-time (i.e., if the downlink is available).	Because of the high data rate the data may be stored onboard the Orbiter by means of special high density tapes (HDT) – the HDT are 12,500 ft long, 33,000 bit/in. packing density with 44 scientific data tracks. The mission will require more than 50 tapes.	None given.	For re ing da (1) de data c checki plottin vehicle tude, (status, ground For qu ing – compr
2. Earth and Ocean Physics	Synthetic Aperture Radar (SAR)	IBM "SAR Ground Data Processing Facility Definition Study," Jan 1976.	Use of sensor during the mission varies from 2.5 to 26 hours. The sensor data rate is approximated at 197 MBPS. The data volume is estimated to vary from 2.84×10^{12} to 29.6×10^{12} bits per mission.					

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PACELAB EXPERIMENTS – MISSION OPERATIONS
IENTS – ON-ORBIT

:	Remote Site Data Requirements (other than POCC)	Application of Special Computational Techniques	POCC Desired Outputs	Method and Type Correlated Housekeeping Data with Scientific Data	Data Storage Requirements at the POCC
1 by gh) – 0 /in. th 1 han	None given.	For real-time housekeeping data processing (1) decommutation and data conversion (2) limit checking, trending and plotting, (3) tabulate vehicle position and attitude, (4) establish sensor status, and (5) manage ground recorders. For quick-look processing – evaluation of data compressed radar images.	One of the major facets of the system is to provide a storage/retrieval capability of the scientific data for the experiment user.	Multiplexed with the scientific data.	Image data stored on HDT's may total between 50 and 200 tapes per mission. (See Fig. 4.5-10). This same data would require between 27,000 & 75,000 computer-compatible tapes (CCT) which are characterized as 2,400 feet long with 9 tracks at a packing density of 1,600 bit/in.

QUESTIONNAIRE RESULTS FOR THE GROUND DATA HANDLING OF SPACELAB
GROUND DATA HANDLING REQUIREMENTS – C

Spacelab Science Discipline	Payload or Experiment	Information Source or Contact	Method and Form of Downlinking the Scientific Data	Method and Form of Downlinking Housekeeping Data	Method of Performing the Command & Control of Experiments	Temporary Storage Reqmts for the Downlinked Data	Rer R (oth
1. Earth Observations	Earth Viewing Applications Laboratory (EVAL) – Payload Analyzed. Consists of 15 Sensors	GE "EVAL Concept Definitions/ Partial Spacelab Payload Technical Report," Sept 1976.	Assuming 11 sensors are on simultaneously, the data rates vary from 320 BPS to 120 MBPS. The data rate of the thematic mapper (TM) is estimated to be 120 MBPS. The sum of the data rates (excluding the TM) is approx. to be 636 kBPS. The TM sensor is estimated to generate 6×10^{11} bits/day. Although downlinking the data is feasible via the TDRSS at 50 MBPS, they feel the current EVAL requirements can be satisfied simply with the data returned by the Shuttle.			The standard equipment onboard the Spacelab can neither buffer nor directly handle the 120 MBPS. It is recommended that a very high-rate data recorder (VHRDR) be added onboard the Spacelab characterized by: • Data rate–120 MBPS • Packing density–20 kBPS • Record/playback speeds–150/50, 20 in./sec • Data Storage–2×10^{11} bits/reel	
2. Earth Observations	EO-06-S Seven-Band Multispectral Scanner (MSS)	IBM "Spacelab User Interaction Study, Phase 2 Review," May 1975.	The estimated data rate $\leq$ 240 MBPS. All data to be returned via the Shuttle and no on-orbit dump of the data is anticipated.		On-orbit control only with MSS displays and controls mounted within the Spacelab. Provide a televised telescopic view of the terrain being observed by the MSS. Use onboard processor providing data sampling technique to screen undesirable data.	Nominal flight duration of 7 days estimated. 30 observations intervals/mission with a 25% duty cycle for each hour of the mission. Data to be recorded onboard the Spacelab and will require approx 27 reels of tape for an estimated 2.7×10^{12} bits of MSS data.	

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Table C-1 (Page 3 of 6)

ESULTS FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS – MISSION OPERATIONS

GROUND DATA HANDLING REQUIREMENTS – ON-ORBIT

ethod and Form f Downlinking usekeeping Data	Method of Performing the Command & Control of Experiments	Temporary Storage Reqmts for the Downlinked Data	Remote Site Data Requirements (other than POCC)	Application of Special Computational Techniques	POCC Desired Outputs	Method and Type Correlated Housekeeping Data with Scientific Data	Data Storage Requirements at the POCC
		The standard equipment onboard the Spacelab can neither buffer nor directly handle the 120 MBPS. It is recommended that a very high-rate data recorder (VHRDR) be added onboard the Spacelab characterized by: • Data rate–120 MBPS • Packing density–20 kBPS • Record/playback speeds–150/50, 20 in./sec • Data Storage–2×10^{11} bits/reel			The current EVAL system was estimated to have 18 tapes (@ 2×10^{11} bits/reel) from the VHRDR and one tape from the standard Spacelab HDRR (@3.44x 10^9 bits/reel) plus film from the large format camera for each 6-day mission.		
	On-orbit control only with MSS displays and controls mounted within the Spacelab. Provide a televised telescopic view of the terrain being observed by the MSS. Use onboard processor providing data sampling technique to screen undesirable data.	Nominal flight duration of 7 days estimated. 30 observations intervals/mission with a 25% duty cycle for each hour of the mission. Data to be recorded onboard the Spacelab and will require approx 27 reels of tape for an estimated 2.7×10^{12} bits of MSS data.					

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QUESTIONNAIRE RESULTS FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS – MIS
GROUND DATA HANDLING REQUIREMENTS – ON-ORBIT

Spacelab Science Discipline	Payload or Experiment	Information Source or Contact	Method and Form of Downlinking the Scientific Data	Method and Form of Downlinking Housekeeping Data	Method of Performing the Command & Control of Experiments	Temporary Storage Reqmts for the Downlinked Data	Remote Site Data Requirements (other than POCC)	Application Comput Techni
1. Advanced Technology Laboratory (ATL) Mission	EO-3, EO-7/8, NV-1, NV-3, and EO-9 are Five of the High Data Rate Experiments (see Table 4.3-1, ref.)	Aeronutronic Ford "Langley Application Experiments Data Management System Study Final Report," Dec 1975.	The data format is byte (8 bits) or multibyte oriented; for format structure (see sec. 4.3.1.2). For data rate and data vol, see Table 4.3-35 Data rate reqmt in bits per sec max: EO-3 23 MBPS EO-7/8 426 MBPS each Min: <1 BPS Data volume is estimated to be 8.8×10^{11} bits per day.	Telemetry data will include Spacelab systems data, experiment equipment data, and Shuttle systems data. Overhead/housekeeping allocated data rates are given in Sec 4.3.2 to 4.3.7 per each experiment. Estimated data rates for info reqd at the POSC: • Air/ground voice at 32 kBPS • Analog or digital duplex voice (4 channels) POSC JSC • Telemetry: Spacelab – 5 kBPS Shuttle – 5 kBPS Expmt – 20 kBPS • Trajectory data at 5 kBPS • Command data at 8 kBPS • Video analog at 4.2 MHz bandwidth • Miscellaneous at 5 kBPS	LRC personnel at JSC to do the ATL commanding; limited command capability should exist at LRC for specialized experiment management and contingency situations – the commands will be routed via JSC. Air-to-ground voice capability for scientific operations at the POSC. The following data categories are required at the POSC: • Telemetry data (i.e., Spacelab/Shuttle systems data and experiment equipment data) • Trajectory data • Command • Video • Misc (i.e., command histories, data logs, status/verification messages, environmental data, simulation, training data, and consumable usage • Voice duplex links POSC/JSC	*Minimum input buffer reqmts for the data reformatting system (DRS) are given per experiment in Table 5.1-1. The data volume for 5 experiment groupings are given in Tables 5.2-1 thru 5.2-5 on a per mission basis – the data volume ranges from 4.24×10^9 to 2.12×10^{12} bits per mission. Approximately 88 reels (7,200 ft/reel) for a medium capacity recorder (at 10 k bits/in.) are required for the major portion of the experiments (on a mission basis)	DRS reqd to accept and reformat the recorded data for each experiment (located at LRC, JSC, or GSFC). A payload control center (PCC) reqd to remotely monitor and control the checkout sequence of the ATL at KSC (located at LRC or KSC). A payload operations support center (POSC) reqd to support missions operations (located at LRC or JSC).	The computa quirements (at the DRS) Tables 5.2-6 for each exp

*Buffer requirements in bytes (8 bits/word) Total = 851,044
Max: EO-3–814,464; EO-7/8–17,598
Mean (excluding EO-3/7/8) = 904
Std dev = 942

**2,400' tapes, 1,600 characters per inch

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of 6)
F SPACELAB EXPERIMENTS – MISSION OPERATIONS
EMENTS – ON-ORBIT

rage he ata	Remote Site Data Requirements (other than POCC)	Application of Special Computational Techniques	POCC Desired Outputs	Method and Type Correlated House keeping Data with Scientific Data	Data Storage Requirements at the POCC
it or the ng re iment e for oup- a u nission vol- n 2.12 88 eel) a- (at e re- najor x-	DRS reqd to accept and reformat the recorded data for each experiment (located at LRC, JSC, or GSFC). A payload control center (PCC) reqd to remotely monitor and control the checkout sequence of the ATL at KSC (located at LRC or KSC). A payload operations support center (POSC) reqd to support missions operations (located at LRC or JSC).	The computational requirements (to be done at the DRS) are given in Tables 5.2-6 and 5.2-7 for each experiment.	Decom of payload data streams (up to 2 MBPS). Deliver payload data greater than 2 MBPS in raw data format. Generation of computer-compatible tapes (CCT) for offsite scientific data processing. Provide hard copy of payload data less than 2 MBPS. Communication links between the POSC and JSC are reqd for voice TM, TV, and trajectory data.		The no. of CCTs** for each experiment is given in Table 5.2-8 – total of 16,584 CCTs (at 1,600 characters per in.).

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Table C-6 (Page 5 of 6)

QUESTIONNAIRE RESULTS FOR THE GROUND DATA HANDLING OF SPACELAB E
GROUND DATA HANDLING REQUIREMENTS – ON-

Spacelab Science Discipline	Payload or Experiment	Information Source or Contact	Method and Form of Downlinking the Scientific Data	Method and Form of Downlinking Housekeeping Data	Method of Performing the Command & Control of Experiments	Temporary Storage Reqmts for the Downlinked Data	Remote S Require (other tha
1. Astronomy	3m Large-Space Telescope 1.5m Cryogenically Cooled IR Telescope 30m IR Interferometer	IBM "Ground Support Requirements for Selected Shuttle Payloads," Aug 1975. (Sec 3)	The ground data handling system requirements for astronomy will be established by data volume as opposed to high data rates. Data dumps may occur at fixed intervals with dump durations ranging from a few sec to min at data rates approx 1 MBPS. The raw downlink data is placed on computer-compatible or high-density tapes.	The data rate attributed to the pointing operation of the Echelle spectrograph was estimated to be 20 kBPS (see Sec 3.2.3½.b) The housekeeping data rate for the Echelle spectrograph was considered a small fraction of the scientific data.	The major data system driver will be the command and control of the experiments and the diversity of sensor applications. A PI requires real-time control of the experiments. Real-time control requires accurate pointing of the telescopes and monitoring the housekeeping data from each instrument. The frequency of the pointing operation depends on the drift of the attitude control system.		The experi data proces will be don command f which is co with remov common in ment effec the spectru data.

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Table C-6 (Page 5 of 6)

ULTS FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS – MISSION OPERATIONS
GROUND DATA HANDLING REQUIREMENTS – ON-ORBIT

and Form nlinking eping Data	Method of Performing the Command & Control of Experiments	Temporary Storage Reqmts for the Downlinked Data	Remote Site Data Requirements (other than POCC)	Application of Special Computational Techniques	POCC Desired Outputs	Method and Type Correlated Housekeeping Data with Scientific Data	Data Storage Requirements at the POCC
rate attribu- e pointing e of the pectrograph ated to be (see ½.b) ekeeping for the pectro- s consid- all frac- e data.	The major data system driver will be the command and control of the experiments and the diversity of sensor applications. A PI requires real-time control of the experiments. Real-time control requires accurate pointing of the telescopes and monitoring the housekeeping data from each instrument. The frequency of the pointing operation depends on the drift of the attitude control system.		The experiment data processing will be done at a command facility which is concerned with removing common instrument effects from the spectrum data.	The data system will be required for instrument limit checking, trend analysis, plotting, and histogramming. Evaluate the functional performance of the calibration sources. Make sure the target source of radiation is a member of the class being studied. The processing is divided into two categories: analytical and experimental data processing. The analytical data processing will be used by the PI to make command & control decisions. Statistical algorithms are required to estimate the spectral SNRs. Preprocessing of the raw data consists of format and unit conversions image distortion and radiometric corrections, data filtering and data compression. Image processing will require spectra convolutions, fast Fourier transform and discrete Fourier transform algorithms and spectrum SNR calculations. Instr modeling algorithms will be used to monitor gradual instr degradation during the mission.	The output is CCTs of scientific data for use in scientific analyses.	Use mean and standard deviations of certain housekeeping data, e.g., spectrograph and vidicon temperatures, voltages, attitude reference data, etc. Quick-look checks should be made of information on the system pointing and in spectral- and spatial- (telescope spacing) sampled data. The telescope ephemeris data should be merged with the processed images which are placed on CCTs. The CCTs should contain a profile of the calibration spectrum.	The estimated data volume for the Echelle spectrograph will range from 10^{11} to 6×10^{13} bits per year (see Figure 3.2-12). The estimated data volume for the mid-IR Fourier spectrometer will range from 10^{13} to 10^{14} bits per year (see Fig. 3.3-5). The spatial interferometer will approach 0.5×10^{6} bits per mission (see Sec 3.4.7).

Table C-1 (Page 6 of 6)

QUESTIONNAIRE RESULTS FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS – M

GROUND DATA HANDLING REQUIREMENTS – ON-ORBIT

Spacelab Science Discipline	Payload or Experiment	Information Source or Contact	Method and Form of Downlinking the Scientific Data	Method and Form of Downlinking Housekeeping Data	Method of Performing the Command & Control of Experiments	Temporary Storage Reqmts for the Downlinked Data	Remote Site Data Requirements (other than POCC)	Applicat Com Te
1. Space Processing Applications	SP-14S Comprised of the following Sub-elements: (1) biological, (2) general purpose, (3) automated furnace, (4) automated levitation, (5) core, and (6) power and cooling.	NASA-MSFC "Spacelab Design Ref. Mission Analysis - Vol IV Mission C – Space Processing Applications"	There is no reqmt for analog, TV, or film data to be downlinked, uplinked, or stored The max data rate anticipated is 14.5 kBPS. The data vol for a 6-day mission is expected to be 3.035×10^9 bits (annotation and calibration data has not been included). The experiment data will be downlinked both in real-time and near real-time (i.e., recorder data playback). The transmission per day is estimated to be 56.8×10^6 bits and the rates may range from 23 kBPS to 1 MBPS from either recorder.	The housekeeping data rate is estimated to be less than 10 BPS.	Voice communications may be used to control the experiments.	The onboard recording rates and storage capabilities of both the Spacelab recorder (rate in: 1, 2, 4, 8, 16 & 32 MBPS and storage of 3.6×10^{10} bits) and the Orbiter's payload recorder (rate in: 25.5 to 1024 kBPS and storage of approx 3.4×10^9 bits total) are more than adequate for storing the data during the mission. For a more efficient design, the high recording rates of the onboard recorders may be adjusted to accommodate the lower data rates of the scientific data.		

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PACELAB EXPERIMENTS -- MISSION OPERATIONS
ENTS -- ON-ORBIT

	Remote Site Data Requirements (other than POCC)	Application of Special Computational Techniques	POCC Desired Outputs	Method and Type Correlated House-keeping Data with Scientific Data	Data Storage Requirements at the POCC
l- e er 10 r's 24 f bits n g t					

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Table C-2 (Page 1 of 5)

QUESTIONNAIRE RESULTS FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS – POSTMISSION OPERATIONS

Spacelab Science Discipline	Payload or Experiment	Information Source or Contact	POCC Special Processing and Desired Scientific Data Outputs	Anticipated Data Volume and Time Constraints	Method and Type of Correlated Housekeeping Data with Scientific Data	Desirability of a Central Processing Facility	Recommended Supplemental Onboard Data Processing/Operations
1. Solar Physics	SO-01-S Dedicated Solar Sortie Mission	IBM " Spacelab User Interaction Study Phase 2." Review, 1975.			Vehicle attitude data should be delivered as soon as possible either separately or consolidated with the scientific data.		Onboard navigation scheme for automatic control with ground updates for data collection. Radiation monitor added to eliminate degraded data sensitive to radiation effects. Instrument for detection/prediction of solar flares to reduce data volume and improve scientific return. Need for improved inflight calibration of instruments.

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Table C-2 (Page 2 of 5)

QUESTIONNAIRE RESULTS FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS – POSTMISSION OPERATIONS

Spacelab Science Discipline	Payload or Experiment	Information Source or Contact	POCC Special Processing and Desired Scientific Data Ouputs	Anticipated Data Volume and Time Constraints	Method and Type of Correlated Housekeeping Data with Scientific Data	Desirability of a Central Processing Facility	Recommended Supplemental Onboard Data Processing/Operations
1. Earth and Ocean Physics	Two key instruments are: imaging radar (synthetic aperture) and the MSS – the MSS was evaluated in the Earth Observations discipline study	IBM "Ground Support Requirements for Selected Shuttle Payloads," Aug 1975.	The system should provide the PI with the capability to observe small segments of the data. The scientific data processing was considered beyond the scope of the study. However, because of the large amount of image data to be processed it was suggested to implement a special programmable signal processor to perform (1) development of an index tape (2) develop selected data segments from the raw SAR data.				In order to provide any real-time downlinking of the image data some form of onboard data compression techniques must be provided.
2. Earth and Ocean Physics	Synthetic Aperture Radar	IBM "SAR Ground Data Processing Facility Definition Study," Jan 1976.	May require state-of-the-art technique for registering image with identifiable ground control point.	The anticipated turnaround time will range from 1 to 6 months. The processing time in sec may be computed on the basis of 16 hr/day at 22 days/month which yields a system throughput data rate range between 1.5 and 245 MBPS.			

Note: It was considered likely that the system would use high-density tapes to store the SAR raw data and that the major part of the scientific data processing would take place during the postmission phase.

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Table C-2 (Page 3 of 5)

QUESTIONNAIRE RESULTS FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS – POSTMISSION OPERATIONS

Spacelab Science Discipline	Payload or Experiment	Information Source or Contact	POCC Special Processing and Desired Scientific Data Outputs	Anticipated Data Volume and Time Constraints	Method and Type of Correlated Housekeeping Data with Scientific Data	Desirability of a Central Processing Facility	Recommended Supplemental Onboard Data Processing/Operations
1. Earth Observations	Earth Viewing Applications Laboratory (EVAL) – payload analyzed consists of 15 sensors	GE, "EVAL Concept Definitions/Partial Spacelab Payload Technical Report," Sept 1976.		The current EVAL system recommendation will require the processing of 18 VHRDR tapes of TM data and 1 high-rate data recorder tape containing the data from the other sensors.* The data are to be made available to the experimenters within 6 to 7 days of acquisition.			They recommend placing a VHRDR onboard the Spacelab (for specs see P 6-5). For later EVAL systems, they recommend placing an onboard experiment data support facility (OEDSF) in the Spacelab which would provide processing for quick-look and data compression techniques
2. Earth Observations	EO-06-S. Seven-Band Multispectral Scanner	IBM "Spacelab User Interaction Study Phase 2 Review," May 1975.					

*Based on a six-day mission

Table C-2 (Page 4 of 5)

QUESTIONNAIRE RESULTS FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS – POSTMISSION OPERATIONS

Spacelab Science Discipline	Payload or Experiment	Information Source or Contact	POCC Special Processing and Desired Scientific Data Outputs	Anticipated Data Volume and Time Constraints	Method and Type of Correlated Housekeeping Data with Scientific Data	Desirability of a Central Processing Facility	Recommended Supplemental Onboard Data Processing/Operations
1. Advanced Technology Laboratory Mission	EO-3, EO-7/8, NV-1, NV-3, and EO-9 are 5 of the data rate experiments	Aeronutronic Ford "Langley Application Experiments Data Management System Study Final Report," Dec 1975.	The DRS generates CCTs and associated tabulations of reformatted experiment data and delivers the data to the PI.	Based on a single mission approximately 7,000 CCTs (at 1,600 characters per in.) would be generated by 5 high data rate experiments (see Sec 4.1.1.4.2 P 4-9)	In addition to reformatting, the DRS will perform: • Data and system health monitoring • Sync loss and data quality checks • Screening capability • Experiment data annotation	The DRS will do the major part of the experiment processing and can be located at LRC, JSC, or GSFC	

Note: The data reformatting system (DRS) performs (1) ATL integration and checkout and (2) Postflight processing. The payload operations support center (POSC) performs the mission operations processing.

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Table C-2 (Page 5 of 5)

QUESTIONNAIRE RESULTS FOR THE GROUND DATA HANDLING OF SPACELAB EXPERIMENTS – POST MISSION OPERATIONS

Spacelab Science Discipline	Payload or Experiment	Information Source or Contact	POCC Special Processing and Desired Scientific Data Outputs	Anticipated Data Volume and Time Constraints	Method and Type of Correlated Housekeeping Data with Scientific Data	Desirability of a Central Processing Facility	Recommended Supplemental Onboard Data Processing/Operations
1. Astronomy	3m Large-Space Telescope 1.5m Cryogenically Cooled IR Telescope 30m IR Interferometer	IBM "Ground Support Reqmts for Selected Shuttle Payloads," Aug 1975. (Sec 3)	The most extensive mass data analysis is required for determining stellar abundances from the spectral line strengths. The following are examples of table look ups to be used for data evaluation • Ionization state and excitation level for each element • Make a table of stored image rectification functions to determine image manipulation required to align the received spectral lines with the calibration lines • Table of radiometric correction factors for the Fourier spectrometer data	See Mission Operations Table, C-1.		All the analytical data processing to be accomplished at a central facility (as opposed to the preprocessing of the data).	

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Appendix D

PAYLOAD OPERATIONS FLOW AND MALFUNCTION IMPACT ANALYSIS (TASK 2.2A)

Early in the contract period, MDAC was directed to conduct a brief systems analysis of the flow of payloads from the developer through integration and operations. The purpose of this analysis was to determine ways to minimize the complexity of the payload integration process, and specifically to minimize the risks of integration-related payload malfunctions that could bottleneck the flow or result in major compromises in launch availability, etc. The scope of the task effort was limited by MSFC direction to a brief overview of two areas of interest, malfunction analysis feasibility and lessons learned.

D.1 MALFUNCTION ANALYSIS FEASIBILITY

A study was conducted to determine the feasibility and practicality of using reliability analyses of planned payloads to predict the quantity and types of malfunctions which might occur during Levels III, II and I payload integration in order to identify preventive upstream measures. The results of the study indicate that sufficient data do not normally exist for experiment hardware to permit the reliability analysis to occur in time to implement preventive actions. In addition, the quantitative results of such analyses would be subject to interpretation and difficult to apply to planned operations, designs, and budgets. Alternate techniques were evaluated with the General Application of Previous Experience to payload design and operations planning appearing to be the most practical approach to both prevent and cope with malfunctions during any level of integration. Section 1 of this Appendix D documents the detailed results of the study.

D.2 LESSONS LEARNED

A brief review was conducted of previous program operations for experience factors and specific lessons learned to identify those with possible applicability to Spacelab payload operations flow planning so as to minimize the probability of flow-stopping problems. The review and analysis for applicability yielded many operational lessons learned which can be applied to the Spacelab program. They are summarized and discussed in Section 2 of this Appendix D along with a series of checklists developed to be responsive to the lessons learned at discrete milestones during payload flow.

Section 1
MALFUNCTION ANALYSIS FEASIBILITY

The Space Transportation System (STS) is expected to operate routinely, somewhat like a modern airline, with regular schedules to be maintained. Many of the payloads, however, have the potential for being nonroutine due to their inherent research and development nature, and could disrupt or bottlemeck the flow schedules if not carefully planned. This study was conceived to determine if reliability analysis techniques could be used to predict the number and type of integration-related malfunctions which might occur during Levels III, II, and I payload integration in order to identify preventive upstream measures. Objectives and general approach are summarized in Figure D-1.

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MALFUNCTION PREDICTION

OBJECTIVE - DETERMINE FEASIBILITY OF PREDICTING MALFUNCTIONS IN LEVEL III, II, AND I INTEGRATION AND SUBSEQUENT IDENTIFICATION OF UPSTREAM PREVENTIVE ACTIONS

APPROACH - THREE TECHNIQUES WERE EXPLORED

1. DESIGN AND STATISTICAL ANALYSIS OF PLANNED HARDWARE
2. STATISTICAL ANALYSIS OF PROBLEM DATA FROM PREVIOUS RELATED PROGRAMS
3. GENERAL APPLICATION OF PREVIOUS EXPERIENCE

REFERENCES - IP&MP INFO NOTE 5, DATED 6-16-76
IP&MP INFO NOTE 16, DATED 7-15-76

Figure D-1. Objectives and Approach

Initially, discussions were held with senior reliability analysis personnel to seek background information and guidance. It was found that the conduct of a malfunction analysis for a specific experiment or experiment group would require knowledge of the hardware design, the design of the Spacelab and Shuttle test equipment interfaces, and the operational usage in the various test levels. Further, it was expected that specific design reliability data would not normally be available at the required time to permit rigorous analysis leading to malfunction predictions for which preventive measures could be identified and implemented in a reasonable time frame. Were it not for this incompatibility in timing, such analysis would be feasible.

After initial discussions, three techniques were identified as possible candidates for predicting integration-related malfunctions:

A. Design and statistical analysis of planned experiment hardware.

B. Statistical analysis of problem data from previous related programs.

C. General application of previous experience to payload design and operations planning.

1.1 ANALYSIS OF PLANNED HARDWARE

A rigorous design analysis of the planned experiment hardware, coupled with available analysis data from Spacelab hardware systems, could yield reliability data for use in subsequent statistical probability analysis. The resulting malfunctions (and rates) could then be assessed for effect on the planned operations, thus completing the Failure Mode and Effects Analysis (FMEA). The following points, summarized in Figure D-2, should be noted for this technique.

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EXPERIMENT DESIGN DATA NECESSARY FOR THIS ANALYSIS NOT GENERALLY AVAILABLE AT THIS TIME

NUMERICAL RESULTS OF ANALYSIS MAY NOT BE DECISIVE AND WOULD REQUIRE EXERCISE OF CONSIDERABLE JUDGMENT IN APPLICATION

ANALYSIS DOES NOT INCLUDE EFFECTS OF POSSIBLE QUALITY PROBLEMS, OPERATOR ERROR, ETC.

ALTHOUGH NOT NOW POSSIBLE, THIS TECHNIQUE MAY LATER PROVE TO BE FEASIBLE BUT MAY NOT BE PRACTICAL DUE TO COSTS AND SUBJECTIVE NATURE OF ITS APPLICATION

Figure D-2. Design and Statistical Analysis of Planned Hardware

A. Experiment design data was not generally available during the study to the depth necessary to support sample analyses. The data needed includes schematics, component design and reliability data, hardware descriptions, operating requirements, time lines, interface data, development test data, etc. Further, it was not expected that this type data would normally be available for given payloads in time to permit timely implementation of analysis and of resultant corrective measures.

B. Analysis does not include effects of possible quality problems, operator or procedure errors, and the cascading effects of other hardware failures.

C. Numerical results of analysis may be difficult to interpret sufficiently to drive decision makers decisively.

D. This technique is expected to be feasible only if unusual efforts are exerted early in a payload program, but, it may not be practical due to costs and the subjective nature of its application. It was thought that consideration should be given to analysis of selected high-cost, complex, high-potential impact payloads as a means of further exploring feasibility while limiting expenditure of resources.

1.2 STATISTICAL ANALYSIS OF PREVIOUS EXPERIENCE

If data from previous payload integration experience, applicable to Spacelab, were available in sufficient quantity and consistency, a statistical analysis could produce numerically related classifications of malfunctions which could lead to numerical predictions of Spacelab integration malfunctions where hardware and/or operational equivalency can be reasonably ascertained. The following comments (summarized In Figure D-3 apply to this technique.

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- ALTHOUGH LOTS OF DATA APPEAR TO BE AVAILABLE, MOST OF THE DATA REVIEWED THUS FAR EXHIBIT INCONSISTENCIES AND CONFUSION FACTORS WHICH WOULD MAKE DIRECT APPLICATION TO SPACELAB DIFFICULT, E.G., SKYLAB DATA CLOUDED BY NONINTEGRATION-RELATED FAILURES
- RETRIEVAL OF DATA FROM EXPERIMENT SUPPLIERS MAY BE DIFFICULT AND COSTLY
- THIS APPROACH WOULD NOT LEAD TO SPECIFIC DESIGN SOLUTIONS, UNLIKE TECHNIQUE 1
- APPLICATION OF NUMERICAL RESULTS WOULD ALSO BE DIFFICULT

Figure D-3. Statistical Analysis of Previous Experience

A. A potentially large amount of data exists for review. The review (up to the point of task termination by MSFC) appeared to indicate some inconsistencies and confusion factors which would make for difficult applicability to Spacelab. For example, the most directly applicable data available, that from Skylab, is clouded by non-integration-related failures of many experiments.

B. Retrieval of raw data from experiment suppliers regarding malfunction cause and corrective actions was not attempted and could be difficult, time consuming, and costly.

C. Unlike technique number one (subsection 1.1), this technique would not lead to specific design solutions for expected problems but would provide clues and criteria for generic approaches to minimizing problems.

D. As with technique number one, numerical results of this technique could be quite subjective in application.

E. This technique appears to lack feasibility due to inconsistencies in data and lack of data directly applicable to Spacelab.

1.3 GENERAL APPLICATION OF PREVIOUS EXPERIENCE

A thorough review by qualified personnel of previous experience applicable to Spacelab could be accomplished similarly to technique number two, (subsection 1.2), but with less emphasis on numbers and more emphasis on experienced judgment. This technique could lead to predictions of generic types of malfunctions and problems and overall guidelines and criteria for minimizing them. The following points (summarized on Figure D-4) should be noted.

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- THIS TECHNIQUE WOULD BE SIMILAR TO NUMBER 2 BUT WITH LESS EMPHASIS ON NUMBERS AND MORE EMPHASIS ON EXPERIENCED JUDGMENT
- THIS APPROACH WOULD APPLY PREVIOUS OVERALL EXPERIENCE FACTORS (QUALITY, DESIGN, HUMAN ERROR, ETC.) TO THE SPACELAB INTEGRATION
- NUMERICAL PREDICTIONS NOT POSSIBLE, BUT RANKED CATEGORIES AND TREND PREDICTIONS COULD BE MADE
- THIS TECHNIQUE APPEARS FEASIBLE, PRACTICAL, AND LEAST EXPENSIVE
- USE OF HIGHLY QUALIFIED AND EXPERIENCED PERSONNEL TO PERFORM STUDY IS OF PARAMOUNT IMPORTANCE

Figure D-4. General Application of Previous Experience

A. This approach could apply the previous overall experience factors (quality, design, human error, test conditions, etc.) to the Spacelab integration effort.

B. Numerical predictions are not possible but ranked categories and trend predictions can be made.

C. This technique appears feasible, practical, and least expensive.

D. The use of experienced and qualified personnel to perform this study and its subsequent implementation is of paramount importance. This, if coupled with the use of similar personnel in the actual integration activities, should minimize the problems to be encountered and expedite solutions as necessary.

Section 2
LESSONS LEARNED

When fully operational, the STS will be required to support a high launch rate (up to 60 per year) in a regularly scheduled airline-type operation. To avoid bottlenecks in the payload integration flow it was thought that experience gained on past programs should be probed for possible applicability to Spacelab flow planning. Toward that end, a brief study was authorized by NASA to review, in concert with Spacelab flow plans, lessons learned on previous programs, and to compile those applicable to Spacelab. This section provides the results of that study.

Spacelab flow plans, as documented in many studies by NASA and contractors, were studied first in order to provide the background against which to evaluate applicability of previous program's lessons learned. The programs reviewed (see Figure D-5) included Skylab-OWS, Skylab-AM/MDA, Saturn/Apollo, Gemini, Mercury, and the AMES ASSESS Program. The types of data reviewed included lessons-learned documents from both NASA and contractors, technical reports of program operations, hardware rejection histories, and personal interviews with veteran program personnel.

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- PREVIOUS PROGRAMS REVIEWED FOR APPLICABLE EXPERIENCE
  - SKYLAB-OWS
  - SKYLAB-AM/MDA
  - GEMINI
  - MERCURY
  - AMES ASSESS
  - DELTA
  - SATURN/APOLLO
  - SPARTAN
- TYPES OF DATA REVIEWED
  - LESSONS LEARNED – MDAC
  - LESSONS LEARNED – NASA
  - TECHNICAL REPORTS OF PROGRAM OPERATIONS
  - HARDWARE REJECTION HISTORIES
  - PERSONAL INTERVIEWS OF KEY PROGRAM PERSONNEL

Figure D-5. Lessons Learned

Although a wide range of source conditions and discrete lessons learned were evidenced, there was a general similarity in some areas from program to program. For example, nearly all programs stressed the importance of early orientation and involvement of operational personnel in order to obtain their input to design and flow planning and to help them in preparations to perform their function. Safety planning was noted to be required in early phases of design and flow planning, not a tag-on afterthought requiring compromising solutions to problems. Another example of similarity is that nearly all programs recognized the need for a well planned, highly disciplined, and timely technique for both visibility and control of all program actions affecting hardware availability, configuration, problems and test requirements. Nearly all programs developed such techniques as their operations matured. Early planning and program direction provides momentum, usefulness, and efficiency to such techniques. Another example which appears to be of great significance to Spacelab is that nearly all previous programs underestimated the magnitude of effort required to plan, support, carry out, document, and control loose flight equipment (stowage items) both before and during flight. Spacelab will add the dimension of between flights to this troublesome area.

A list of those lessons learned, thought to be directly applicable to Spacelab payload integration flow planning, is contained in Table D-1. In addition, a series of checklists (Tables D-2 through D-7) has been compiled to be responsive to the lessons learned at discrete milestones in the payload hardware flow planning.

An account of problems encountered during checkout of the Skylab Orbital Workshop (OWS) at Huntington Beach was reviewed. The distribution of problems was of interest, indicating that only 11% of the total number of problems were due to hardware system malfunction and that 9% were mechanical fit problems. The remaining 80% were due to factors unrelated to hardware malfunctions. These were largely problems generated upstream in manufacturing, engineering, and documentation processes, and all found by the integration team. A breakdown of the problems can be seen in Table D-8.

Table D-1 (Page 1 of 3)

LESSONS LEARNED

1. Early orientation and involvement of all functional personnel is desirable to obtain their input and help them get prepared to do their job.

2. Flight crew involvement is a special application of item 1 to be emphasized.

3. Early identification of organizational relationships and specific individuals responsible for certain functions is mandatory to effect a smooth, efficient flow. This includes all NASA agencies and contractors.

4. A single, unified technique is necessary for both visibility and control of all program actions affecting hardware availability, configuration, problems, and test requirements. Should span all agencies and locations, and be automated.

5. A design journal should be kept to document the design evolution, reasons for changes, etc.

6. A concept should be considered in which all hardware is identified as falling into a subsystem with an assigned subsystem engineer manager who is responsible to the chief engineer and program manager for all program operations affecting subsystem hardware.

7. The hardware designer should be in-the-loop from design-to-manufacturing-to-test and checkout-to-operation.

8. A clearly identified document should be The Source for all test requirements for given systems.

9. Checkout requirements and provisions must be considered in the design phase. Built-in test points and access features should be provided for test and troubleshooting.

10. Early use should be made of mockups and development fixtures to foresee problems, train personnel, etc.

11. Safety planning and reviews must be built in from the start and not be a tag-on afterthought.

12. Uniformity of terminology, disciplines, and test procedures is desirable at all locations to more easily compare operations, use transferred personnel, etc.

13. Flight hardware should be mated and tested as a system as early as possible, even though subsequent operations such as shipping may require disassembly.

Table D-1 (Page 2 of 3)

LESSONS LEARNED

14. Include debugging of flight operations procedures in ground checkout operations.

15. Use identical GSE at different locations to enable procedure similarity, comparison of data, personnel familiarity, etc.

16. Bench testing of complex hardware should be of high fidelity, representing, to the extent possible, in-use conditions and interfaces. Use of other related flight hardware in test set-ups is desirable.

17. Less reliance on simulators and more emphasis on installed, all-up systems tests is highly desirable.

18. Discipline is necessary to force spares to be properly configured and rigorously tested to the same requirements as the primary flight units.

19. Guidelines to experiment developers are necessary for both technical planning and operational planning. (Reference Ames ASSESS Program Experimenter's Handbooks).

20. A central experiment repair, maintenance, and minor modification facility is necessary to avoid unnecessary hardware shipping, recycling, etc.

21. Loose equipment to support experiment checkout must be identified and tracked for each location (includes GFE, CFE, miscellaneous GSE, etc.).

22. Loose flight equipment (stowed in various ways) represents a huge problem needing special treatment for logistics, documentation methods, stowage location, scheduling, change traffic, etc (both before and during flight).

23. A fit check matrix should be planned for all critical interfaces of loose equipment, tools, etc.

24. Every previous program has experienced severe contamination problems. Contamination control, and personnel education therefore must start early (includes both internal and external systems).

25. Special attention and education for all personnel who handle hardware is required to preclude damage by providing tender-loving-care attitudes.

26. Modular packaging, access for planned operations and repairs, and vulnerability to damage should all be considered in designing for minimum operations problems.

27. Organization and operating disciplines are required to insure rapid feedback of problems to the appropriate personnel and to insure a rapid response and solution.

Table D-1 (Page 3 of 3)

LESSONS LEARNED

28. Commonality of design for connecting devices must be paired with consideration for the hazards of crossed-connections and appropriate choices made.

29. Formal test procedures and disciplines are inexpensive compared with the alternatives.

30. Every redundant path must be isolated and verified to know that it works.

31. Electromagnetic interference can be a big problem. Electromagnetic compatibility must be engineered.

Table D-2

PRELIMINARY LIST OF PAYLOAD FLOW CONSIDERATIONS — HARDWARE ATP

1. Provide Hardware Developer with Following:
   - Overall management plan
   - Overview and familiarization with STS
   - Detailed organizational interfaces
   - Operational requirements
   - Systems test requirements
   - Safety Criteria
   - Design criteria checklist
   - Detailed hardware interface requirements
   - Detailed flow plan
2. Provide all Affected Agencies and Contractors with:
   - Familiarization with planned payload and hardware
   - Specific organizational contacts
   - Schedule anticipated

Table D-3

PRELIMINARY LIST OF PAYLOAD FLOW CONSIDERATIONS — DESIGN DEVELOPMENT

1. PDR - Plan for Items Listed Below
2. CDR - Measure Performance to Items Below
3. Criteria to be Considered:
   - Design criteria checklist
   - Safety criteria
   - Systems test requirements
   - Operational requirements
   - Detail hardware interfaces
   - Identification of potentially hazardous operations
   - Identification of damage-vulnerable hardware
   - Malfunction and failure effects on operations
   - Identification of test equipment requirements throughout flow
   - Initiate and maintain test control plan
   - Initiate and maintain design and analysis journals (logs)
   - Initiate and maintain design requirements input to visibility system

Table D-4

PAYLOAD FLOW CONSIDERATIONS DURING FABRICATION

1. Initiate and Maintain Fabrication Status Input to Overall Visibility System
2. Close Follow-Up by Designers
   - Solve problems
   - Verify design intent satisfied
3. Initiate and Maintain Quality Control Plan
4. Initiate and Maintain Configuration Control Plan
   - Open items reported via visibility system

Table D-5

PAYLOAD FLOW CONSIDERATIONS DURING DEVELOPMENT TESTING

1. Initiate and Maintain Development Test Input to Overall Visibility System
2. Designers Responsible for Development Tests
3. Operators and Users Monitor Tests
   - Develop inputs for downstream operations
   - Training
4. Develop Inputs for Quality Control Plan
5. Monitor and Feedback Information for Configuration Control Plan

Table D-6

PAYLOAD FLOW CONSIDERATIONS DURING ACCEPTANCE TEST

1. Initiate and Maintain Test Status Input to Overall Visibility System
2. Designers Involved in Acceptance Test
3. Operators and Users Monitor (Perform) Tests
   - Develop inputs for downstream operations
   - Training
4. Review Development Test Problems and React, as Required
5. Maintain Quality Control Plan
   - Problem reporting via visibility system

Table D-7

PAYLOAD FLOW CONSIDERATIONS DURING LEVEL V & IV INTEGRATION

1. Initiate and Maintain Integration Status Input to Visibility System
2. Maintain Quality Control Plan
   - Problem reporting via visibility system
3. Review Acceptance Test Problems and React, as Required
4. Operators and Users Monitor Tests
5. Maintain Configuration Control
   - Report via visibility system
6. Hardware Test
   - Fit check all interfaces (real, if possible)
     — High-fidelity templates, fixtures, etc., if required
   - Exercise all functional paths
   - Identify all systems and subsystems and treat individually and collectively
     — Identify complex interfaces and test realistically, e.g., composite data-check with RAU or high-fidelity simulator, etc.
   - Exercise all mechanical devices possible in 1-g environment
     — Provide 1-g adaptors and supports for selected payloads
   - End-to-end calibration verifications
   - Verify redundancy elements
   - Verify data channelization
   - Include all loose and stowed flight hardware
   - Consider system proof tests

Table D-8

OWS PROBLEM DISTRIBUTION

- OWS No. 1 Experiment Checkout Problem Summary:

  19% - Improper identification

  33% - Test procedure deficiencies

  28% - Minor discrepancies (loose, scratched, damaged)

  9% - Mechanical fit or interface

  11% - Hardware system malfunction

  100%