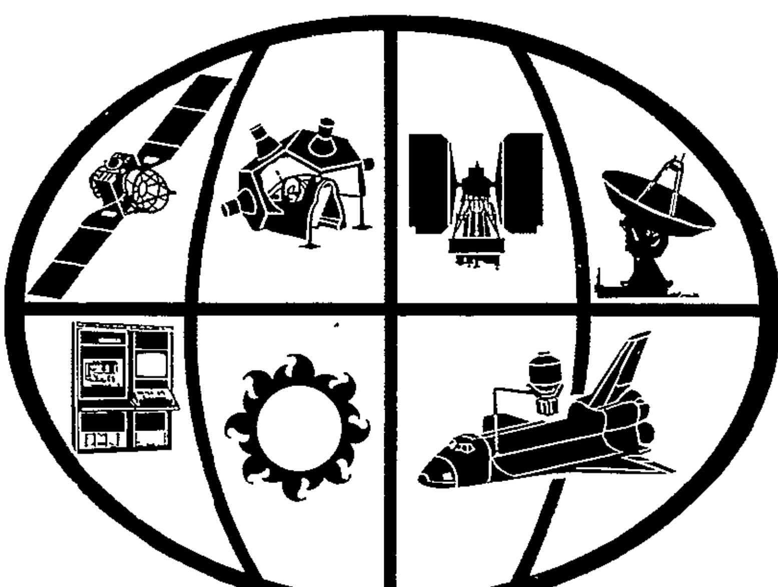
76SDS4269
30 SEPTEMBER 1976

EVAL SYSTEM CONCEPT DEFINITION

PARTIAL SPACELAB PAYLOAD

TECHNICAL REPORT



space division

CONTRACT NAS 5-24022
AMENDMENT NO. 152

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SPACE DIVISION
Valley Forge Space Center
P O Box 8555 • Philadelphia, Penna 19101

PREFACE

The experiments and missions* described in this report, and the primary sensors required for their successful accomplishment, have been extracted from a recommended list prepared by the EVAL Steering Committee and discipline Working Groups. These earth-viewing experiments generally embody the characteristics of near term monetary value and human impact; and the required sensors have been judged to be available for a 1981 flight. The actual selection and mix of the experiments and sensors from this list was performed under the guidelines of creating a cost-effective payload.

The EVAL Steering Committee is comprised of the following individuals:

D. McConnell	NASA Headquarters	Chairman
H. Plotkin	NASA GSFC	Executive Secretary and Study Scientist
F. Flatow	NASA GSFC	Study Manager
J. Raper	NASA LARC	Environmental Quality
C. Laughlin	NASA GSFC	Weather and Climate
R. Moke	NASA JSC	Earth Resources
J. McGoogan	NASA WFC	Earth and Ocean Dynamics
E. Wolff	NASA GSFC	Communication and Navigation

*The terms "experiment" and "mission" are used somewhat interchangeably within this report to describe the various applications associated with this payload. In general, the distinction is on the degree of operationality of the application - those applications performing an operational function or end-to-end systems test are considered missions; while applications involved with sensor or technique development are identified as experiments.

ACKNOWLEDGEMENTS

Appreciation is expressed to the team of NASA/MSFC individuals led by C. Quantock, R. Valentine and R. Davies for their evaluation of, and contribution to, the Earth Viewing Shuttle/Spacelab payload described within this report. Inputs in the areas of payload weight and balance, power and thermal, crew allocations, and cloud cover have significantly enhanced the content of this study.

Previously published reports relating to this payload analysis include the following:

- EVAL Mission Requirements, General Electric, 76SDS4227, 7 May 1976
- Space Shuttle Earth Observation Sensors Pointing and Stability Requirements Study, General Electric, 76SDS4228, 7 May 1976
- Earth Viewing Applications Laboratory Instrument Catalog, General Electric, 25 May 1976

TABLE OF CONTENTS

Section		Page
1	INTRODUCTION	1-1
2	ACCOMMODATIONS	2-1
	2.1 Orbiter	2-1
	2.1.1 Orbital Position Determination	2-1
	2.1.2 Pointing and Attitude Control	2-1
	2.1.3 Crew Support	2-3
	2.2 Spacelab	2-3
	2.2.1 Pressurized Core Module	2-3
	2.2.2 Pallets	2-4
	2.3 SEOPS	2-9
3	PAYLOAD DESCRIPTION	3-1
	3.1 Missions	3-2
	3.2 Synergistic Payload Benefits	3-4
	3.3 Equipment Commonality	3-5
	3.4 EVAL Payload	3-7
4	PHYSICAL ACCOMMODATIONS	4-1
	4.1 Payload Weights and Locations	4-1
	4.2 Payload Center of Gravity	4-4
	4.3 Pressurized Volume	4-5
	4.4 Field of View	4-9
	4.5 Interfaces	4-11
5	OPERATIONS	5-1
	5.1 Experiment Observations	5-1
	5.2 Mission Timelines	5-18
	5.3 Crew Requirements	5-20
6	SYSTEM REQUIREMENTS AND ACCOMMODATIONS	6-1
	6.1 Data Management	6-1
	6.2 Pointing and Stability	6-10
	6.2.1 Earth Resources Sensors	6-10
	6.2.2 Solar Observing Sensors	6-11
	6.2.3 Sea State Sensors	6-14
	6.2.4 Cloud Climatology Sensors	6-16

TABLE OF CONTENTS (Cont'd)

Section		Page
	6.3 Power Analysis	6-16
	6.4 Thermal Analysis	6-18
	6.5 Vibroacoustic Test Plan	6-21
7	CONCLUSIONS	7-1

LIST OF ILLUSTRATIONS

Figure		Page
1-1	Spacelab Elements	1-1
1-2	SEOPS Bridge Configuration	1-2
1-3	Typical SEOPS Bridge Installation With Spacelab	1-2
2-1	Core Module Cutaway	2-4
2-2	Spacelab Pallet	2-5
2-3	Pallet Structure	2-5
2-4	Power Distribution Scheme, Module/Pallet Configurations (Combines Mission Independent and Mission Dependent Equipment)	2-6
2-5	Cold Plate Mounting	2-7
2-6	Limiting Fields of View	2-8
2-7	Orbiter Field of View-Side	2-8
2-8	SEOPS Bridge Configuration	2-9
3-1	The Four Roles for Sortie D Flights	3-1
3-2	EVAL/ESA Payload	3-8
4-1	EVAL Configuration	4-4
4-2	Payload CG Along X-Axis	4-7
4-3	Payload CG Along Y-Axis	4-7
4-4	Payload CG Along Z-Axis	4-8
4-5	EVAL Expt. Schematic	4-11
4-6	EVAL Experiment Schematic	4-13
4-7	Payload System Schematic	4-17
5-1	EVAL Mission Ground Trace	5-3
5-2	Ocean Waves	5-6
5-3	Ocean Currents	5-7
5-4	Sea Surface Temperature	5-8
5-5	Ozone Mapping	5-9
5-6	Timber Inventory	5-10
5-7	Mineral Exploration	5-11
5-8	Minerals - Non-CONUS	5-12
5-9	Urban and Regional Planning	5-13
5-10	Millimeter Wave	5-14
5-11	Electromagnetic Environment	5-15
5-12	Sample Mission Timeline	5-19
5-13	Crew Timeline	5-21
6-1	Ku-Band Antenna Locations	6-3
6-2	Tape Changing Logic	6-5
6-3	Data Systems	6-6

LIST OF ILLUSTRATIONS (Cont'd)

Figure		Page
6-4	Expanded Data Systems	6-9
6-5	Sample Power Profile	6-17
6-6	Beta Angle History	6-19
6-7	Heat Dissipating Capability	6-19
6-8	Orbital Heat Rejection Capability	6-20

LIST OF TABLES

Table		Page
2-1	Expected On-Orbit Navigation Accuracies (3 Sigma) for 100 Nautical Miles (185 km) Orbital Altitude	2-2
3-1	Sensor Commonality	3-6
3-2	Payload Description	3-9
3-3	Payload Support Requirements	3-10
4-1	Payload and Payload Chargeable Weights	4-2
4-2	Spacelab and SEOPS Weights	4-3
4-3	Payload Center of Gravity	4-6
4-4	Pressurized Equipment	4-8
4-5	Experiment Field of View Assessment	4-10
5-1	Target Requirements	5-2
5-2	CONUS Target Opportunities/Selections	5-4
5-3	Non-CONUS Target Opportunities/Selections	5-4
5-4	Probabilities for Cloud Conditions	5-16
5-5	Probability of Mission Success	5-17
6-1	Sensor Commonality	6-2
6-2	TDRSS Contact Time (Assuming the Availability of Either of Two TDRS)	6-4
6-3	Tape Usage	6-7
6-4	Mission Power/Energy Requirements	6-18

SECTION 1

INTRODUCTION

SECTION 1

INTRODUCTION

This report addresses the preliminary design of an earth-viewing Spacelab payload, with accommodations shared by both NASA and ESA. Mission parameters for this flight include a launch date of September 1981, an inclination of 57°, and an orbital altitude of 325 km. A seven-day mission is planned. The NASA portion of this payload is assumed to be assigned to the EVAL (Earth Viewing Applications Laboratory) program. The ESA complement is designated as a multiuser payload, and has been coordinated by NASA/MSFC. Under this division of responsibility, GE has been responsible for the intra-EVAL payload compatibility and Spacelab accommodation; while MSFC has been responsible for assuring compatibility between the total payload complements (EVAL and ESA) and working out accommodations between the total payload and Spacelab/Shuttle.

The basic payload carrier associated with this flight consists of the Spacelab configuration defined as the short module plus 9-meter pallet, complemented by a SEOPS (Standard Earth Observation Package for Shuttle). The Spacelab configuration is shown in Figure 1-1.

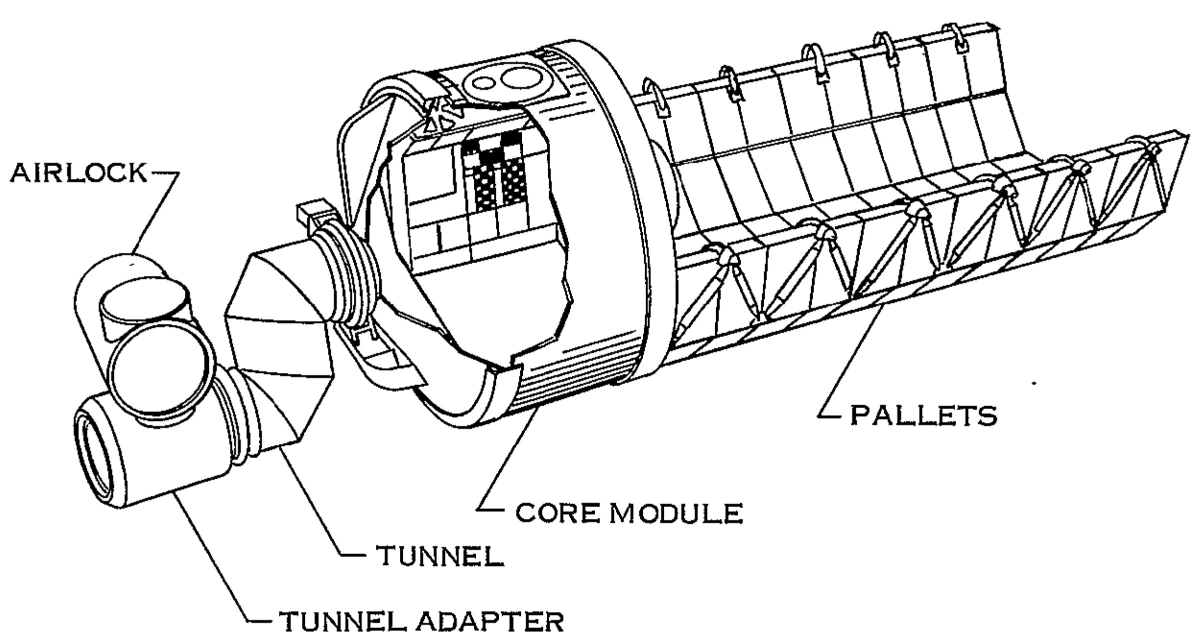


Figure 1-1. Spacelab Elements

A SEOPS bridge configuration, pictured in Figure 1-2, is used around the Spacelab transfer tunnel. The SEOPS is a modular system of structures and subsystems which accommodates various sensors and interfaces with Shuttle in a nearly autonomous manner. The combined Spacelab plus SEOPS configuration considered for this payload is illustrated in Figure 1-3.

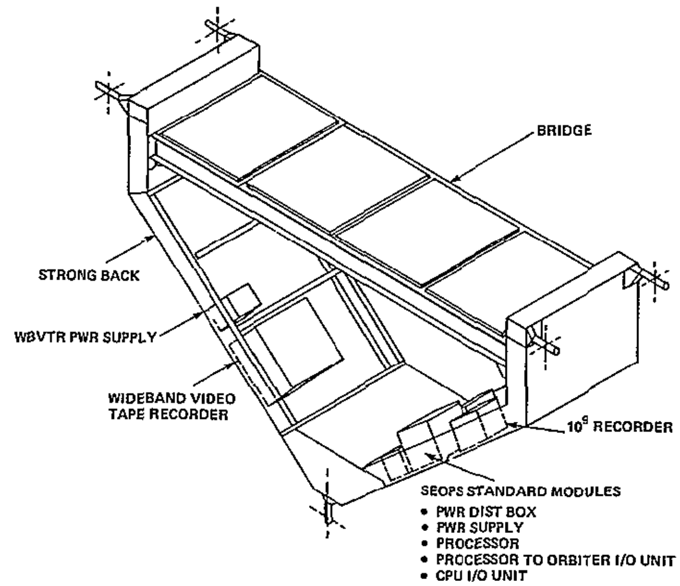


Figure 1-2. SEOPS Bridge Configuration

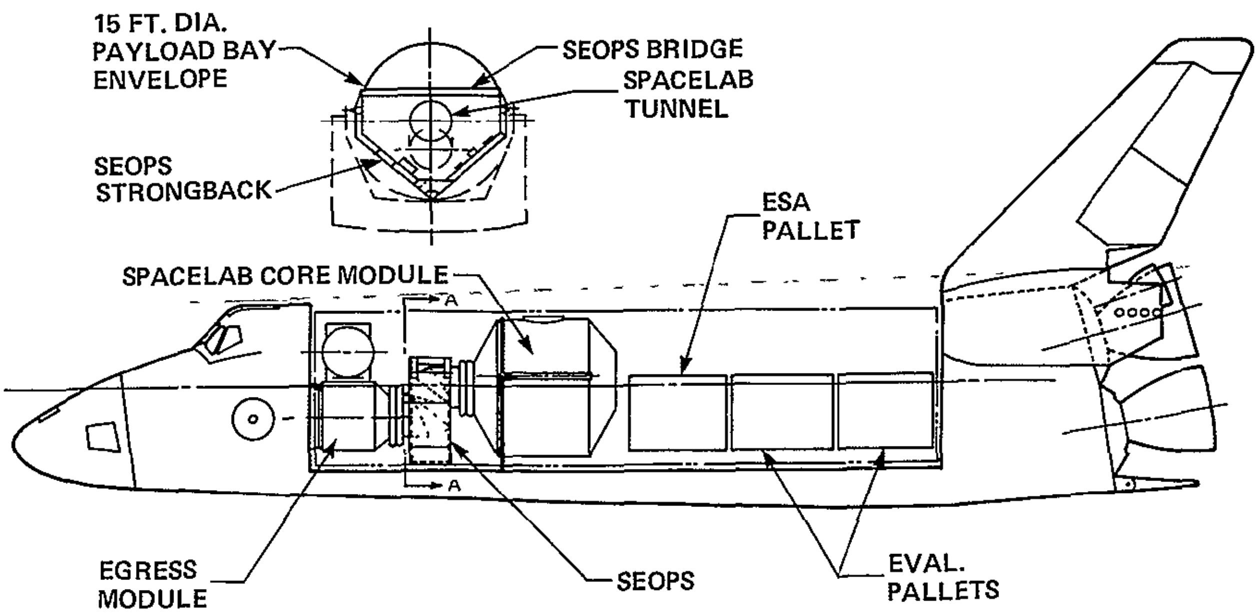


Figure 1-3. Typical SEOPS Bridge Installation with Spacelab

SECTION 2

ACCOMMODATIONS

SECTION 2
ACCOMMODATIONS

Accommodations for EVAL experiments will be provided by elements of Spacelab, SEOPS, and, to some extent, the Shuttle Orbiter. Details of the pertinent capabilities provided by these systems are described in the following paragraphs.

2.1 ORBITER

From an experimental standpoint the Orbiter provides orbital position and location, gross pointing and attitude control, and crew support.

2.1.1 ORBITAL POSITION DETERMINATION

Knowledge of the orbital position of the Orbiter/Spacelab/experiment at any time is dependent on the elapsed time since the last tracking pass and the tracking system used. The on-orbit navigation accuracies, using the Spacecraft Tracking and Data Network (STDN) and the Tracking and Data Relay Satellite (TDRS) system are given in Table 2-1 for a 185 km (100 nm) altitude case. (This is the only information presently available). These expected accuracies will obviously be somewhat degraded for the 325 km (200 nm) orbit considered for this payload.

2.1.2 POINTING AND ATTITUDE CONTROL

The Shuttle Orbiter has the capability of achieving and maintaining any desired space or earth referenced attitude with respect to either the Orbiter navigation base or a payload provided and mounted sensor. The pointing accuracy, however, is a function of the error sources associated with the characteristics of the particular attitude sensor, the type of control system, and the Orbiter flexure.

Table 2-1. Expected On-Orbit Navigation Accuracies (3 Sigma) for 100 Nautical Miles (185 km) Orbital Altitude

Navigation System	Position, Feet (Meters)				Velocity, Feet/Sec (Meters/Sec)			
	Altitude	Down-track	Cross-track	Root Sum Square	Altitude	Down-track	Cross-track	Root Sum Square
STDN								
After last tracking pass	440 (130)	370 (110)	430 (130)	730 (220)	3.9 (1.2)	0.5 (0.15)	2.0 (0.6)	4.4 (1.3)
After one revolution	470 (150)	850 (260)	430 (130)	1030 (315)	4.3 (1.3)	0.5 (0.15)	2.0 (0.6)	4.8 (1.4)
TDRS								
After last tracking pass	300 (90)	1400 (430)	1520 (460)	2070 (630)	1.6 (0.5)	0.35 (0.11)	0.5 (0.15)	1.7 (0.5)
After one revolution	300 (90)	2010 (610)	1520 (460)	2400 (740)	2.4 (0.7)	0.3 (0.1)	0.5 (0.15)	2.5 (0.7)

The Orbiter Inertial Measurement Unit (IMU), located in the Orbiter cabin, is used to supply inertial attitude reference signals; and, in conjunction with the onboard navigation system, can provide a pointing capability of the navigation base accurate to within $\pm 0.5^{\circ}$ for earth-viewing missions. This pointing accuracy can degrade to approximately $\pm 2.0^{\circ}$ for payloads located in the aft bay due to structural flexure of the Shuttle vehicle, payload structural and mounting misalignments, and calibration errors with respect to the navigation base. In order to provide greater accuracy in payload pointing, the Orbiter is capable of accepting error signals from a more accurate payload supplied and mounted sensor. In this case, the Orbiter is capable of maintaining a specified attitude to within ± 0.1 deg/axis by using the full capability of the Reaction Control System (RCS) jets, and a stability rate of ± 0.01 deg/sec/axis.

2.1.3 CREW SUPPORT

The Orbiter crew consists of the commander and pilot to operate and manage the Orbiter, a mission specialist, and one or more payload specialists. While both the commander and pilot will be primarily occupied with operating the Orbiter, they may support/perform specific payload operations if appropriate, and at the discretion of the individual experiment sponsors. The mission specialist will be responsible for the coordination of overall Orbiter operations in the areas of flight planning, consumable usage and other activities affecting payload operations. At the discretion of the individual experiment sponsors he may also assist in the experiment operations, and may in specific cases serve as the payload specialist. The payload specialist(s) will be responsible for the attainment of experiment objectives (these individuals may be the actual experimenter or a designated representative); including the operation of experiment equipment.

2.2 SPACELAB

Spacelab as utilized by EVAL consists of two basic elements - a pressurized core module and unpressurized pallets. The module provides a controlled pressurized environment for the users and their equipment, and supplies basic services such as power, thermal control, and data management together with certain basic support equipment such as standard racks, scientific airlocks, etc., which may be used as required. The pallet is an unpressurized platform to which instruments such as cameras and antennas that require direct exposure to space may be mounted. The pallet provides some basic services, such as power conditioning and distribution, data distribution, and thermal control.

2.2.1 PRESSURIZED CORE MODULE

The module is a cylindrical pressure shell measuring 4060 mm in diameter and 4209.3 mm in length. It contains subsystem equipment for Spacelab, crew work space, rack volume for experiment installation, and an optical window on the top for mounting small instruments which may require manned operation. Figure 2-1 depicts cutaway sections of the core module. The subsystem control station and workbench are located in the forward section, with 7.6 m^3 space available for experiment equipment, including all rack space and ceiling storage compartment. Two double and two single racks (19-inch) are available in the core module and will be shared between the EVAL and ESA payload.

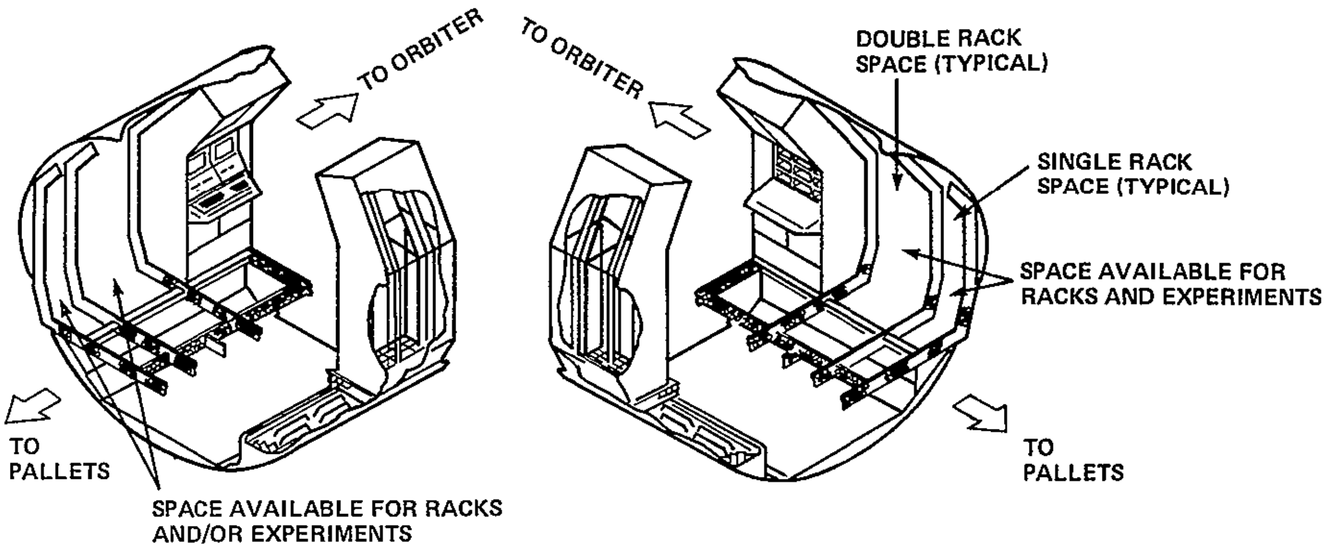


Figure 2-1. Core Module Cutaway

2.2.2 PALLETS

Basically, the Spacelab pallet is an unpressurized platform to which instruments that require direct exposure to space may be mounted. The U-shaped pallet, shown in Figure 2-2, is approximately 2.9 meters long and 4.0 meters in width; and provides basic services such as power conditioning and distribution, data distribution, and thermal control. The pallet structure for accommodating experiment equipment, Figure 2-3, provides mounting support for the experiments either directly on skin panels or through specific hardpoints for better dispersion of concentrated loads. The inner side and floor panels can support loads of 50 kg/m^2, whereas the outer panels can support 10 kg/m^2. If experiment equipment exceeds the panel load capability, it can be mounted only on standard equipment hard points. Provisions for 24 hard points are located on the inner surface at the intersection of the frames and longitudinal members, as shown in Figure 2-3. Each hard point provides a dynamic load-carrying capability of: X_p = 28,547N, Y_p = 18,443N, and Z_p = 75,046N. The overall payload carrying capability of the pallet is 1100 kg/m (uniformly distributed over the pallet) with a CG

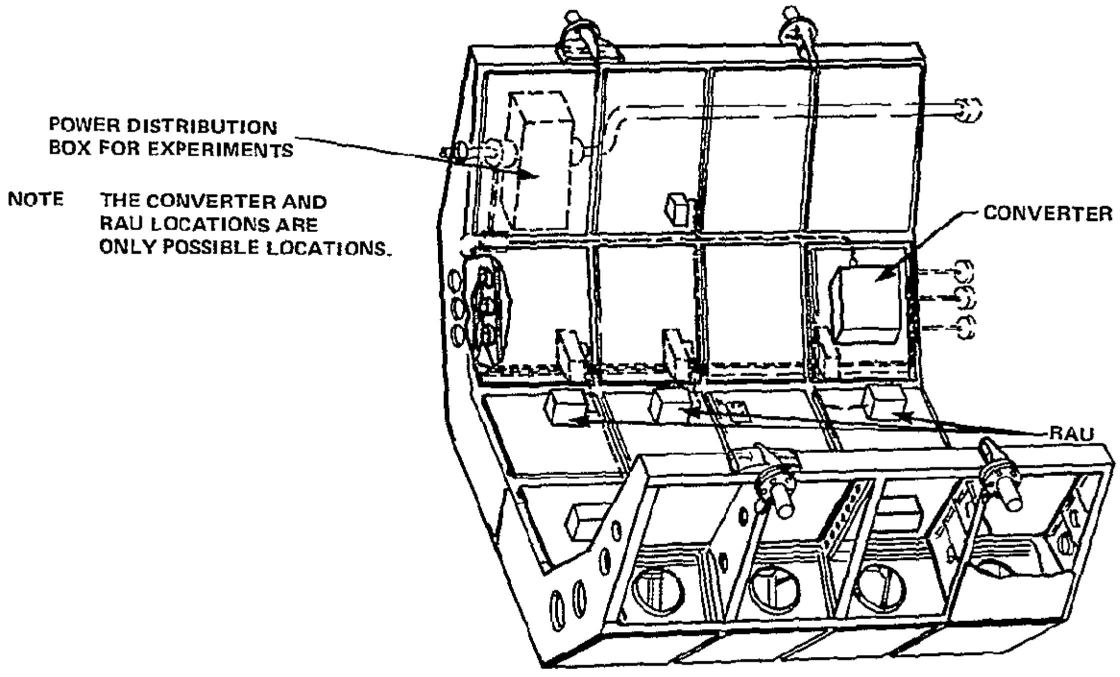


Figure 2-2. Spacelab Pallet

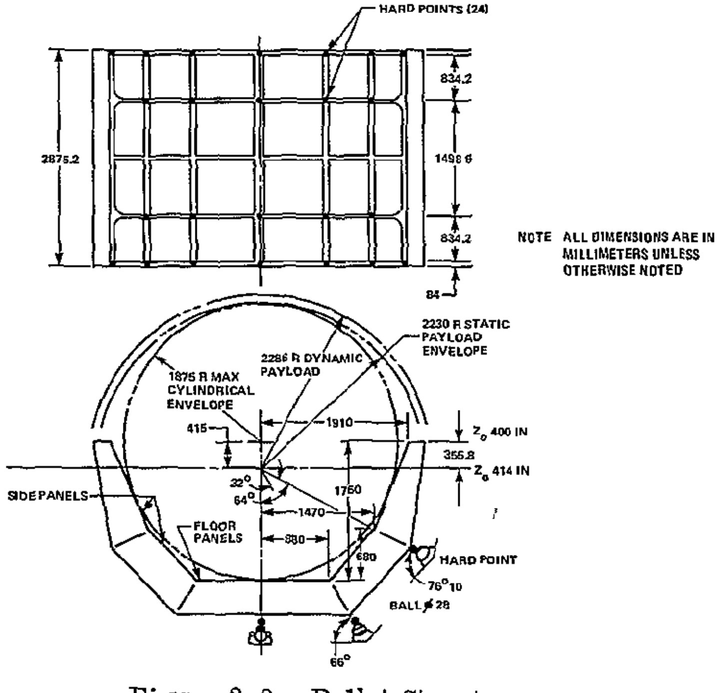


Figure 2-3. Pallet Structure

limitation between 25 mm above the pallet floor line and the Orbiter bay horizontal centerline. From an area and volume standpoint a single pallet provides approximately 17 m^2 of mounting area and 33 m^3 volume above the floor. The pallet area and volume available for EVAL is therefore 34 m^2 and 66 m^3 respectively based on the assignment of two pallets.

The Spacelab Electrical Power and Distribution Subsystem (EPDS) receives its primary power from the Orbiter: 7 kW average and 12 kW peak are delivered during orbital operations. The power available for experiments is the resultant after mission dependent and mission independent equipment power consumption is subtracted from that supplied by the Orbiter. For the short module plus three pallet Spacelab configuration used for this payload, maximums of 3.4 kW average and 7.4 kW peak exist for the payload. The total energy available to the payload is 369 kWh. The power bus system running through the module and pallets provides the wiring for primary dc (28 Vdc nominal) and 115/200 Vac at 400 Hz. On the pallet, payload equipment is hardwired into the distribution bus. Figure 2-4 illustrates the power distribution scheme for the core module plus three pallets Spacelab configuration.

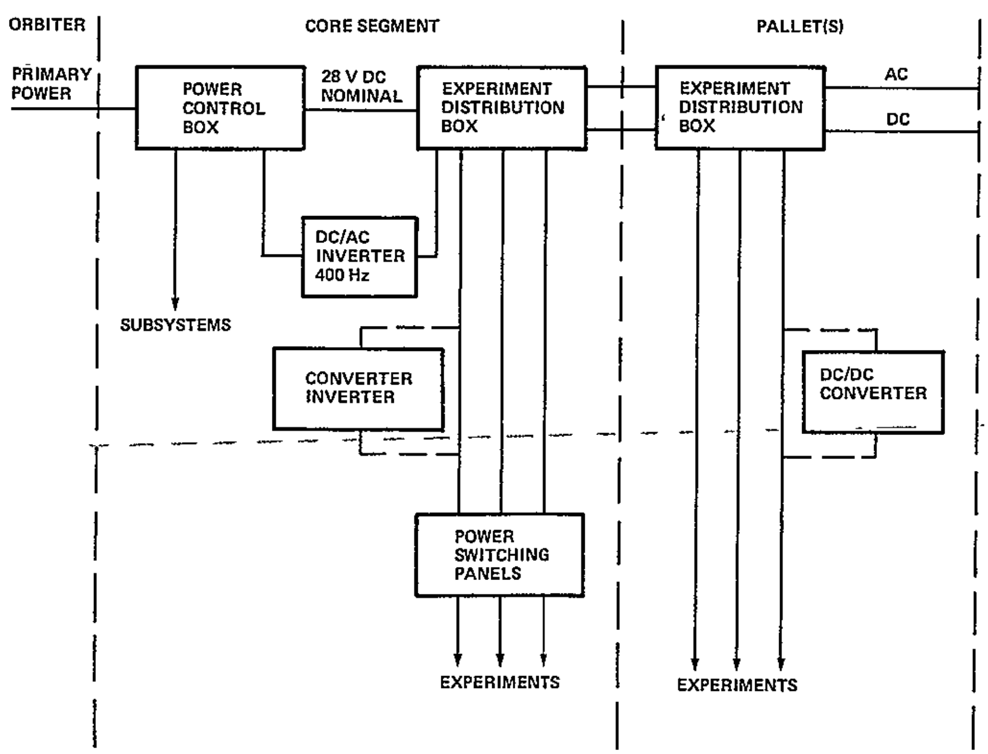


Figure 2-4. Power Distribution Scheme, Module/Pallet Configurations (Combines Mission Independent and Mission Dependent Equipment)

Environmental control for experiments on the pallet is provided by cooling loops and the use of cold plates and thermal capacitors. Eight cold plates (capability 24-40°C) and up to four thermal capacitors are available to dissipate peak heat loads. The maximum capability per cold plate is 1 kW. Figure 2-5 shows the characteristics and location of these devices. Air cooling loops control the module atmosphere between 18-27°C. Experiment racks are cooled (22-40°C) by the avionics air cooling loop and a liquid-to-liquid experiment heat exchanger.

Remote acquisition units (RAU's) are the principal interface between experiments and the command and data management subsystem. Up to four RAU's can be provided on the pallet. High frequency analog data is accommodated by an analog channel using a high rate multiplexer. Digital data can be stored by a recorder; however, the maximum data rate allowable is 30 Mbps. Up to 20 minutes of data storage can be accommodated at the 30 Mbps rate.

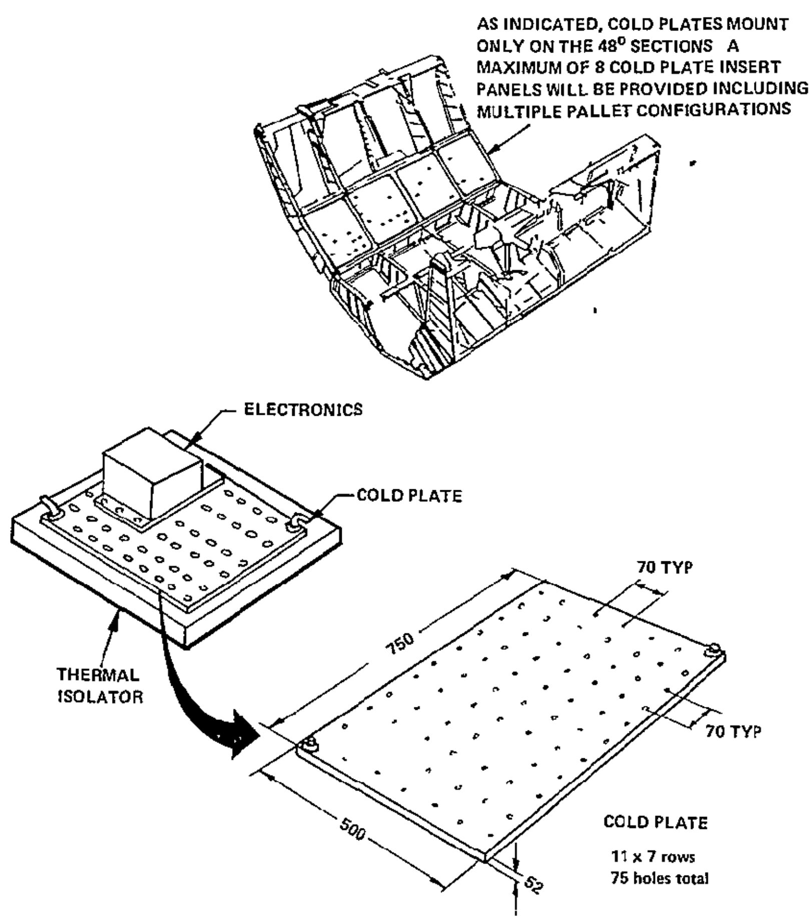


Figure 2-5. Cold Plate Mounting

The available field of view above the Spacelab pallet with the Orbiter cargo bay doors and radiators open is variable forward and aft dependent upon the Spacelab configuration and the location of the pallet. The field-of-view is restricted in these directions by either the Spacelab pressurized module or the Orbiter cabin and the Orbiter empennage. Figure 2-6 shows limiting examples for this situation. The side field-of-view limitations are constant as shown in Figure 2-7.

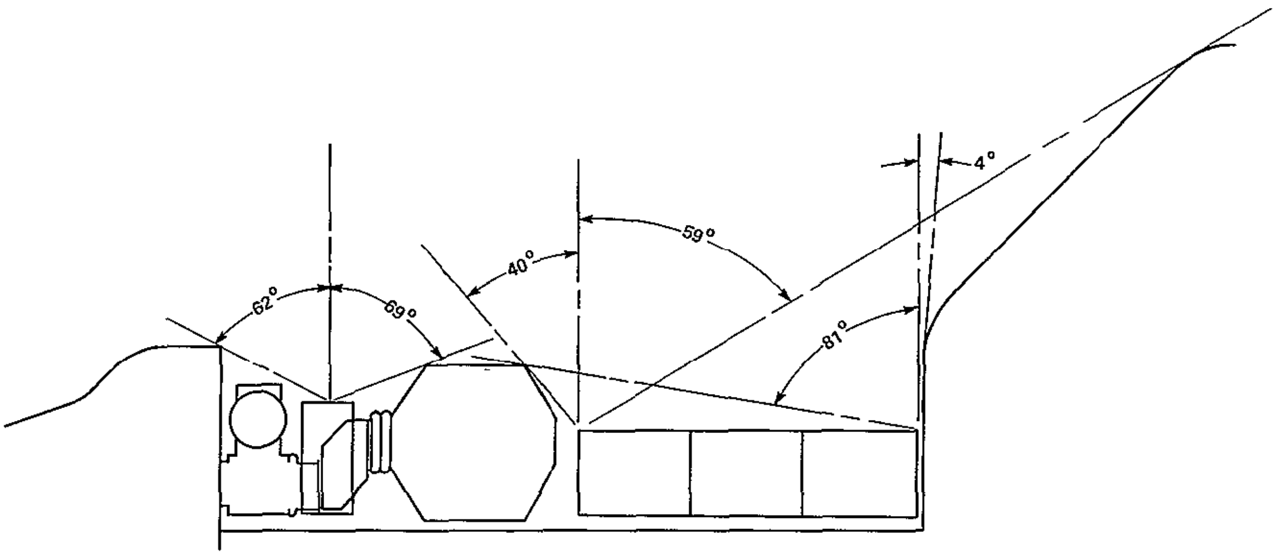


Figure 2-6. Limiting Fields of View

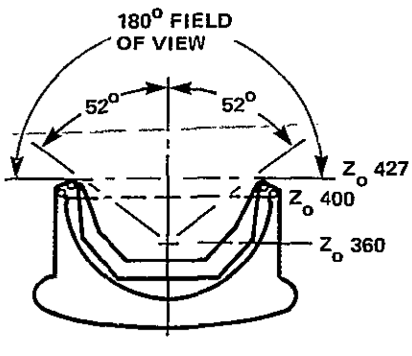


Figure 2-7. Orbiter Field of View-Side

2.3 SEOPS

The SEOPS system shown in Figure 2-8, consists of a modular structure and support subsystems. Since SEOPS is independent of Spacelab, its accommodations are somewhat unique.

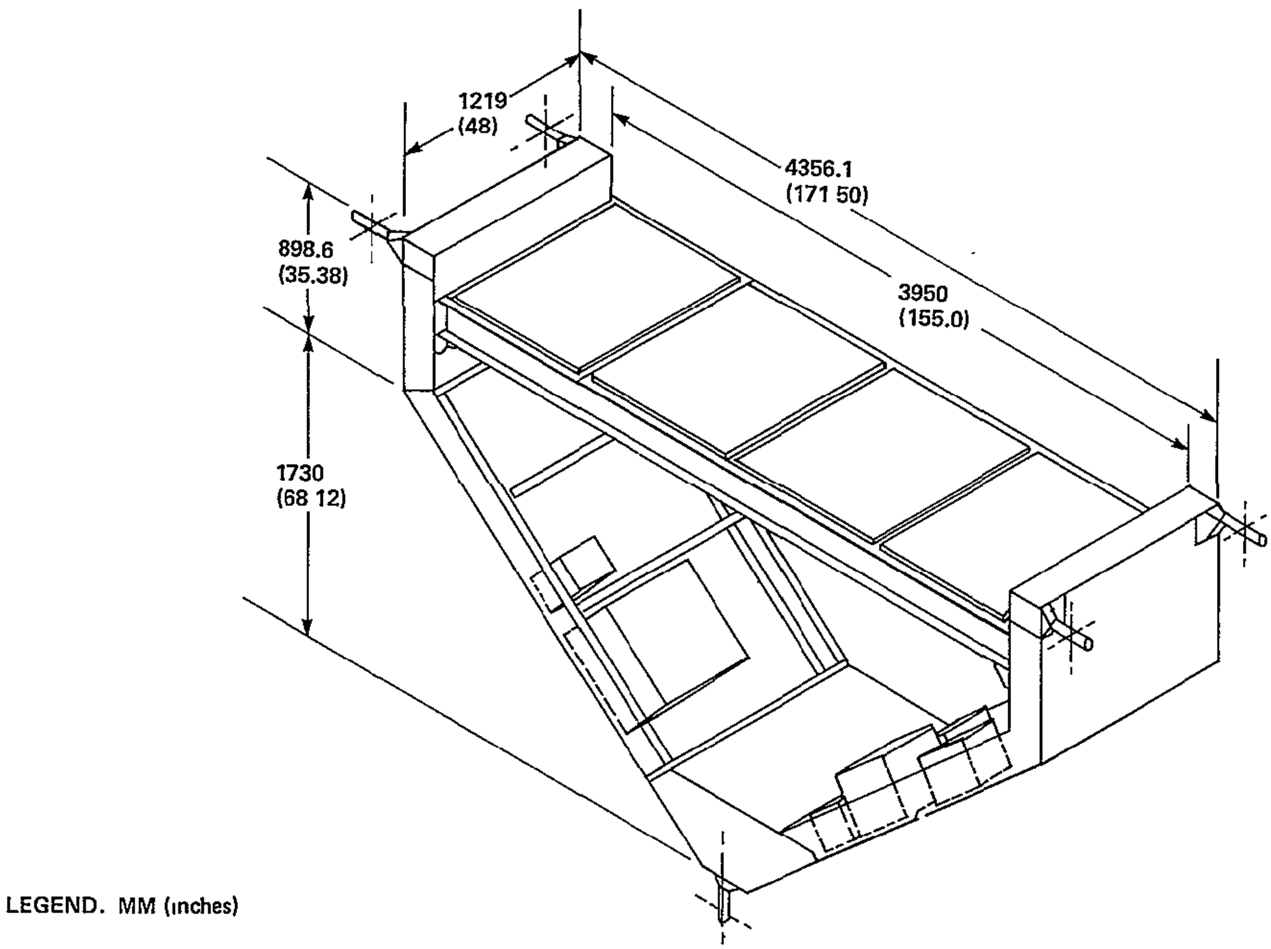


Figure 2-8. SEOPS Bridge Configuration

The SEOPS structure consists of a strongback, which provides the base for the bridge. The strongback is U-shaped, providing clearance around the Spacelab tunnel, and transmits the SEOPS loads to the trunnion fittings at the keel and side attachment points. Generally the sensors are mounted on the bridge with the SEOPS support subsystems attached to the strongback. The structural weight for the SEOPS bridge configuration is 313 kg. This configuration can support a payload weight of 1043 kg. For earth viewing applications approximately 6 m^2 and 23.7 m^3 of mounting surface and volume are available.

The SEOPS support subsystems provide alignment and rate knowledge, conditioned electrical power, temperature control, and data management and processing. SEOPS basically depends on the Orbiter attitude control subsystem for target pointing and stability.

SEOPS does provide alignment of the instruments with the Orbiter plane within 0.5^{o} and utilizes a self-contained star tracker to provide attitude update for pitch, roll and yaw. Residual rate knowledge to 0.0001^{o} per second is provided via a gyro package.

SEOPS uses electrical energy from the Shuttle Orbiter main DC-2 bus, regulates it, and distributes it to the attached sensors and electronic boxes. Maximum power availability with this system is 3 kW at +28 Vdc $\pm 2\%$.

Thermal control is maintained within $\pm$ $8^{o}C$ between $5^{o}C$ and $21^{o}C$ using a passive and louver system. SEOPS can provide its own data handling, processing, and storage. Specific functions performed by this subsystem include sensor and subsystem command generation, housekeeping data formatting and processing, system checkout and evaluation, sensor data processing, recording and transmission control, and signal routing. The SEOPS can be reprogrammed from the ground, or it can transmit data to the ground through the Orbiter command and data management system. SEOPS capabilities include command and telemetry provided by the modular addition of hardware and firmware circuits capable of handling up to 240 mbps, and two types of tape recorders: a 240 mb wideband tape recorder and a NASA standard narrowband (10^8, 10^9) tape recorder.

Orbiter data available to SEOPS payloads include ephemeris, time, attitude, and caution/warning.

SECTION 3

PAYLOAD DESCRIPTION

SECTION 3

PAYLOAD DESCRIPTION

The payload specified for this flight is a multi-discipline grouping of experiments selected from a collection of high priority experiments designated by MSFC (for the ESA complement), the EVAL Steering Group, and the individual discipline Working Groups, as being available for early (1981-1983) Shuttle flights. Experiments are included in this payload representing the disciplines of Earth Resources, Weather and Climate, Earth and Ocean Dynamics, Communications and Navigation, and Environmental Quality. The function of the experiments involve one or more of the following roles: technique development, sensor development, application development, operational platform. See Figure 3-1. The selection of specific experiments was based on the principle of maximizing benefits while minimizing costs. Commonality of equipment and synergistic enhancement of experiments thus were important factors in selecting the payload.

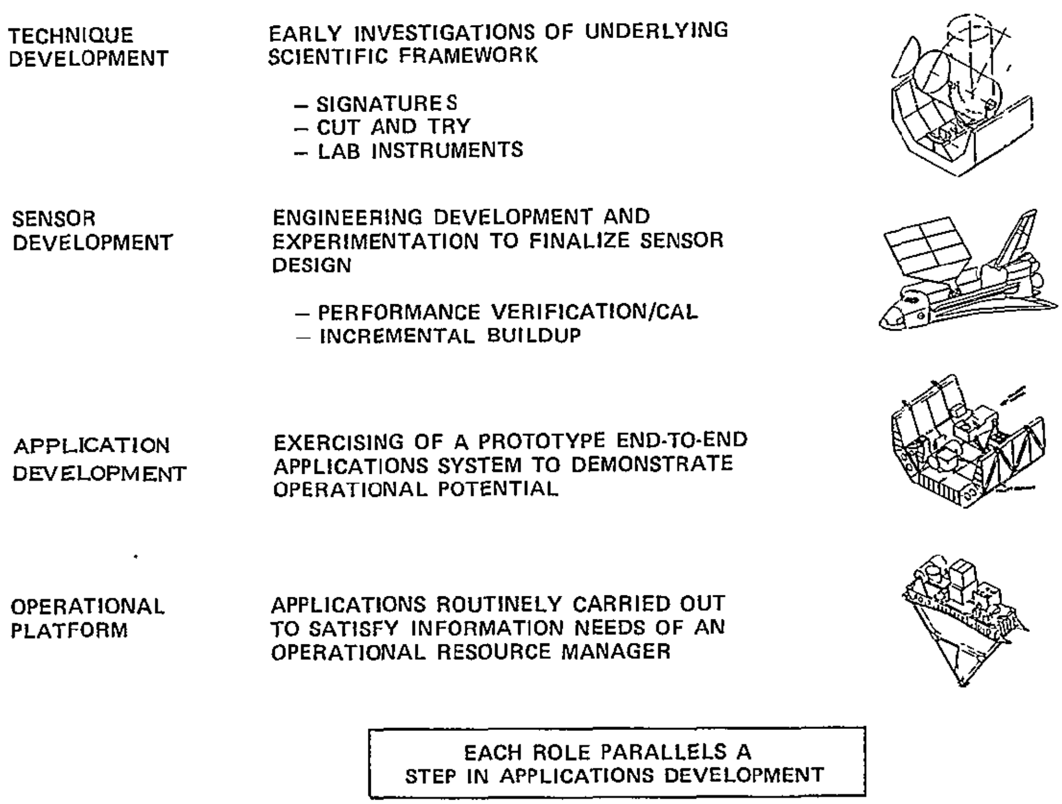


Figure 3-1. The Four Roles for Sortie Flights

3.1 MISSIONS

The EVAL experiments tentatively selected for this flight are:

- Earth Resources
  - Urban and Regional Planning (Applications Development)
  - Timber Inventory (Applications Development)
  - Mineral Survey (Applications Development)
- Weather and Climate
  - Cloud Climatology (Sensor Development, Applications Development)
  - Solar Energy Monitoring (Operational Platform)
  - Ozone Sounding (Applications Development)
- Environmental Quality
  - Constituent Measurements (Sensor Development, Applications Development)
- Earth and Ocean Dynamics
  - Sea Surface Temperature (Applications Development)
  - Ocean Currents (Technique Development)
  - Ocean Waves (Applications Development)
- Communications and Navigation
  - Electromagnetic Environment (Applications Development)
  - Millimeter Wave Propagation (Applications Development)

The ESA experiments added to the payload by MSFC include:

Earth and Ocean Dynamics

- Microwave Scatterometer (Sensor Development)

Weather and Climate

- Passive Atmospheric Sounding (Technique Development)

A brief description of these experiments is provided in the following paragraphs. For a more detailed explanation the reader is referred to "EVAL Mission Requirements", 76SDS4227, General Electric Co., 7 May 1976, developed under NASA Contract No. NAS5-24022.

Urban and Regional Planning - Provide survey of land use information to public, private, and government agencies. This particular mission involves obtaining data to support urban and regional planners in the preparation of legally required plans on land use and landform characteristics. Instruments required for this mission include a thematic mapper and a high resolution large format camera.

Timber Inventory - Monitor forest land to develop forecasts of timber production, productive status, and efficiency and ecological soundness of timber production and harvesting operations. Instruments required for this experiment include a thematic mapper and a high resolution large format camera.

Mineral Survey - Investigate the use of remotely sensed data for detection of surface indicators of mineral deposits: in particular, to locate new domestic supplies of copper resources. Instruments required for this experiment include a thematic mapper, and a high resolution stereo camera.

Cloud Climatology - Gather global statistics of cloud properties to a geographic scale of 200 km and a temporal scale covering both diurnal and seasonal variations. The observing system consists of both an active and a passive instrument: the laser ranging system and the cloud physics radiometer.

Solar Energy Monitoring - Measure the solar constant and solar spectral irradiance from 0.25 to 4.0 um and the variability of the parameters. The candidate sensor for this mission is an eclectic satellite pyrheliometer.

Ozone Sounding - Calibrate ozone monitoring sensors on free flying satellites by use of a standardized instrument utilizing the backscattered ultraviolet technique. The solar/backscatter ultraviolet spectrometer is required for this mission.

Constituent Measurements - Determine whether there are changes in the radiating transfer characteristics of the atmosphere and a depletion of the stratospheric ozone concentration due to the introduction of man-made pollutants into the stratosphere, and identify the critical constituents. The experiment objectives can be satisfied by a grouping of photometers, radiometers, and interferometers such as: LACATE, HALOE, SER, HSI, SBUV, ESP*.

*See Table 3-2 for identification

Sea Surface Temperature - Demonstrate high spatial resolution mapping of sea surface temperature for application to circulation studies and modeling, fog prediction, upper ocean forecasting, and fisheries operations. A scanning microwave radiometer complemented by a microwave scatterometer are required for this experiment.

Ocean Currents - Develop signatures for the detection and mapping of ocean currents, eddies, and internal waves; and to further the understanding of the interaction of currents with waves. The ultimate objective is to measure magnitudes and directions of current flows. Primary sensors for this experiment are an altimeter and a microwave scatterometer.

Ocean Waves - Provide verification data for wave forecasting models and coastal zone wave climatology. Partial experiment data can be obtained with an altimeter and a thematic mapper.

Electromagnetic Environment - Measure and characterize electromagnetic environment interference at frequencies allocated for space use by establishing a capability for monitoring the RF spectrum in the frequency range from 0.4 to 43 GHz. A sensor system consisting of multiple antennas and receivers is required for this experiment.

Millimeter Wave Propagation - Determine propagation losses resulting from absorption and scattering caused by hydrometeors at frequency bands above 10 GHz. The millimeter wave experiment consists of an uplink, a downlink, and a transponder.

Microwave Scatterometer - Optimize sensor characteristics for acquiring surface reflecting measurements to be used in determining surface roughness, wind speed, and precipitation level. The candidate sensor is a microwave scatterometer.

Passive Atmospheric Sounding - Develop profiles for atmospheric characteristics such as density and temperature to be used for atmospheric transport studies.

3.2 SYNERGISTIC PAYLOAD BENEFITS

From a synergistic standpoint, the experiments included within this payload provide many opportunities for enhanced information. This synergism occurs for both intradiscipline experiments as well as cross-discipline combinations. Examples of payload synergism are provided in the following paragraphs.

The Urban and Regional Planning and Timber Inventory missions are both land area delineating processes. Each may contribute data to regional land use inventories or may interact with regard to establishing boundaries.

The effects of solar energy on climate, and perhaps weather, can be determined by flying a Solar Energy Monitoring experiment with a Cloud Climatology experiment.

Measurement data obtained for the Millimeter Wave Propagation experiment will include RF attenuation and phase distortion caused by atmospheric phenomena. The Cloud Climatology, Solar Energy Monitoring, and Constituent Measurement experiments will provide valuable information about atmosperhic disturbances and their effect on Millimeter Wave Propagation.

The predominant species of concern in the atmosphere is ozone. The Ozone Sounding mission will benefit from association with the Constituent Measurement experiment by determining to what extent there is a depletion of the stratospheric ozone concentration due to the introduction of man-made pollutants into the stratosphere, and the identification of the critical constituents.

Grouping the Sea Surface Temperature, Ocean Currents, and Ocean Waves experiments together essentially results in another larger experiment focused on the study of tropical storms. The combined measurement of water vapor, liquid water content, surface winds, sea surface temperature, wave fields, and water level should lead to a better understanding of the growth and movement of storms, and the development of storm surges.

3.3 EQUIPMENT COMMONALITY

Commonality of equipment for the EVAL experiments included within this payload is shown in Table 3-1. From this chart it can be seen that almost all of the sensors have application in more than one experiment, and within more than one discipline. In particular, an instrument such as the thematic mapper is required, or desired, for half of the experiments.

Table 3-1. Sensor Commonality

Sensors \ Missions	Urban & Regional Planning	Timber Inventory	Mineral Survey	Cloud Climatology	Solar Energy Monitoring	Ozone Sounding	Constituent Measurements	Sea Surface Temperature	Ocean Currents	Ocean Waves	Electromagnetic Environment	Millimeter Wave Propagation
Thematic Mapper	(X)	(X)	(X)				X	X	X			
Photo Pack (Large Format Camera)	(X)	(X)	(X)									
S-193 Rad/Scat/Alt		X	X					X	(X)	X		
GEOS C Altimeter									(X)	(X)		
Scanning Microwave Radiometer								(X)	X			
Laser Ranging System				(X)								
Cloud Physics Radiometer				(X)								
LACATE						X	(X)					X
HALOE							(X)					X
SER						X	(X)					
HSI						X	X					X
SBUV						(X)	X					
ESP					(X)		(X)					
EEE											(X)	(X)

Legend: (X) Required

X Desired

Observation of Table 3-1 also provides an indication of potential instrument sub-groups which should be considered when assigning the various sensors to the pallets and SEOPS. For instance, the thematic mapper and photo pack (large format camera) are required instruments for all of the Earth Resource missions considered on this payload. This sub-group might therefore be developed and grouped as a facility type complement of instruments. Similarly, a sub-group consisting of LACATE, HALOE, SER, HSI might be considered as a facility type complement for use by Environmental Quality investigators, and assigned a specific portion of the payload. Another grouping of the S-193, SSMR/SMMR, and GEOS altimeter might also be considered as a facility group for Earth and Ocean Dynamics. An attempt is made in the subsequent payload layouts to preserve these sub-groups to the extent possible.

3.4 EVAL PAYLOAD

The complete payload for this flight is pictured in Figure 3-2. The EVAL complement is located on the last two pallets and the SEOPS, while the ESA complement is contained on the first pallet. Scientific descriptions of the various EVAL sensors shown in these illustrations are provided in Tables 3-2 and 3-3. (The scientific description and engineering details of the ESA payload are unavailable and have been omitted from these tables). The engineering details associated with this payload are provided in the following sections.

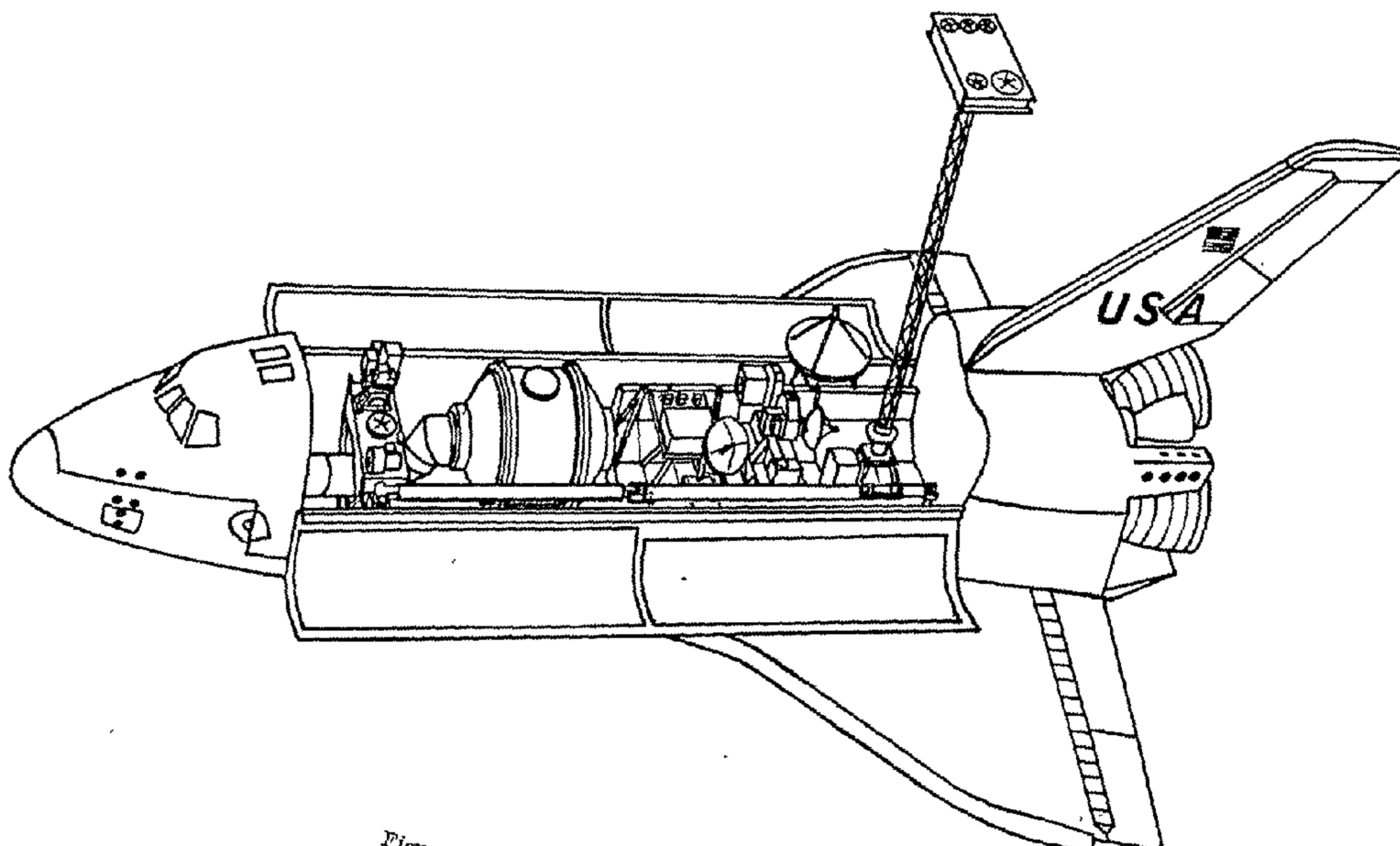


Figure 3-2. EVAL/ESA Payload

Table 3-2. Payload Description

Sensor Generic Name	Type	Objective	Spectral Bands		Viewing	Total Angular Coverage	Instantaneous Field-of-View
			Number	Location			
Electromagnetic Environment Antenna Assembly (EEE)	Passive Microwave	Map RF Interference	6	0 1 - 105 GHz	Nadir ±80°	±180° Azimuth, ±80 Elevation	0 4° - 30°
Millimeter Wave Transponder (MW)	Active Microwave	Measure RF Propagation Losses	2	30 GHz, 20 GHz	Nadir (Auto-track)	±180° Azimuth, ±80 Elevation	0 85° - 1.4°
GEOS-C Altimeter	Active Microwave	Measure Altitude Above Ocean	1	13 9 GHz	Nadir	1 5°	1 5°
Scanning Multichannel Microwave Radiometer (SMMR)	Dicke Type Radiometer	Measure Ocean Surface Temperature and Currents	8	6 6 - 37 GHz	Along Velocity Vector, Down 45° (Conical ± 25° Scan)	4 0	0 71° - 2 5°
Microwave Scatterometer (S-193)	Microwave Radiometer/Scatterometer	Measure Ocean Temperature Distribution	1	13 9 GHz	Nadir	18°	1 5°
Cloud Physics Radiometer (CPR)	Scanning Imaging Radiometer	Measure Cloud Height, Temperature, and Water Content	8	0 75 - 10 99 um	Nadir	90°	0 4°
Laser Ranging System (LRS)	Active Optical	Measure Cloud Height and Water Droplets	1	Nd Yag	Nadir	130°	0 028°
Lower Atmospheric Composition and Temperature Experiment (LACATE)	Scanning Spectral Radiometer	Measure Stratospheric Profiles of Constituent Species and Aerosols	10	6 1 - 17.5 um	Earth's Limb	+6°, -5° Elevation + 15° Azimuth	014° x 286°, 028° x 143° 057° x 143°
Halogen Occultation Experiment (HALOE)	Extinction Photometer	Measure Stratospheric Profiles of Halogens	5	2 1 - 5 9 um	Solar View at Horizon	Solar Occultation	017°
Solar Extinction Radiometer (SER)	Extinction Radiometer	Measure Stratospheric Profiles of Ozone Aerosols	4	0 38 - 1.0 um	Solar View at Horizon	±180° Azimuth, -21° ± 10° Elevation	017°
High Speed Interferometer (HSI)	Michelson Interferometer	Measure Content of Molecular Species	NA	2 - 6 um	Solar View at Horizon	1 25°	1 25°
Solar Backscatter Ultraviolet (SBUV)	Spectral Radiometer	Measure Solar Irradiance	12	160 - 400 um	Nadir	11 3°	11.3°
Eclectic Satellite Pyrheliometer (ESP)	Spectral Radiometer	Measure Solar Constant	3	0 25 - 4.0 um	Solar (Full Sun)	1 6°	1 6°
Thematic Mapper (TM)	Scanning Spectral Radiometer	Obtain High Resolution Multispectral Imagery	4 1 1 1	0 5 - 1 1 um 1 55 - 1 75 um 2 1 - 2 35 um 10 1 - 12 6 um	Nadir ±20°	14° Azimuth, 2° Elevation	0017° Azimuth, 0068° Elevation
Large Format Camera (LFC)	Framing Mapping Camera	Provide High Resolution, Stereo Imagery	1	0 5 - 0.85 um	Nadir	40° Cross Track 80° Along Track	0017°

Table 3-3. Payload Support Requirements

	Size			Weight	Ave Pwr	Peak Pwr	Data Rate			Pointing Accuracy (Deg)	Stability Amplitude (Sec)
	CM	CM	CM	kg	Watts	Watts	BPS	Field-of-View	View Angle		
MW	300	300	30	70	250	250	50K	0.85°-1.4°	Nadir		
EEE/(Pallet)	350	280	250	265	550	600	83K ave.	1°-30°	Nadir ±80°	0.1	180
(Spacelab)	48	76	50	25			1M max.				
GEOSC Altimeter (Electronics)	66 56	66 64	15 61	68	150	150	15K	1.5°	Nadir	0.1	72
SMMR (Electronics)	80 15	80 30	18 17	24	61	61	1.5K	0.7°(37GHz) 4° (6.6GHz)	±25° Cross-track	0.1	72
LRS	82	57	36	260	250	250	50K	0.5 m rad	±65° Nadir	2 m rad	0.2 m rad
Cloud Physics Rad	81	25	36	187	25	25	500K	0.4°	90°	0.2	TBD
μW Scatterometer (S-193)	193	56	12	95	153	350	5.3K	27 m rad	48°	2.0	180
LACATE (Electronics)	82 15	37 30	37 17	77	50	80	4K	2.5 m rad	±6° Along Track ±45° Cross Track	0.01	5
HALOE (Electronics)	45 20	36 10	56 25	20	20	50	1K	.017°	±6° Along Track ±TBD Cross	0.5	TBD
SER	42	42	42	22	17	50	4K	.017°	±6° Along Track	0.5	TBD
HSI (Electronics)	40 40	40 40	20 20	23	50	50	50K	1.25°	TBD	.06	20
SBUV (Electronics)	53 33	38 15	21 20	20	15	19	650	12°	±45° Cross Track	0.3	100
ESP (Sun Tracker)	25 14	18 34	15 9	14	3.5	23	320	1.6°	TBD	0.5	TBD
TM	116	93	60	180	55	80	120M	14° Azimuth 2° Elevation	±20° Off Nadir Pointing	0.5	6
LFC	79	64	73	136	120	500 f or 10ms/frame	N/A	74° x 38°	74° x 38°	2.5	6

SECTION 4

PHYSICAL ACCOMMODATIONS

SECTION 4
PHYSICAL ACCOMMODATIONS

The physical accommodation of payload equipment on the Spacelab pallets, in the pressurized module, and on the SEOPS presents a multi-faceted challenge to the payload designer. Available volumes and areas are limited, field-of-view requirements are often conflicting, and weight and balance constraints can be critical. The combined EVAL/ESA payload meets all design constraints with some minor restrictions on experiment operation and the addition of 1800 kg of ballast on the aft pallet to achieve an acceptable c. g. location.

4.1 PAYLOAD WEIGHTS AND LOCATIONS

Payload and payload chargeable weights of experiments, experiment support equipment, carriers (Spacelab and SEOPS), excess crew, and contingency allowance are summarized in Table 4-1. The payload launch weight of 12, 871 kg noted in this table is well below the allowable launch weight of ~ 25, 000 kg associated with the launch conditions specified for this flight.

Spacelab and SEOPS weights are broken down in Table 4-2. Mission-dependent subsystems (consisting of Spacelab racks and other mounting structure; habitability equipment; EPDS, C&DMS, and ECS equipment; common payload support equipment; and a Spacecraft weight reserve) are estimated to weigh 1379 kg based on the weight budget for Spacelab No. 1. Weights for mission independent subsystems, the transfer tunnel, and mission independent Orbiter support are the latest available Spacelab element mass properties values (8/10/76).

A payload layout drawing is shown in Figure 4-1. Significant features of the drawing are:

1. The SER, ESP, HSI, and HALOE are installed on a small stabilized pointing platform, Minimount, which is attached to the port side of the SEOPS bridge section. For a morning launch and a nose forward, inverted (X-IOP, Z-LV) attitude, the port side is the sunlit side.
2. The LRS, CPR, and SMMR are mounted to the port side bracket of the small instrument pointing system (SIPS), allowing the S-193 antenna and electronics to be mounted on the starboard side of the pallet. The SMMR antenna faces in the opposite direction from the LRS and CPR. (SMMR does not operate when LRS and CPR operate).

Table 4-1. Payload and Payload Chargeable Weights

	Launch Weight (kg)	Landed Weight (kg)
Experiment Sensors	1512	1512
HALOE	(20)	(20)
SER	(22)	(22)
ESP	(14)	(14)
HSI	(23)	(23)
ALT	(68)	(68)
SBUV	(20)	(20)
TM	(180)	(180)
ESA-PAS	(101)	(101)
ESA-MWS	(150)	(150)
LRS	(60)	(60)
CPR	(187)	(187)
SMMR	(24)	(24)
S-193	(95)	(95)
LFC	(136)	(136)
LACATE	(77)	(77)
EEE/MW	(335)	(335)
Experiment Support Equipment	1748	1748
Minimount	(200)	(200)
SIPS	(764)	(764)
Cryostats	(14)	(14)
PAS Scan Platform	(40)	(40)
EEE/MW	(25)	(25)
VHDRR	(230)	(230)
OEDSF	(115)	(115)
Cloud Climatology Electronics	(50)	(50)
Misc. Expt. Support Equipment	(310)	(310)
Other Payload Chargeable Weight	416	416
Crew, Eqpt, Consumables (above baseline)	(268)	(268)
Payload Weight Contingency	(148)	(148)
Spacelab and SEOPS	9195	8752
Mission Independent Subsystems	(5724)	(5668)
Mission Dependent Subsystem	(1379)	(1379)
Transfer Tunnel	(352)	(352)
Orbiter Support Equipment	(1377)	(990)
SEOPS	(363)	(363)
Total Payload Weight at Launch	12871	
Total Payload Weight at Landing		12428
Payload Weight Margin (P/L Limit = 14515)		2087

Table 4-2. Spacelab and SEOPS Weights

	Launch Weight (kg)	Landed Weight (kg)
Mission Independent Subsystems	5724	5668
Module	(3452)	(3396)
Pallets (3)	(1939)	(1939)
Utility Harness (Forward)	(236)	(236)
Payload Specialist Station (Orbiter Aft Flight Deck)	(97)	(97)
Transfer Tunnel	352	352
Tunnel/Air Duct	(352)	(352)
Mission Dependent Subsystems	1379	1379
Racks, RAU's, EPDS Eqpt, etc.	(1379)	(1379)
Mission Independent Orbiter Support	1377	990
Orbiter Energy Kit (Electrical Energy)	(756)	(369)
Heat Rejection Kit	(88)	(88)
Retention Fittings (1 Set)	(125)	(125)
Tunnel Adapter	(408)	(408)
SEOPS	363	363
Bridge Structure	(313)	(313)
Support Subsystem	(50)	(50)
Total Spacelab and SEOPS Weight	9195	8752

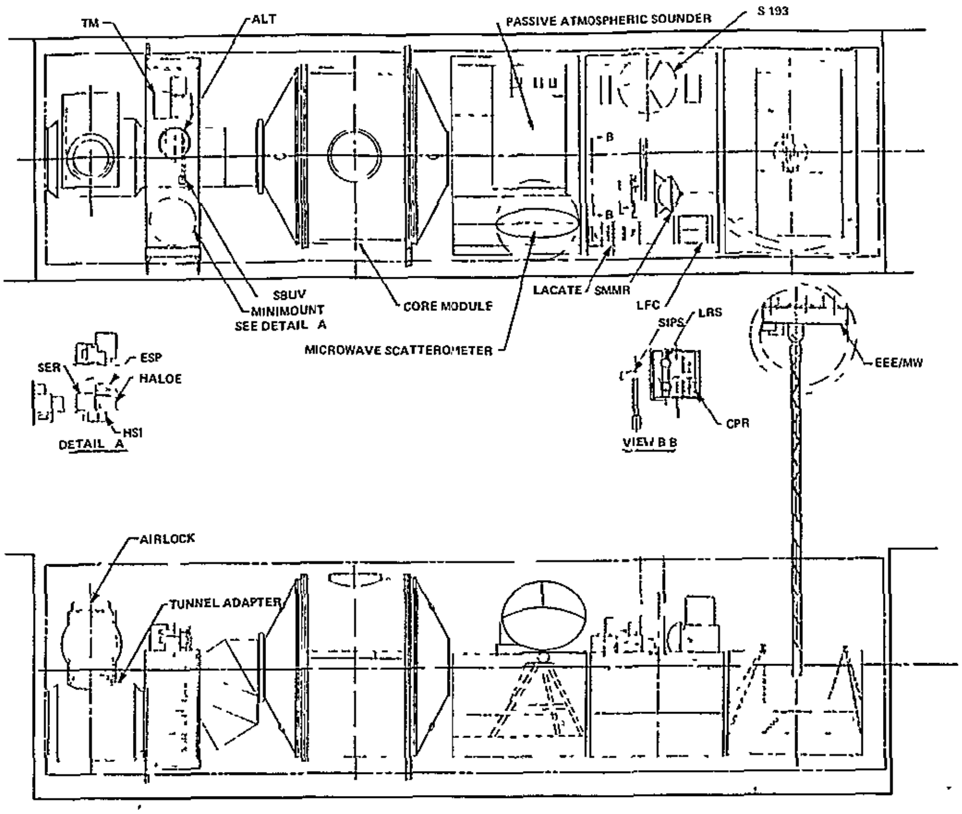


Figure 4-1. EVAL Configuration

3. The aft pallet is ballasted for c.g. purposes. The ballast (assumed to be lead shot in suitable containers) is attached to available hardpoints not utilized by the EEE/MW equipment.

4.2 PAYLOAD CENTER OF GRAVITY

The aerodynamic flight phases of the Shuttle Orbiter (entry and landing, boost phase abort) place rigid center of gravity constraints on Shuttle payloads. The most severe are the X-axis limits which require payload c.g. to be in the aft portion of the payload bay, and the y-axis limits which require payload c.g. to be within a few inches of the payload bay center line. Z-axis limits are less stringent, allowing c.g. locations up to 4 feet above or below the payload bay centerline.

All payload chargeable items are included in c. g. determination, including payload equipment in the Orbiter Aft Flight Deck and crew consumables, crew equipment, and mission extension kits over and above baseline allowances. For a Spacelab mission, all mission independent and mission dependent equipment is payload chargeable, including the Transfer Tunnel and Tunnel Adapter. The Orbiter Airlock is not payload chargeable.

Payload c. g. locations for the combined EVAL/ESA mission are shown in Table 4-3. The unballasted payload c. g. falls outside the x-axis limit for both landing and launch (See Figure 4-2). Return payload weight of 12428 kg leaves a payload weight margin of 2087 kg. If 1800 kg of ballast is added to the aft pallet in order to move payload longitudinal, e.g., within the acceptable envelope, a mission weight margin of 287 kg results. 1800 kg of ballast is therefore assumed to be added to the payload.

Return payload weight of 12428 kg leaves a payload weight margin of 2087 kg. If 1800 kg of ballast is added to the aft pallet in order to move payload longitudinal, c. g., within the acceptable envelope, a mission weight margin of 287 kg results.

Payload c. g. locations in the Y and Z axis directions are well within limits for both the ballasted and unballasted case (Figures 4-3 and 4-4).

4.3 PRESSURIZED VOLUME

The Short Module (Core Segment only) configuration provides 5.30 m^3 of payload volume in two double racks and 2 single racks. Table 4-4 indicates that only about 1/3 of this capability is required by the combined EVAL/ESA payload. This is at best an estimate - the Control and Display (C&D) and electronic support requirements of most experiments are not defined at present. It would appear, however, that ample pressurized volume is available for this payload.

The total payload weight capability of the Core Segment racks is 1740 kg. The currently identified weight of pressurized equipment is 513 kg, which is well within this limit. Hence, ample payload weight capability is available for pressurized equipment, except as constrained by total payload weight margin and c. g. requirements. These constraints are discussed in the next section.

Table 4-3. Payload Center of Gravity

	Weight (kg)	Xcg (m)	Ycg (m)	Zcg (m)
Experiment Sensors				
HALOE	20	3.17	1.45	1.35
SER	22	2.72	1.45	1.15
ESP	14	3.10	1.14	1.10
HSI	23	3.07	1.83	1.20
ALT	68	2.97	0.50	0.60
SBUV	20	3.15	-0.33	0.65
TM	180	2.97	-1.23	0.65
ESA-PAS	101	9.75	-0.70	0.45
ESA-MWS	150	11.27	1.45	1.35
LRS	60	13.32	0.70	0.50
CPR	187	13.28	1.23	0.50
SMMR	24	13.84	0.95	0.50
S193	95	14.35	-1.56	0.10
LFC	136	14.47	1.80	1.00
LACATE	77	12.51	1.85	0.55
EEE/MW	335	16.40	0	0.45
Expt. Support Eqpt.				
Minimount	200	2.97	1.45	0.60
SIPS	764	13.38	0.25	-0.25
Cryostats	14	9.75	0	-1.80
PAS Scan Platform	40	9.75	-0.40	0
EEE/MW Control & Display	25	5.91	-1.50	0
VHDRR	230	5.91	-1.50	0
OEDSF	115	5.91	-1.50	0
Cloud Climatology Elect	50	6.17	-1.50	0
Misc Expt Support Eqpt.	279	13.42	0.50	0
Other P/L Weights				
Crew Eqpt	268	-0.81	0	1.50
P/L Contingency	122	13.42	0	0
Spacelab & SEOPS				
Miss. Ind Syst	5724 (launch)	8.57	-0.01	-0.55
Miss. Ind Syst	5668 (land)	8.57	-0.01	-0.55
Miss. Dep. Syst	1379	8.13	0	0
Transfer Tunnel	352	3.60	0	-0.46
Orb Support Eqpt	1377 (launch)	7.26	0	0
Orb Support Eqpt	990 (land)	7.26	0	0
SEOPS	363	2.97	0	-0.70
Center of Gravity at Launch		8.49	0.041	-0.18
Center of Gravity at Landing		8.52	0.042	-0.18
Ballast	1800	17.5	0	-1.60
Center of Gravity at Launch		9.60	0.036	-0.35
Center of Gravity at Landing		9.66	0.037	-0.36

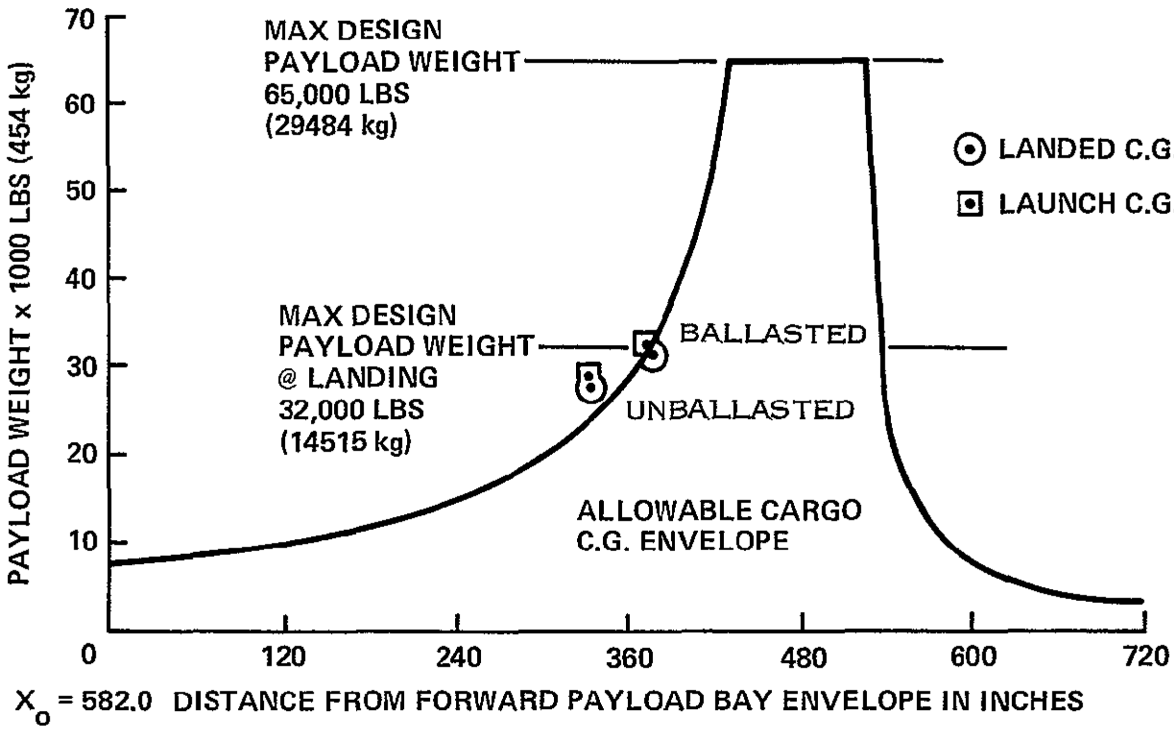


Figure 4-2. Payload CG Along X-Axis

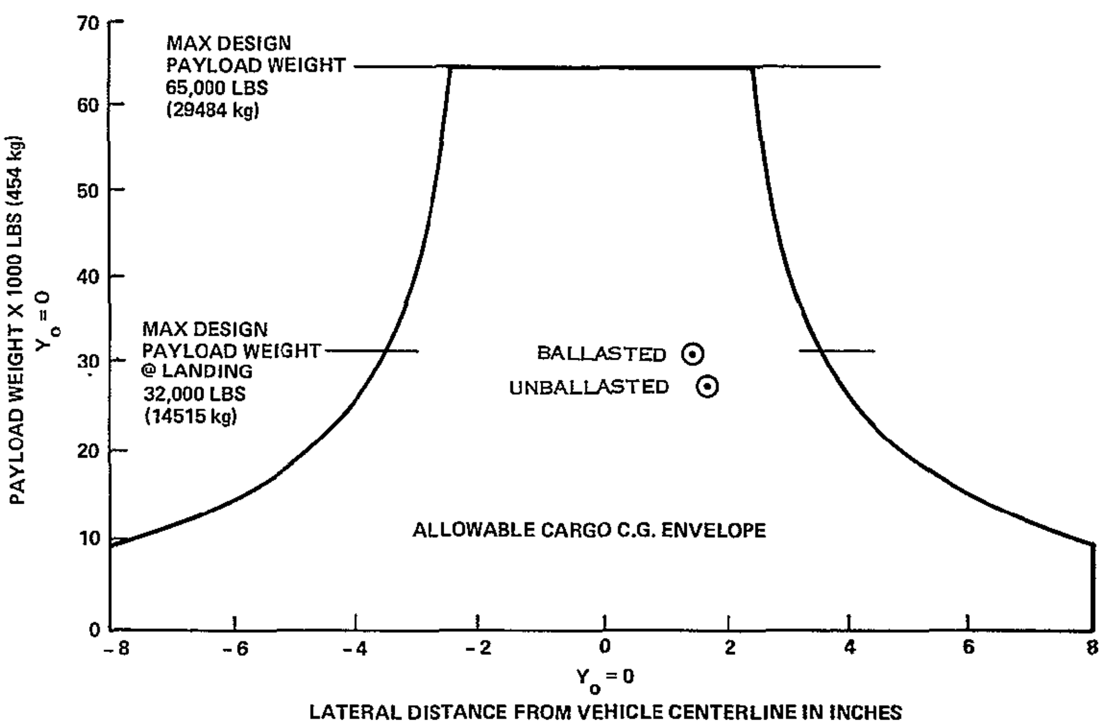


Figure 4-3. Payload CG Along Y-Axis

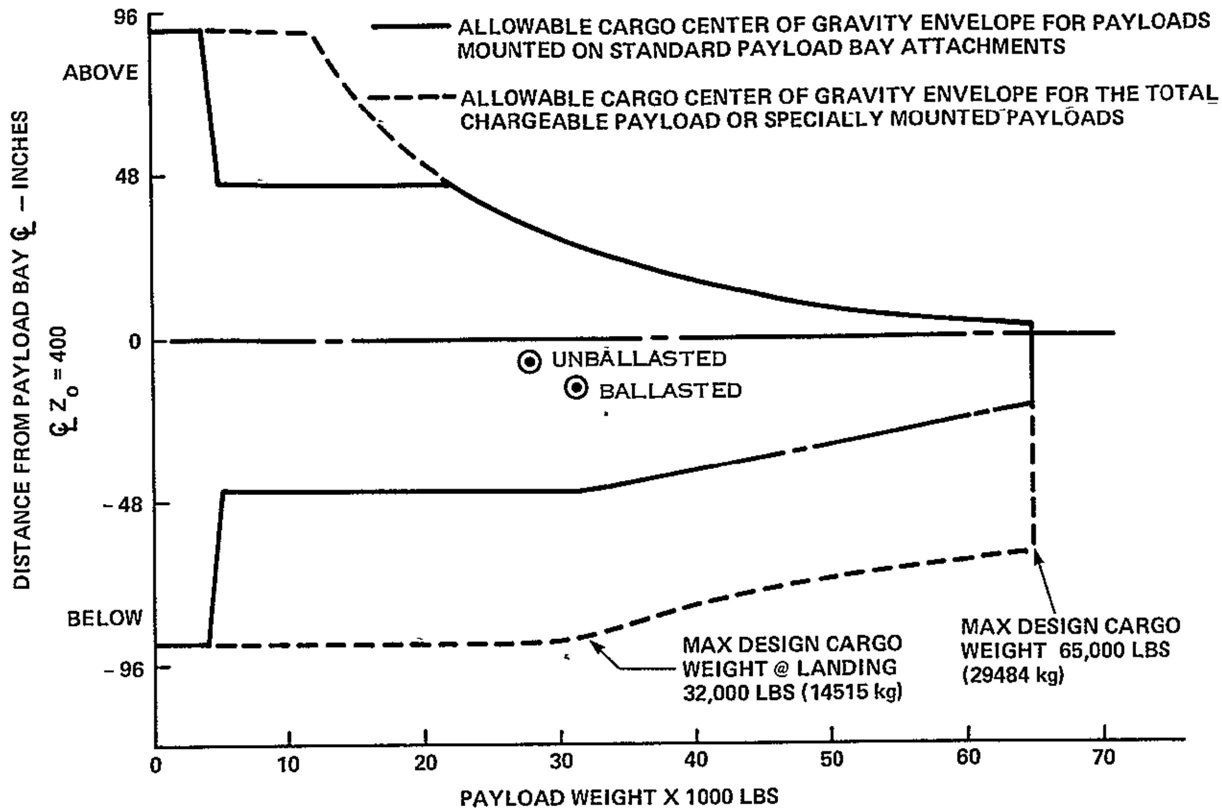


Figure 4-4. Payload CG Along Z-Axis

Table 4-4. Pressurized Equipment

Equipment	Weight	Volume	Remarks
EEE/MW C&D	25 kg	.18 m^3	Included in EEE/MW req'ts.
VHDRR	230 kg	.42 m^3	Best available information
OEDSF	115 kg	.17 m^3	Conservative for 2-array system
CC Electronics	50 kg	.36 m^3	Estimated; same density as EEE/MW
Other Electronics	93 kg	.67 m^3	1/3 of Misc. Expt Support Eqpt.
Total Pressurized	513 kg	1.80 m^3	

4.4 FIELD OF VIEW

An assessment of EVAL experiment fields-of-view (FOV) appears in Table 4-5. The EVAL/ESA payload arrangement (Figure 4-1) satisfies all experiment viewing requirements with the following provisions:

1. The SBUV can view the sun for calibration at dusk but not at dawn due to obstruction by the Minimount.
2. The Minimount must not gimbal toward the starboard when SBUV is in operation or it will protrude into the FOV of the SBUV. (No such gimballing is planned).
3. The Cloud Climatology sensors lose a small portion of their viewing cone due to obstruction by the Orbiter vertical tail.
4. The EEE/MW antenna can not remain deployed when other pallet experiments operate. (Retraction is planned).
5. SIPS must be in the stowed position when the LFC operates. (No operational conflicts are expected).
6. With the single exception of the LFC, the EVAL sensors located on the second pallet cannot be operated when the ESA scan platform is being operated. (The ESA missions involving this platform have been timelined to avoid interference).

The Minimount experiments that want to look at the sun (HALOE, SER, ESP, HSI) can do so at each and every orbital dawn and dusk throughout the mission. The time during which the sun is visible (above the horizon and below the open cargo bay doors) varies from about 5 minutes early in the mission to over 7 minutes late in the mission. This variation is due to changing β angle. The sun is always seen off the port side of the orbiter, in the forward quarter at dawn and the aft quarter at dusk. Viewing azimuths (measured aft from the orbiter X-axis) vary from about 35^o at dawn and 145^o at dusk early in the mission to 55^o at dawn and 120^o at dusk late in the mission.

Table 4-5. Experiment Field of View Assessment*

Experiment	Viewing Requirement	Viewing Capability
HALOE	Solar View at Horizon, .017° Instantaneous FOV, TBD Total FOV	Minimount on port side of SEOPS provides solar viewing at dawn and dusk.
SER	Solar View at Horizon, .017° Instantaneous FOV, TBD Total FOV	Minimount on port side of SEOPS provides solar viewing at dawn and dusk.
ESP	Solar View (Full Sun), 1.6° Instantaneous FOV, 1.6° Total FOV	Minimount on port side of SEOPS provides full sun viewing for 5 to 7 minutes after dawn and before dusk.
HSI	Solar View at Horizon, 1 25° Instantaneous FOV, 1 25° Total FOV	Minimount on port side of SEOPS provides solar viewing at dawn and dusk.
ALT	Nadir Viewing, 1.5° Instantaneous FOV, 1.5° Total FOV	Location on SEOPS provides unobstructed nadir view.
SBUV	Nadir Viewing, Solar View (Full Sun) for Cal, 11 3° Instantaneous FOV, 11.3° Total FOV	Location on SEOPS provides unobstructed nadir view and full sun viewing for 5 to 6 minutes before dusk. Solar viewing at dawn is obstructed by Minimount. Nadir viewing could be obstructed by Minimount if unplanned gimballing occurs Solar viewing at dusk may be obstructed by Minimount late in the mission as β angle decreases.
TM	Nadir Viewing, ±20° Offset (Cross Track), .0017°x.0068° Instantaneous FOV, 14° Total FOV (Cross Track), 2° Total FOV (Along Track)	Location on starboard side of SEOPS provides unobstructed nadir view and 20° offset pointing to either side.
LRS	Discrete Targets (Cloud Tops), ±65° Off Nadir (Conical), 03° Instantaneous FOV, .03° Total FOV	SIPS on 2nd pallet provides full 130° conical view obstructed only by the Orbiter vertical tail and the EEE/MW antenna when extended.
CPR	Discrete Targets (Cloud Tops), ±65° Off Nadir (Conical), 0.4° Instantaneous FOV, 0.4° Total FOV	SIPS on 2nd pallet provides full 130° conical view obstructed only by the Orbiter vertical tail and the EEE/MW antenna when extended.
SMMR	45° Ahead of Nadir, ±25° Cross Track Scan, 0.7° to 2.5° FOV (Freq Dep), 4° Total FOV	SIPS on 2nd pallet provides unobstructed view up to 80° ahead of nadir.
S193	Nadir viewing, 1 5° Instantaneous FOV 48° Total FOV	Location on starboard side of 2nd pallet provides unobstructed nadir view.
LFC	Nadir viewing, 40°x80° Instantaneous FOV, 40° Total FOV (Cross Track), 80° Total FOV (Along Track)	Location on port side of 2nd pallet provides unobstructed nadir view with SIPS in stowed position.
LACATE	Earth's Limb (Not at Sun) .014° to .286° Inst FOV (Freq Dep), ±6°, - 5° Total FOV (Elevation, ref Horizon), ±45° Total FOV (Azimuth, ref Orbiter Y-axis)	Location on port side of 2nd pallet provides unobstructed view of horizon up to 70° fore and aft of Orbiter Y-axis direction.
EEE/MW	Nadir Viewing ±80° Off Nadir (Conical), 0.4° to 30° Instantaneous FOV, ±180° Total FOV (Azimuth, about Nadir), ±80° Total FOV (Elevation, ref Nadir)	Deployment to 7 meters above 3rd pallet provides unobstructed hemispherical view

*The ESA experiments field-of-view requirements are unavailable, therefore, an assessment of the payload ability to accommodate these requirements has been omitted from this table

4.5 INTERFACES

Payload to Shuttle/Spacelab interface definition is begun with schematic diagrams that define the payload accommodation resources utilized by each experiment. Two examples of these experiment schematics are given in Figures 4-5 and 4-6. The first figure shows required connections between the HSI sensor and the SEOPS mounting systems; while the second shows connections between the EEE/MW experiment and the Spacelab module and pallet. Electric power, command/telemetry, data, C&W, thermal control, mounting, and pointing system connections are defined. A full set of schematics for the EVAL experiments are given in Appendix A. Once again, lack of definition prevents the inclusion of schematics for the ESA experiments.

The experiment schematics identify the experiment to Shuttle/Spacelab interfaces that must be designed. For example, the pallet mounted EEE/MW equipment must tie into pallet hard points because of its large size and weight. (Smaller equipment can mount directly to pallet floor or skin panels). Spacelab unregulated dc power can be used if the experiment design incorporates the proper power conditioning/supply equipment. Provisions must be made to route experiment data through the Spacelab high rate digital channels. Caution and warning circuits are required to monitor antenna deployment and retraction.

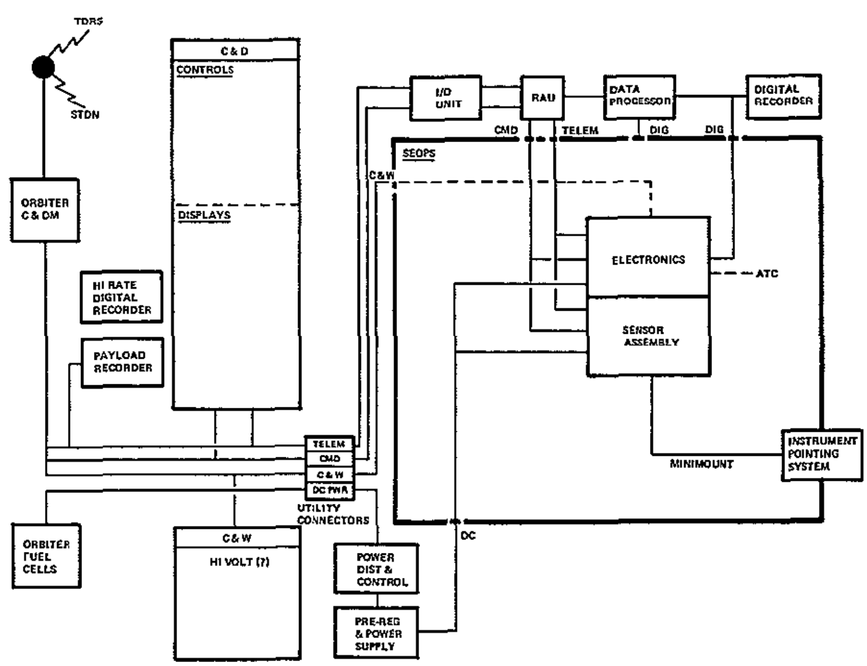


Figure 4-5. EVAL Expt. Schematic (HSI)

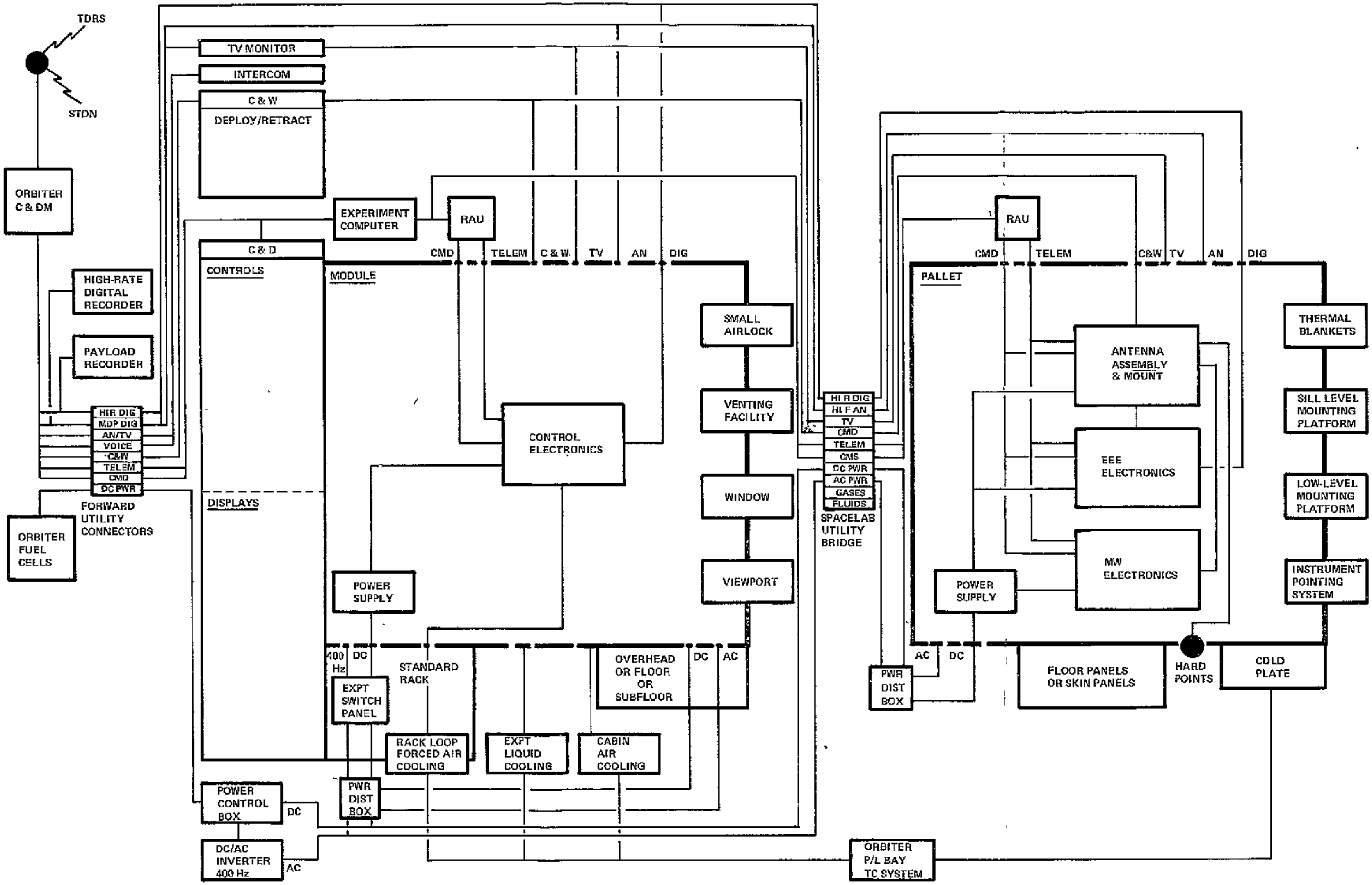


Figure 4-6. EVAL Experiment Schematic (EEE/MW)

FOLDOUT FRAME 1

FOLDOUT FRAME 2

On SEOPS, the HSI equipment requires a pointing system such as Minimount. Electric power will be used as provided, and all experiment data will be recorded. High voltages in the HSI electronics may require C&W monitoring. Active thermal control (ATC) may be required; and if so, it can be provided by the Minimount cannister.

Once the individual experiment interfaces have been identified, the combined payload to Shuttle/Spacelab interfaces can be investigated. This is accomplished with a system schematic as shown in Figure 4-7. Payload equipment is assigned a specific rack, pallet, or other location; and all required connections are shown. Each connection is analyzed to ensure that combined payload requirements are compatible with the payload accommodation capabilities of each carrier element (rack, pallet, SEOPS, etc). When compatibility is ensured, detailed interface design can proceed.

The EVAL portion of the EVAL/ESA payload shows no interface incompatibilities. The thematic mapper requires a special line to transmit very high rate data to the VHDRR in the Spacelab module. This line uses available capability in the forware end cone feed through panel. Electric power, command/telemetry, and caution & warning connections between SEOPS and Orbiter are mounted through utility service panels on the forward bulkhead of the cargo bay (Sta 576) and on the starboard sidewall (Sta 695). These locations are shared with Spacelab, resulting in a common power bus and a common data (Command/telemetry) bus for SEOPS and Spaçelab.

SECTION 5

OPERATIONS

SECTION 5
OPERATIONS

5.1 EXPERIMENT OBSERVATIONS

An assessment of on-orbit mission operations related to the EVAL/ESA payload has been performed to determine experiment observation periods, crew requirements and timelines, and profiles for mission resources such as power and data.

The approach involved fitting the requirements of the various experiments/missions to the orbital conditions of the flight in the most judicious manner. Initially, earth oriented target locations, both point and area, were identified for the specific experiments and spotted on a global map. Table 5-1 correlates this data along with lighting and operation requirements for each experiment.

Next, orbits were run for a 7-day sortie mission having the specified conditions of 325 km altitude and 57° inclination; and assuming a launch from the ETR at Cape Kennedy. Orbit eccentricity and decay rate are both specified as zero, and injection is assumed to be over Cape Kennedy at the time of launch for simplicity. The launch time and data were selected as 0700 Eastern Standard Time on the 15th of September (the prescribed month) to ensure significant daylight observation time over CONUS, the N. Atlantic, and the N. Pacific - which are prime target areas for many of the experiments. As a consequence, the southern hemisphere is generally overflown at night.

Recovery was accomplished on Orbit 115 on a Northwest to Southeast pass just West of Florida. (This necessitates a short cross range maneuver of approximately 110 miles. Shuttle is capable of maneuvers up to 800 miles; therefore, this requirement is well within its. capability.) Estimated landing time is approximately 13:50 Eastern Standard Time.

From the orbit calculations, ground tracks are obtained which indicate which orbits overfly the various target areas. A sample of these ground tracks for a typical one day time frame, approximately 16 orbits, is shown in Figure 5-1. The times and lighting conditions associated

Table 5-1. Target Requirements

Experiment	Target	Lighting	Operation
Ocean Waves	N. Atlantic, N. Pacific	Daytime	10 Min. Per Data Pass; 3 Passes Minimum in ea. Area
Ocean Currents	Gulf Stream, Sea of Japan	Daytime	2 Passes Minimum in ea. Area
Sea Surface Temp.	Grand Banks, Spanish Sahara Coast, Peruvian Coast, Inter-tropical Convergence Zone	Daytime	2 Passes Minimum in ea. Area
Urban Planning	CONUS (56 Cities) Plus Hawaii	Daytime	1 Photographable Pass Sufficient Over Each Designated City
Timber Inventory	CONUS	Daytime	1 Photographable Pass Sufficient Over Each Designated Area
Mineral Survey	CONUS, Chile, Peru, Zaire, Zambia	Daytime	1 Photographable Pass Sufficient Over Each Designated Area
Electromagnetic Environment	CONUS	Day and Night	As Many Passes as Possible
Millimeter Wave	CONUS, (Virginia Polytechnic Institute, Goddard Space Flight Center, Ohio State University, Rosman, North Carolina)	Day or Night	As Many Passes as Possible, Preferably During Rain
Cloud Climatology	Global (0 to $\pm$ 15^{o} Latitude, 30^{o} to 50^{o} Latitude)	Day or Night	As Many Passes as Possible. 10 Minutes Duration on Each Pass
Solar Energy Monitor	Total Sun	Day	3 Times a Day Ea. Day - Minimum 3 Min. Per Data Take
Ozone Mapping	Global (20^{o} to 50^{o} N and S Latitude Over Continental Areas)	Daytime	3 Observations of 15 Min. Ea., Plus 2 Sun Calibration
Constituent Meas.	Anywhere	Sunrise and Sunset	18 Observations Desired, 5 Minutes Each
Microwave Scattermoter	Broad Ocean Areas	Day and Night	A Minimum of Three 10 Minute Passes Each During Daylight and Night-time
Passive Atmospheric Sounding	Global	Day and Night	As Many Data Takes as Possible

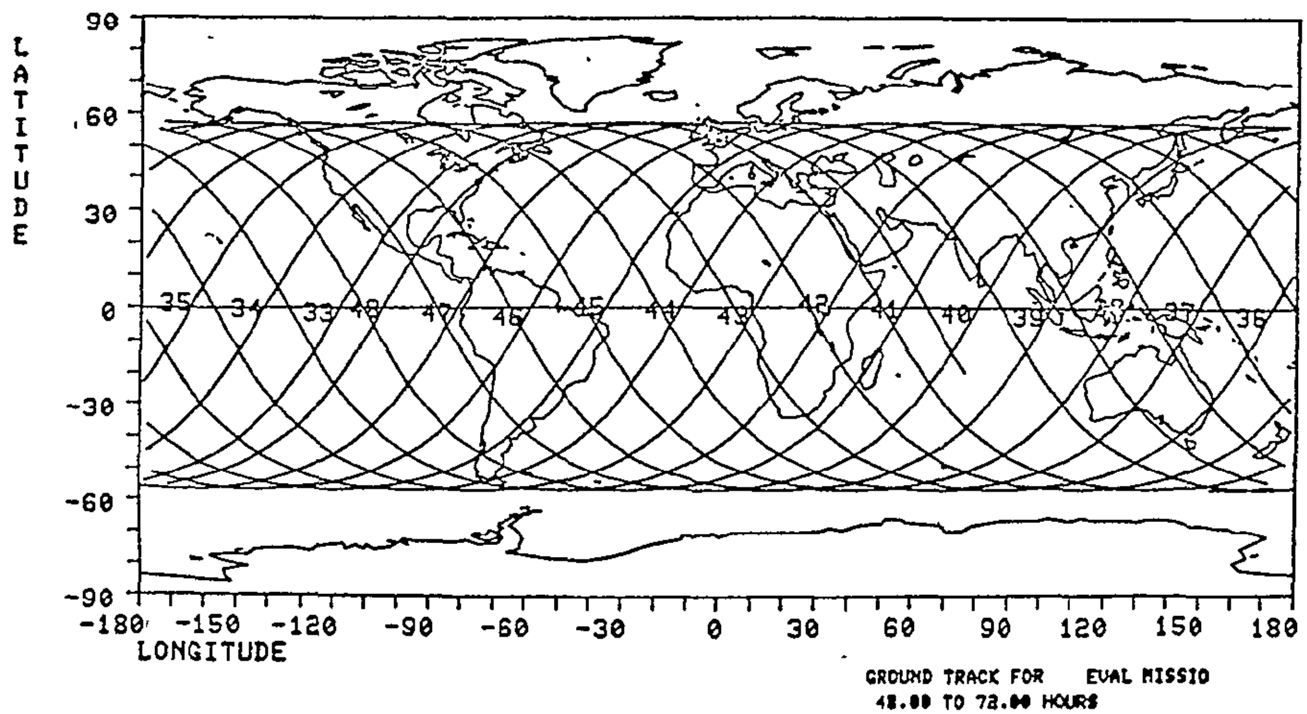


Figure 5-1. EVAL Mission Ground Trace

with these target crossings have been tabulated and are included as Appendix B. Tables 5-2 and 5-3 summarize the target opportunities and selected data taking operations. A nominal cross track distance of 100 nm was assumed to be in the range of experiment pointing capabilities. Any ground locations falling within the ground track swath of 200 nm was therefore considered to be a potential experiment opportunity. It is evident from this data and Appendix B that several target locations; i.e., the Gulf Stream and Chile, are observed only a few times throughout the entire flight; while other target areas, such as Zaire and Zambia are overflown more frequently, but have relatively few data gathering opportunities during daylight.

The assignment of orbital data taking segments was predicated on obtaining sufficient data over those targets observed only a few times as a first priority. (It should be noted here that the first and final eight orbits were arbitrarily excluded from any data taking and reserved for STS operations.) Next, orbital passes over CONUS were divided among the experiments based on geographical proximity of the target to the ground track, lighting, and number of

Table 5-2. CONUS Target Opportunities/Selections

Experiment	Area	# of Opportunities	# of Selections	Total Minutes of Data
Millimeter Waves	VPI, GSFC, OSU, Rosman	11	8	19.5
Electromagnetic Environment	CONUS	12	12	74
Mineral Survey	S.W. United States	15	4	18
Timber Inventory	CONUS	41	5	30
Urban Planning	CONUS	41	11	56
Urban Planning	Hawaii	4	2	4

Table 5-3. Non-CONUS Target Opportunities/Selections

Experiment	Area	# of Opportunities	# of Selections	Total Minutes of Data
Ocean Currents	Gulf Stream	4	4	6.5
Ocean Currents	Sea of Japan	14	10	20.5
Sea Surface Temp.	Newfoundland Banks	10	5	11.5
Sea Surface Temp.	Spanish Sahara Coast	8	5	12.5
Sea Surface Temp.	Peruvian Coast	5	2	12
Mineral Survey	Northern Chile	3	2	4.5
Mineral Survey	Peru	4	2	12
Mineral Survey	Zaire	8	5	21
Mineral Survey	Zambia	6	3	6.5

opportunities. Finally, those experiments involving global or large area coverage were accommodated as fillers in the timelines. The Solar Monitoring, Constituent Measurement, Cloud Climatology, and Ozone Mapping experiments are included in this category for the following reasons:

1. Solar Monitoring - independent of geographic location, target is the full sun; opportunities exist twice each orbit during the post sunrise/pre sunset time frames.

2. Constituent Measurement - global coverage is the ultimate goal, but observation must occur during the sunrise and sunset time frames.

3. Cloud Climatology - essentially independent of geographic area since the targets are clouds, which can be found almost globally; however, statistical probabilities indicate latitudes between 0-15° and 30-50° are most promising.

4. Ozone Mapping - total earth coverage is the ultimate goal; however, continental areas between 20-50° North and South latitude are first priorities.

5. Passive Atmospheric Sounding - global coverage is the ultimate goal.

Similarly, the Ocean Waves experiment over the North Atlantic and North Pacific, the Sea Surface Temperature experiment over the Intertropical Convergence Zone, and the ESA Microwave Scatterometer over broad ocean areas are used as fillers since they are overflown many times and have many data taking opportunities with essentially no competition for operations during that time. A definite attempt was made here to achieve a patterned coverage over the entirety of these areas. Snapshot illustrations for each experiment requiring definitive target coverage are shown in Figures 5-2 through 5-11.

Also considered in the assignment of data taking opportunities for the various experiments was the probability of experiment success as it is influenced by cloud cover. Experiments such as Urban Planning, Mineral Survey, and Timber Inventory are dependent upon the ability to acquire good photographic data. For the purposes of this study, photographable skies are defined as those skies in which there is at least 75% visibility (up to 25% obscurity by haze or partly cloudy skies may exist). Information obtained from a reference document - "Further Developments in Cloud Statistics --," NAS CR-61389 - indicates the probability of clear and photographable conditions for various geographic locations. Table 5-4 summarizes this data for the period between August and September for the geographic areas of interest.

It is observed from Table 5-4 that there is a relatively high probability (70%) of encountering photographable conditions for the Mineral Survey experiment over the CONUS target area - Southwestern U.S. The probability of photographable conditions for the non-CONUS areas of

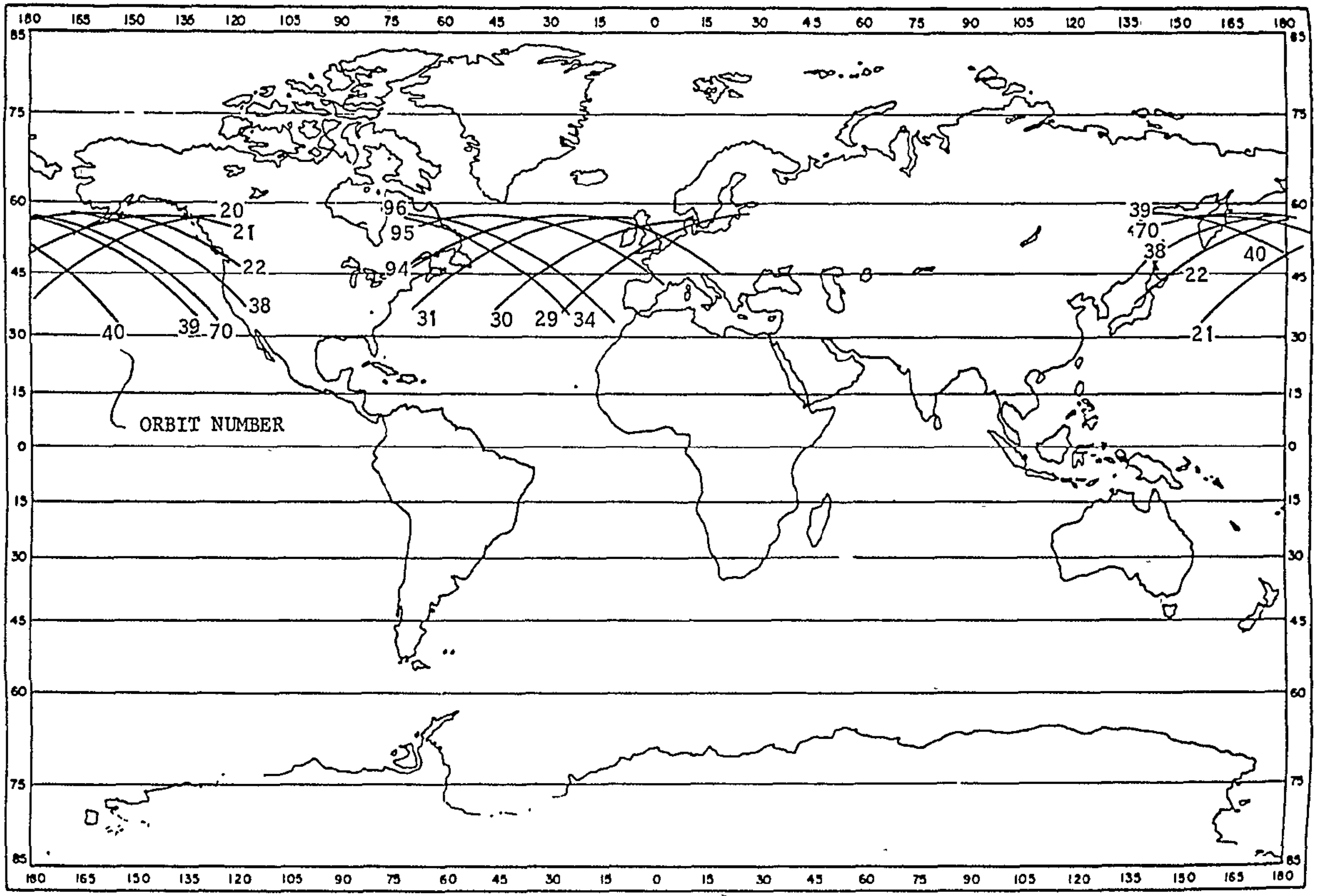


Figure 5-2. Ocean Waves

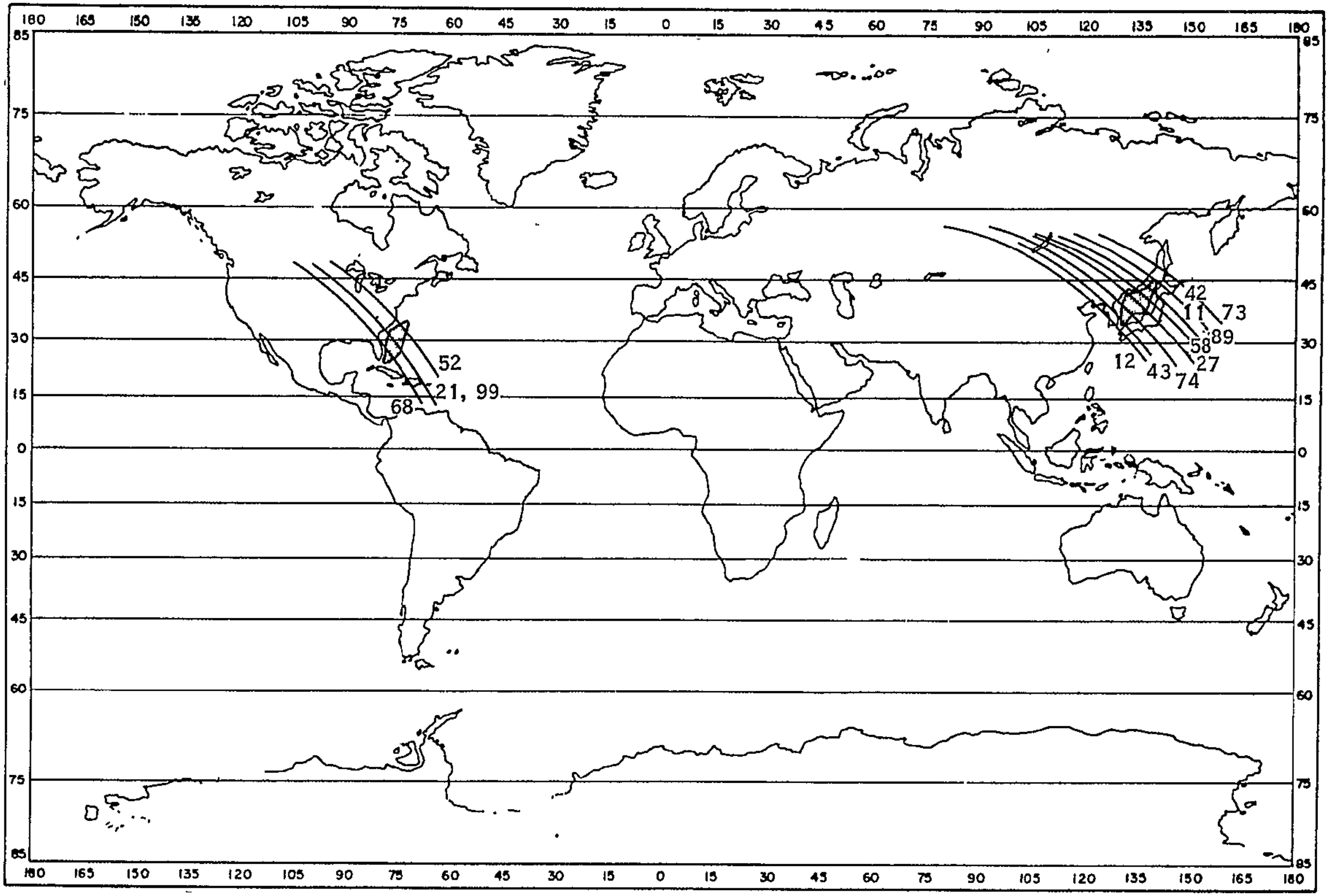


Figure 5-3. Ocean Currents

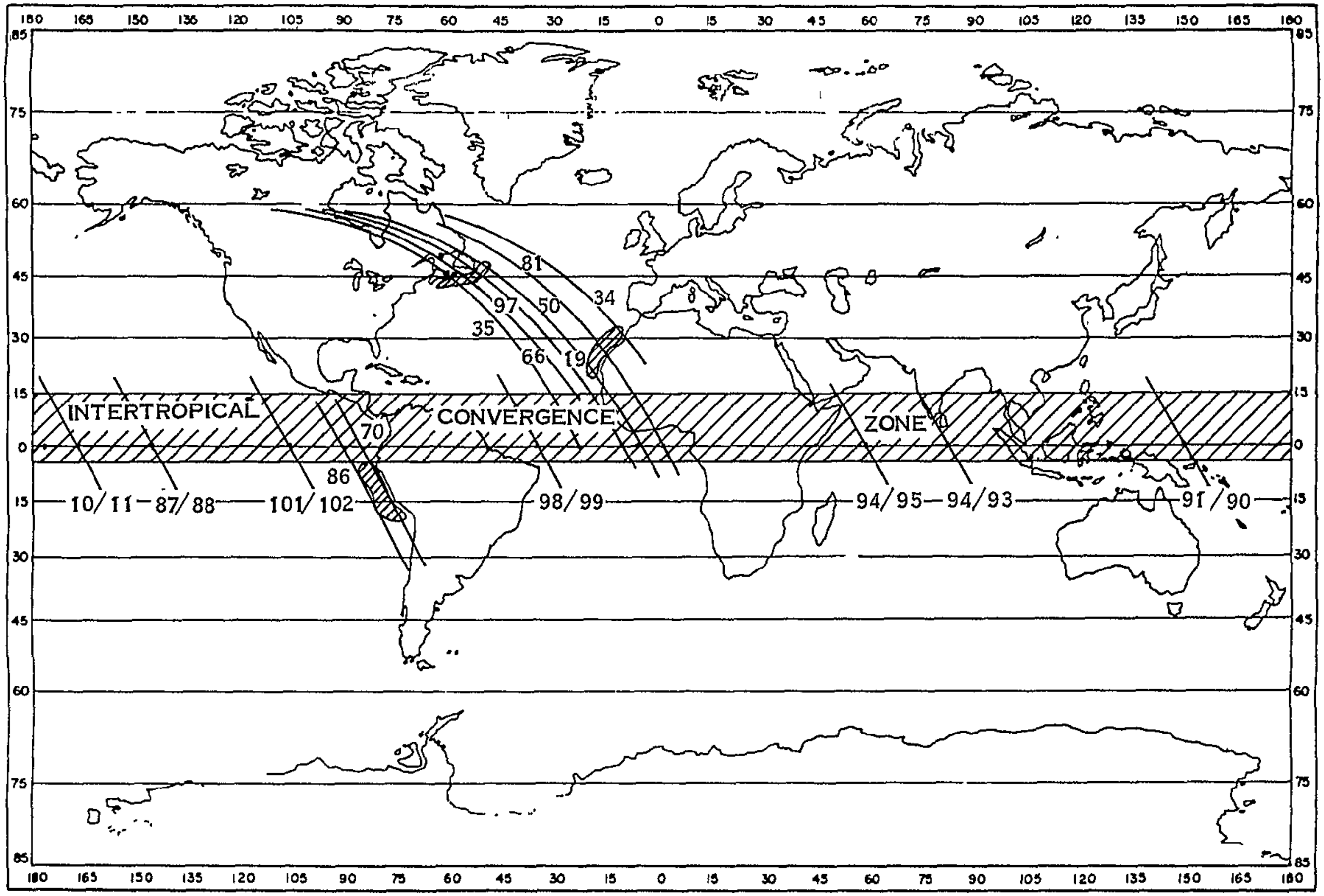


Figure 5-4. Sea Surface Temperature

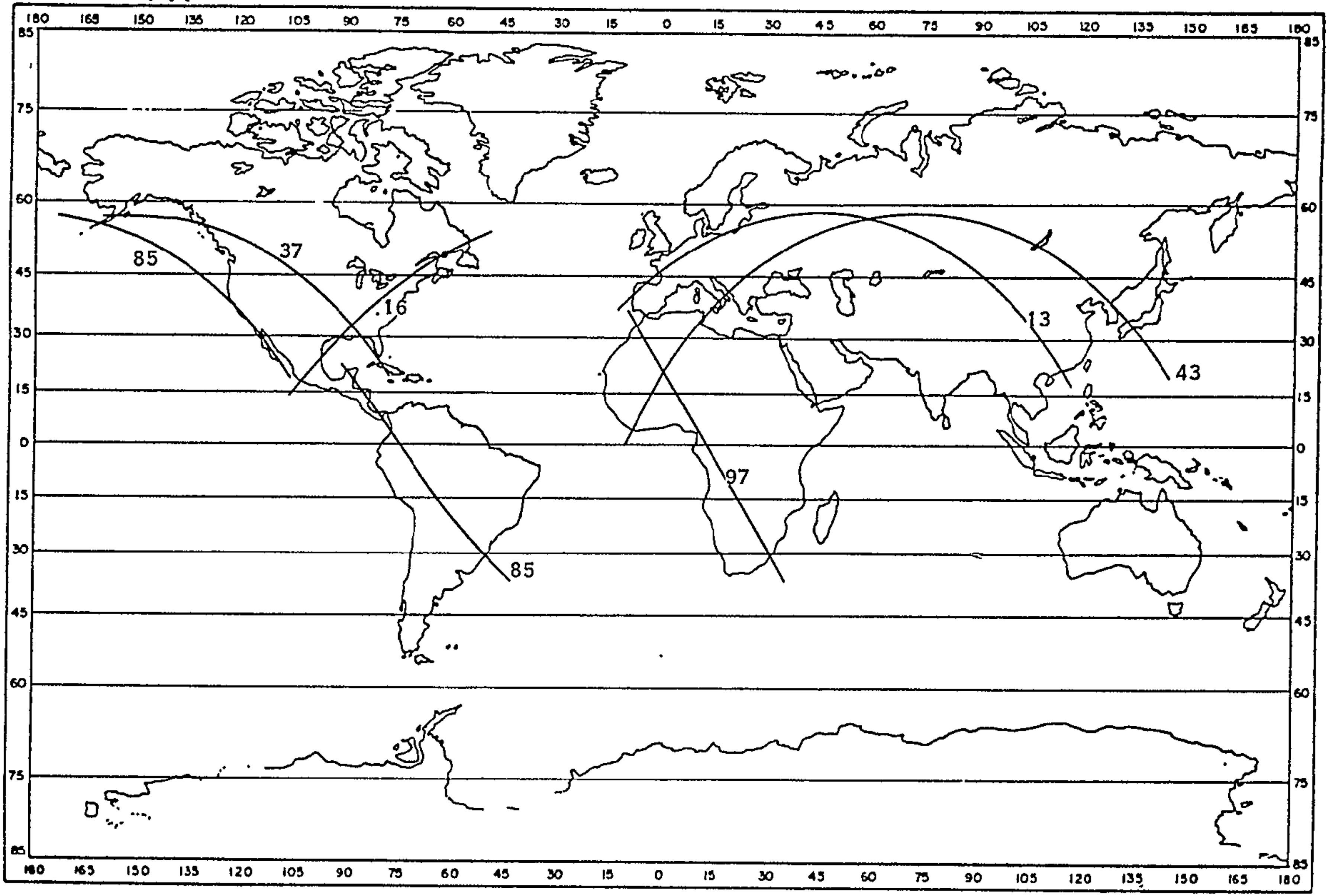


Figure 5-5. Ozone Mapping

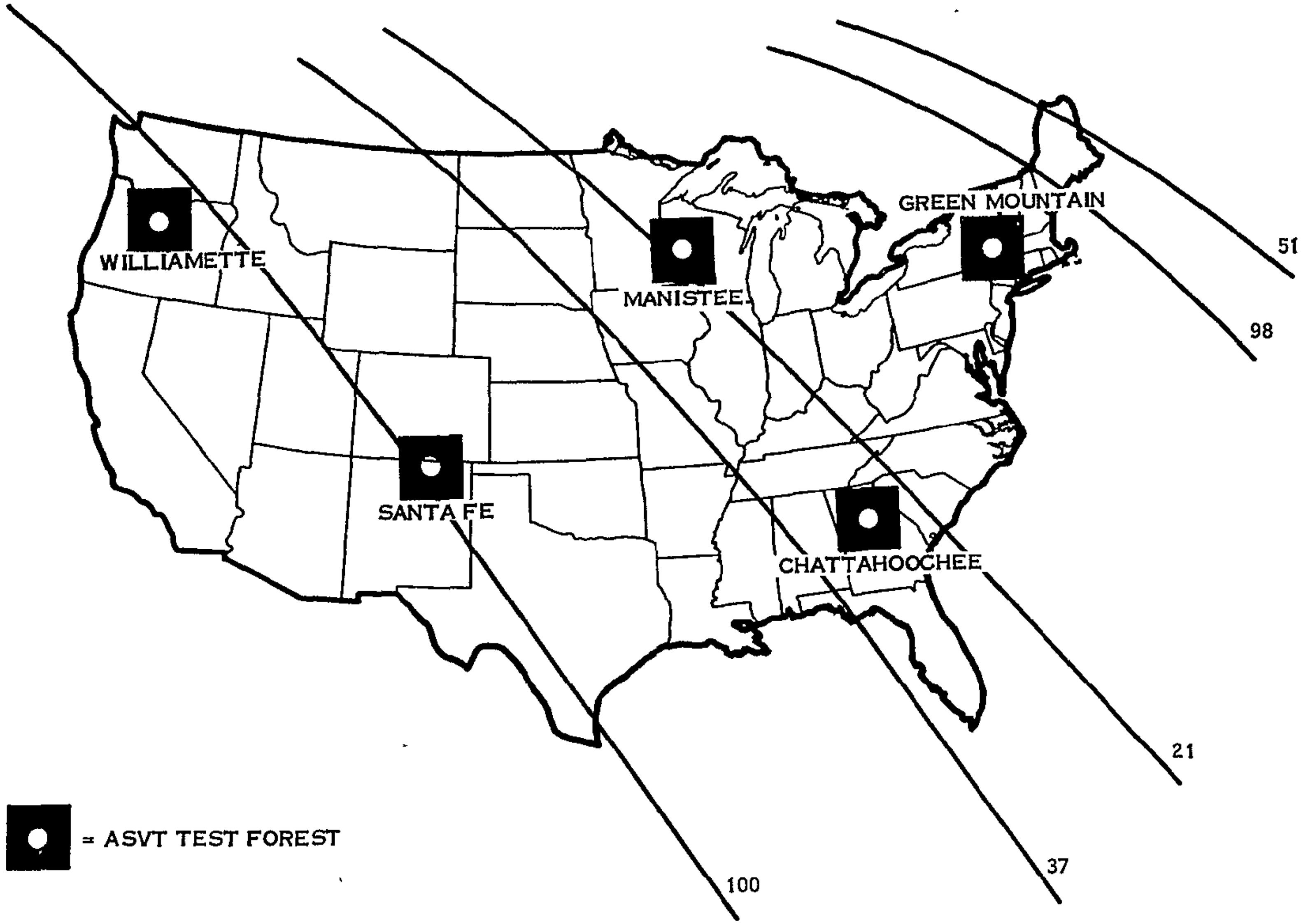


Figure 5-6. Timber Inventory

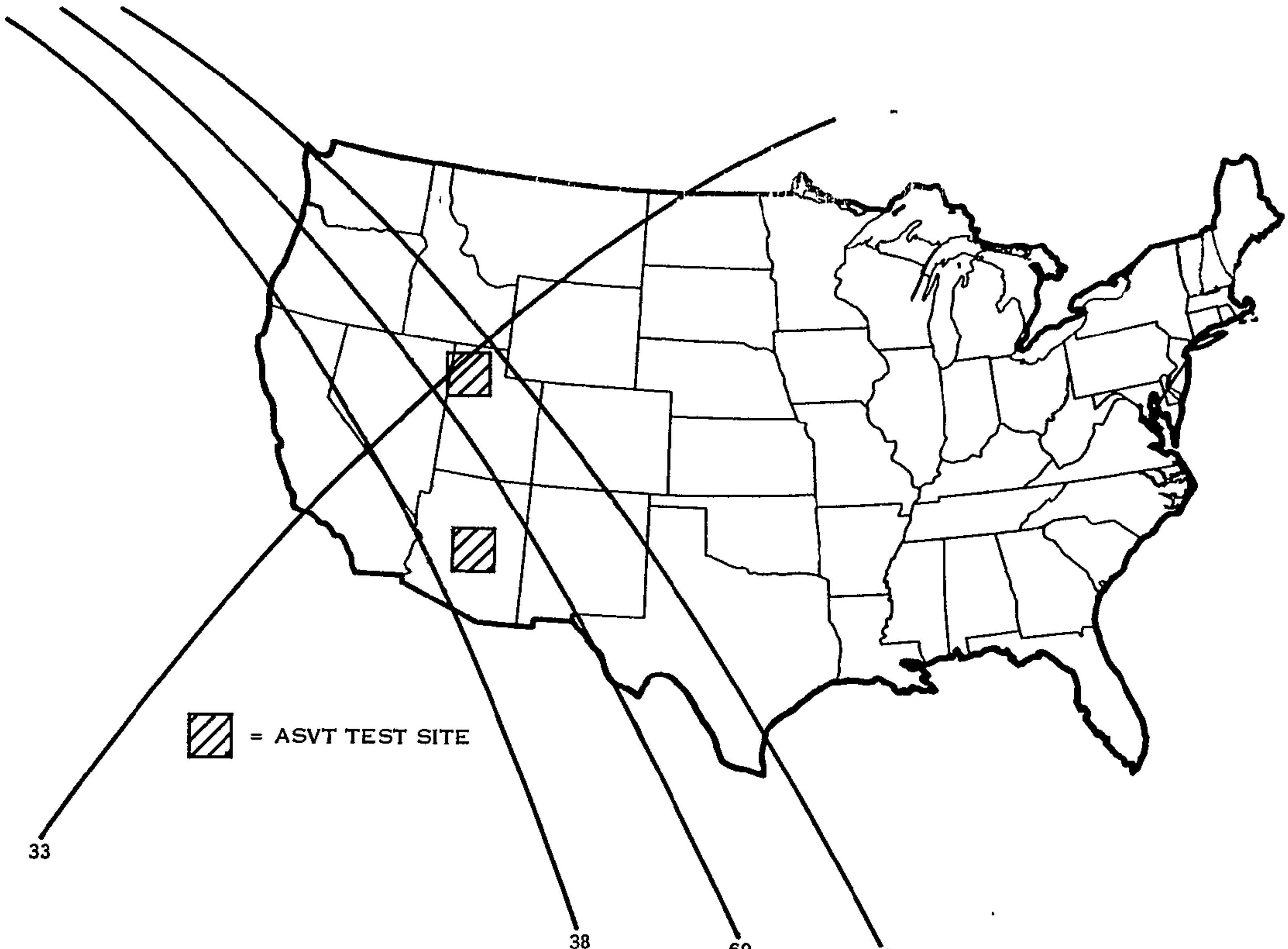


Figure 5-7. Mineral Exploration

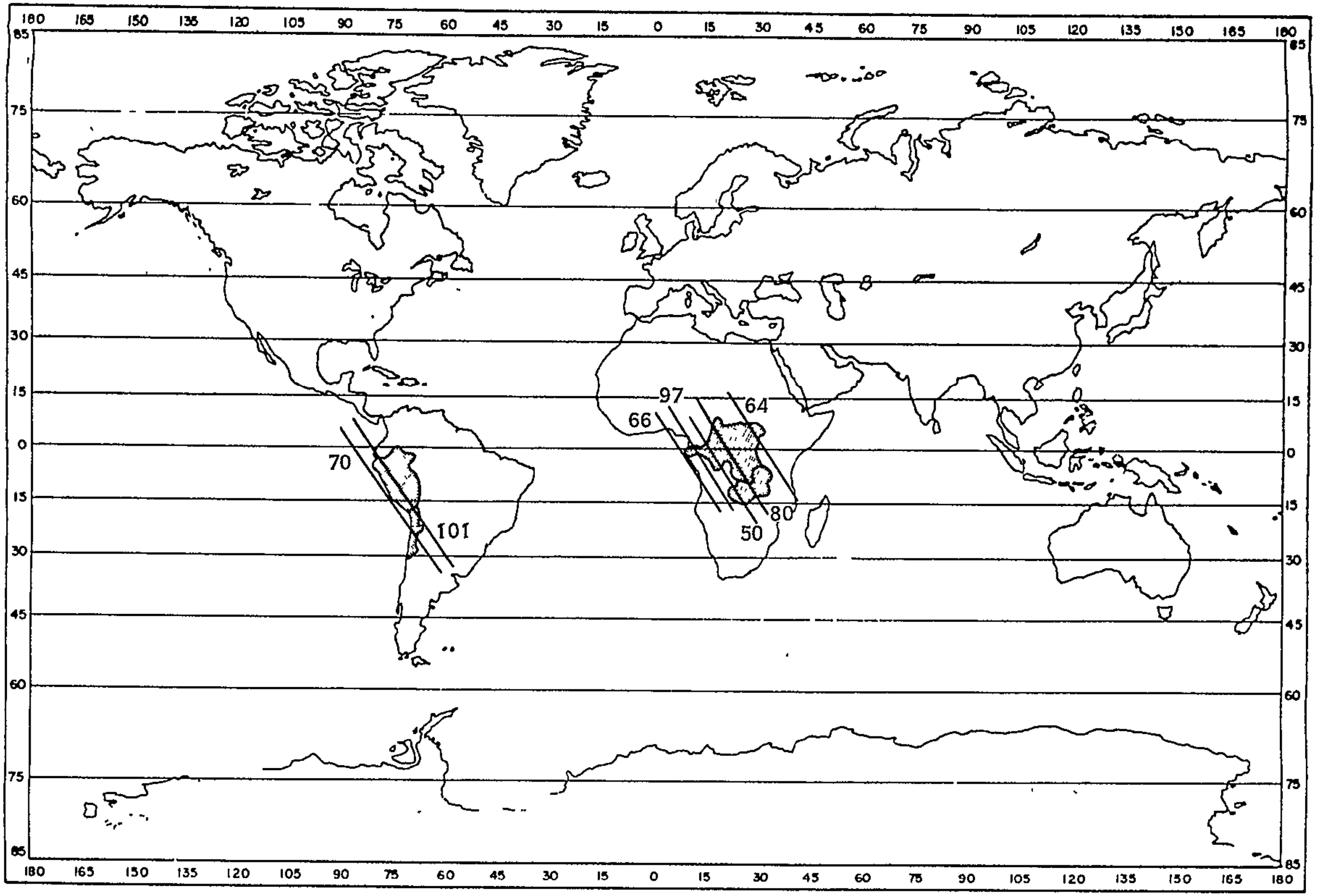


Figure 5-8. Minerals - Non-CONUS

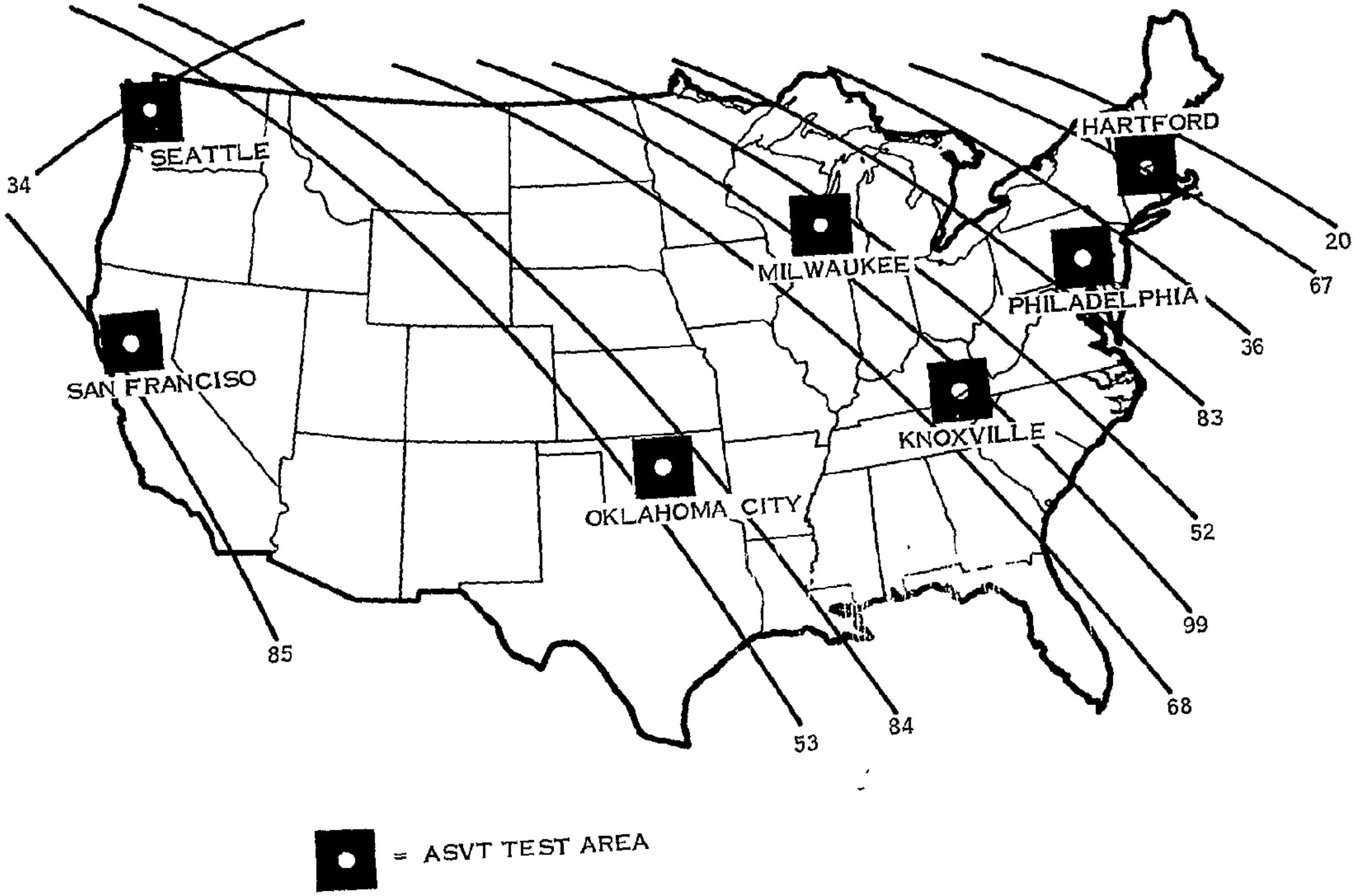


Figure 5-9. Urban and Regional Planning

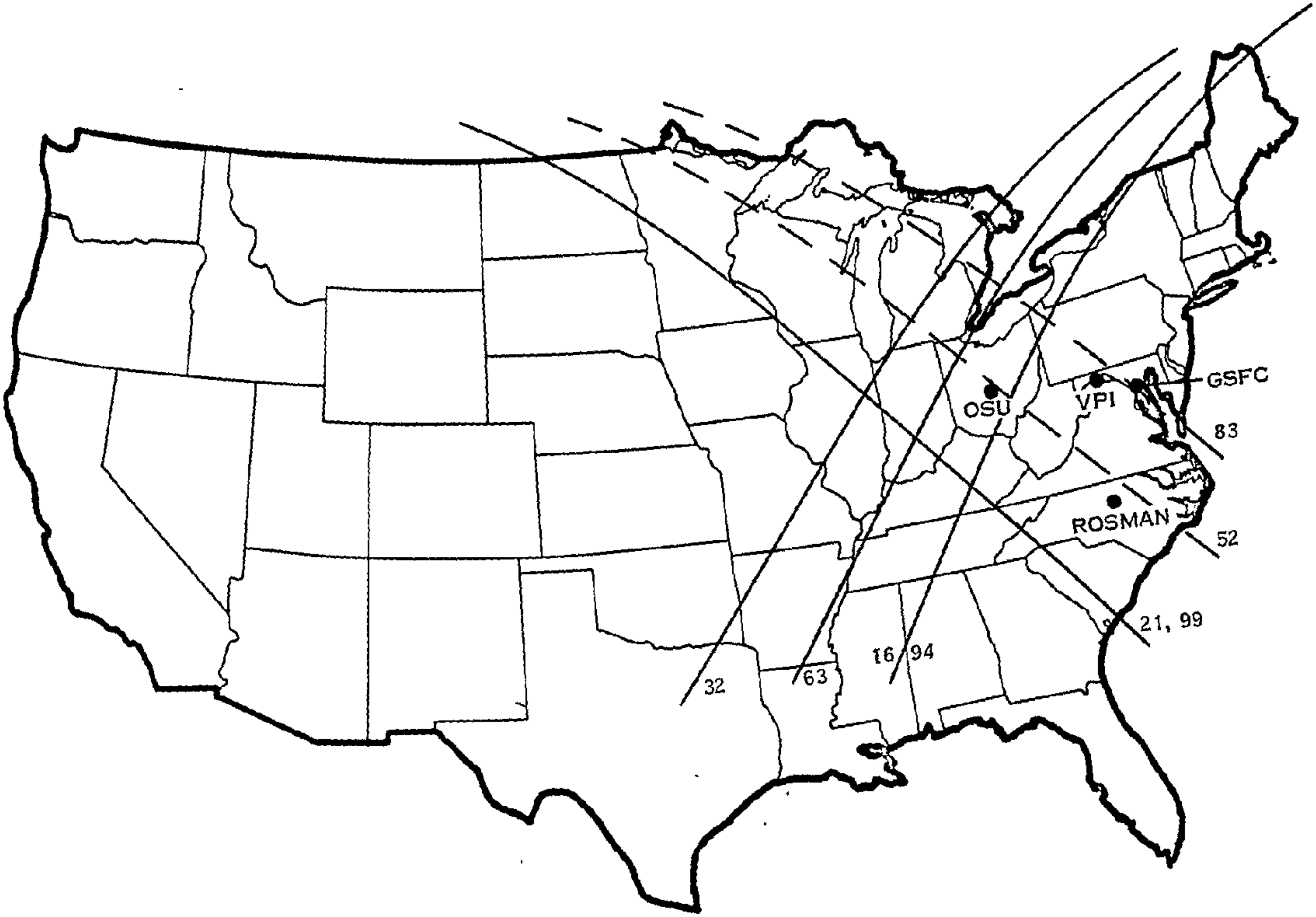


Figure 5-10. Millimeter Wave

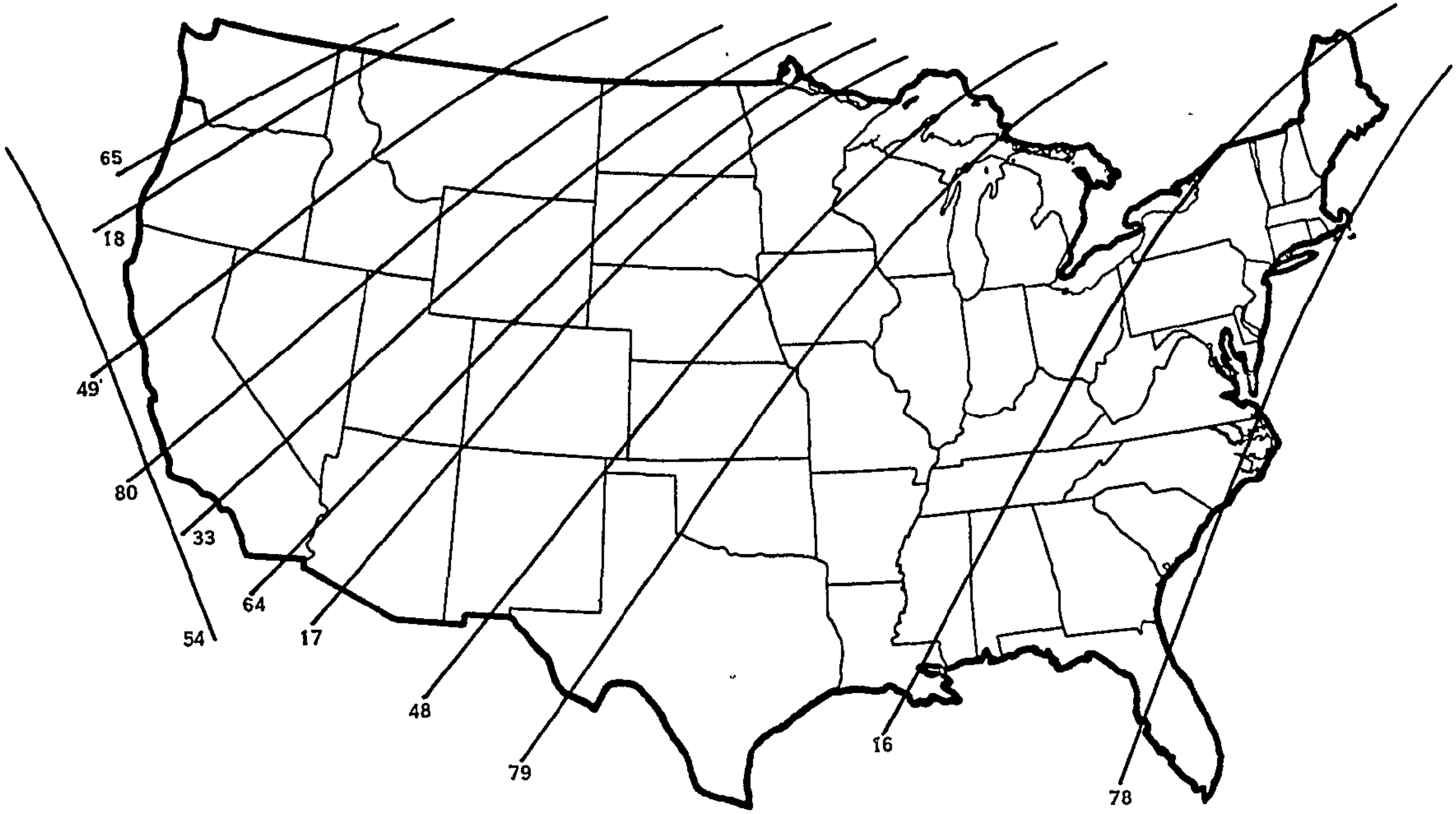


Figure 5-11. Electromagnetic Environment

the Mineral Survey experiment (Chile, Peru, Zambia, Zaire) is approximately 50%, with the exception of the northern Chile area, which is 70%. Table 5-5 indicates the number of passes over these target areas, and the overall probability of experiment success for the flight.

Table 5-4. Probabilities for Cloud Conditions

	Clear	Photographable	Rain Clouds
Northeastern CONUS	28	45	19
Northwestern CONUS	45	64	11
Southwestern CONUS	41	70	4
Southeastern CONUS	23	43	20
Hawaii	3	25	-
Northern Chile	41	70	-
Southern Peru	20	50	-
Zambia	22	52	-
Zaire	20	51	-

Somewhat different results are noted for the Urban Planning mission, in that more data passes are required over areas such as the northeastern and north-central CONUS to achieve a high probability of mission success. In those areas where only one or two opportunities are available (Northwestern CONUS, Southeastern CONUS, Hawaii), the probability of mission success is only moderate.

The probability of having photographable conditions on any one pass over the target areas for the Timber Inventory experiment are similar to the conditions which exist for the Urban Planning mission (i.e., 40% to 70%). The number of available opportunities to accomplish this experiment in the specified areas are also limited however, therefore, the overall probability of experiment success for the flight is not generally as high as for the other experiments.

Table 5-5. Probability of Mission Success

	Probability of Photographable Conditions	Number of Passes	Probability of Mission Success
Mineral Survey			
Southwestern CONUS	70	4	99
Northern Chile	70	2	91
Southern Peru	50	2	75
Zambia	52	3	89
Zaire	51	5	97
Urban Planning			
Northeastern CONUS	45	7	98
Northwestern CONUS	64	1	64
Southwestern CONUS	70	4	99
Southeastern CONUS	43	1	43
Hawaii	25	2	44
Forest Inventory			
Northeastern CONUS	45	3	84
Northwestern CONUS	64	1	64
Southeastern CONUS	43	1	43
Millimeter Wave Propogation			
Mid Atlantic States	19 (Rain)	8	75

For the larger geographical target areas, the probability of mission success can probably be improved by some form of adaptive cloud avoidance. Optical and/or microwave systems could be developed to look ahead and discern cloud free areas to which the Orbiter could be maneuvered; or the system might be as simple as using a crewman to visually look ahead and select the most promising areas. Real-time coordination with observers physically located in the target areas might also prove feasible.

In the case of the Millimeter Wave Propagation experiment, the situation is reversed in that the primary interest is transmitting microwaves through rain clouds rather than photographing through clear skies. (A few transmissions in clear skies are also required, however, for calibration purposes.) Consequently the statistic of interest in this case is the probability of rain clouds in the target area, which is the mid-Atlantic states. Table 5-5 indicates that while the probability of rain clouds existing over the target area is quite low (19%), the probability of experiment success is high because of the number of opportunities which are scheduled.

5.2 MISSION TIMELINES

In addition to satisfying the previously mentioned experiment observation requirements, experiments were also timelined to achieve synergistic benefits whenever possible, and a self-imposed viewing constraint was observed for other sensors whenever the EEE/MW antenna assembly was deployed or the ESA scan platform was operating.

The overall process involved several iterations, with the resultant being a set of mission timelines. A sample of this mission timeline is shown in Figure 5-12, while the complete set is provided as Appendix C. The power and data profiles shown across the bottom of these timelines indicate the power and data profiles for the EVAL sensors only. The mission "on" times are indicated by the horizontal dark lines, while the interval encompassed by the vertical tick marks on these lines denotes the actual data gathering period.

It is observed from the EVAL timelines that throughout the mission, operations are characterized by periods of high activity, followed by approximately one hour of no observations or measurements, and then another period of activity followed by another period of inactivity. This cycle is essentially repeated throughout the flight, and is caused by a combination of factors involving lighting and geographical locations. Because of the launch conditions chosen, the southern hemisphere and India/Asia/China are generally overflown during periods of darkness. This lack of lighting, coupled with the fact that few experiment target areas are located over these areas, accounts for the cyclical periods of inactivity. This characteristic is highly desirable in that it allows the Shuttle/Spacelab crew, as well as the principle investigators on the ground, time to briefly evaluate the just-acquired data and plan for the next data take. In

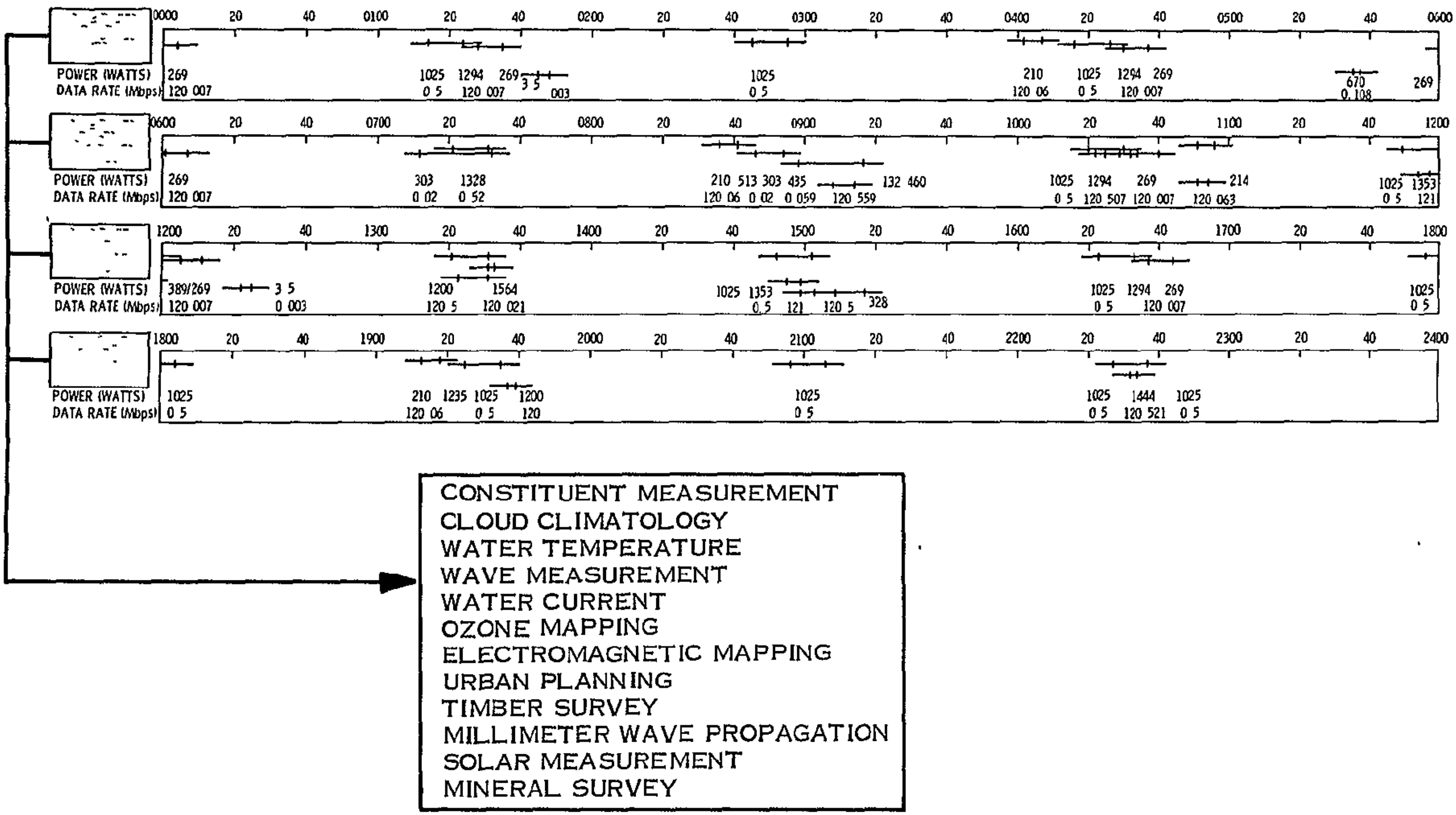


Figure 5-12. Sample Mission Timeline

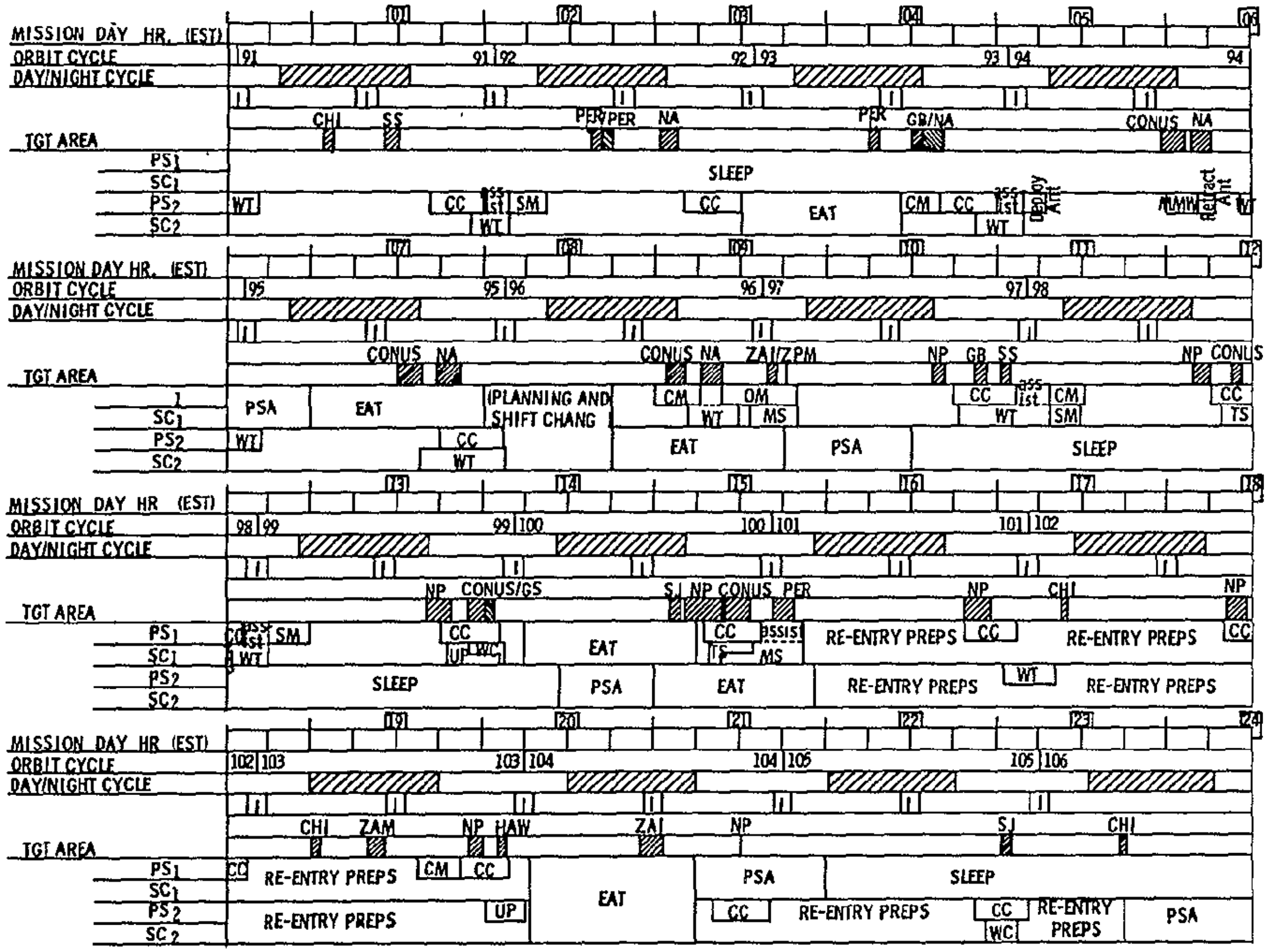
this study, the ESA payloads were frequently fitted into these gaps since their target areas of interest are quite flexible.

5.3 CREW REQUIREMENTS

Crew requirements emanating from the mission timelines indicate a two shift on-orbit operation. The Cloud Climatology experiment is conducted intermittently throughout the flight and requires a high degree of training and on-orbit dedicated operation; therefore, two payload specialists are required to operate this experiment and be responsible for the majority of the other experiments. Because of simultaneous experiment operations, Orbiter crew support was also utilized for monitoring selected payload experiments. (It is assumed that the Orbiter mission specialist would be the primary crew member assisting in the experiments, with additional support provided by either the commander or co-pilot, as available). The total number of personnel required on board for this flight, therefore, is five; commander, co-pilot, mission specialist, and two payload specialists. Crew operational assignments were developed under the following ground rules:

1. Each work day contains an eight hour sleep period where possible.
2. A minimum of six hours of sleep is required by all crewmen prior to re-entry.
3. Three hours of each workday is required for the three meal periods.
4. 1-1/4 hours of each work day is allocated to crew pre- and post-sleep activities (PSA).
5. 1-1/2 hours of each work day is allocated to crew planning and shift change activities.
6. Payload Specialists are the prime operators of Payload Equipment with Orbiter crew support as required.
7. The first and last eight orbits are dedicated to Orbiter/Spacelab activation functions.
8. Midnight of day six terminates Payload experiment operations.

Figure 5-13 shows a typical timeline for a particular day while the total integrated crew timeline is provided as Appendix D.



PS - Payload Specialist

SC - Shuttle Crewman

Figure 5-13. Crew Timeline

SECTION 6

SYSTEM REQUIREMENTS AND ACCOMMODATIONS

SECTION 6

SYSTEM REQUIREMENTS AND ACCOMMODATIONS*

6.1 DATA MANAGEMENT

The EVAL payload analyzed within this report consists of fifteen sensors, which are frequently used in combinations as shown in Table 6-1 to satisfy the requirements of the various experiments. In addition, multiple experiments are frequently being conducted simultaneously; therefore, as many as eleven sensors may be operated at a single time. This creates a very complex data handling problem with data rates varying from a few hundred bits per second to over 120 megabits per second.

The EVAL data management problem therefore consists of three parts: providing sufficient time to either transmit and/or record the data, identifying equipments required, and ensuring compatibility with the Spacelab data handling system.

Shuttle will operate in the TDRSS era; thus this system is a possible solution. Data transmission can be accomplished between Shuttle and TDRSS at a 50 mbps rate via a Ku band link, and low bit rate (< 64 kbps) data can be transmitted directly over the S-band link to the STDN. Unfortunately most of the EVAL missions have data rates well above the S-band link's capabilities and the STDN stations are not observed for long enough periods to be feasible. The TDRSS link is another matter. The operational mode of EVAL is Earth Viewing. This requires pointing the positive Z-axis (orbiter coordinates) toward the local vertical. In this position the possibility of line of sight blockage due to wing and tail surfaces between the Ku-band antenna on Shuttle and the TDRS is greatly increased over conventional flights with the positive axis pointing outward. This will invariably create communication gaps in addition to the "Indian Ocean" gap inherent in the TDRSS coverage.

*Consideration of the ESA experiments have been omitted from the discussion on data handling and pointing and stability due to lack of detail requirements. Equipment characteristics for these experiments have been sufficient, however, to include them in the analysis on power and thermal.

Table 6-1. Sensor Commonality

Sensors \ Missions	Urban & Regional Planning	Timber Inventory	Mineral Survey	Cloud Climatology	Solar Energy Monitoring	Ozone Sounding	Constituent Measurements	Sea Surface Temperature	Ocean Currents	Ocean Waves	Electromagnetic Environment	Millimeter Wave Propagation
Thematic Mapper	(X)	(X)	(X)				X	X	X			
Photo Pack (Large Format Camera)	(X)	(X)	(X)									
S-193 Rad/Scat/Alt		X	X					X	(X)	X		
GEOS C Altimeter									(X)	(X)		
Scanning Microwave Radiometer								(X)	X			
Laser Ranging System				(X)								
Cloud Physics Radiometer				(X)								
LACATE						X	(X)					X
HALOE							(X)					X
SER						X	(X)					
HSI						X	X					X
SBUV						(X)	X					
ESP					(X)		(X)					
EEE											(X)	(X)

Legend: (X) Required

X Desired

The standard Shuttle Ku-band antenna can be augmented, however, by an optional "add-on" system. (The locations of the standard and add-on Ku-band antenna on Shuttle are shown in Figure 6-1). Estimates of the TDRS contact time available with one and two antennas is provided in Table 6-2. This dual antenna system results in a charge of 131.5 kg against the payload and requires somewhat more sophistication to operate (mode selection, etc). It does, however, provide greater flexibility in eliminating antenna line-of-sight blockage to the TDRS by the Orbiter and Spacelab. Table 6-2 shows that the management of data readout may require substantial buffering to accommodate the contact with TDRS gaps.

The standard equipment available in the Spacelab accommodations can neither buffer nor directly handle the 120 mbps rate associated with the Thematic Mapper (TM). Thus, special means of accommodating this data must be provided.

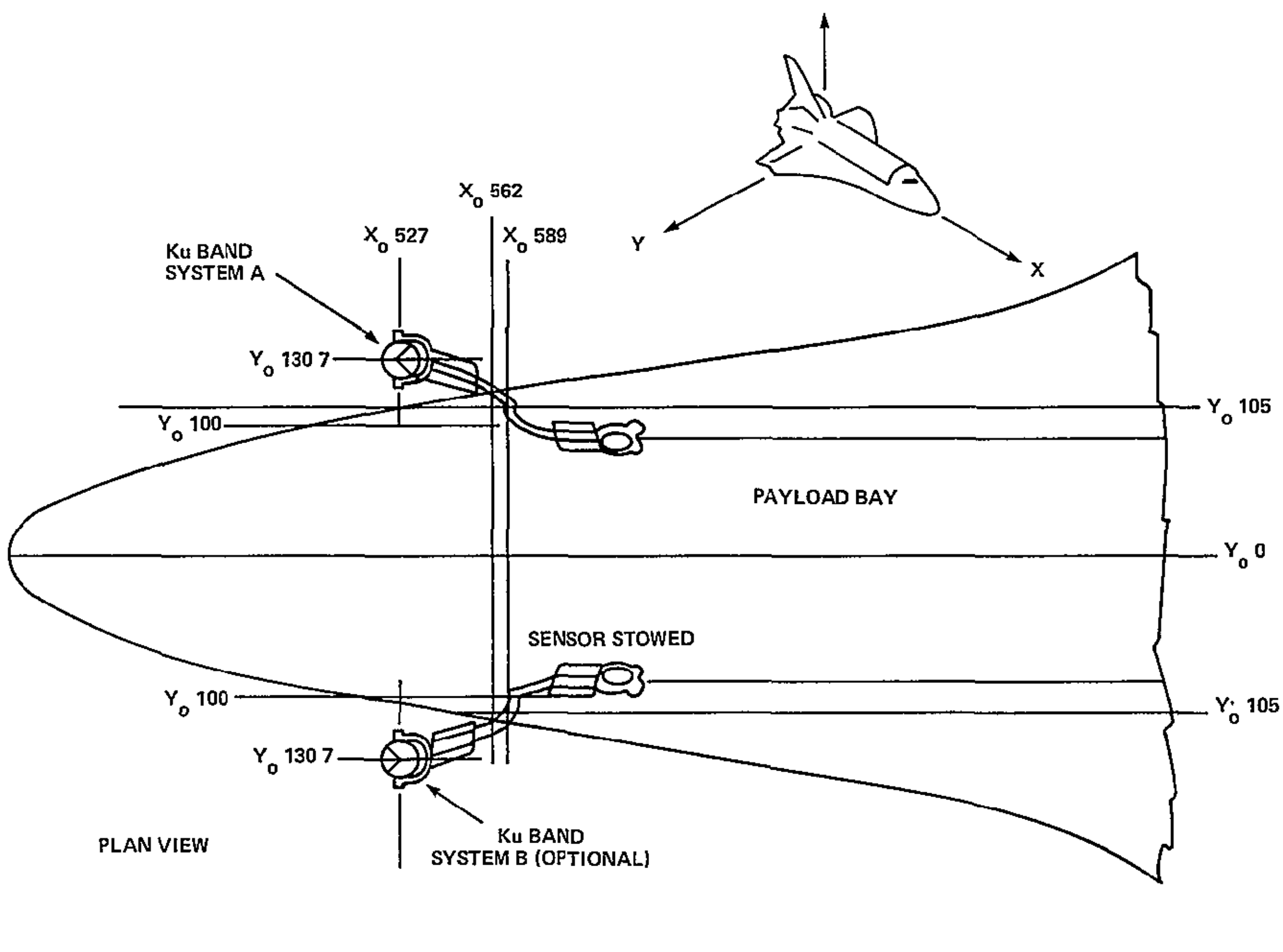


Figure 6-1. Ku-Band Antenna Locations

Table 6-2. TDRSS Contract Time (Assuming the Availability of Either of Two TDRS)

	System A, Base Line Ku-Band Antenna	System B, Two Ku-Band Antennas
% Coverage	60	81
Avg. Continuous Coverage (Min.)	23	35
Avg. Coverage Gap (Min.)	15	8

The timeline analysis shows that the TM will be utilized between 55 to 82 minutes per day, or that close to 6×10^{11} bits per day are accumulated. Recording this data is an economical solution and can provide the buffering both for slowing down the data rate and for bridging the TDRS communications gaps. A search for a suitable recorder revealed that a development is in progress at RCA, sponsored by NASA Goddard Space Flight Center, which may provide a solution. The development is based upon a proposed design for an automatic recorder for advanced Landsat vehicles. The version currently in design will operate in a pressurized cabin with an operator interface (for tape changes, servicing, etc.). Data storage capability will be 2×10^{11} bits per reel of tape (2" wide on 14" diameter reels). The device is not directly applicable to the EVAL problem but is early enough in the development stage to allow minor redirection to the requirements for a very Very High Rate Data Recorder (VHRDR)

The VERY HIGH RATE DATA RECORDER has the following tentative specifications:

Data Rate	240 mbps (2 parallel channels of 120 mbps)
No. of Data Tracks	120
No. of Timing Tracks	12
Data Density	20 KBpi
Record Speed	100 ips
Readout Speed	100 ips
Rewind	18 minutes and 100 ips
Track Width	8 mils
Medium	2" tape on 14" dia. glass reel, 10 kg each
Tape Change Time	4-5 minutes

To be applicable to EVAL, the following specifications would apply:

Data Rate	120 mbps
No. of Data Tracks	120
No. of Timing Tracks	12
Data Density	20 Kbpi
Record Speed	50 ips (36 minutes)
Readout Speed	50 ips (36 min), 20 ips (90 min)
Rewind Time	18 minutes (100 ips) acceptable, 4.5 minutes (300 ips) desired.
Track Width	8 mils
Medium	2" tape on 14" dia. glass reels, 10 kg each
Tape Change Time	4-5 minutes
Start Time	10 sec. or less
Stop Time	5 sec. or less
Tape Replacement Time	5 minutes or less

The slow readout option (20 ips) makes the data rate compatible with transmission over the Ku-band TDRSS link.

The 36-minute record time is compatible with the utilization of the TM for the required missions associated with this flight. The timeline study showed that the TM is used for periods ranging from 1-14 minutes with an average "on time" being 5 minutes. The time between "on times" exceeds 5 minutes in almost all cases. Thus, a viable tape management scheme can be evolved using a 36-minute record capability, start time of 10 second, stop time of 5 seconds, and tape replacement time of 5 minutes or less (see example Figure 6-2).

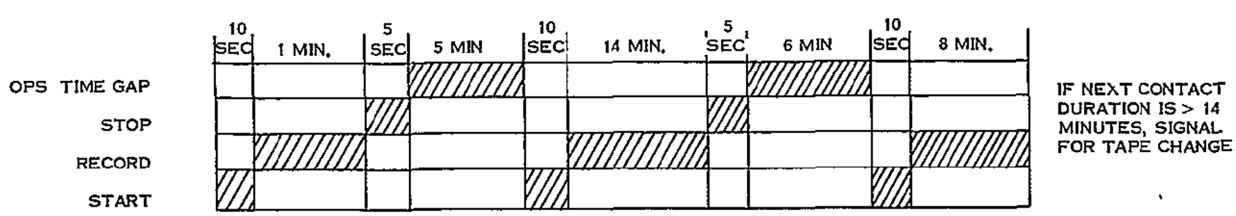


Figure 6-2. Tape Changing Logic

An alternative solution is possible if the requirement for ground receipt of the data prior to landing is removed. The data from EVAL can be logically partitioned into two segments, the very high rate data from the TM, and all other data. There is no specific urgency associated with the receipt of any of the experiment data, in fact the Large Format Camera data (used in 5 of the missions) is available only after completion of the orbital mission. Thus, an initial ground rule that data be available within 6 to 7 days of acquisition seems viable. This allows consideration of the possibility of returning all data in recorded form at the conclusion of the mission. The sum of the data rates associated with all sensors, excluding the Thematic Mapper, is 635.8 kbps. Sampling will increase the apparent data rate seen by the experiment data bus (which is rated at 1 mbps). To reduce the data rate at the experiment bus, the three highest rate sensors (Electromagnetic Environment Antenna/ Millimeter Wave Transponder, Cloud Physics Radiometer, and the High Speed Interferometer) are routed directly to the Spacelab High Rate Multiplexer and the lower data rate sensors are routed to the experiment data bus (see Figure 6-3).

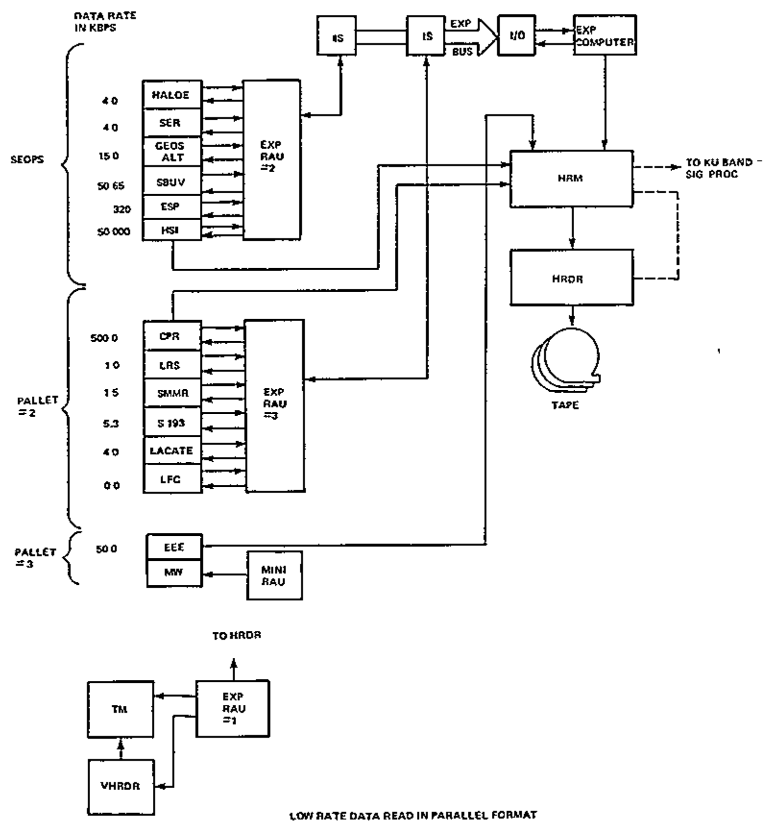


Figure 6-3. Data Systems

This implies that all data is recorded directly from the data bus (experiment computer rejects redundant data and compacts format) onto the High Rate Data Recorder (HRDR); while the TM data is recorded onto the Very High Rate Data Recorder (VHRDR). The estimated tape usage for this mode is shown in Table 6-3. The data in this table is calculated based on the fact that nighttime experiment operations contribute only a very small portion of the total data for this payload, and that the daytime duty cycle (time on/total daylight pass) is 50% (or 22 min) for all non-TM operations.

Table 6-3. Tape Usage

Data	Recorder	No. of Tapes for 6 Day Flight	Cost of Tapes	Wt/Tape	Total Tape Wt.
TM	VHRDR	18	$4500	10 kg	180
All Other	HRDR	1	$180	4.8 kg	4.8

This appears to be a very cost and weight effective solution. Both the VHRDR and HRDR are required by the system for data buffering. Thus, their cost and weight are non-negotiable (on a system basis). The weight penalty incurred by not transmitting experiment data is 170 kg (18 tapes at 10 kg each for recording all the data versus a single tape at 10 kg for temporary recording prior to playback). This practically offsets the 131.5 kg weight of the additional Ku-band antenna that would be required to ensure sufficient TDRS contact time for real time (or close to real time) readout.

The problem involved with reading out the TM data deserves some additional discussion. The record time is approximately 85 minutes per day on the average (at 50 ips). Rewind at 100 ips would require 40 minutes per day and readout at 20 ips another 243 minutes per day, plus three tape changes (total 15 minutes).

This results in a total time required for rewind and readout of 3 tapes of 328 minutes per day, or about 1-3/4 hours per reel. Conceivably, the data could be readout from partially-filled reels during the night portion of the orbit. If 10 minutes of TM data is accumulated during the daytime pass, it would require 5 minutes rewind time and 25 minutes readout time, plus another 5 minute rewind cycle. The total time required would be 35 minutes. The time available between successive TM activities varies from 5 minutes to 9.7 hours. Thus, some form of managed timeline involving line-of-sight to TDRS availability could achieve complete data readout. The cost of using the TDRSS downlink is about $\$4.72 \times 10^{-9}$/bit $\times 6 \times 10^{11}$ bits/day x 6 days = \$16,992. This is about four times the cost of the tapes shown in Table 6-3, but still relatively significant. In addition, the cost of implementing the "management" of this scheme should be considered. The cost of reading out the non-TM data is 9×10^{8} bits/day x 6 days x $\$4.72 \times 10^{-9}$/bit = \$25.51 which is essentially negligible, and the option could be included with almost no impact on system cost (see dotted lines on Figure 6-3).

The current system requirement (EVAL) can be satisfied by return of experiment data after orbiter landing. It can be expected that future missions may require "quick look" capability (both on board and on the ground) or faster data return, including real time or near real time transmission via TDRSS.

A data management approach capable of providing the expanded requirements is shown in Figure 6-4. This concept utilizes the same equipment as used in the minimal cost solution, plus an On-board Experiment Data Support Facility (OEDSF) and its associated Remote Acquisition Unit (RAU). This configuration has the capability to do on-board processing of data for quick look, data compression, etc. Instruments requiring convolution of output signals may show data rate reductions of the order of 60/1 when used in conjunction with OEDSF. A properly sized (5 x 5 matrix) OEDSF can perform on-board image geometric and radiometric correction on TM data (reducting the correlation problem for ancilliary data). The system shown in Figure 6-4 has the flexibility to use the on-board computer for low data rate processing, the OEDSF for high data rates, and special formating for the HRM.

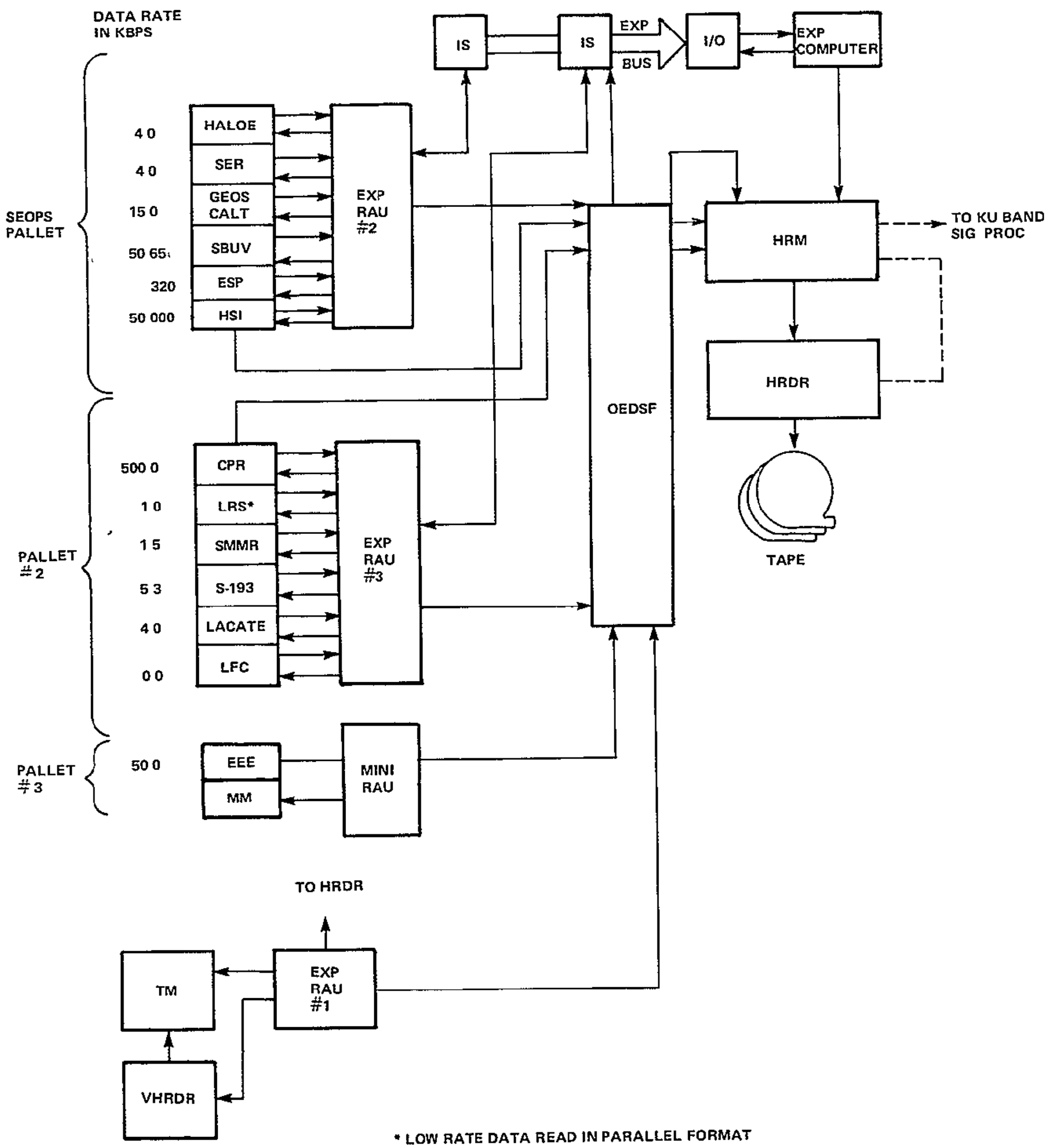


Figure 6-4. Expanded Data Systems

6.2 POINTING AND STABILITY

6.2.1 EARTH RESOURCES SENSORS

Candidate sensors for use in the Timber Inventory, Mineral Survey and Urban Planning experiments are the Thematic Mapper and the Large Format Camera. Shuttle attitude and rate limit cycle performance has been investigated and found to be sufficient to allow these sensors to be body fixed. Ground smear on the LFC film due to Shuttle roll rates of 0.01 deg/sec is held to 1 meter by using camera shutter times of 10 milliseconds (0.04 meter ground smear results from .01 deg/sec yaw rates). On the Thematic Mapper, Shuttle rates will cause misregistration of the data which can be corrected on a frame-by-frame basis through use of accurate rate measurements. Resolution between the lines of each frame due to Shuttle rate is held within the 7.75 micro-radian requirement.

The body fixed mount is preferred because:

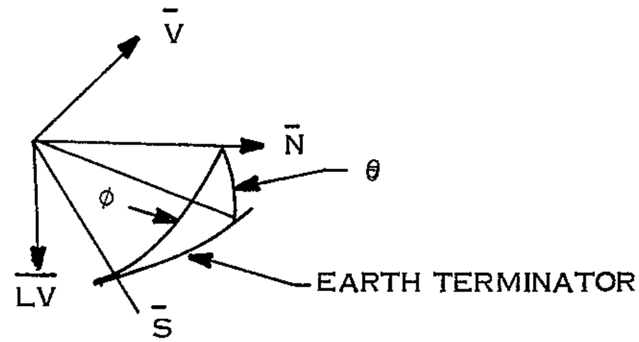
1. The LFC has internal compensation for reductions of smear due to Shuttle motion along track (v/h compensation). Gimballing the camera would require incorporation of the ground track profile as part of the gimbal commands.
2. The LFC focal length is fixed at launch assuming a specific circular orbit with constant orbit altitude. Offset pointing over a significant angle will force the capability of on-orbit adjustment of focal length.
3. Although not inhibited by focal length constraints, the Thematic Mapper does require transfer of large data rates. This high data rate transfer requirement is to be achieved by parallel transfer from the sensor detector elements, forcing use of a relatively large wire bundle. The present side-to-side sensor coverage is obtained through use of a stepping mechanism (internal to the sensor) that orients the optical line of sight to discrete angles within a range of ± 20 degrees about nadir before the experiment is started. This is a positive (or detent) mechanism not requiring closed loop servo control; hence, not subject to errors as the result of harness torques from the data transfer wire bundle. During operation of the experiment, a ± 7 degree cross-track field of view sweep is obtained by driving a flat surface mirror (linear scan) leaving the detector elements fixed. Thus, data transfer cables do not have to be flexed while the experiment is being operated unless a gimbal mount is used.

Since the Thematic Mapper and the Large Format Camera are body mounted, these sensors are not only subject to Shuttle limit cycle motion, but may also be misaligned as much as 2 degrees from the Shuttle attitude reference frame. Since their coverage angle is large, there is no direct concern as long as actual pointing knowledge is made available at the time the sensors are used. In addition to pointing, low frequency limit cycle rates can be useful in processing thematic mapper data after it is received on the ground. As a result, a set of attitude sensors (two Ball Bros. 401 star trackers) and inertial quality rate sensors (two 2-axis Kearfott dry gyros) are introduced to provide accurate attitude determination data during operation of the TM as well as other bridge mounted sensors as discussed later (ALTIMETER AND SBUV/TOMS). The Large Format Camera is not mounted on the bridge platform and cannot be aligned to its attitude determination sensors before installation into the Shuttle. There is, however, a valid requirement for equally useful sensors mounted on a SIPS gimbal system for cloud coverage experiments. Therefore, calibration of the LFC to the SIPS mount prior to Shuttle installation is all that is necessary to be able to provide adequate attitude determination data during its use.

6.2.2 SOLAR OBSERVING SENSORS

Orbit characteristics for this Shuttle launch have been chosen such that the angle between the sun line and the orbit plane (β) lies between 35 and 53 degrees. As a result, only one side of the Shuttle is illuminated during lighted portions of each orbit for the entire seven day mission. Solar observing sensors are gimbal mounted, with the mount located on the sun side to avoid interference with the Shuttle structure ($<$ 65 deg looking forward) and other payload hardware ($<$ 75 deg looking aft). Orbit altitude places the horizon 18 degrees below orbit normal at the subsatellite point, such that a sunrise and sunset is guaranteed on each pass.

Angles discussed above are shown in the following sketch:



$\bar{V}$; $\bar{N}$; $\overline{LV}$ Spacecraft co-ordinate frame

$\bar{N}$ = orbit normal

θ = terminator from the sub-satellite point

$\bar{S}$ = sun line

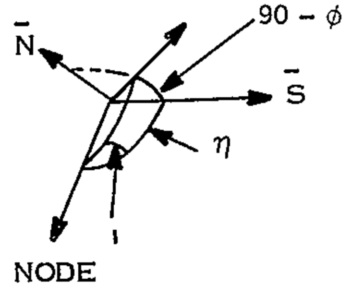
ϕ = location of S at satellite sunset

Calculation of ϕ requires knowledge of the Shuttle orbit parameters:,

Launch Date: 15 September (Sun approx. in plane of the equator)

Line of Nodes: such that the angle between ascending mode and sun is $\approx$ 100 degrees at launch date. Note that this angle will change daily due to orbit precession.

ϕ is determined from



i = orbit inclination = 57°

η = S with respect to ascending node = 100° at start of mission

$$\sin\eta = \frac{\tan(90-\phi)}{\tan i} \quad \therefore \quad \tan\phi = \frac{1}{\tan i \sin\eta}$$

ϕ = 33.4 degrees

As shown, ϕ defines the angle between the sun and orbit normal. It is large enough to force sunrise and sunset to occur in the Shuttle orbit (greater than 18 degrees) but small enough to avoid the limitations in forward or aft look angles (less than 75 degrees). As the mission progresses, the angle "η" changes due to precession of the node line, forcing "ϕ" to increase. This precession will not however, cause the angle "ϕ" to exceed 45 degrees.

Sensors that require sun orientation are essentially those associated with the Environmental Quality experiment and include the SER, ESP, HALOE and HSI. The HSI may also require nadir pointing. Each of these sensor's accuracy and stability requirements ($<.1$ degree) are well within the capability of the Minimount to which they are attached. All that is required is to decouple the sensor axes from an earth-oriented Shuttle frame plus the limit cycle motion and a possible 2 degree mis-alignment between the Shuttle reference and the sensor mounting frame.

The sun on the horizon will occur 72 degrees above local vertical; hence, those sensors that require sun orientation only should be located with their LOS along orbit normal with the mount in its null position. Assuming the HSI will also be pointed down, it should be located along local vertical with the 90 degree outer gimbal freedom used to obtain sun pointing data. Software for combining Shuttle ephemeris, sun location and Shuttle attitude must be made available for external commands to the Minimount control processor. A sun sensor detecing errors about the mount inner gimbal must be oriented along the experiment sensor's LOS for closed loop control within the Minimount processor while obtaining data. Isolation from Shuttle high frequency disturbances is not required; therefore, isolation mounts are not recommended for this experiment group.

Two other sensors are related to atmospheric composition experiments, LACATE and SBUV/TOMS.

Since LACATE is used to identify the composition of the atmosphere at the horizon (limb viewing) it becomes very sensitive to Shuttle motion in pitch and roll. This accurate pointing control requirement forces use of the SIPS mount that carries the CPR and LRS. An additional benefit in using this mount is its capability to extend the sensor along the Shuttle local vertical axis, allowing forward and aft look angles without interference from adjacent Shuttle hardware.

The LACATE sensor supplies two degrees of freedom internally, one supplies horizon crossing motion of ±6 degrees, and the second provides cross-track pointing capability of ±45 degrees. Since the SIPS mount must be used to decouple this sensor from Shuttle motion, the sensor design could be simplified by eliminating its off-set pointing capability. Eliminating the horizon crossing motion is not recommended.

SBUV/TOMS has accuracy requirements similar to those of the thematic mapper and is body mounted. Its field-of-view requirements are satisfied internally by rotating a mirror (single axis). Modification of the sensor optics is required to synchronize ground track coverage with its instantaneous field-of-view, accounting for the difference between Shuttle orbit altitude and the original design altitude of NIMBUS.

As with the thematic mapper, SBUV experiment data can be enhanced after the data is taken if knowledge of Shuttle attitude and rate is recorded simultaneously. Accordingly, the sensor LOS is calibrated to the bridge platform attitude determination sensors prior to installation into the Shuttle. Attitude information is used to start the experiment and is also recorded as useful data during its operation.

6.2.3 SEA STATE SENSORS

Sea State experiment data is received from three separate sensors, the GEOS-C Altimeter, S-193, and SMMR. Each sensor requires location of the local vertical either for reference (SMMR and S-193) or for obtaining useful data (Altimeter).

Altimeter. The Altimeter is required to remain within 0.1 degrees of local vertical, forcing (as a minimum) use of a simple 2-axis gimbal to remove the effect of static mis-alignment between it and the Shuttle reference. This sensor is mounted on the bridge platform which already has the requirement for obtaining attitude determination information to process data from the SBUV and thematic mapper. Calibration of the Altimeter gimbal frame to this attitude determination sensor before launch will supply the data required to remove static errors from its LOS on orbit. This minimum requirement could be satisfied through use of a simple, open loop stepper drive actuated gimbal set with a position readout that is used for the calibration process, assuming the 0.1 degree Shuttle limit cycle motion can be tolerated. Note that attitude determination data used to set up the altimeter can be provided throughout the time interval when data is taken.

S-193 Scatterometer. Pointing accuracy for this experiment in excess of that provided by the Shuttle is not required. Knowledge of sensor LOS to within 0.1 deg is required, relating experiment data to the ocean co-ordinates being studied. This attitude determination data will be available from the control sensors mounted on the SIPS, normally used to orient the cloud climatology sensors. Since both of these gimbal systems are located on the same pallet, a calibration process similar to that discussed on the Altimeter will be undertaken prior to launch (with the SIPS gimbals in a caged mode).

By caging SIPS on-orbit when S-193 is used, its sensor data can be used to supply attitude determination information on the pallet. The combination of this data, S-193 gimbal readout, and Shuttle ephemeris will be used to locate those ocean areas swept out by the scatterometer.

SMMR. As with the Altimeter, this experiment requires removal of static alignment uncertainties between sensor line of sight and the Shuttle reference. Location of the SMMR on SIPS (with its own reference system) removes this source of error. The SIPS gimbals are held fixed throughout use of the SMMR. Further improvement in sensor pointing can be realized if SIPS is driven "closed loop", allowing removal of the $\pm .1$ degree Shuttle limit cycle motion.

Cross-track area coverage is provided by a gimbal mechanism supplied as part of the sensor configuration. Thus, the SIPS gimbal need only decouple the sensor from Shuttle uncertainties.

6.2.4 CLOUD CLIMATOLOGY SENSORS

The sensors used for observation of cloud formations (LRS and CPR) require accurate pointing control due to small instantaneous fields of view as well as accurate knowledge of pointing to orient these sensors to specific geographic locations. This control and knowledge requirement forces use of an accurate gimbal mount such as the SIPS to isolate the sensors from Shuttle motion.

The CPR also requires orientation to specific areas of interest since no internal gimbal mechanism is provided. Location of these target areas will require the use of Shuttle ephemeris, target location, and sensor platform attitude. Control software can be written, compatible with the Shuttle computer, to provide command data profiles to the SIPS control electronics. This software will accept attitude and rate data from sensors mounted on the gimbal and aligned to the experiment sensors LOS. All available clouds lie essentially within the earth cone angle, which has already been calculated at ± 72 degrees with respect to local vertical. This range is well within the gimbal freedom available from the SIPS platform. Local interference (from adjacent payload hardware) is avoided by extending the SIPS platform along the Shuttle local vertical.

6.3 POWER ANALYSIS

The power requirement for the payload is a function of the supporting systems (Spacelab and SEOPS), the mission dependent equipment required in the Spacelab for accomplishing the experiments (i.e. racks, cold plates, hardpoints, etc.), and the sensors themselves.

The sensor power requirements are obtained from the mission timelines by summing the instantaneous power requirements for the various sensors associated with each experiment throughout their "on" time. This "on" time includes a five-second warmup, actual operation or data taking, and a five-second shutdown period. In circumstances where multiple experiments requiring the same sensor are being conducted either simultaneously or in an overlapping mode, a definite attempt to avoid double accounting is made in that the power requirement of the sensor is only considered once.

The power requirements for the other elements of the power budget were obtained from reference documents: (1) Spacelab Accommodations Handbook, (2) Space Shuttle System Payload Accommodations, (3) Standard Earth Observation Package for Shuttle.

When all of the above elements are factored into a power profile for this payload, the result is similar to the sample shown in Figure 6-5 for the on-orbit period between 48 and 72 hours. The total payload power profile for the entire mission is provided as Appendix E. It is observed from Figure 6-5 that there is a steady state level of approximately 5.5 kw required, with peaking to values of 7.5 kw. These values are well within the Shuttle capabilities of providing 7 kw average and 12 kw peak for payloads.

A breakdown of the average power and total energy required for each element of the payload is shown in Table 6-4. It is noted that the actual payload sensors included in the figures for SEOPS and the pallets constitute only a small fraction of the total power and energy used. The total energy requirement of 887 kwh is just within the energy available of 890 KWH; and was achieved by cutting back on the flight duration by approximately seven hours from the planned full seven days. This cut-back does not affect the success of any of the experiments.

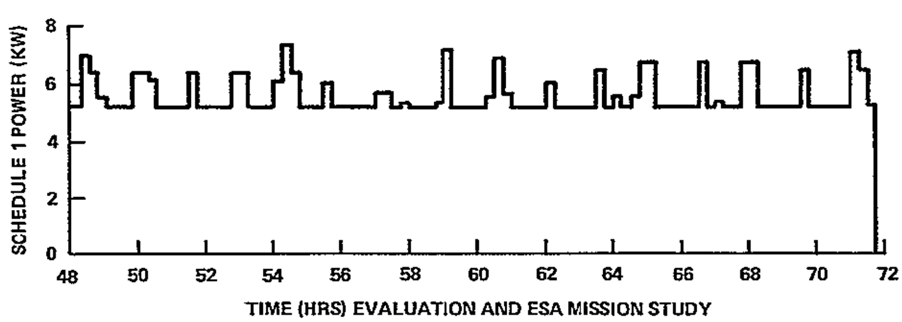


Figure 6-5. Sample Power Profile

Table 6-4. Mission Power/Energy Requirements

Payload Element	Avg. Power (Watts)	Energy (KWH)
Orbiter	168	26.2
Bridge (SEOPS) Pallet	278	41.7
Spacelab Only	3800	559.8
Mission Dep. Equipment	1151	158.8
Pallet No. 1 (ESA)	305	45.8
Pallet No. 2 (EVAL)	321	48.2
Pallet No. 3 (EVAL)	69	10.3
Total	6092	887

6.4 THERMAL ANALYSIS

Solar radiation and thermal loads generated by the payload combine to influence the requirements for heat dissipation. For the particular launch conditions associated with this flight the Beta angle (angle between the sun and orbital plane) is as shown in Figure 6-6. Assuming an average Beta angle of 50°, the heat dissipating capability of Shuttle is shown to be approximately $40 W/M^2$ in Figure 6-7. Calculating the total passive dissipating capability:

$$40 \frac{\text{Watts}}{M^2} \times 50\ M^2 \text{ (conservative pallet area)} = 2000 \text{ watts}$$

Subtracting this value from the total payload load (6092-2000) leaves 4092 watts to be dissipated by the Shuttle radiators. Figure 6-8 shows the Orbiter radiator heat rejection capability for continuous earth pointing at 325 Km. The conclusion from this figure is that for the Beta angles associated with this flight, which are always less than 53°, there is no practical limit to Shuttle's ability to handle the residual load of 4092 Watts. Consequently the mission will not require any solar induced Orbiter roll maneuvers to control temperatures to $< 25^{\circ}C$.

The question of thermal control of the sensors themselves is essentially an unresolvable problem at the present time since many of the sensors, as well as the pointing systems to which they are frequently mounted, are still largely conceptual; and thermal requirements have not yet been defined. However, the instruments on the SIPS can potentially dissipate up to 1086 Watts if they were all operated simultaneously; although in actual mission operation a

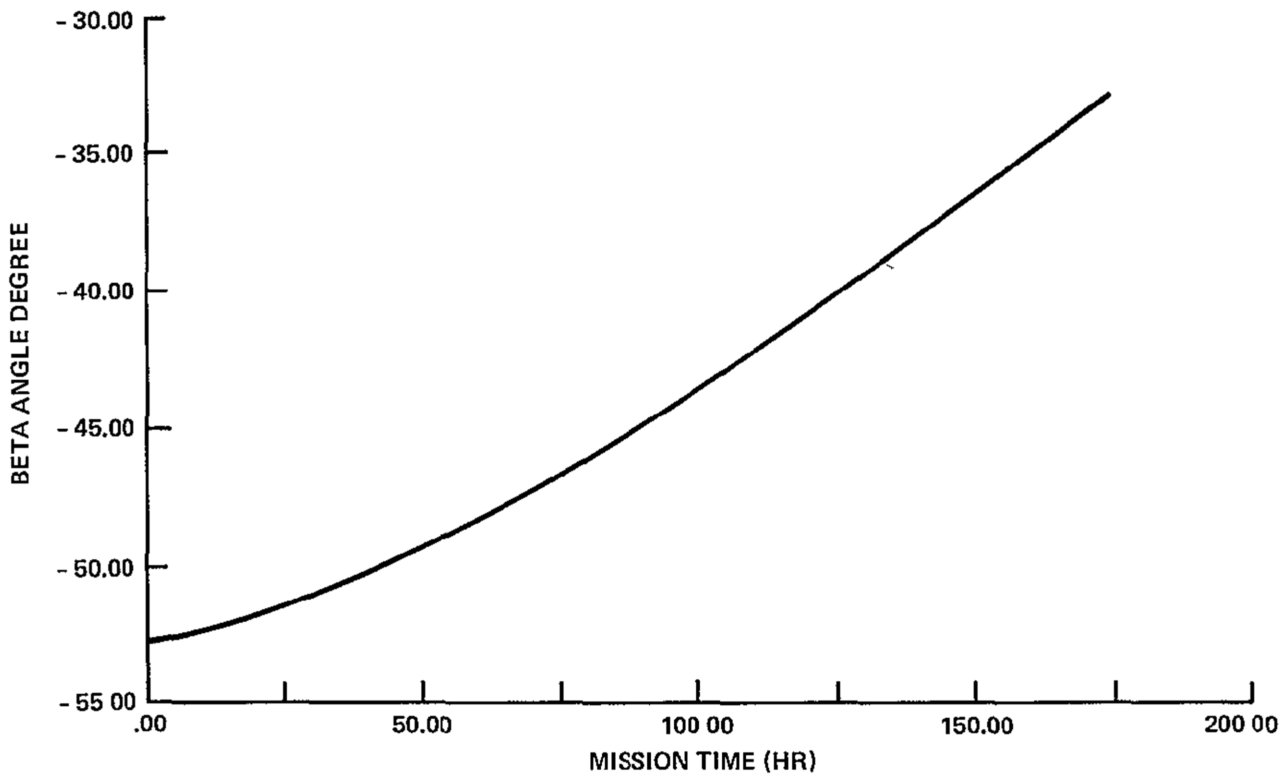


Figure 6-6. Beta Angle History

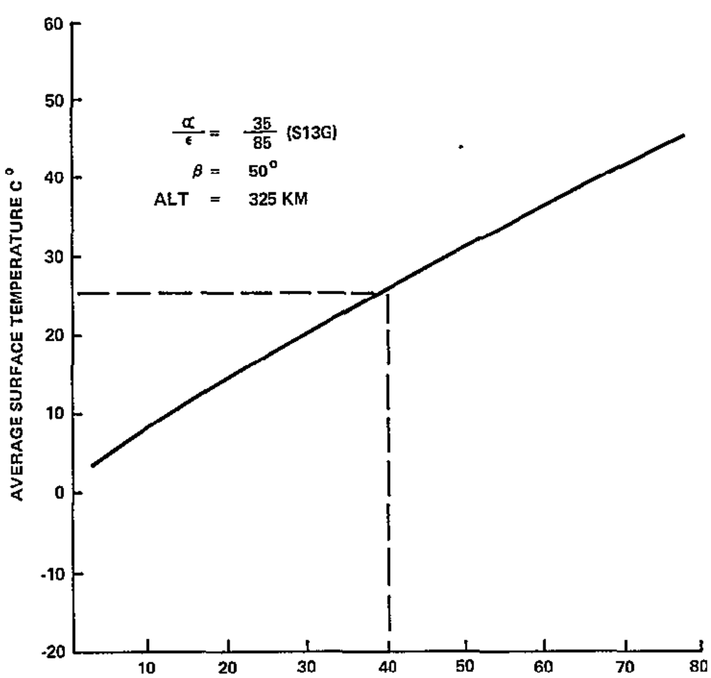


Figure 6-7. Heat Dissipating Capability.

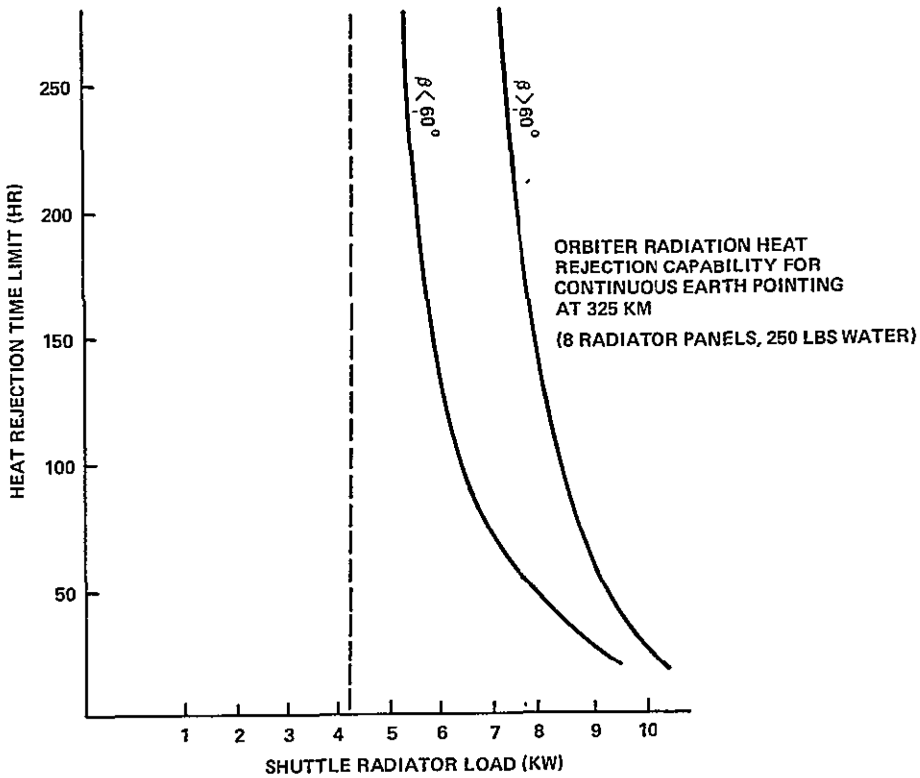


Figure 6-8. Orbiter Heat Rejection Capability

maximum of 1025 watts is indicated for operation of the Cloud Climatology sensors. A study of the timelines show that this experiment has a duty cycle of approximately 21%. Based on this, the average dissipation will be approximately 215 Watts. The thermal design of SIPS* indicates that it will be capable of dissipating a minimum of 347 Watts and a maximum of 587 Watts. Without the addition of additional equipment (thermal control cannisters), the mass of the instruments (79 kg) will experience a temperature excursion of less than 8°C.

*ASP Study for a Low Cost Small Instrument Pointing System, Ball Brothers Research Corporation

Similar heat dissipation values are not available for the Minimount; however the mission timeline shows a maximum sensor dissipation of 91 Watts. The relative size of the Minimount with respect to SIPS indicates this is probably ample area to dissipate the 91 Watts and maintain adequate temperature control.

Those sensors which are hardmounted to SEOPS (the Altimeter, Thematic Mapper, and Solar Backscatter Ultraviolet Spectrometer) all dissipate relatively small quantities of power - 15 to 150 Watts. Using its own passive and louver thermal subsystem, SEOPS will be able to maintain component surface temperatures between a maximum average of 21°C and a minimum of 5°C.

The Large Format Camera and the Scanning Multichannel Microwave Radiometer will be hard mounted to the second pallet, and be thermally controlled through the use of the pallet cold plates. Both of these instruments dissipate relatively low power (136 and 61 Watts respectively) and can easily be maintained between 24° and 40°C since the maximum capability of the cold plates is 1 KW.

The EEE/MW antenna assembly must be designed to control its own temperature since it operates at the end of a deployed 7 meter mast. It is essentially the electronics which are associated with the assembly which must be protected from the dissipation of 550 Watts during operation, and the ambient temperature while stowed. Power dissipation is accomplished by incorporating a passive radiator area; while heaters located on the antenna support mount can protect the electronics when the system is inoperative and stowed.

6.5 VIBROACOUSTIC TEST PLAN

The EVAL payload was subjected to a vibroacoustic test plan evaluation as an added exercise. Statistical decision theory is used to quantitatively evaluate seven alternate test plans which include component subassembly, or payload testing, and combinations of component and assembly test plans. The expected cost of failures are determined for each test plan. By including the direct costs associated with each test plan and the probablistic costs due to ground tests and flight failures, the test plans which minimize project cost are determined.

The results of this analysis indicate that a test plan encompassing subassembly and structure test of the protoflight payload is preferable from both a cost and reliability standpoint. It should be noted that while these results are considered valid for the assumption used; a different set of assumptioning may change the results. Also, vibroacoustic are only part of the total environment to which the payload must ultimately be totaled. Incorporation of thermal vacuum testing, shock, EMI, etc. may also affect these results. The details of this analysis are included in Appendix F.

SECTION 7

CONCLUSIONS

SECTION 7

CONCLUSIONS

The following conclusions are derived from the study results described in the preceding sections:

MISSION SUITABILITY

1. Earth viewing applications experiments/missions involving operational data gathering, technique development, sensor development, and end-to-end system demonstrations can be accomplished on Shuttle/Spacelab.

2. Shared Spacelab payloads, e.g., NASA/ESA, can be integrated into compatible payloads.

3. Significant synergistic benefits, both intra and cross discipline, can be derived by selective payload planning involving multiple experiments/missions.

4. Cost effective payloads can be configured by commonizing on equipment and timelining their operations.

SYSTEM CONSIDERATIONS AND CONSTRAINTS

1. All Spacelab module plus pallet configurations tend to exhibit undesirable longitudinal center of gravity locations.

2. Multiple passes should be planned over targets requiring visual observation since cloud cover can significantly reduce the probability of mission success (dependent upon the target area).

3. The Shuttle crew can efficiently be utilized to supplement the payload specialist(s) in payload operations.

4. Very high data rates in excess of Shuttle/Spacelab capability will be a frequent payload characteristic, and will require special equipment for handling.

5. Shuttle pointing and stability capabilities are inadequate for many payloads and must be supplemented by other systems.

6. There is relatively little power/energy available for sensor operation after the budget for Spacelab and other mission dependent/independent equipment is subtracted.

The above conclusions effectively establish the requirement for a variety of mission unique equipments to serve in a support or interface role between the sensors themselves and Shuttle/Spacelab. The following items have been identified as a result of this study.

- Multiple size pointing systems
- Earth sensors
- Position and location sensors
- Very high data rate recorders
- Onboard processors
- Flexible modular support structures
- Booms (deployable and retractable)
- Adaptive cloud avoidance system
- Ballast (distributed and free-form)

While these requirements have been derived from the analysis of a single EVAL payload; it is fully anticipated that future analyses of additional earth viewing payloads will result in similar requirements.

ACRONYMS

EVAL	-	Earth Viewing Applications Laboratory
ESA	-	European Space Agency
NASA	-	National Aeronautics and Space Agency
GSFC	-	Goddard Space Flight Center
MSFC	-	Marshall Space Flight Center
LARC	-	Langley Research Center
JSC	-	Johnson Space Center
WFC	-	Wallops Flight Center
SEOPS	-	Standard Earth Observation Package for Shuttle
STDN	-	Spacecraft Tracking and Data Network
TDRS(S)	-	Tracking and Data Relay Satellite (System)
IMU	-	Inertial Measurement Unit
RCS	-	Reaction Control System
EPDS	-	Electrical Power and Distribution System
RAU	-	Remote Acquisition Unit
LACATE	-	Lower Atmosphere Composition and Temperature Experiment
HALOE	-	Halogen Occultation Experiment
SER	-	Solar Extinction Radiometer
HSI	-	High Speed Interferometer
SBUV	-	Solar Backscatter Ultraviolet
ESP	-	Eclectic Satellite Pyrheliometer
GEOS	-	Geodetic Satellite
SMMR	-	Scanning Multichannel Microwave Radiometer
EEE	-	Electromagnetic Environment Experiment
MW	-	Millimeter Waves
SIPS	-	Small Instrument Pointing System
LRS	-	Laser Ranging System
CPR	-	Cloud Physics Radiometer
TM	-	Thematic Mapper
LFC	-	Large Format Camera
VHDRR	-	Very High Data Rate Recorder
OEDSF	-	Onboard Experiment Data Support Facility
PAS	-	Passive Atmospheric Sounding
MWS	-	Micro Wave Scatterometer
FOV	-	Field of View
ATC	-	Active Thermal Control
ETR	-	Eastern Test Range
CONUS	-	Continental United States
IS	-	Interface Station
I/O	-	Input/Output
HRM	-	High Rate Multiplexer
HRDR	-	High Rate Data Recorder
TOMS	-	Total Ozone Mapping Spectrometer
EMI	-	Electromagnetic Interference
ECS	-	Environmental Control System
C&DMS	-	Command and Data Management System

GENERAL ELECTRIC

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