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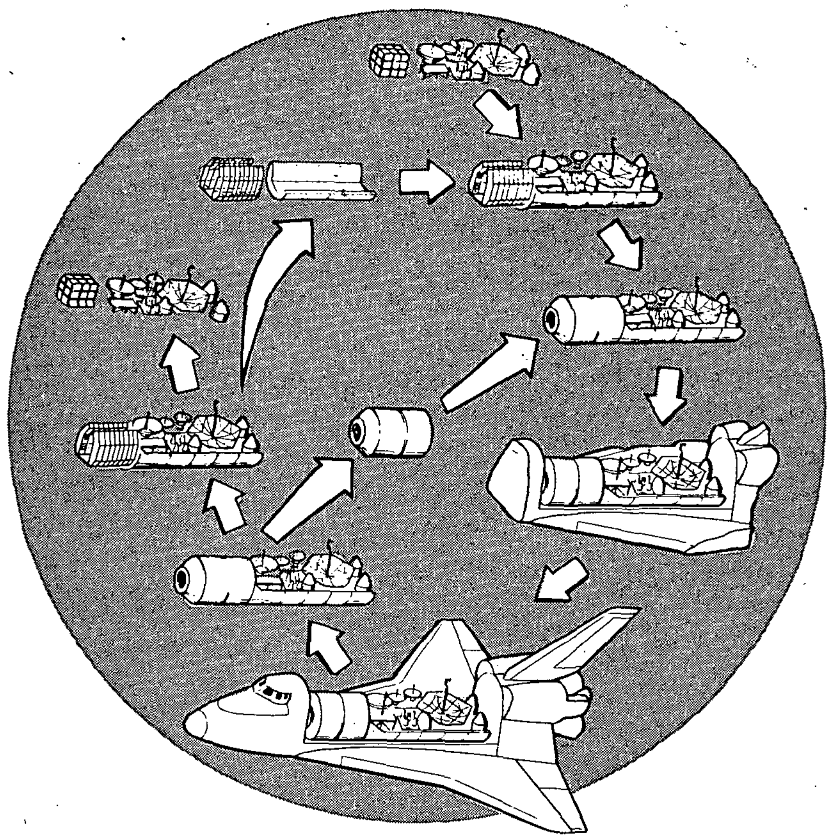

SPACELAB USER IMPLEMENTATION ASSESSMENT STUDY

Volume I

Concept Development and Evaluation

CR-132580

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Rockwell International
Space Division
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Downey, California 90241

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FINAL REPORT

SPACELAB USER IMPLEMENTATION ASSESSMENT STUDY

Volume I
Concept Development and Evaluation

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FEBRUARY 1975

SUBMITTED TO
LANGLEY RESEARCH CENTER
NATIONAL AERONAUTICS & SPACE ADMINISTRATION

Space Division
Rockwell International

FOREWORD

The Spacelab User Implementation Assessment Study was conducted to assess and minimize the capital investment of the National Aeronautics and Space Administration for the integration and checkout of Spacelab payloads such as Langley's Advanced Technology Laboratory. The study was conducted by the Space Division of Rockwell International Corporation under Contract NAS1-12933 for the Langley Research Center. Mr. F. O. Allamby was the technical study manager for the Langley Research Center. In addition, this study received agency-wide guidance and evaluation from the Steering Group for Payloads Operations Concept Studies, directed by Mr. W. O. Armstrong, to maximize the objectivity and applicability of the study data.

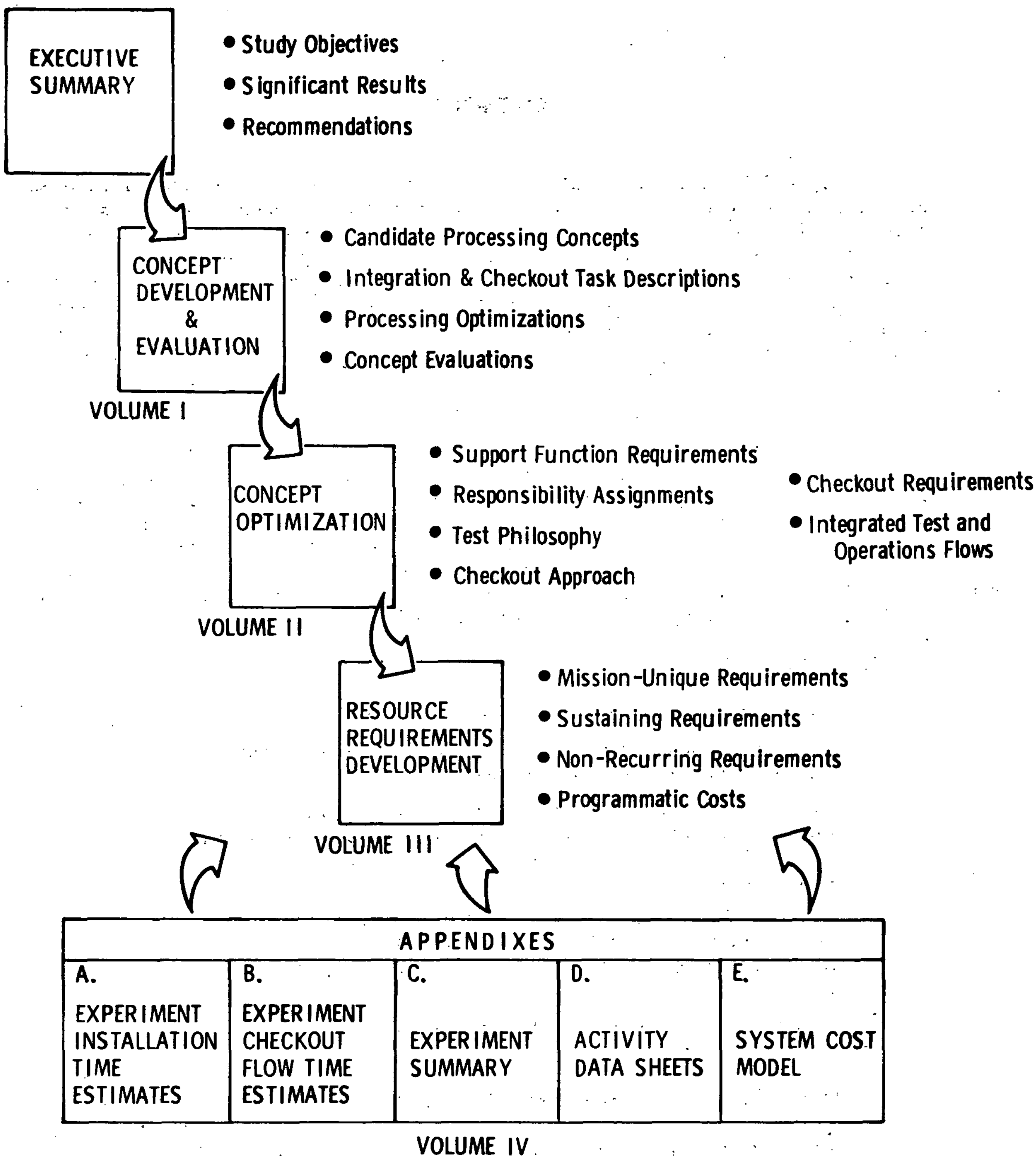
The final report consists of an executive summary and four technical volumes as illustrated in the accompanying figure. A succinct summary of the study is presented in the executive summary. Three of the four technical volumes present the analyses and trades performed during the course of the study. The fourth volume contains five appendixes, which delineate detailed data pertaining to the installation and checkout of Spacelab payloads such as the ATL, and a computer cost model utilized in the compilation of programmatic resource requirements. The contents of the volumes are described below.

EXECUTIVE SUMMARY

- Study overview--objectives, study approach.
- Synopsis of development of candidate processing concepts--complete Spacelab and pallet-only configurations.
- Summary of integration and checkout optimizations--checkout approach, ground operations processing cycle, personnel, ground support equipment and facility requirements.
- Programmatic costing--mission-unique, sustaining, and non-recurring cost estimates for required personnel, material, travel, documentation, ground support equipment, and facilities.
- Concept evaluations--flight-rate sensitivities and concept applicabilities.

VOLUME I. CONCEPT DEVELOPMENT AND EVALUATION

- Complete Spacelab processing concept development.
- Pallet-only processing concept development.



Study Reports

- Results of study optimizations in the areas of checkout requirements, simulator utilization, and configurational changes.
- Flight-rate sensitivities--flight hardware, GSE, facility, and personnel.
- Concept evaluations--integration center/launch site co-location, support module cognizance, WTR implications, general applicability, recommended ATL approach.

VOLUME II. CONCEPT OPTIMIZATIONS

- Supporting functions--development, definitions, and responsibility assignments. Identifies potential software applications.
- Test requirements--checkout approach and requirements, test philosophy, and environmental test requirements.
- Test and operations sequence--development of functional flows, detailed operations, activity data sheets, and integrated flows for both the complete Spacelab and pallet-only processing concepts.

VOLUME III. RESOURCE REQUIREMENTS DEVELOPMENT

- Requirements for mission-unique, sustaining, and non-recurring resources--includes personnel, travel, transportation, material, documentation, GSE, and facilities.
- Programmatic costing--presents cost estimates for all resource requirements.
- Cost-risk analysis--parametric evaluation of deletion of vibra-acoustic, thermal-vacuum and repeat functional tests.

VOLUME IV. APPENDIXES A, B, C, D, AND E

- *Appendix A. Experiment Installation Time Estimates* - Time estimates of the required experiment installation activities including (1) physical installation of experiment hardware in a rack, igloo, or on a pallet; (2) performance of electrical bonding checks; (3) complete mechanical interconnection including fluid and electrical lines; and (4) performance of end-to-end continuity checks between the experiment connector and the interface connector at the experiment module/pallet, support module/experiment module or igloo interfaces.
- *Appendix B. Experiment Checkout Flow Time Estimates* - The general experiment checkout flow plus the time estimates for

each individual experiment in the ATL experiment complement. These time estimates detail the time required for:

- Equipment setup and activation, including controls and display equipment.
- Verification of the operation of mechanical devices of both pallet and rack-mounted sensors and auxiliary equipment.
- Verification of data processing/recording equipment and instrumentation concurrent with checkout of the experiments.

- *Appendix C. Experiment Summary* - A summary of the requirements and equipment utilized for each experiment included in the study. The experiments are listed by discipline.

    - Navigation
    - Earth Observations
    - Physics and Chemistry
    - Microbiology
    - Environmental Effects
    - Components and Systems Testing

  The summary for each experiment includes the objectives or purpose, the description of the equipment utilized, the operation of the equipment, and the physical parameters of mass properties and equipment installation location (pallet, rack, igloo).

- *Appendix D. Activity Data Sheets* - Detailed definitions of the test operations associated with each activity defined in the expanded functional blocks (detailed functional flows). The activity data sheets describe the operations involved and the resources utilized to accomplish the processing cycle. They cover the entire cycle from initial experiment installation through the various integration levels (Experiment, III; Spacelab, II; Orbiter Cargo, I), and the refurbishment of the pallets, racks and/or igloos, following the completion of the mission.

- *Appendix E. System Cost Model* - Description of computer cost model utilized in the study to compile the derived resource requirements into mission-unique, sustaining, and non-recurring cost categories.

Within each volume, the term "concept" is used repeatedly and data are presented with respect to Concepts I through VIII. The concepts referred to pertain to alternate integration and checkout approaches for both the complete Spacelab (support module, experiment module, and pallet) and the pallet-only Spacelab configuration. The following two tables define, in general terms, each of the eight processing concepts that were definitized in this study.

Complete Spacelab Processing Concepts

CONCEPT	OWNER			INTEGRATION SITE	
	SM/EM SHELL*	RACKS & RACK SETS	PALLET	EXPERIMENT EQUIPMENT	SPACELAB
I	IC	IC	IC	IC	IC
II	LS	IC	IC	IC	LS
III	LS	IC	IC	USER	LS
IV	LS	USER	USER	USER	LS
V	USER	USER	USER	USER	USER

*SUPPORT MODULE, SUPPORT SYSTEMS, & EXPERIMENT MODULE STRUCTURE

Pallet-Only Processing Concepts

CONCEPT	OWNER		INTEGRATION SITE	
	PALLET	IGLOO*	EXPERIMENT EQUIPMENT	SPACELAB
VI	IC	LS	USER	LS
VII	IC	LS	IC	LS
VIII	USER	LS	USER	LS

*SUPPORT SYSTEMS IGLOO AND EQUIPMENT

ABBREVIATIONS AND ACRONYM LIST

AAFE	Advanced Application Flight Experiments
ADDAS	Automated Digital Data Acquisition System
AEDC	Atomic Energy Development Center
AIM	Apogee Insertion Motor
AM	Airlock Module (Skylab)
ARINC	Aeronautical Radio, Inc.
ARS	Atmospheric Revitalization System
ASO	Airborne Science Office
ATCS	Active Thermal Control Subsystem
ATL	Advanced Technology Laboratory
ATM	Apollo Telescope Mount (Skylab)
CCTV	Closed Circuit Television
CDMS	Command and Data Management System
CER	Cost Estimating Relationship
C.G.	Center of Gravity
CKTS	Circuits
CM	Command Module (Apollo)
CPSE	Common Payload Support Equipment
CRT	Cathode Ray Tube
CSM	Command and Service Module (Apollo)
CV-990	Convair airplane used as test bed in airborne research by NASA-Ames Research Laboratory
DOMSAT	Domestic Satellite (commercial geosynch communications relay)
DPC	Data Processing Center
DWGS	Drawings
ECLSS	Environmental Control and Life Support System
ECS	Environmental Control System
EDS	Experiment Discipline Specialist
EGSE	Electronic Ground Support Equipment
E/I	End Item (hardware)
EM	Experiment Module
EMC	Electromagnetic Compatibility
EMI/RFI	Electromagnetic Interference/Radio Frequency Interference
EPDS	Electrical Power and Distribution System
ERNO	European consortium developing Spacelab
ESRO	European Space Research Organization

FMEA	Failure Mode Effects Analysis
FO	Flight Operations
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
IC	Integration Center (sometimes inferred to be MSFC)
ICD	Interface Control Drawing
I/F	Interface
IMS	Information Management System
INSP	Inspection
IPS	Instrument Pointing System
IU	Instrument Unit (Saturn V Program)
JCL	Job Control Language
JSC	Lyndon B. Johnson Space Center
KSC	John F. Kennedy Space Center
LL	Lower Limit
LS	Launch Site
MCC	Mission Control Center (at JSC)
MCP	Monitor and Control Panel
MDA	Multiple Docking Adapter (Skylab)
MGT	Management
MIL-SPEC	Military Standard Specification
MSFC	Marshall Space Flight Center
MSOB (O&C)	Manned Spacecraft Operations Bldg (now Operations & Checkout)
MSS	Modular Space Station
MP	Mission Planning
NASCOM	NASA Communications Network
NCR	Non-Conformance Report
OBCO	On-Board Checkout
OCC	Operations Control Center (at Spacelab user's site)
O&C	Operations & Checkout Building (formerly MSOB)
OCP	Operational Checkout Procedure
OIT	Orbiter Integrated Test
OMS	Orbital Maneuvering System (Shuttle)
OWS	Orbital Workshop (converted S-IVB structure--Skylab)
OPF	Orbiter Processing Facility
P	Pallet or Pallet Section
PI	Principal Investigator
PS	Payload Shroud (Skylab)
PSS	Payload Specialist Station
QC	Quality Control
R	Rack or Rack Sets
RAU	Remote Acquisition Unit
R/I	Receiving/Inspection
R&QA	Reliability and Quality Assurance

SC 105	Spacecraft 105 (Apollo)
SCM	System Cost Model
SE	Systems Engineering
SIM	Scientific Instrument Model
SL	Spacelab
SM	Support Module
SPECS	Specifications
SSP	Space Shuttle Program
STDN	Space Tracking and Data Network
STS	Space Transportation System
SUIAS	Spacelab User Implementation Assessment Study
TCR	Test and Checkout Requirements
TDRS	Tracking and Data Relay Satellite
T&O	Test and Operations
U	User (inferred to be Langley)
UL	Upper Limit
WBS	Work Breakdown Structure
WTR	Western Test Range

CONTENTS

ILLUSTRATIONS

TABLES

1.0 INTRODUCTION

Volume I presents an overview of the Spacelab User Implementation Assessment Study (SUIAS). The total matrix of alternate Spacelab processing concepts and the rejection rationale utilized to reduce the matrix of 243 alternates to the final candidate processing concepts are developed.

The work breakdown structure (WBS) used for the systematic estimation and compilation of integration and checkout resources is presented. Included with the WBS are descriptors of each element.

Program models of the Space Transportation System (STS), the Spacelab, the Orbiter, and the ATL that were used as the basis for the study trades, analyses, and optimizations are provided.

Succinct summaries of the resource requirements for all processing concepts are presented. The optimizations of the processing concepts are also summarized. Concept evaluations including flight-rate sensitivities of the GSE, facilities, Spacelab hardware elements, and personnel are delineated.

An analysis of the applicability of the candidate concepts to potential Spacelab users is presented. The impact of the use of the Western Test Range (WTR) as an Orbiter/Spacelab launch site on the candidate processing concepts is evaluated. An assessment of the geographical co-location of experiment, Spacelab, and Orbiter-cargo integration is included. Ownership options of the support module/systems igloo are discussed. The recommended processing concept for the Langley ATL program and the supporting rationale are presented.

2.0 SUMMARY

Based upon the two key drivers of ownership of flight hardware elements and location of the integration site, a matrix of 243 alternate options was developed. A combination of rejection rationale and similarity of data between concepts resulted in the reduction of this matrix to the selected group of five complete Spacelab processing concepts that were identified for detailed analysis during the study. Table 2.0-1 illustrates the five selected complete Spacelab concepts.

Table 2.0-1. Complete Spacelab Processing Concepts

CONCEPT	OWNER			INTEGRATION SITE	
	SM/EM SHELL*	RACKS & RACK SETS	PALLET	EXPERIMENT EQUIPMENT	SPACELAB
I	IC	IC	IC	IC	IC
II	LS	IC	IC	IC	LS
III	LS	IC	IC	USER	LS
IV	LS	USER	USER	USER	LS
V	USER	USER	USER	USER	USER

*SUPPORT MODULE, SUPPORT SYSTEMS, & EXPERIMENT MODULE STRUCTURE

The scope of the study was expanded to include three pallet-only processing concepts. They are shown in Table 2.0-2.

Table 2.0-2. Pallet-Only Processing Concepts

CONCEPT	OWNER		INTEGRATION SITE	
	PALLET	IGLOO*	EXPERIMENT EQUIPMENT	SPACELAB
VI	IC	LS	USER	LS
VII	IC	LS	IC	LS
VIII	USER	LS	USER	LS

*SUPPORT SYSTEMS IGLOO AND EQUIPMENT

During the study analysis, it was demonstrated that the three pallet-only concepts (VI, VII, and VIII) correspond almost exactly to complete Spacelab concepts III, II and IV, respectively. This interrelationship of processing concepts was used throughout the study.

The integration and checkout tasks of each of the processing concepts were determined utilizing a work breakdown structure (WBS) approach, as illustrated in Figure 2.0-1. This method provided the tool to determine each separable task and task responsibility for each processing concept being evaluated. The selected WBS is specifically organized to present only the integration and checkout aspects of a Spacelab payload. It is not a programmatic WBS in that experiment equipment development and checkout, and certain hardware elements (i.e., Spacelab elements--SM/EM shells, rack sets, pallet segments, and the individual experiment hardware) have been omitted. The WBS and its associated descriptors were defined to assist in the accounting and organizing of the manpower and resource requirements that are needed for the integration and checkout of a Spacelab payload.

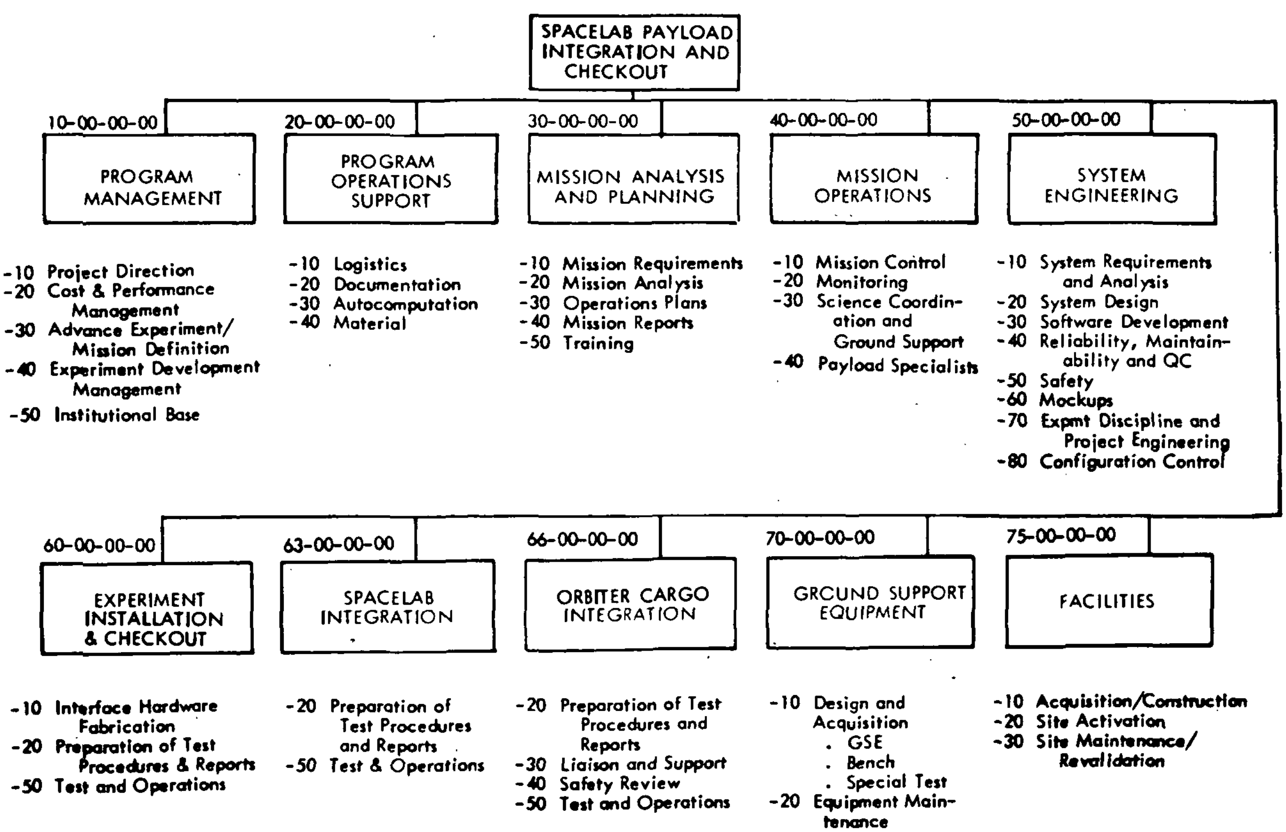


Figure 2.0-1. ATL Integration and Checkout WBS (to Level V)

Four program models were established to provide a framework or baseline for the major trades, analyses and optimizations of the integration and checkout of the program elements. The models are: (1) Space Transportation System (STS), (2) Orbiter, (3) Spacelab, and (4) ATL. They provide a baseline set of definitions of the major hardware elements and are necessary for the determination of the interfaces and interrelationships that will occur during ground and flight operations that will impact the integration and checkout of a Spacelab payload.

The final section of Volume I contains the concept evaluations. A succinct summary of the optimizations and resource requirements for the eight (five complete Spacelab and three pallet-only) processing concepts that were definitized in this study is presented to facilitate concept comparison. The resource requirement summaries are presented in three areas: mission-unique, sustaining, and non-recurring requirements. The costs by center and by concept are also presented in these three categories.

As part of the concept evaluations, a flight-rate sensitivity analysis of four principal factors (flight hardware, GSE, facilities, and personnel) was conducted.

Based upon the traffic model utilized in the study, if single-shift operations are used, three SM's are required to support 15 complete Spacelab flights per year, and two support systems igloos (SI's) are required for nine pallet-only flights per year. If two-shift operations are implemented, the required complements for each of these items is decreased by one. The recommended approach is single-shift operations for Level III (experiment installation and checkout) integration, and two shifts for Level II (Spacelab) and Level I (Orbiter-cargo) integration during the operational era of the program. This results in seven rack/pallet sets for 15 complete Spacelab flights per year, and four experiment equipment canisters for nine pallet-only flights per year.

The flight-rate sensitivity of the baseline set of GSE equipment items defined in the study indicated that this complement could support up to four flights per year.

The analysis of the planned facilities/accommodations at MSFC and the LS indicated that both sites could support approximately 24 flights per year (Level III and Level II integration, respectively). The Langley facility was sized to support two flights per year, but could support up to eight flights per year in Concept III/VI, seven per year in IV/VIII, and six per year in V.

The impact of flight rate on the staffing of personnel was also evaluated. The data indicate that staffing to accomplish each of the three phases of the integration and checkout activities (operations analysis and requirements definition, design and fabrication of interfacing hardware, and test and operations) in six-month increments is the preferred approach. Maximum utilization of personnel is achieved with this scheduling of tasks.

The configuration sensitivity analysis demonstrated that there are no significant differences between the complete Spacelab and the pallet-only processing concepts in terms of flight hardware, processing times, manpower requirements, support services, and facilities. In the area of GSE requirements, the complete Spacelab configuration requires approximately 25 percent more GSE end items than the pallet-only configuration but with the addition of only two items (PSS simulator and igloo handling equipment) the complement of equipment needed to support a complete Spacelab will also permit the processing of a pallet-only configuration.

The applicability of the candidate concepts to various classes of Spacelab users was evaluated. In general, Concept II/VII is preferred for periodic users and users that will only have a partial Spacelab payload. Concept IV is recommended for multi-flight-per-year/multi-year Spacelab payload programs.

Because of the evolving standardization of the SM/SI and associated payload support systems, and the anticipated Spacelab flight rate, Level II integration could probably be more efficiently accomplished if the Orbiter and SM/SI were processed only at the launch site. The SM/SI could evolve to the status of an Orbiter "kit" and one Orbiter would be dedicated to Spacelab flights.

Geographical co-location of Levels III, II and I integration was evaluated. There were minor advantages in the recurring activities of transportation and travel. But the availability of adequate facilities at one site to accomplish all three levels of integration for flight rates of up to 24 per year precluded the co-location approach. Adequate facilities are available at MSFC to support all Level III integrations; KSC facilities will support all Level II integrations. Although both sites can perform either integration level, neither site can accommodate both levels of integration for the entire yearly traffic model.

Based upon the planned yearly flight rate and the duration of the Langley ATL program, the preferred approach for this program is Concept IV/VIII. Langley would be cognizant of the rack/rack sets and pallet segments and perform Level III integration on site. The integration and checkout activities would be the primary responsibility of Langley.

3.0 CANDIDATE CONCEPT SELECTION

The principal objective of this task was to identify candidate integration and checkout processing concepts that would provide adequate visibility to the NASA agency to determine the preferred approach(es) for integration of Spacelab payloads. Initially, only the complete Spacelab configurations (SM, EM, pallet train) were considered, but during the course of the study the pallet-only Spacelab configuration was included.

The concept drivers and resulting matrix of processing alternatives for the complete Spacelab configuration are developed in this section of the report. The rationale to reduce the total matrix of 243 alternate concepts to five is developed.

Three pallet-only processing concepts that were added to the scope of the study are defined. The basic similarities between the pallet-only and corresponding complete Spacelab processing concepts are indicated.

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3.1 CONCEPT DEVELOPMENT

In the development of ground processing concepts, several factors (see Figure 3.1-1) must be considered. However, the two primary drivers are (1) the ownership of the flight hardware, and (2) the integration site. Ownership implies cognizance, configuration management, maintenance, and primary responsibility for the hardware. Integration sites for Levels I, II, and III integration (Orbiter/cargo, Spacelab, experiment installation/checkout, respectively) at separate geographical locations will directly influence the concept options.

A basic approach in this study is that experiment equipment ownership will be maintained by the Spacelab user. But the ownership of the three elements of the Spacelab (support module, experiment module, and pallet) is a variable. Shuttle integration will always occur at the launch site, so only experiment and Spacelab integration sites are variables.

The three options considered for each variable are the user center, an integration center, and the launch site. At the beginning of the study it was assumed that none of the sites were co-located. This permitted the development of data pertaining to transportation and logistics problems resulting from the processing of flight hardware at different sites.

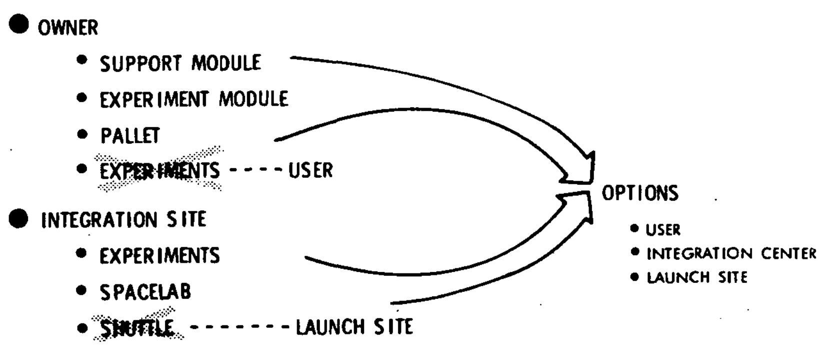

Figure 3.1-1. Concept Drivers

Responsibilities, resources, and documentation requirements may vary significantly between concepts, but do not of themselves establish additional processing alternatives. During the study, these requirements were analyzed and optimized for each of the selected candidate concepts. A discussion of the impact that these factors can have on each candidate concept is presented in Volumes II and III.

Analysis of concept drivers indicated that the two principal elements in defining options were: (1) ownership of Spacelab hardware, and (2) location of the integration sites. The development of the total sets of concept options was accomplished with the utilization of a two-step matrix approach. Each matrix was based upon one of the elements that is considered a major factor in distinguishing one viable concept from another.

OWNERSHIP OF SPACELAB END ITEM HARDWARE

The Spacelab configuration utilized was that of a three-element Spacelab. It consisted of a support module (SM), experiment module (EM), and pallet (P) sections. The SM is separable from the EM and is the habitable module that contains the support subsystems (electrical power, data management, thermal control, etc.) that are needed to support the experiments for a given flight. Also, rack space is available for experiment equipment. The EM contains racks that are dedicated to experiment equipment. Those experiment equipments that require exposure to the space environment when the payload is on orbit would be accommodated on the pallet (P) sections.

Because rack space for experiment equipment is available in the SM, the feasibility/practicability of simultaneously assemblying and handling the rack sets of the EM and the available experiment rack sets in the SM was evaluated. Although the basic design of the Spacelab provides for the separation of the SM and EM, the complete train of experiment equipment racks (10 in the EM and 6 in the SM) can be handled and installed at one time into mated support and experiment modules. A single interface plane for interconnection between SM support systems and experiment equipment racks is provided. Also, it is anticipated that numerous Spacelab payloads will not require the experiment module; the rack space in the SM will suffice. Therefore, a more logical division of Spacelab assemblies to develop alternate processing concepts was determined to be: (1) support module and support system racks and experiment module shell (SM/EM), (2) experiment equipment racks/rack sets (R), and (3) pallet/pallet sections (P). In all subsequent study analyses, it is assumed that the EM shell remains with the SM and SM support systems. Unless specifically noted otherwise, the term "support module or SM" includes the EM shell.

Ownership as used in the study refers to the control and responsibility for the configuration, maintenance, and refurbishment of the hardware. Implicit with this definition is the ground rule that the owner of a particular Spacelab end item would also be responsible for the maintenance and refurbishment of that equipment at his site. Thus, if the integration center (IC) was the owner of the SM, it would imply that, following a flight, the SM would be returned to the IC for refurbishment prior to reuse.

The first matrix developed examined the options of ownership of the three elements of Spacelab hardware end items (SM, R, P). Single center ownership, as well as multiple center ownership of the Spacelab end items, was used in the development of the matrix. The total set of possible combinations is 27 (see Figure 3.1-2), and they are developed from the three sets that can be generated using user (Set 1), IC (Set 2), and LS (Set 3) as the SM owner and then establish the other nine possible combinations of rack and pallet ownership. The 27 combinations (all ownership combinations taken three at a time) are illustrated in Figure 3.1-2.

SET 1

END ITEM / OPTION	SM	R	P	
1	User	User	User	
2	User	User	IC	C
3	User	User	LS	E
4	User	IC	User	N
5	User	IC	IC	T
6	User	IC	LS	E
7	User	LS	User	R
8	User	LS	IC	
9	User	LS	LS	

SET 2

END ITEM / OPTION	SM	R	P	
10	IC	User	User	
11	IC	User	IC	C
12	IC	User	LS	E
13	IC	IC	User	N
14	IC	IC	IC	T
15	IC	IC	LS	E
16	IC	LS	User	R
17	IC	LS	IC	
18	IC	LS	LS	

SET 3

END ITEM / OPTION	SM	R	P	
19	LS	User	User	
20	LS	User	IC	C
21	LS	User	LS	E
22	LS	IC	User	N
23	LS	IC	IC	T
24	LS	IC	LS	E
25	LS	LS	User	R
26	LS	LS	IC	
27	LS	LS	LS	

LEGEND:

SM = Support Module and Experiment Module Shell
R = Racks
P = Pallet
IC = Integration Center
LS = Launch Site

Figure 3.1-2. Spacelab Ownership Options

LOCATION OF INTEGRATION SITES

The integration and checkout of the Spacelab has been subdivided into four major phases. The major steps or integration levels in the ground operational processing of the Spacelab are defined in Table 3.1-1.

Table 3.1-1. Test and Checkout Integration Levels

LEVEL I	*ORBITER CARGO INTEGRATION* - Integration and checkout of the Spacelab and its payloads with the Orbiter. Testing will be of the actual interfaces to be functionally verified.
LEVEL II	*SPACELAB INTEGRATION* - Integration and checkout of the integrated experiment equipment and experiment mounting elements (e.g., racks, rack sets, and pallet segments) with the flight subsystem support elements (i.e., support module, or support system igloo) when applicable. It also includes pre-Orbiter installation testing with simulated Orbiter interfaces.
LEVEL III	*EXPERIMENT INSTALLATION AND INTEGRATION* - Combination of activities including both the installation of experiments on their particular mounting elements (e.g., rack, rack sets, and pallet segments) and also their integration and checkout with the other experiments of a particular payload.
LEVEL IV	*EXPERIMENT PRE-INSTALLATION ACTIVITY* - Covers the period preceding experiment installation during which each experiment and its associated experiment support equipment undergo acceptance testing. This activity is the responsibility of the PI and/or his experiment equipment vendors.

Since Level I (Orbiter cargo integration) is the final verification of the Spacelab and Orbiter interfaces prior to launch, it would not be practical to conduct this checkout and integration at any site other than the launch site. Level IV is the responsibility of the PI and/or the experiment equipment vendor. Therefore, since the locations of Levels I and IV have been fixed, the determination of the location options for Levels II and III are the issues to be resolved and must be superimposed upon the ownership matrix of Figure 3.1-2.

Superimposing of the integration site variables on the ownership variables in the matrix of Figure 3.1-2 would result in a 3^5 matrix (three options--user, IC, LS; five variables--SM, R, P ownership and Level III, II integration site) of alternate processing concepts. A matrix of 243 possible combinations would be unwieldy and cumbersome. Therefore, the reduction of the options was accomplished in a three-step approach that is presented in the next section.

3.2 REJECTION RATIONALE

The reduction of alternate processing concept options was accomplished in three steps: (1) reasonable/logical combinations of Spacelab hardware ownership, (2) logical progression of integration phases and sites, and (3) similarities in the definitized data of concepts. Each step is discussed in subsequent paragraphs.

OWNERSHIP

In Figure 3.1-2 of the previous section, 27 primary hardware end item ownership options were indicated. Twenty-one of these options can be rejected by the application of the following rationale.

> *RATIONALE 1.* User ownership of the support module (SM) should also imply user ownership of the racks (R) and pallet (P). Since the user is the experiment owner and integrator, it is logical that if the user owns any Spacelab modules they would at least include the R and P since the user's primary interest is in the experiment-oriented hardware. Therefore, any option that had the user as the SM owner only, was rejected.

> *RATIONALE 2.* Ownership of the R should also imply ownership of the pallet. Since the pallet is an extension of the R, only needless complexity can be served by one agency owning the R and another the pallets. The coupling of these two items is so close that they might as well be considered as one piece of equipment.

> *RATIONALE 3.* IC ownership of the SM and LS ownership of the R is the wrong combination of center characteristics. These cases represent the situations where the piece of the Spacelab hardware (SM) that tends to be unchanging and contains the Shuttle interface is owned by the development center (IC). Conversely, the R and P (which are changed for each flight) are owned by the launch site (an operational center), which would likely operate more efficiently with a more constant set of interfaces. Within the currently defined charters of the LS and IC, this combination of split ownership does not appear to offer any aspects that would warrant further study.

The application of these three rationale to the ownership matrix of options is indicated in Figure 3.2-1. The particular rationale that eliminated an option is indicated. For example, Option 11 was eliminated from further consideration based upon Rejection Rationale 2.

SET 1

END ITEM / OPTION	SM	R	P		
1	User	User	User		
~~2~~	~~User~~	~~User~~	~~IC~~	C	1
~~3~~	~~User~~	~~User~~	~~LS~~	E	
~~4~~	~~User~~	~~IC~~	~~User~~	N	
~~5~~	~~User~~	~~IC~~	~~IC~~	T	
~~6~~	~~User~~	~~IC~~	~~LS~~	E	
~~7~~	~~User~~	~~LS~~	~~User~~	R	
~~8~~	~~User~~	~~LS~~	~~IC~~		
~~9~~	~~User~~	~~LS~~	~~LS~~		

SET 2

END ITEM / OPTION	SM	R	P		
10	IC	User	User		
11	~~IC~~	~~User~~	~~IC~~	C	2
12	~~IC~~	~~User~~	~~LS~~	E	2
13	~~IC~~	~~IC~~	~~User~~	N	2
14	IC	IC	IC	T	
15	~~IC~~	~~IC~~	~~LS~~	E	2
16	~~IC~~	~~LS~~	~~User~~	R	3
17	~~IC~~	~~LS~~	~~IC~~		3
18	~~IC~~	~~LS~~	~~LS~~		3

SET 3

END ITEM / OPTION	SM	R	P		
19	LS	User	User		
20	~~LS~~	~~User~~	~~IC~~	C	2
21	~~LS~~	~~User~~	~~LS~~	E	2
22	~~LS~~	~~IC~~	~~User~~	N	2
23	LS	IC	IC	T	
24	~~LS~~	~~IC~~	~~LS~~	E	2
25	~~LS~~	~~LS~~	~~User~~	R	2
26	~~LS~~	~~LS~~	~~IC~~		2
27	LS	LS	LS		

LEGEND:

SM = Support Module and Experiment Module Shell
R = Racks
P = Pallet
IC = Integration Center
LS = Launch Site

X Refers to Rejection Rationale

Figure 3.2-1. Ownership Option Reduction

In summary, the rationale used for the rejection of 21 of the ownership options is shown in Table 3.2-1.

Table 3.2-1. Ownership Rejection Rationale

	FOR CONCEPTS WHERE . . .	REJECT COMBINATIONS CALLING FOR . . .
OWNERSHIP	———	Split-ownership of R/P
	User is SM owner	Other R/P owners
	IC is SM owner	LS is R/P owner

Only a single owner of the R and the P is considered because of their integral and interdependent relationship. Ownership of the relatively standard support module by the Spacelab user center is only logical if the user center also owns the rack and pallet, which accommodate the user's mission-unique equipment. Similar rationale applies to the case where the integration center owns the support module. It would be illogical for the launch site to own the varying rack and pallet and an "integration center" owning the relatively standard support module.

The six remaining options are shown in Table 3.2-2. They represent the most viable and promising sets of ownership combinations.

Table 3.2-2. Final Ownership Options

Option No.	Hardware Element		
	SM	R	P
1	User	User	User
10	IC	User	User
14	IC	IC	IC
19	LS	User	User
23	LS	IC	IC
27	LS	LS	LS

INTEGRATION SITE

There are nine possible combinations (see Table 3.2-3) of Level III and Level II integration and checkout sites. These nine are developed by combining the three possibilities (user, IC, or LS) for experiment installation and integration (Level III) with the same three possibilities for Spacelab (Level II) integration.

Table 3.2-3. Integration Site Options

Option No.	Integration and Checkout	
	Experiment (III)	Spacelab (II)
1	User	User
2	User	IC
3	User	LS
4	IC	User
5	IC	IC
6	IC	LS
7	LS	User
8	LS	IC
9	LS	LS

Utilizing the final six ownership options of Table 3.2-2 and combining them with the nine possible combinations of integration and checkout locations, the 54 location and ownership alternatives (shown in Figure 3.2-2) were developed.

OWNER			INTEG & C/O		OWNER			INTEG & C/O		OWNER			INTEG & C/O		OWNER			INTEG & C/O		OWNER			INTEG & C/O		OWNER			INTEG & C/O	
SM	R	P	EXP	SL	SM	R	P	EXP	SL	SM	R	P	EXP	SL	SM	R	P	EXP	SL	SM	R	P	EXP	SL	SM	R	P	EXP	SL
U	U	U	U	U	IC	U	U	U	U	IC	IC	IC	U	U	LS	U	U	U	U	LS	IC	IC	U	U	LS	LS	LS	U	U
				IC					IC					IC					IC					IC					IC
				LS					LS					LS					LS					LS					LS
			IC	U				IC	U				IC	U				IC	U				IC	U				IC	U
				IC					IC					IC					IC					IC					IC
				LS					LS					LS					LS					LS					LS
			LS	U				LS	U				LS	U				LS	U				LS	U				LS	U
				IC					IC					IC					IC					IC					IC
				LS					LS					LS					LS					LS					LS

- MATRIX REPRESENTS 54 COMBINATIONS POSSIBLE
- THE FIRST THREE COLUMNS REPRESENT OWNERSHIP OF THE THREE ELEMENTS OF THE SPACELAB. THE NEXT TWO ENTRIES ARE POSSIBLE LOCATIONS FOR THE EXPERIMENT INTEGRATION AND CHECKOUT, AND THE SPACELAB INTEGRATION AND CHECKOUT

Figure 3.2-2. Location and Ownership Matrix

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The following six rejection rationale were developed and used to reduce the integration location and ownership matrix (Figure 3.2-2) from 54 options to nine concepts.

RATIONALE 4. If the user owns all of the Spacelab hardware elements, then the experiment and Spacelab integration and checkout should occur at the user's site. The rationale for this statement is that if a user owned all of the hardware (SM, R, and P), the user would certainly have the personnel, procedures, and checkout equipment necessary to conduct the Spacelab integration and checkout function at his facility. To complete an individual checkout and integration of each piece of the Spacelab at the user site and then ship all of the elements and key personnel (experiment experts) to an IC for assembly, checkout and integration, and then ship the elements to a separate launch site would not seem to be a viable option worth studying.

RATIONALE 5. If Spacelab integration and checkout occur at the user site, then experiment integration should also occur at the user site. Any option that would have the experiments installed in the racks and pallets, integrated and checked out, and then moved to the user site for subsequent Spacelab integration, is not considered reasonable.

RATIONALE 6. The options that would have experiment integration and checkout at the launch site, and Spacelab integration and checkout at the integration center, are not reasonable combinations. This rejection rationale is related to Item 5, above. Its most objectionable feature is the repeated movement of the Spacelab modules between sites, after they have been checked out and integrated. Installation, checkout and integration of experiments into the rack and pallet at the launch site, and then shipping the entire set to an integration center for Spacelab integration and checkout, with subsequent return to the launch site for the flight, was considered to be illogical.

RATIONALE 7. If the user owns the rack/pallet, then experiment installation, integration and checkout should occur at the user site. This rationale was based upon the assumption that user ownership would carry with it the personnel and equipment necessary to not only refurbish and maintain the R/P, but also to perform the experiment installation, alignment, and checkout. The logical extension would be to also have the user handle the integration of the rack/pallet with the experiments.

RATIONALE 8. If the launch site or the IC owns all of the hardware (SM, R/P), then the Spacelab checkout and integration should occur at either the LS or the IC. Again, as in Item 7, this rationale is based upon the availability of all the necessary equipment and trained personnel.

RATIONALE 9. If the LS owns the support module, then the Spacelab integration and checkout should occur at the LS. For those options where the LS owns the support module, it would be responsible for maintenance and refurbishment of the support module after each flight. Since the launch site would have the trained personnel and the equipment necessary for SM checkout and integration, it would not appear reasonable to send the SM to another facility for Spacelab checkout and integration.

The numbering of these rationale was made continuous with those utilized to reduce the ownership matrix, in an attempt to avoid possible confusion that may result from there being two items both numbered "1". Figure 3.2-3 shows which rejection items eliminated particular options. Table 3.2-4 is a summary of the integration location rejection rationale.

Owner SM	Owner R	Owner P	Integration & C/O Exp	Integration & C/O SL
U	U	U	U	U
				IC
				LS
			IC	U
(4)				IC
				LS
			LS	U
				IC
				LS

Owner SM	Owner R	Owner P	Integration & C/O Exp	Integration & C/O SL
~~IC~~	~~U~~	~~U~~	~~U~~	~~U~~ (9)
IC	U	U	U	IC
				~~LS~~ (9)
			~~IC~~	~~U~~ (5)
				~~IC~~ (7)
				~~LS~~ (7)
			~~LS~~	~~U~~ (5)
				~~IC~~ (6)
				~~LS~~ (7)

Owner SM	Owner R	Owner P	Integration & C/O Exp	Integration & C/O SL
~~IC~~	~~IC~~	~~IC~~	~~U~~	~~U~~ (8)
IC	IC	IC	U	IC
				~~LS~~ (8)
			~~IC~~	~~U~~ (5)
IC	IC	IC	IC	IC
				~~LS~~ (8)
			~~LS~~	~~U~~ (5)
				~~IC~~ (6)
				~~LS~~ (8)

Owner SM	Owner R	Owner P	Integration & C/O Exp	Integration & C/O SL
~~LS~~	~~U~~	~~U~~	~~U~~	~~U~~ (9)
				~~IC~~ (9)
LS	U	U	U	LS
			~~IC~~	~~U~~ (5)
				~~IC~~ (7)
				~~LS~~ (7)
			~~LS~~	~~U~~ (5)
				~~IC~~ (6)
				~~LS~~ (7)

Owner SM	Owner R	Owner P	Integration & C/O Exp	Integration & C/O SL
~~LS~~	~~IC~~	~~IC~~	~~U~~	~~U~~ (9)
				~~IC~~ (9)
LS	IC	IC	U	LS
			~~IC~~	~~U~~ (5)
				~~IC~~ (9)
LS	IC	IC	IC	LS
			~~LS~~	~~U~~ (5)
				~~IC~~ (6)
~~LS~~	~~IC~~	~~IC~~	~~LS~~	~~LS~~ (9)

Owner SM	Owner R	Owner P	Integration & C/O Exp	Integration & C/O SL
~~LS~~	~~LS~~	~~LS~~	~~U~~	~~U~~
				~~IC~~ (8)
LS	LS	LS		LS
			~~IC~~	~~U~~ (5)
				~~IC~~ (8)
~~LS~~	~~LS~~	~~LS~~	~~IC~~	~~LS~~ (6)
			~~LS~~	~~U~~ (5)
				~~IC~~ (6)
LS	LS	LS	LS	LS

LEGEND:

SM = Support Module and Experiment Module Shell
R = Racks
P = Pallet
U = User
IC = Integration Center
LS = Launch Site
( ) Refers to Rejection Rationale

Figure 3.2-3. Viable Concepts

Table 3.2-4. Integration Site Rejection Rationale

	FOR CONCEPTS WHERE . . .	REJECT COMBINATIONS CALLING FOR . . .
INTEGRATION SITE	LS is R/P owner	Experiment integration at IC
	IC is R/P owner	Experiment integration at LS
	LS is SM owner	Spacelab integration other than at LS
	All Spacelab hardware (SM, R/P) is owned by one center)	Spacelab integration other than at owner's site
	Experiment integration is at LS	Spacelab integration other than at LS

The first two criteria imply that ownership of the experiment racks and pallet by either the integration center or the launch site precludes experiment integration at the non-owner's site; however, experiment integration at the user's site is acceptable. Undesirable transfers of flight hardware and a logical sequence of integration-level buildup are encompassed by the last three criteria. If the support module expertise is at a particular site, then the Spacelab integration should occur at that site. Accomplishing one level of integration at a site, shipping the assembly to a second site for the next level of integration, and then transferring the flight hardware back to the first site for the final level of integration is not a desirable concept.

DATA SIMILARITY

After the application of the six rationale items (see Table 3.2-4), there are nine remaining viable concepts; these are shown in Figure 3.2-4. From this set of nine viable alternatives, five candidate processing concepts were selected for in-depth analysis. Since these last nine cases had survived all of the previous rejection rationale, and all nine were viable, the choice of a final five was based upon characteristics that would widen the scope of the study analysis. The five selected concepts and their distinguishing characteristics are analyzed in the following paragraphs.

Evaluation of the first two viable alternatives indicates that the data that would be generated in the analyses through Spacelab integration would be similar for either concept. The first alternative was selected as a candidate concept to facilitate the identification of activities associated with the transfer of the Spacelab between two geographically separated sites. Co-location of the integration center and the launch site will be evaluated as a part of the Concept Evaluation (Section 6.0, Volume I) analysis.

The third viable alternative offered several unique features and was selected as a candidate. The principal characteristic of this alternative is the identification of a site dedicated to mission-unique activities.

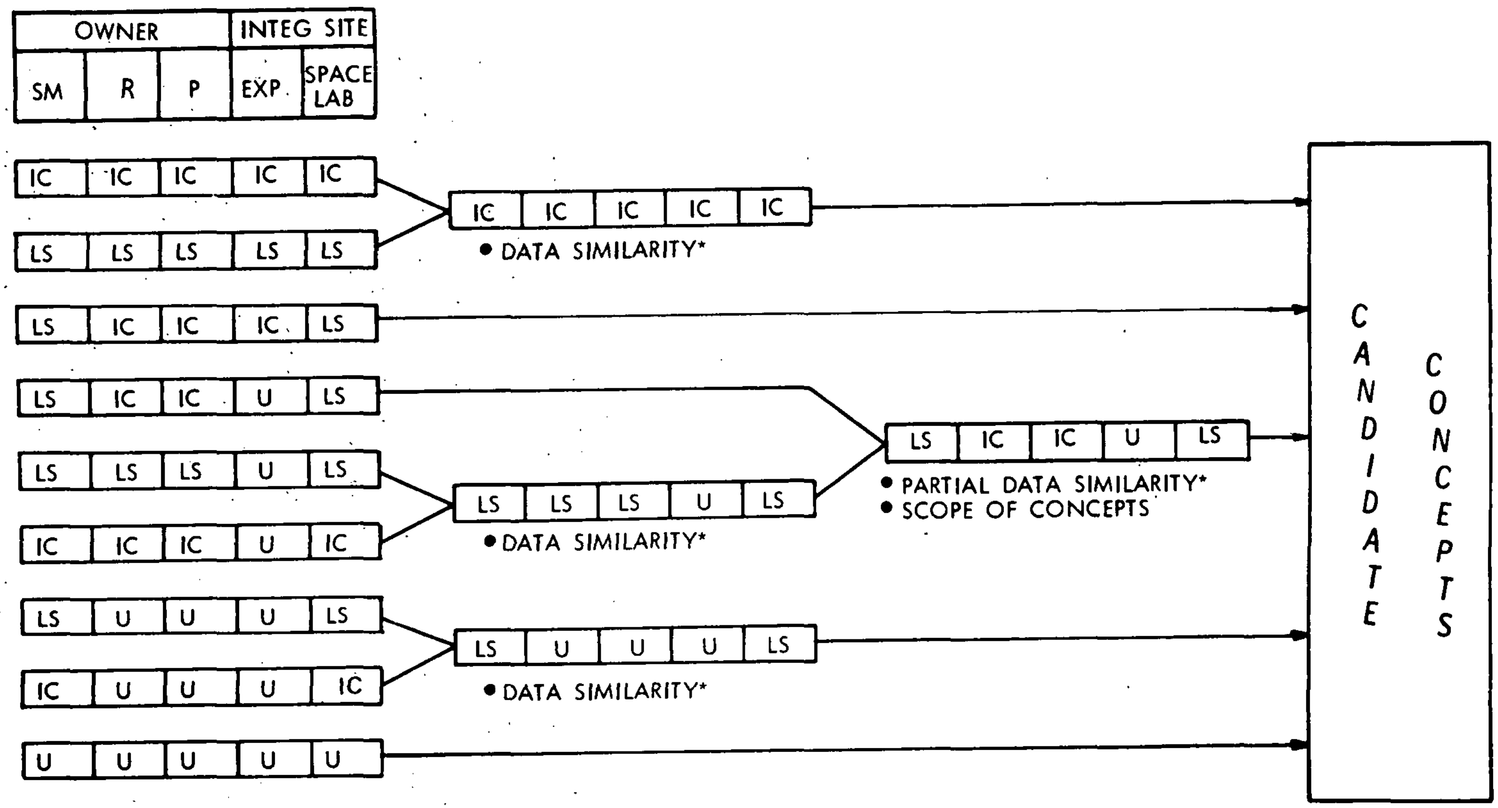

Figure 3.2-4. Viable Concept Comparisons

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The fifth and sixth viable alternatives have several similar characteristics through Spacelab integration. Ownership and Spacelab integration site are either integration center or launch site. Both alternatives include provisions for "bailing" or "leasing" the rack and pallet to the user center for experiment integration. Initially, the fifth alternative was arbitrarily selected. However, comparison of this alternative with the fourth viable alternative resulted in the selection of the fourth alternative. The fourth alternative included the primary characteristic of the fifth and sixth ones plus the added feature of split-ownership of the Spacelab modules.

The basic data generated by the analyses of either the seventh or eighth viable alternative would also be similar. As the activities associated with Spacelab transfer will be defined in the first concept, the seventh alternative was selected to facilitate the identification of the differences for this particular phase of the ground processing operations.

The ninth alternative was unique and selected as a candidate.

It should be noted that, although the nine viable alternatives were reduced to five concepts, the data generated in the analyses of the five could be applied to the other alternatives if desired. It is believed that the characteristics and scope of the five candidate concepts permitted the development of a broad spectrum of data that could be utilized in evaluating all alternatives.

At this point in the study, no two alternatives were considered to be geographically co-located. Subsequent analysis of transportation, GSE, facilities, and personnel requirements will determine the preferred geographical location of certain processing activities. Also, identification of the roles and responsibilities of each participating center during each processing activity was accomplished in subsequent study tasks. Therefore, the centers listed in the ownership matrix and the checkout and integration site matrix are to be considered as geographically different locations. Only one launch site (KSC) was considered in the development of the detailed data for the processing concepts. The potential impact on the concepts with a second launch site (WTR) is presented in Section 6.4 of this volume.

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3.3 SELECTED CANDIDATE CONCEPTS

The five selected candidate complete Spacelab concepts are summarized in Table 3.3-1. The principal characteristic of each concept that pertains to generalized Spacelab users is indicated. The first concept centralizes the entire Spacelab integration process and would provide a single point of contact for users.

Table 3.3-1. Selected Candidate Concepts

OWNER			INTEGRATION SITE		
SUPPORT MODULE	RACKS	PALLET	EXPMT EQUIP	SPACELAB	CHARACTERISTIC
IC	IC	IC	IC	IC	MINIMIZES USER CAPITAL INVESTMENT CENTRALIZES MULTI-CONTRIBUTOR ACTIVITY
LS	IC	IC	IC	LS	SEPARATES MISSION-UNIQUE FROM RELATIVELY STANDARD OPERATIONS
LS	IC	IC	USER	LS	FACILITATES DIRECT USER PARTICIPATION FOR COMPLEX/LONG-TERM EXP. INTGR.
LS	USER	USER	USER	LS	ENABLES USER TO CONTROL MISSION-UNIQUE EQUIPMENT CONFIGURATION
USER	USER	USER	USER	USER	PERMITS MAXIMUM USER CONTROL BY LONG-TERM/SINGLE SPONSOR CENTER

The second concept also provides the user with a single point of contact, but focuses the mission-unique activities at the integration center and relatively standard functions at the launch site.

In both the first and second concepts, the user is required to conduct experiment integration off site at an integration center. Because the user does not have to purchase any of the complete Spacelab elements (SM/EM shell, rack, or pallet), the third concept also minimizes the capital investment for flight hardware by the user, but permits experiment integration at the user's site.

The fourth and fifth concepts provide the user with the opportunity to directly control the Spacelab flight hardware associated with his experiments. The fifth concept extends this control to include the entire Spacelab. In general, the set of candidate concepts reflects a progressive control by the user of the Spacelab integration and checkout activity. As depicted on Figure 3.3-1, the selected concepts vary from one that defines a centralized integration center to complete user control of and responsibility for the Spacelab. The concepts in between vary the interfaces between centers and the degree of direct involvement of the centers in Spacelab integration. Thus, a broad cross-section of responsibility and documentation requirements can be derived with this spectrum of concepts. It is believed that the variances of ownership and integration encompassed within the selected candidate concepts permitted the generation of the most meaningful and applicable data for final selection of an optimum, cost-effective, ground-processing concept for the Spacelab user. This selection is discussed in Section 6.5 of this volume.

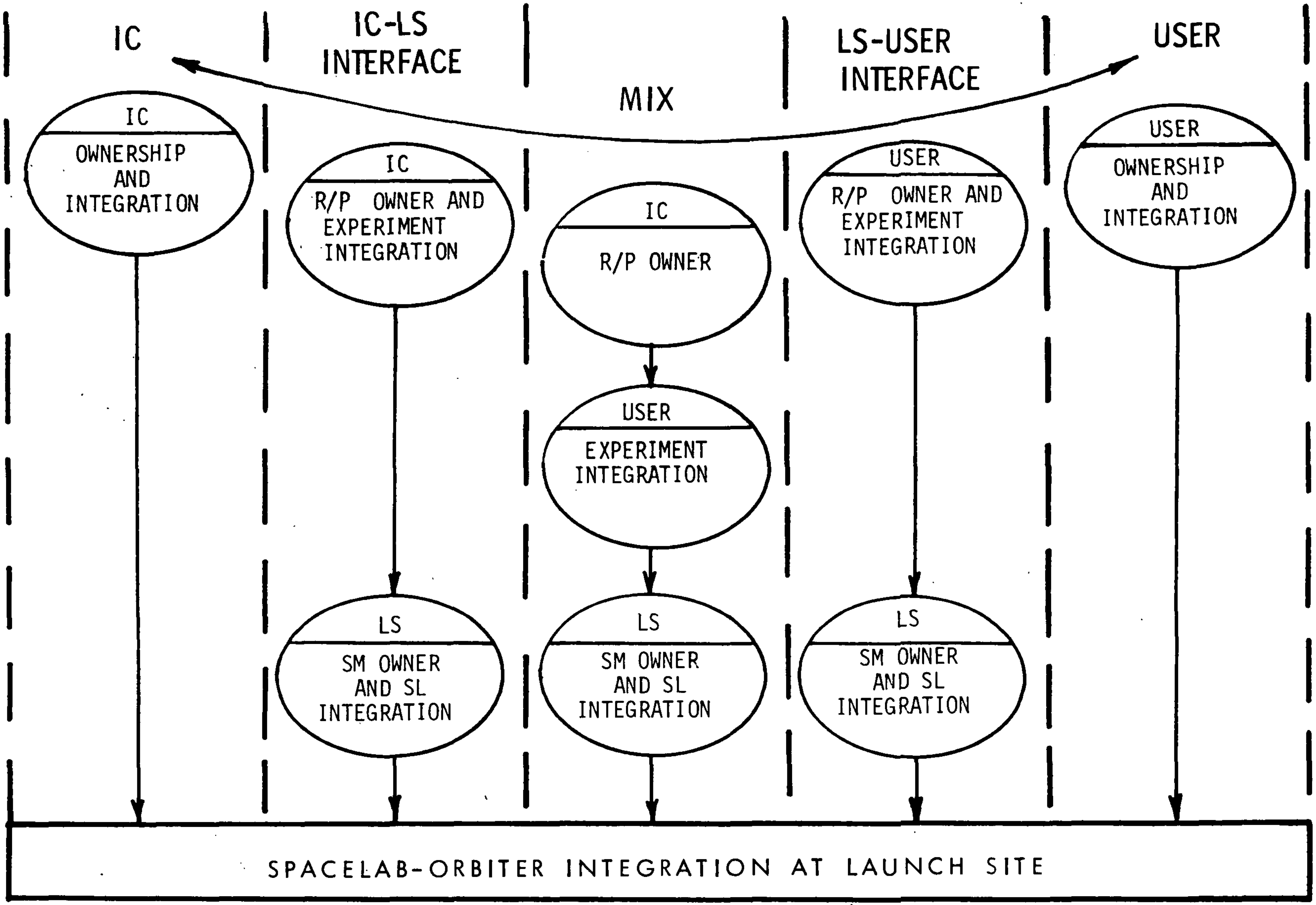

Figure 3.3-1. Spectrum of Concepts

3.4 PALLET-ONLY CONCEPTS

During the course of this study, the scope of the candidate concepts was expanded to include an analysis and evaluation of the integration and checkout activities associated with the processing of a non-habitable Spacelab (pallet-only) configuration. Payload equipments were to be mounted only on pallet segments in the Orbiter cargo bay and, space permitting, in the Orbiter crew compartment. The control of the experiments was to be accomplished either by remote control from the payload specialist station (PSS) in the Orbiter, or by automating the experiment. Three pallet-only Spacelab processing concepts (VI, VII and VIII) were defined and evaluated. This section describes these concepts and identifies those aspects of the pallet-only configuration that influence the ground processing cycle.

CONCEPT IDENTIFICATION

The contract statement of work was amended to add the definitization of pallet-only Spacelab processing concepts. The three pallet-only concepts that were recommended for detailed evaluation were as follows.

CONCEPT VI. This concept involves all three centers in the processing cycle. The integration center (IC) is the pallet and experiment canister owner and is responsible for the post-mission removal of experiments and associated equipment (including experiment canisters) from the pallet. The IC then has the responsibility to refurbish/reconfigure the pallet and experiment canisters at its facility prior to the next mission. Experiment installation and checkout are conducted at the user's facility with user personnel. Level II (Spacelab) and Level I (Orbiter cargo) integration are performed at the launch site (LS) under the cognizance of the LS personnel. The support system igloo installation, checkout and subsequent refurbishment are also the responsibility of the launch site. This pallet-only concept closely approximates complete Spacelab (habitable) Concept III in terms of equipment ownership and integration sites and responsibility.

CONCEPT VII. This concept utilizes the IC and the LS as the principal hardware owners and locations for integration. The user experiments are shipped to the IC who owns and maintains the pallet segments and the experiment canisters. Experiment installation and integration are provided by the IC personnel at their facility. The non-habitable Spacelab is then shipped to the LS for physical mating with the support systems igloo and Level II (Spacelab) and Level I (Orbiter cargo) integration. These two major integration functions are conducted under the responsibility of the LS. This concept (VII) is similar to complete Spacelab Concept II.

CONCEPT VIII. This concept involves only the user and the LS. The impact on the integration and checkout process and particularly a Spacelab user when the user is both a Spacelab element owner (pallet segments and experiment equipment canister) and the responsible/performing center for Level III integration, can be evaluated with this concept. Again, as in the other two pallet-only processing concepts, Levels II and I integration are performed under LS cognizance. Post-mission refurbishment of the pallet segments, experiment canisters, and the experiments are the responsibility of the user. This concept (VIII) is similar to complete Spacelab Concept IV.

Table 3.4-1 illustrates in matrix format who the principal pallet-only (non-habitable) Spacelab hardware element owners are, and where the major Spacelab integrations take place. As in the five complete Spacelab concepts, ownership here refers to the responsibility for maintenance, configuration control, and refurbishment of that particular hardware element. It does not imply that the Spacelab integration level involving that hardware occurs at the owner's facility. For example, in Concept VI* the IC owns the pallet and experiment canisters but experiment integration is accomplished at the user's site, and Spacelab integration occurs at the LS.

Table 3.4-1. Pallet-Only Processing Concepts

Concept	Owner		Integration Site	
	Pallet	Igloo[1]	Expmt Equip	Spacelab
VI	IC	LS	User	LS
VII	IC	LS	IC	LS
VIII	User	LS	User	LS

[1]Support system igloo and equipment.

CONFIGURATION

The pallet-only configuration, shown in Figure 3.4-1, is a non-habitable Shuttle payload. It is comprised of the following modular units:

- Pallet segments (5)
- Canisters - experiment (2)
- Igloo - support systems (1)
- Utility harness

The pallet segments can be arranged in groups of one, two or three segment "trains." The particular pallet-only payload configuration utilized during the study was a two- and a three-segment train. The first three segments of Figure 3.4-1 are connected, and the last two are connected in a separate train.

*The concept numbers for pallet-only have been assigned in sequence with the five for the complete Spacelab (habitable) concepts to avoid any confusion that might result from two concepts both being numbered "I".

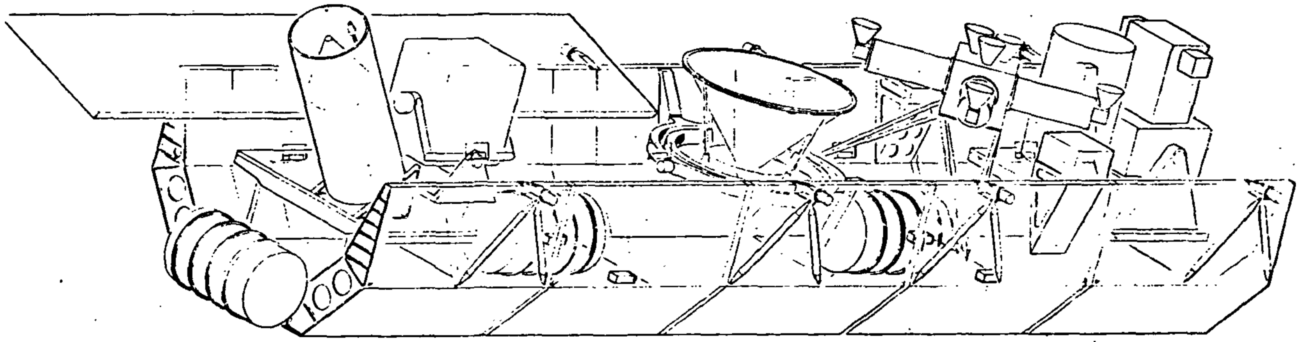

Figure 3.4-1. Pallet-Only Configuration

Through the arrangement of the pallet segments in the Orbiter cargo bay, it is possible to provide an extended experiment platform for the space exposure of experiments such as those shown in Table 3.4-2. These experiments are ATL Payload No. 3. Specific details on the support requirements for each of these experiments can be found in Appendix C (Experiment Summary).

Table 3.4-2. Representative ATL Pallet-Only Payload Complement

NV-1	Microwave Interferometer
NV-2	Autonomous Navigation
EO-1	Lidar Measurements
EO-4	Microwave Radiometer
EO-7	Search and Rescue Aids
EO-8	Imaging Radar
PH-2	Barium Cloud Release
PH-4	Neutral Gas Parameters
PH-6	Meteor Spectroscopy
EN-1	Micro-Organism Sampling
EN-3	Non-Metallic Materials
XST-	Contamination Monitor

Experiment equipment is installed in three primary locations:

1. Within the Orbiter crew compartment (Figure 3.4-2). This area will be used for those experiments that have a high degree of crew involvement required as well as the need for installation in a pressurized environment.

2. On the pallet itself. The majority of the sensors and auxiliary equipment will be mounted out in the Orbiter cargo bay, Support functions (electrical power, thermal control, data processing, etc.) will be supplied to these sensors by the support systems igloo mounted on the pallet.

3. Experiment canisters. There are provisions in the Rockwell baseline design for up to five pressurizable canisters to house experiment support equipment to be mounted on the pallet (Figure 3.4-3). The canisters (up to five) have been included in the estimates to house experiment equipment that cannot effectively be designed to operate in a non-pressurized environment and cannot be accommodated in the Orbiter crew compartment.

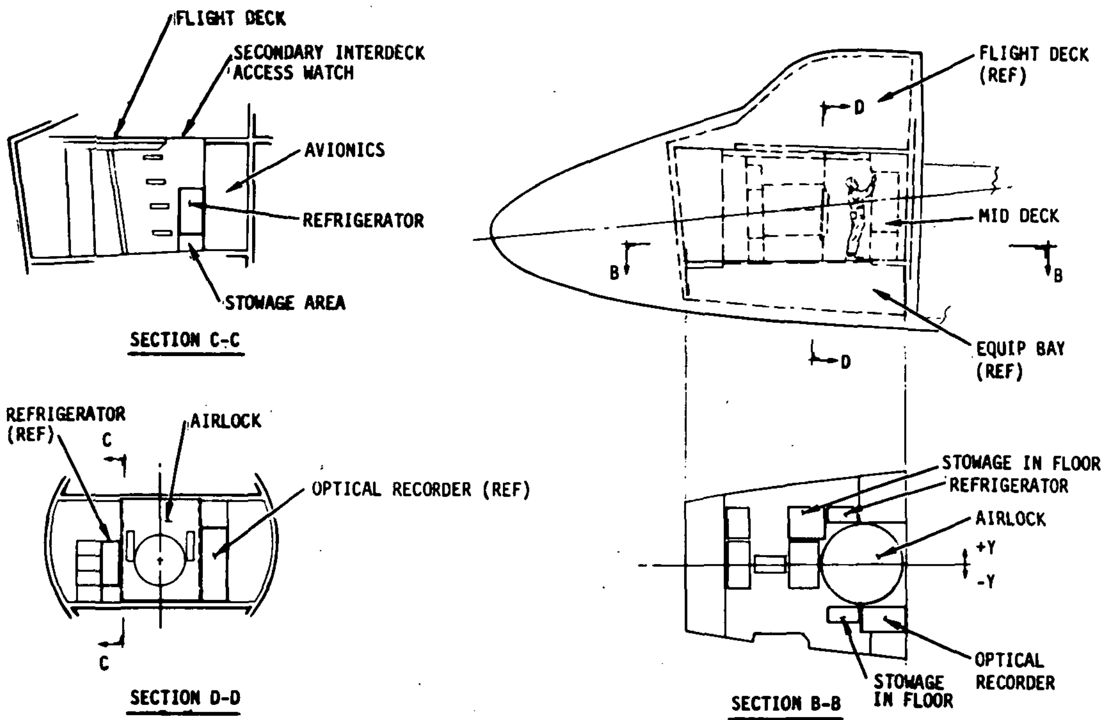

Figure 3.4-2. Crew Compartment Storage Space

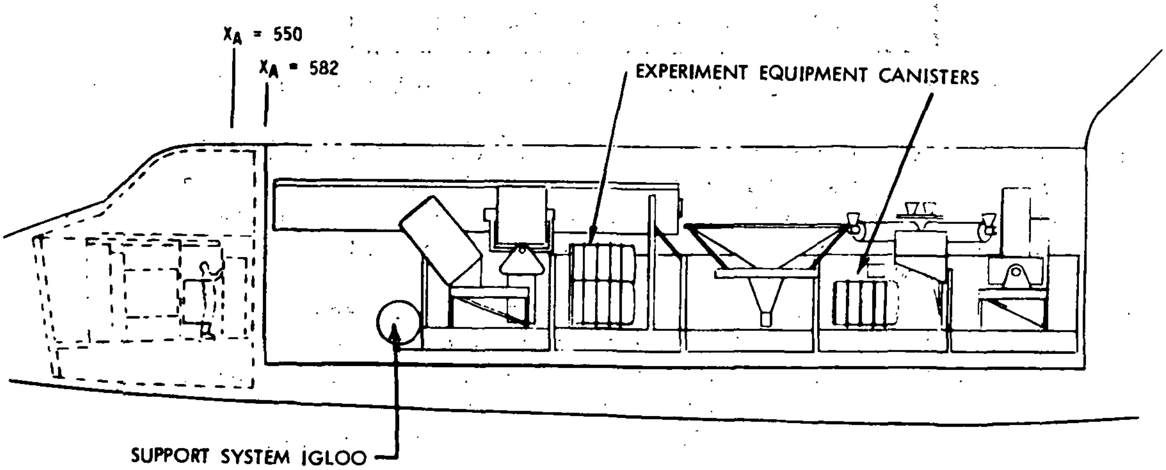

Figure 3.4-3. Pallet-Only Layout (Side)

The composite experiment layout is shown in Figure 3.4-4.

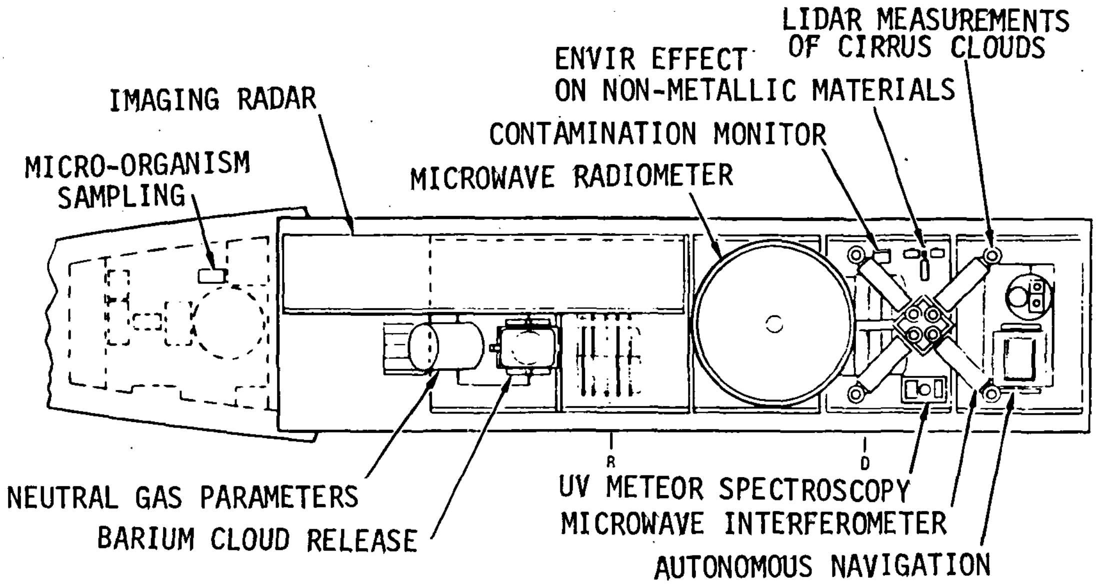

Figure 3.4-4. Pallet-Only Layout (Top)

There is a cylindrical container (igloo) that provides a controlled pressurized environment for certain Spacelab subsystem equipment normally located in the support module (SM) of the complete Spacelab configuration. Thermal control, electrical power, communications data lines and caution and warning interconnects will be provided to the canisters and to the pallet segments from the support systems in the igloo.

The pallet-mounted sensors (see Figures 3.4-3 and 3.4-4) will be operated from the crew compartment of the Orbiter. Figure 3.4-5 illustrates a typical payload specialist station (PSS) where the integrated experiment command and control panels and experiment displays are located. Analog and digital tape recorders will also be located in the PSS in the Orbiter crew compartment.

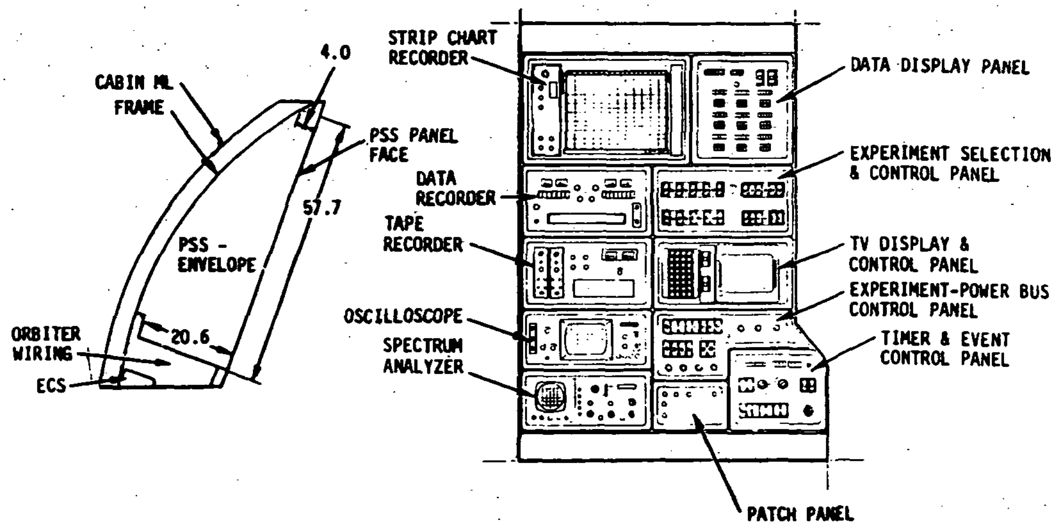

Figure 3.4-5. Payload Specialist Station Layout (Conceptual)

As previously mentioned, the ownership of the pallet-only hardware elements is principally concept-dependent. There is, however, one notable exception: the support system igloo will be owned and maintained by the launch site. In all three concepts, this major hardware element is kept at the launch site following each mission. This igloo contains the subsystems that provide the support to the experiments mounted on the pallet. In the habitable Spacelab concepts this equipment is located in the support module. Ownership of the canisters or experiment equipment igloos is varied between the user and the integration center in the three pallet-only concepts.

4.0 INTEGRATION AND CHECKOUT ELEMENTS

One of the primary objectives of this study was to identify every separable element of the activities associated with the integration and checkout of a Spacelab payload. The many and varied tasks, support services, management functions, non-flight hardware, and facilities required to integrate and check out a payload by eight different processing concepts made it imperative that a bookkeeping technique be developed. The selected technique was a work breakdown structure (WBS) that was primarily task-oriented. The WBS facilitates the compilation of resource requirements and costs by center (user, IC and LS) and cost category.

Three cost categories were established for this study. They are:

1. *MISSION-UNIQUE*. Activities directly attributable to the ground processing of one Spacelab payload.

2. *SUSTAINING*. Activities that pertain to the management and administration of integration and checkout of Spacelab payloads.

3. *NON-RECURRING*. Activities that are required to implement integration and checkout of Spacelab payloads with an operational Spacelab and Shuttle.

Estimates of resource requirements and costs for each item of the WBS were made for each applicable cost category. Compilation of the data was accomplished by a cost model computer program adopted for this study. The program is described in Appendix E. In this section of the report, the WBS that was used in the identification of the tasks and the collection of data for each cost category is presented. Detailed descriptors of each WBS entry are provided.

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4.1 WORK BREAKDOWN STRUCTURE

Figure 4.1-1 presents the WBS that was developed to systematically identify and define the requirements for integration and checkout of a Spacelab payload. The WBS is not programmatic. Experiment equipment development and individual experiment checkout are not included. Also, the procurement of Spacelab end items is excluded.

In most cases the WBS entries of Figure 4.1-1 were subdivided to lower levels. For example, some of the Systems Engineering entries were subdivided into two lower levels in order to definitize and separate discrete task requirements. With the exception of the test and operations entries of Experiment Installation & Checkout, Spacelab Integration, and Orbiter Cargo Integration, a tabulation of the total subdivision of WBS entries is presented. Test and Operations subdivisions were accomplished by functional flow charts and activity data sheets that are presented in Volume II and Appendixes A and B.

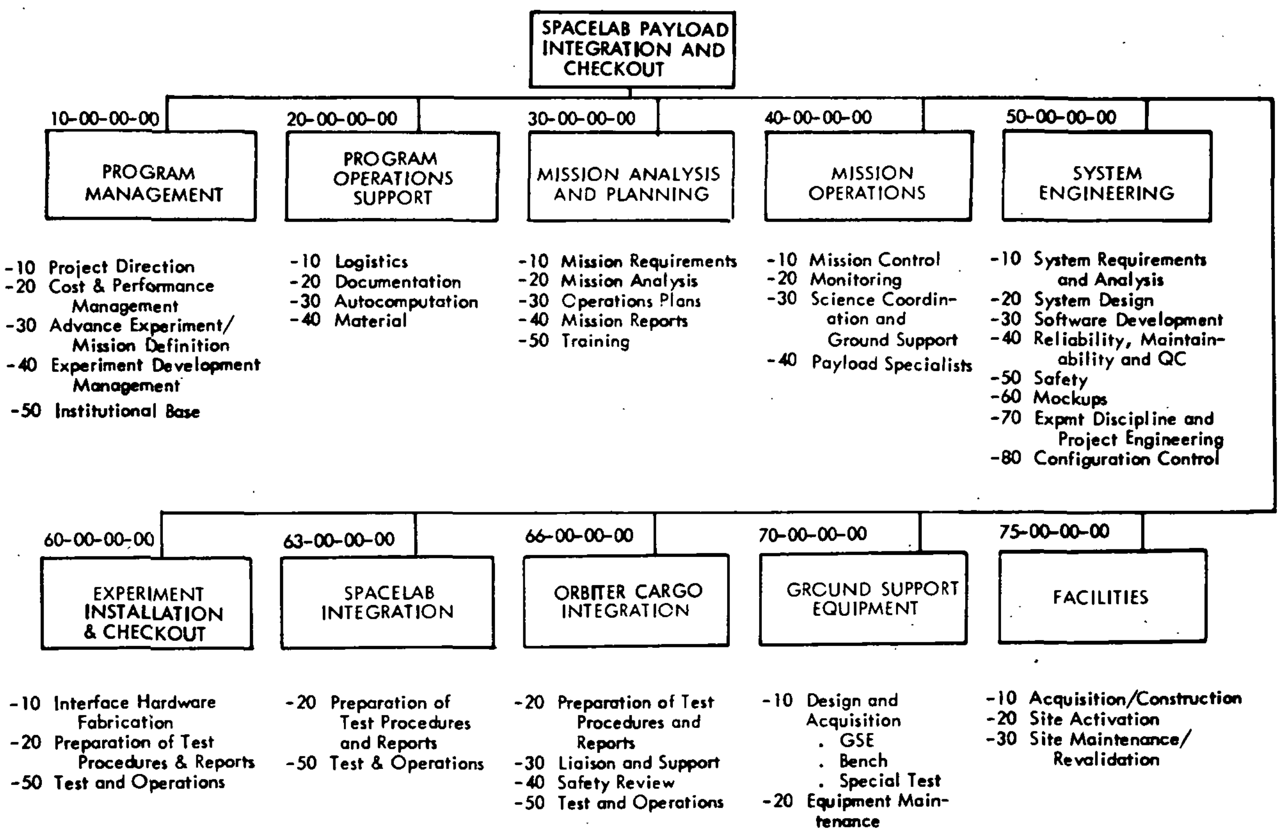

Figure 4.1-1. ATL Integration Program WBS (to Level V)

WORK BREAKDOWN STRUCTURE TABULATION

10-00-00-00

PROGRAM
MANAGEMENT

- -10 Project Direction
- -20 Cost and Performance Management
- -30 Advanced Mission/Experiments Definition
- -40 Experiments Development Management
- -50 Institutional Base

20-00-00-00

PROGRAM
OPERATIONS
SUPPORT

- -10 Logistics
  - -10 Shipping and Receiving
  - -20 Personnel Travel
- -20 Documentation
- -30 Autocomputation Time
- -40 Material

30-00-00-00

MISSION ANALYSIS
AND PLANNING

- -10 Mission Requirements
  - -10 Experiment Requirements (Flight and Ground Support)
  - -20 Orbit and Trajectory Analysis
  - -30 Mission Timelines
- -20 Mission Analysis
  - -10 Operations Planning
  - -20 Resource Allocation Plans
  - -30 Crew Task Timelines
  - -40 Crew Skills
- -30 Operations Plan and Procedures
  - -10 Mission Plans
  - -20 Operating Instructions
  - -30 Ground Support Plans
- -40 Mission Reports
  - -10 Experiment Flight Data Analysis
  - -20 Report Preparation
- -50 Training
  - -10 Plans and Procedures
  - -20 Training Activities

40-00-00-00

MISSION
OPERATIONS

- -10 Mission Control
- -20 Monitoring
  - -10 Operations Monitoring Room(s)
  - -20 Data Transmission/Communications
- -30 Science Coordination and Ground Support
  - -10 Ground Target and Truth Site Activities
  - -20 Spacelab Subsystem Support
- -40 Payload Specialists

50-00-00-00

SYSTEM
ENGINEERING

- -10 System Requirements and Analysis
  - -10 System Operations Analysis
    - -10 Performance Evaluation
    - -20 Expendables, Electrical Loads, Alignments, Calibration
    - -30 Electromagnetic Interference
    - -40 Experiment/System Design and Use Criteria
  - -20 Flight and Ground Requirements
  - -30 Test and Checkout Requirements
    - -10 Tests, Parameters and Limits
    - -20 Confidence Cost-Risk Analysis
  - -40 Integration Equipment Requirements
- -20 System Design
  - -10 Design Requirements and Specifications
    - -10 Operating Instructions
    - -20 Equipment Specifications
    - -30 Common Payload Support Equipment Requirements
  - -20 Design
    - -10 Layout and Installation
    - -20 Interface Hardware
    - -30 Turnaround and Refurbishment Plans
  - -30 Interface Control Requirements
  - -40 Cost and Commonality Analysis
- -30 Software Development
  - -10 *Data and Software Requirements*
    - -10 Orbiter and Mission Control Software Modification Requirements
    - -20 *Spacelab/Experiment Software Requirements*
  - -20 Software Development and Verification
    - -10 *Flight Operations Software (Experiment/Spacelab)*
    - -20 Checkout/Performance Monitoring
    - -30 *Fault Isolation Diagnostic*
    - -40 Repair/Refurbishment
    - -50 *Test and Validation*
- -40 Reliability, Maintainability and Quality Control
  - -10 *Plans and Specifications*
  - -20 Analyses
  - -30 *Inspection*
- -50 Safety
  - -10 *Standards and Criteria*
  - -20 Analyses
  - -30 Reviews and Approvals

-60 Mockups
-70 Experiment Discipline Project Engineering
    -10 Experiments/Integration Program Liaison
    -20 Preparation of Data and Specifications
-80 Configuration Control

60-00-00-00

EXPERIMENT
INSTALLATION
AND CHECKOUT

-10 Interface Hardware Fabrication
    -10 Cables and Wiring
    -20 Structures and Mountings
    -30 Protective and Environment Isolation
-20 Preparation of Test and Operations Procedures and Reports
    -10 Test and Operations Planning and Procedures
    -20 Test and Operations Data and Reports
-50 Test and Operations
    (See T&O flow charts for next level of detail)

63-00-00-00

SPACELAB
INTEGRATION

-20 Preparation of Test and Operations Procedures and Reports
    -10 Test and Operations Planning and Procedures
    -20 Test and Operations Data and Reports
-50 Test and Operations
    (See T&O flow charts for next level of detail)

66-00-00-00

ORBITER CARGO
INTEGRATION

-20 Preparation of Test and Operations Procedures and Reports
    -10 Test and Operations Planning and Procedures
    -20 Test and Operations Data and Report
-40 Safety Review
-50 Tests and Operations
    (See T&O flow charts for next level of detail)

70-00-00-00

GROUND SUPPORT
EQUIPMENT

-10 Design and Acquisition/Fabrication
    -10 GSE (list individual items)
    -20 Bench Equipment
    -30 Special Test Equipment
-20 Equipment Maintenance

75-00-00-00

FACILITIES

- -10 Acquisition/Construction
  - -10 Integration Facility (includes offices and supporting facilities)
  - -20 Data Processing Center
  - -30 Operations Support Room
  - -40 Test Facilities
    - -10 Environmental Test Facilities
    - -20 Other Test Facilities
  - -50 Support Shops
- -20 Site Activation
- -30 Site Maintenance/Revalidation

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4.2 WBS DESCRIPTORS

To further definitize the integration and checkout WBS used in this study, a succinct descriptor was prepared for each WBS entry except the test and operations entries. The descriptions of the test and operations entries are detailed in Volume II and Appendixes A and B. The descriptors in the following tabulation were utilized in the establishment of the task logic, manpower estimates, and interface responsibilities for the candidate Spacelab processing concepts.

WBS DESCRIPTOR TABULATION

10-00-00-00 PROGRAM MANAGEMENT. The management of all program activities and the planning, scheduling, and control of program activities.

10-10-00-00 Project Direction. Management of all activities of the program. This item includes the salaries of managers, their assistants, staffs, and secretaries.

10-20-00-00 Cost and Performance Management.

10-20-10-00 Planning, Scheduling and Control. Preparation of program plans and the development and statusing of program schedules for all ATL activities.

10-20-20-00 Cost Analysis. Analysis of costs and operations for the purpose of reducing costs, including cost estimating and cost control records and systems.

10-20-30-00 Contracts Management. The preparation, monitoring, control of payments, and other processing and maintenance of contracts.

10-30-00-00 Advanced Mission/Experiments Definition. Advanced planning related to the authorization of experiments, their development, selection, and assignment to missions and funding. (This item is not considered a part of the integration portion of the program, but is included because of common management and direct interfaces with integration and checkout activities.)

10-40-00-00 Experiment Development Management. All activities related to the research, development, fabrication and testing of the experiments prior to installation in the Spacelab. (This item is not considered a part of the integration portion of the program but is included because of common management and direct interfaces with integration and checkout activities.)

10-50-00-00 Institutional Base. All activities at a center that support all programs in progress at that center. Includes such items as industrial security and safety, utilities, personnel, library, public relations, payroll, traffic, and general maintenance.

20-00-00-00 PROGRAM OPERATIONS SUPPORT. Services from common-usage support activities at a center that can be directly attributed to the integration and checkout of a Spacelab payload.

20-10-00-00 Logistics. The packaging and shipping of all equipment, and the travel of personnel.

20-10-10-00 Shipping and Receiving. Processing of equipment including the scheduling of carrier movers for both intra- and inter-center transfer of hardware.

20-10-20-00 Personnel Travel. Scheduling and processing of all personnel travel including travel for support of off-site testing, real-time mission support, activation and operation of ground truth sites, and inter-center coordination of operations, etc.

20-20-00-00 Documentation. Services related to the preparation, storage, control, and distribution of ATL program information and documents, including: editing, graphic arts and reproduction services, document control and distribution, and library and archive services.

20-30-00-00 Autocomputation Time. Charges made by local or other data processing centers to support Spacelab payload software development, record keeping, and data reduction.

20-40-00-00 Material. Costs associated with purchases of components and raw materials used to fabricate payload interfacing hardware such as cables, brackets, shields, etc.

30-00-00-00 MISSION ANALYSIS AND PLANNING. Analysis and planning associated with the actual operation of the missions including trajectory analysis, preparation of procedures, training, and ground support operations.

30-10-00-00 Mission Requirements. The assembly and definition of requirements to plan mission operations.

30-10-10-00 Experiment Requirements. Assembly and definition of the objectives, requirements and constraints which the experiments will impose on the conduct of the flight missions and associated ground support operations. This includes definition of such items as target locations, range, line of sight, attitude, stability, hazards, data output, and ground truth requirements.

30-10-20-00 Orbit and Trajectory Analysis. Analytical and computational support to mission planners with respect to orbital trajectory characteristics, timing, ground tracks, sensor line-of-sight/field-of-view characteristics, etc.

30-10-30-00 Mission Timelines: The preparation of a detailed sequence of mission events that relate to the planned Shuttle/Orbiter trajectory including: launch and boost phase operations, communications coverage, ground truth site and other terrestrial points, and night, day, and solar lighting profiles.

30-20-00-00 Mission Analysis. Analytical work related to the sequencing, optimization and planning of mission and ground support operations, including the selection and grouping of experiments for particular flights, allocation of resources, and analysis of workloads.

30-20-10-00 Operations Planning. Analytical work based on experiment requirements and the selection of orbit alternatives to determine the selection of suitable target sites, the optimum sequencing of experiment operations, and the feasibility/availability of supporting ground truth coverage, ground target activities, and other ground support.

30-20-20-00 Resource Allocation Plans. Analysis and optimization of the allocation of resources in support of missions and associated ground operations. The resources include flight crew personnel, communications, data processing facilities, supporting ground truth, aircraft, monitoring and control stations, and other mission supporting items.

30-20-30-00 Crew Task Timelines. The preparation and analysis of timelines of payload specialist activities and tasks, and the analysis of payload specialist workloads.

30-20-40-00 Crew Skills. The determination of mission-related skill requirements including payload specialists and ground support personnel.

30-30-00-00 Operations Procedures and Support. The planning of flight missions, procedures, and ground support operations.

30-30-10-00 Mission Flight Plans. Preparation of complete plans for the operation of the flight missions. The plans include mission objectives, equipment identification, orbit and trajectory definition timelines, experiment operating sequences, target locations, safety requirements, contingency plans, etc.

30-30-20-00 Operating Instructions. Preparation of step-by-step instructions for operation of the experiments and Spacelab equipments in flight. These include operating steps, checklists, anticipated parameter values and limits, hazards, recycling sequences, coordination with ground operations, etc.

30-30-30-00 Ground Support Plans. Preparation of plans for ground operations in support of missions including planning of monitoring operations, control center operations, and ground target and truth site activities.

30-40-00-00 Mission Reports. Data processing, analysis, and preparation of reports derived from mission/experiment operations.

30-40-10-00 Experiment Flight Data Analysis. Processing of flight tapes, ground tapes, and other data derived from flights.

30-40-20-00 Report Preparation. Analysis of data derived from flights and preparation of reports by integration and checkout personnel (i.e., not experimenters' analyses and reports).

30-50-00-00 Training. Experiment plans and procedures for training of all program personnel and particularly the payload specialists.

30-50-10-00 Plans and Procedures. The analysis of the experiments and mission to develop plans and procedures for training programs and training equipment design.

30-50-20-00 Training Equipment. The design and fabrication of experiment related training aids and equipment including training devices and visual aids.

30-50-30-00 Training Activities. The conduct of crew training for Spacelab mission operations including work load analysis, flight procedure verification, and experiment/support equipment layout and operation compatibility evaluation.

40-00-00-00 MISSION OPERATIONS. All operations relevant to the conduct of missions, both on the ground and in orbit, immediately prior to, during, and following the missions.

40-10-00-00 Mission Control. Operation of mission and launch control rooms (so far as costs are chargeable to the Spacelab user) including on-station user personnel at JSC and the launch site.

40-20-00-00 Monitoring. Operation of user mission monitoring rooms and equipment. (Monitoring control room facility and equipment costs are under Facilities.)

40-20-10-00 Operations Monitoring Room(s). Real time mission support personnel (except PI's/experimenters) assigned to the operations room(s) during flight operations.

40-20-20-00 Data Transmission/Communications. Cost of leased telephone lines and other methods of transmitting information to and from the operations monitoring room(s).

40-30-00-00 Ground Support. Operations of ground target and truth site activities, laboratory support of the experiment/mission operations, and Spacelab subsystems performance.

40-30-10-00 Ground Truth Site Activities. All operations at ground targets and truth sites conducted by the Spacelab user.

40-30-30-00 Spacelab Subsystem Support. Engineering operations in the evaluation of Spacelab subsystems during the mission including nominal and off-nominal performance, consumables profiles, alternate operational modes, and corrective actions.

40-40-00-00 Payload Specialists. Astronaut-scientists assigned to a mission, including primary and backup personnel.

50-00-00-00 SYSTEM ENGINEERING. The engineering involved in the planning and preparation of Spacelab payloads for checkout and integration. System engineering will be involved in the integration, design, and analysis of the candidate experiments and support systems, and GSE. It will also be involved in the interface control and test requirements definition, software development, flight data analysis, safety, reliability and quality assurance, and the mockups.

50-10-00-00 System Requirements and Analysis. Analysis and definition of requirements for the design and operation of the integrated system.

50-10-10-00 System Operations Analysis. Analysis and preparation of data on the performance and required characteristics of the experiments and system.

50-10-10-10 Performance Evaluation. Definition of performance parameter values of the experiments and the system including limitations and tolerances; estimates of the performance (sensor response) values of the experiments in flight, and evaluation of the adequacy of design.

50-10-10-20 Expendables, Electrical Loads, Alignments, Calibration. Analytical engineering work in support of system design including analysis of the use of expendables and utilities, analysis of pointing and stability requirements, and analysis of sensor and system calibration requirements.

50-10-10-30 Electromagnetic Interference. Analysis and definition of electromagnetic power, spectral densities, and interference; and engineering support to the design and test of electromagnetic interference protection systems.

50-10-10-40 Experiment/System Design and Use Criteria. The preparation of the Spacelab User's Guide, Experimenter's Design Manual, and similar documentation.

50-10-20-00 Flight and Ground Requirements. Engineering analysis and definition of requirements for operation of the experiments in flight and the operations of ground support.

50-10-30-00 Test and Checkout Requirements. The preparation of requirements for experiment/Spacelab test and checkout.

50-10-30-10 Tests, Parameters, and Limits. The determination of tests to be conducted and specification of performance and test parametric values and tolerances.

50-10-30-20 Confidence, Cost-Risk Analysis. Estimation of the costs of tests and operations, and evaluation of the risk of omitting tests versus the cost of reprocessing and reflight in the event of failure.

50-10-40-00 Integration Equipment Requirements. Identification of GSE, facilities, and logistics/transportation support equipment for a specific mission payload.

50-20-00-00 System Design. All design activity required for installation of experiments in the Spacelab and preparation of associated specifications and operating instructions. Includes, in particular, the layout of experiments, common controls and displays and interface hardware. (Does not include initial design of GSE and facilities.)

50-20-10-00 Design Requirements and Specifications. Compilation of requirements and preparation of specifications for the design of equipment.

50-20-10-10 Operating Instructions. Preparation of operating instructions for equipment designed under System Design.

50-20-10-20 Equipment Specifications. Preparation of design specifications for equipment designed under System Design.

50-20-10-30 Commmon Payload Support Equipment. Analysis of mission equipment requirements to ascertain applicability of standard/common usage of flight hardware. Scheduling, coordinating, and obtaining standard equipment for incorporation into the Spacelab and the payload specialist station of the Orbiter.

50-20-20-00 Design. Preparation of design drawings and supporting analysis.

50-20-20-10 Layout and Installation. Preparation of layout drawings and installation drawings for experiments and experiment support equipment in the Spacelab, the Orbiter, and Payload Specialist Station.

50-20-20-20 Interface Hardware. Design of all interfacing hardware including wiring, cables, structures, mounting and protective devices between the experiments and the Spacelab modules, the Orbiter, and Payload Specialist Station.

50-20-20-30 Turnaround and Refurbishment Plans. Definition of requirements and plans for the reconfiguring and refurbishing of the Spacelab SM/EM shell, racks, and pallet segments, their equipment, and the experiments, as required, between flights.

50-20-30-00 Interface Control. Preparation and coordination of interface control drawings (ICD's).

50-20-40-00 Cost and Commonality Analysis. Estimating and evaluating the cost of design alternatives and equipment use alternatives with the objective of reducing integration program costs.

50-30-00-00 Software Development. The assembly of requirements, development and verification of payload software.

50-30-10-00 Data and Software Requirements. Assembly and compilation of data requirements which impact software and software requirements.

50-30-10-10 Orbiter and Mission Control Software Modification Requirements. Specification of requirements imposed by experiments and the Spacelab for modification of Orbiter and mission control software for particular missions.

50-30-10-20 Spacelab/Experiment Software Requirements. Compilation of experiment data output requirements and definition of requirements for experiment/Spacelab software. The item covers both in-flight software, ground checkout software, and ground processing of flight data.

50-30-20-00 Software Development and Verification. Development, debugging, and verification of software programs required for the payload. (Excludes modifications to Orbiter and mission control software.)

50-30-20-10 Flight Operations Software. Development and verification of flight operations software (software used in-flight in the Spacelab support module computer which performs command, control and data handling functions).

50-30-20-20 Checkout/Performance Monitoring. Development and verification of checkout and performance monitoring software (software used to acquire engineering data, configuration status, comparison with pre-selected tolerances or conditions, develop caution/warning advisory signals, etc.; this software may be used during flight or ground checkout).

50-30-20-30 Fault Isolation Diagnostic. Development and verification of fault isolation diagnostic software (software generally used on the ground to isolate problems in Spacelab subsystems).

50-30-20-40 Repair/Refurbishment. Development and verification of repair/refurbishment software (software which is used to evaluate Spacelab systems telemetry data to predict maintenance actions including allocation of resources).

50-30-20-50 Test and Validation. Development and verification of test and validation software (software used to prepare, test, debug, and validate other software; this software is used in the computer supporting the development of the software and includes compilers, assemblers, translators, interpreters, and the programming language itself).

50-40-00-00 <u>Reliability, Maintainability, and Quality Control</u>. Activities related to reliability, maintainability, and quality control which are performed to ensure acceptable experiment performance and compatibility with Spacelab and Orbiter constraints.

50-40-10-00 Plans and Specifications. Preparation of plans for reliability and control programs and criteria, guidelines, and specifications for reliability and maintainability considerations to be followed in the development of system and equipment designs.

50-40-20-00 Analyses. Numerical analysis of reliability, failure modes effects analyses (FMEA), failure reporting, and other data compilation and analytical work relating to reliability, maintainability, and quality control.

50-40-30-00 Inspection. Administrative portion of quality control, including the preparation of paperwork records and approvals.

50-50-00-00 <u>Safety</u>. Development and administration of criteria and controls to ensure safety of all personnel and equipment, configurations, and procedures in all integration, checkout and flight activities.

50-50-10-00 Standards and Criteria. Generation of safety requirements, standards, and criteria, and identification of hazards for the design, test, and operation of the system; also, the definition of safety tests which may be required.

50-50-20-00 Analyses. Analyses of system designs and procedures for safety (e.g., hazard analyses). Analyses of parts and materials for safety and compatibility (e.g., fire resistance, nontoxicity, outgassing, contamination, etc.) including support by materials and processes laboratory as required.

50-50-30-00 Reviews and Approvals. Conduct of reviews and exercise of approval/disapproval authority over all materials, hardware, and procedures.

50-60-00-00 Mockups. Design and fabrication of mission-unique payload equipment required for payload specialist training. Integration of experiment-related training equipment and Spacelab support system equipment for a mission. (Development of basic mockup is included in Facilities.)

50-70-00-00 Experiment Discipline Project Engineering. Engineering work associated with the interface between the experimenters and integration and checkout activities to provide the experimenters with advice and to convert data obtained from the experimenters into a format required by the integration and checkout process, and to make certain that requirements and functions are adequately specified.

50-80-00-00 Configuration Control. The maintenance and control of records of the source, processing, and testing of elements of the experiments and system hardware--particularly flight hardware. It includes a system for identification of each element, its composition, and the location and timing as well as the nature of each process, test, or use.

60-00-00-00 EXPERIMENT INSTALLATION AND CHECKOUT. Activities associated with the test, checkout, and operations processing of the flight-ready experiments from receiving inspection through installation and test and checkout in the R and P . Includes refurbishment and mating of the R and P.

60-10-00-00 Interface Hardware Fabrication. The fabrication of hardware required by the interface between the experiments and the Spacelab.

60-10-10-00 Cables and Wiring. Fabrication of wiring, cables, and special controls or displays required for the interface between experiments and the Spacelab, the Orbiter and Payload Specialist Station.

60-10-20-00 Structures and Mountings. Fabrication of racks, supports, and other structural devices not part of standard Spacelab equipment for the interface between the experiments and the Spacelab, the Orbiter and Payload Specialist Station.

60-10-30-00 Protective and Environment Isolation. Fabrication of equipment for the purpose of protecting or isolating experiments from the Spacelab/Shuttle and/or test and operations environment that is not part of the experiment equipment nor of standard Spacelab equipment.

60-20-00-00 Preparation of Test Procedures and Reports. Preparation of procedures and reports associated with the test and operations flows of the experiment/Spacelab hardware during experiment integration.

60-20-10-00 Test Planning and Procedures. Development of detailed plans and step-by-step procedures for conducting the tests and operations processing of the experiments and Spacelab through the applicable portion of the integration process--experiment integration in this case. (Test procedures are derived from the test requirements definition, provided by System Engineering, and are utilized to direct an orderly, efficent test or operation. The procedures specify the test objective, timelines, step-by-step procedures, personnel, GSE, support requirements, constraints, safety hazards and emergency procedures in the event of failures during test.)

60-20-20-00 Test Data and Reports. Analysis of data and preparation of test reports derived from the test and operations processing of the experiments and Spacelab hardware through the applicable portion of the integration process--experiment integration in this case.

60-50-00-00 Tests and Operations. All tests, checkout, and operations associated with experiment integration (see the Test and Operations Flow Charts and Activity Data Sheets for descriptive material).

63-00-00-00 SPACELAB INTEGRATION. Activities associated with the test and checkout from experiment integration up to preparation for installation in the Shuttle (Orbiter-cargo integration). Includes refurbishment of the SM and mating of the R/P with the SM and integrated checkout of the mated system.

63-20-00-00 Preparation of Test Procedures and Reports. Preparation of procedures and reports associated with the test and operations flows of the experiment/Spacelab hardware during Spacelab integration.

63-20-10-00 Test Planning and Procedures. See 60-20-10-00 applied to Spacelab Integration.

63-20-20-00 Test Data and Reports. See 60-20-20-00 applied to Spacelab integration.

63-50-00-00 Tests and Operations. All tests, checkout, and operations associated with Spacelab integration (see the Test and Operations Flow Charts and Activity Data Sheets for descriptive material).

66-00-00-00 ORBITER CARGO INTEGRATION. Activities associated with the test, checkout, and operations processing of the flight-ready Spacelab and experiments from preparation for installation in the Shuttle through post-landing operations, demating of the Orbiter-Spacelab, and preparation for shipment.

66-20-00-00 Preparation of Test Procedures and Reports. Preparation of procedures and reports associated with the test and operations flows of the experiment/Spacelab hardware during Orbiter cargo integration.

66-20-10-00 Test Planning and Procedures. See 60-20-10-00 applied to Orbiter cargo integration.

66-20-20-00 Test Data and Reports. See 60-20-20-00 applied to Orbiter cargo integration.

66-30-00-00 Liaison and Support. Liaison and coordination of user and/or integration center with the launch site other than during Orbiter cargo integration (i.e., not included in the Test and Operations flow charts). Includes user and integration center personnel stationed at the launch site on a permanent basis.

66-40-00-00 Safety Review. Activity required for the assembly of data, analysis, review, and approval with respect to range safety of payload equipment and operations conducted at the launch site.

66-50-00-00 Test and Operations. All tests, checkout and operations associated with Orbiter cargo integration (see Test and Operations flow charts and activity data sheets for descriptive material).

70-00-00-00 GROUND SUPPORT EQUIPMENT. Activity related to the acquisition and maintenance of ground support equipment and other ground equipment for integration and checkout activities including ground handling and shipping equipment.

70-10-00-00 Design and Acquisition/Fabrication. The design and fabrication or acquisition of ground support equipment and other ground equipment for the processing of Spacelab payloads.

70-10-10-00 GSE. The complete design and acquisition or fabrication including initial test and checkout of GSE. End items of GSE are listed individually under this item.

70-10-20-00 Bench Equipment. The complete design, acquisition and/or fabrication of bench maintenance and launch test equipment and includes initial test and checkout.

70-10-30-00 Special Test Equipment. The complete design, acquisition and/or fabrication of special test equipment and special support equipment required to integrate experiment equipment. Includes initial test and checkout.

70-20-00-00 Equipment Maintenance. Maintenance and repair (revalidation) of GSE, bench equipment, and support equipment.

75-00-00-00 FACILITIES. Acquisition, activation, and maintenance of all Spacelab integration and checkout facilities. Excludes experiment development facilities and Shuttle facilities.

75-10-00-00 Acquisition/Construction. The complete design, acquisition (or construction/modification) and initial validation of facilities and equipment installed for the integration and checkout operations, excluding experiment development and test.

5.0 PROGRAM MODELS

In order to definitize the Spacelab payload processing concepts and establish the necessary resource requirements, a set of program models was required. These models consist of baseline definitions of the major operations and flight hardware end items that are currently planned for the Space Shuttle era. Four key programmatic models were used throughout this study. They are as follows.

1. *SPACE TRANSPORTATION SYSTEM MODEL.* Defines the procedures, operations, and associated interrelationships between the various elements that comprise Space Shuttle/Spacelab activities in support of all potential Spacelab users.

2. *ORBITER MODEL.* Defines the Orbiter support capabilities and principal Orbiter/Spacelab interfaces that are to be checked and verified during Orbiter/cargo integration.

3. *SPACELAB MODEL.* Defines the configuration and support capabilities of both the complete Spacelab and pallet-only configurations. The model is based upon the preliminary release of the "Spacelab Payload Accommodations Handbook," dated October 1974.

4. *ATL MODEL.* Defines three candidate Spacelab payloads planned by the Langley Research Center as part of their Advanced Technology Laboratory program. These three payloads were the basis for all the data developed in this study associated with experiment integration and checkout.

Each of the models is defined in this section to that level of detail that would effect the integration and checkout of Spacelab payloads. Although the models were baselined at the initiation of the study, they were continually updated and expanded. The data in this section reflect available information as of October, 1974.

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5.1 SPACE TRANSPORTATION SYSTEM MODEL

On all previous programs, a payload was defined; then a delivery vehicle and support complex was developed, designed or modified to serve it. The STS reverses this order, which means the payload must be designed to match the delivery system. The impact on payloads such as the ATL is two-fold:

1. ATL hardware and procedures are constrained to use the standard elements of the STS, including compliance with all standard operating procedures. The ATL program may "own" a developed Spacelab but that Spacelab will be standardized to be compatible with the Shuttle and support a broad spectrum of users.

2. The ATL program is responsible only for those efforts that customize a standard Spacelab/Orbiter to unique ATL requirements. ATL thus has transferred to it, at no development cost, all the services and support functions available within the STS operational system.

The first aspect directly affects this development of options, approaches, analyses, and optimizations for the processing of Spacelab payloads. The processing must be a corollary to and complementary to the overall Space Transportation System (STS). A Spacelab payload such as the ATL cannot be considered as an independent autonomous program like previous space satellite projects; the ATL is more like the cargo carried by a commercial airline, or perhaps more appropriately like the experiments of the airborne research program conducted by Ames Research Center utilizing a Convair-990 aircraft.

The STS is the concurrent development of a total delivery system, Shuttle hardware, and support facilities that in the operational phase can be leased by many users. KSC is the initial operating base where the Shuttle is maintained, loaded with cargo, launched, and recovered. KSC will also develop and institute procedures for orderly operations, and the cargo will be required to conform to these procedures, among which is the constraint that the payload must be packaged in a carrier that is compatible with Orbiter physical constraints.

The carrier of concern in this study is the Spacelab, which is currently being developed by ESRO/ERNO. As the Spacelab, like the Shuttle, is being developed to support a broad spectrum of users, standardization of design and operations will be required. The Spacelab will, in effect, be an integral part of the STS. There will be standard procedures for the installation, and checkout of the Spacelab in the Orbiter, operations with the Orbiter and the launch complex, and interfaces with the mission control complex. These standardized modes of operations associated with the Spacelab will further impact payloads such as the ATL in that conformance to Spacelab procedures will also be required.

A standardized real-time data dissemination network is anticipated. That portion of the network that will be applicable to on-orbit payload operations involves the Tracking and Data Relay Satellite (TDRS). Current planning indicates that on-orbit payload data will be relayed from the Orbiter via a geosynchronous satellite system to a ground terminal at White Sands, New Mexico. Payload data bandwidths and formatting must be compatible with Spacelab processing capabilities, and Orbiter and TDRS communication capabilities. At this time the technique for data dissemination to the Spacelab user has not been baselined. It is assumed that this link of the data flow is the responsibility of the user.

The second aspect, utilization of a developed and operational STS, is a distinct advantage to Spacelab users such as the ATL. Other than activities directly related to experiment equipment, all integration and checkout activities can be considered to be for the Nth mission. This situation should significantly reduce the required effort for a Spacelab user as compared to previous space programs where almost every flight required a first-time in-depth analysis and verification of the entire system. The delivery system (Shuttle/Spacelab) is proven and standardized, integration and checkout personnel are experienced, and procedures and documentation have been established. The total resources of an operational STS are available to the Spacelab user.

5.2 ORBITER MODEL

Those characteristics of the Shuttle Orbiter that impact the integration and checkout of Spacelab payloads are delineated in this section. The primary data source was JSC Document 07700, Volume XIV, Revision C, "Space Shuttle System Payload Accommodations," July 1974. On-going Orbiter design studies were also used as appropriate.

The Orbiter crew compartment consists of a two-level cabin, the flight deck, and the mid-deck. The forward area of the flight deck is dedicated to Orbiter flight operations, with displays, controls, and seats for the commander and pilot. The aft area of the flight deck includes and integrated crew station arranged for flight control, rendezvous, Spacelab and payload operations, remote manipulator system control, and Orbiter systems control. This integrated crew station is the work area in the Orbiter cabin for the mission and payload specialist(s). The provisions in the aft flight deck provide the capability to check out, monitor, and control Spacelab subsystems and Spacelab payloads as required. The payload specialist would be active only during on-orbit operations. Displays and control panels will be installed in standard racks. The caution and warning panel is located so that the mission specialist can monitor the displays during launch and entry. The panel surface area, volumes, and shapes allocated for the Spacelab and its payload are in the design definition phase.

The mission specialist will be proficient in Spacelab operations. He will have a detailed knowledge of the Spacelab requirements, objectives, and supporting equipment. He will be knowledgeable of Orbiter and Spacelab support systems and will be the prime crewman for EVA operations. He will be responsible for the coordination of overall Orbiter operations in the areas of flight planning, consumable usage, and other activities affecting payload operations. He may perform special Spacelab handling or maintenance operations via the remote manipulator system. At the discretion of the Spacelab sponsor, he may assist in the management of Spacelab operation and may, in specific cases, serve as the payload specialist. Because of training requirements and mission responsibilities, he should be selected by NASA on a career basis.

The payload specialist will be responsible for the achievement of the payload objectives. The payload specialist will be proficient in experiment operations. He will have a detailed knowledge of the experiment instrumentation, operations, requirements, objectives, and supporting equipment. He will be responsible for the management of Spacelab operations and for the detailed operations of particular instruments or experiments. He must be knowledgeable of certain Orbiter systems, e.g., accommodations, life support, hatches, tunnels, and caution and warning systems.

Detailed responsibilities of the mission specialist and payload specialist will be tailored to meet the requirements of each individual mission.

The crew size will be a function of the mission complexity and duration but the maximum crew, including commander and pilot, is seven persons.

In addition to crew accommodation and attitude control, the Orbiter provides various services which are available for use by the Spacelab and its payload. These services are listed below.

Hydrogen/oxygen fuel cells provide the dc electrical energy for the Orbiter and Spacelab. The required fuel is stored in tank sets, referred to as energy kits; each energy kit provides 840 kWh. These kits are located outside the volume available for the Spacelab and its payload. The Orbiter baseline provides 50 kWh of electrical energy for Spacelab use; the weight of one additional energy kit is included in the Spacelab baseline design so that 890 kWh are available to the Spacelab and its payload. More energy kits may be added, but their weight would be charged to the Spacelab payload.

The Orbiter environmental control and life support (ECLS) subsystem provides for the environment to support a shirtsleeve operation within the pressurized cabin of the Orbiter during all mission phases. The ECLS subsystem will perform the functions of (1) atmospheric revitalization; (2) food, water, and waste management service, (3) active thermal control; and (4) fire supression. The heat generated by the Spacelab and the payload is dissipated via Orbiter radiators. A heat exchanger is used for the transfer of heat from Spacelab-to-Orbiter coolant loops. An on-orbit heat rejection capability of 8.5 kW for the Spacelab and its payload is provided with the doors of the Orbiter cargo bay open. It is achieved by supplementing the basic Orbiter capability (6.3 kW) with a heat rejection kit which is included in the basic Spacelab, i.e., the increased heat rejection capability is not weight chargeable to the Spacelab payload.

The Orbiter communications and tracking subsystem provides for:

- Receiving, transmission, and distribution of voice
- Transmission of operational telemetry
- Receiving, processing, and transmission of Spacelab telemetry
- Receiving, decoding, and transmission of commands
- Transmission and distribution of television signals
- Tracking cooperative and passive targets
- Transmission and reception of EVA data and voice

This Orbiter subsystem also provides the interface between the Spacelab and

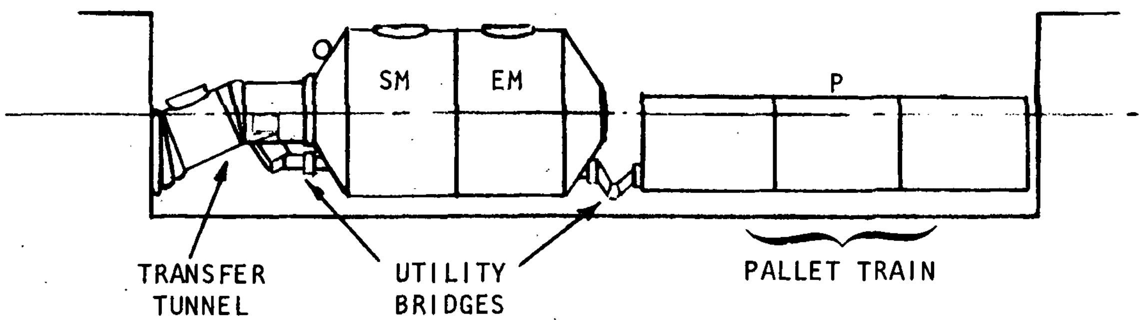
- Tracking and data relay satellite (TDRS)
- Space tracking and data network (STDN)
- Spacelab
- EVA crewmen
- Other space vehicles
- Landing site facilities of the Orbiter

5.3 SPACELAB MODEL

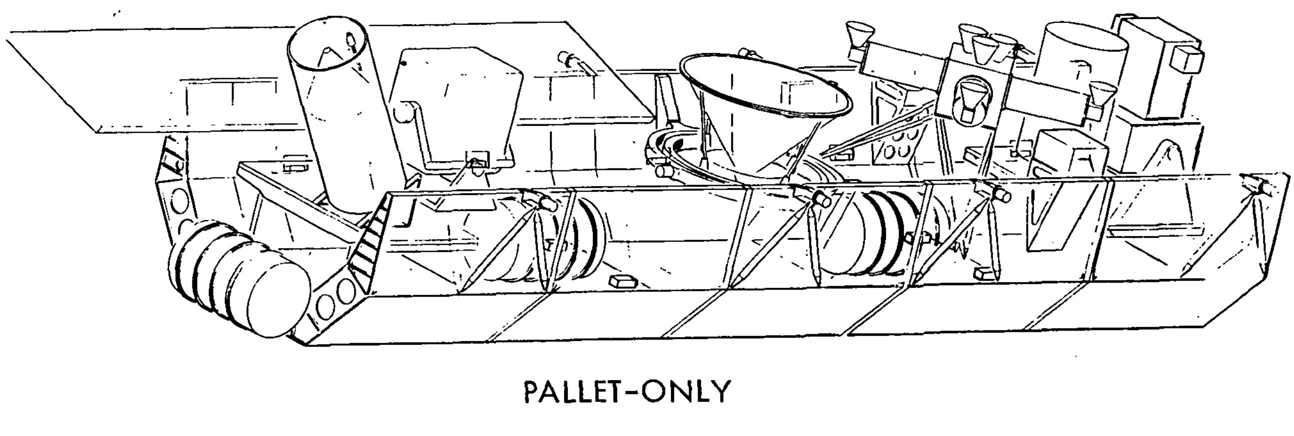
Although numerous documents were used during the course of the study as a source for Spacelab configuration and capability data, the final data package was based upon the preliminary issue of "Spacelab Payload Accommodations Handbook," dated October 1974. Extracts from this document, which were of significance to the study, are presented below.

SPACELAB PHYSICAL ACCOMMODATIONS

The modular elements of the Spacelab can be arranged in various flight configurations to accommodate the needs of specific mission/payload requirements and Orbiter constraints. Two of the possible Spacelab configurations were utilized in this study and are illustrated in Figure 5.3-1.



COMPLETE SPACELAB



PALLET-ONLY

Figure 5.3-1. Two Representative Spacelab Flight Configurations (Conceptual Layout)

The complete Spacelab configuration consists of the support module, the experiment module, and pallet train. The configuration is located toward the center of the Orbiter cargo bay because of Orbiter c.g. constraints. The SM and EM are accessible from the Orbiter cabin through the transfer tunnel. Utility services from the Orbiter are routed through the forward utility bridge. The 9-meter pallet train is comprised of three rigidly connected pallet segments. Utility services to the pallet are routed through the aft utility bridge. This configuration provides a pressurized volume for experiment equipment in the SM and EM and also the pallet mounting area for experiment equipment that requires exposure to the space environment.

The pallet-only configuration (15-meter pallet) provides the longest possible experiment platform for Spacelab payloads requiring exposure to the environment of space. The configuration described here consists of two independently suspended pallet trains separated by a dynamic clearance gap. The pallet trains consist of three and two structurally connected pallet segments. The "igloo" mounted on the forward pallet provides a controlled pressurized environment for certain Spacelab subsystems equipment located in the support module of the complete Spacelab configuration. Utility services from the Orbiter are routed through a utility bridge.

Pressurized Volume

The pressurized volume consists of two 4060-mm-diameter cylindrical modules of 2689-mm length. Each module is equipped with a flange ring of 1300-mm internal diameter on the top to provide accommodation for the following mission-dependent items: airlock or optical window, or viewport, or optical window and viewport. When not used for any of these items, a coverplate is used instead.

The end closures are conical sections of equal cone angle. The forward end cone is truncated at the diameter required to interface with the crew transfer tunnel which connects to the Orbiter and provides a 1600-mm opening. The aft end cone is truncated to provide a 1300-mm opening for the aft airlock. The module exterior is covered with high-performance insulation over which a protective corrugated fiberglass cover is installed. EVA mobility aids are also located on the exterior.

Each module can accommodate ten racks of equipment. Four of the racks in the SM are required for Spacelab support system equipment and controls and displays. The remaining six racks in the SM, and all ten racks in the EM, are available for mounting of experiment equipment.

The floor is designed to carry the racks with their equipment and consists of segments which may be interconnected at the integration site and transported in this mode. The floor itself consists of a load-carrying beam structure and is covered by a quickly removable cover on the main walking surface. It allows underfloor access to subsystems in orbit, and also provides for noise attenuation and acts as a debris barrier. The floor also contains openings (equipped with screen and filters) to admit cabin air return flow.

Figure 5.3-2 shows a cross-section of the support module taken at the forward end of the cylinder. Major features shown are the removable, segmented floor with attached equipment rack assemblies, the coverplate, and the underfloor subsystem equipment installation. The underfloor subsystem equipment is mounted on a subfloor attached to the primary structure.

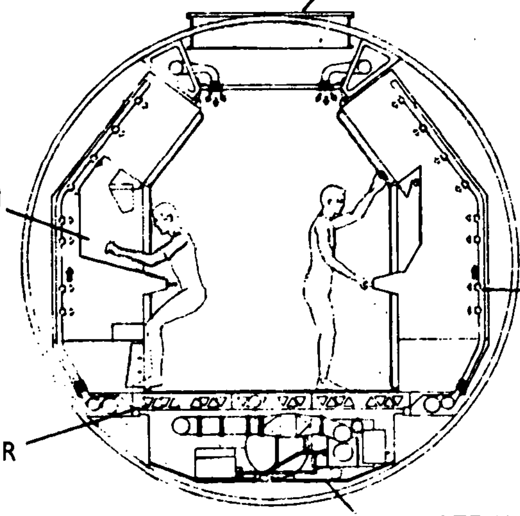


Figure 5.3-2. Core Segment Cross-Section

Figure 5.3-3 shows longitudinal sections through the module and illustrates the subsystem arrangement. Figure 5.3-4 depicts cut-away sections of the SM. It shows the subsystem control station and work bench in the forward part and the space available for experiments in the aft part, with the experiment racks removed. Besides space in the racks, additional stowage space is available in the overhead compartments and in the subfloor area of the experiment module. Further equipment and stowage containers can be floor-mounted in the aisle of the module, in accordance with applicable safety requirements.

There is only a single interface plane between the subsystem rack assembly and experiment racks for electrical and avionics cooling loop connections after roll-in and before roll-off of the floor. The roll-in/roll-out concept for loading and unloading rack assemblies is shown in Figure 5.3-5.

Figure 5.3-6 shows the details of the standard racks available for experiments and how they are attached. Location and arrangement of the racks inside the module are as indicated previously. Two types of racks are available--single racks with an overall width of 572 mm, and double racks with an overall width of 1060 mm. Both racks are 760 mm deep at their greatest depth, and extend from the floor to the overhead structure.

The double rack will accommodate two side-by-side mounted 19-inch standard GSE MIL-Spec-864 equipment, or three and one-half ATR, ARINC 404 or MIL-C-172 electronics packages, while the single rack accommodates a single row of standard equipment packages.

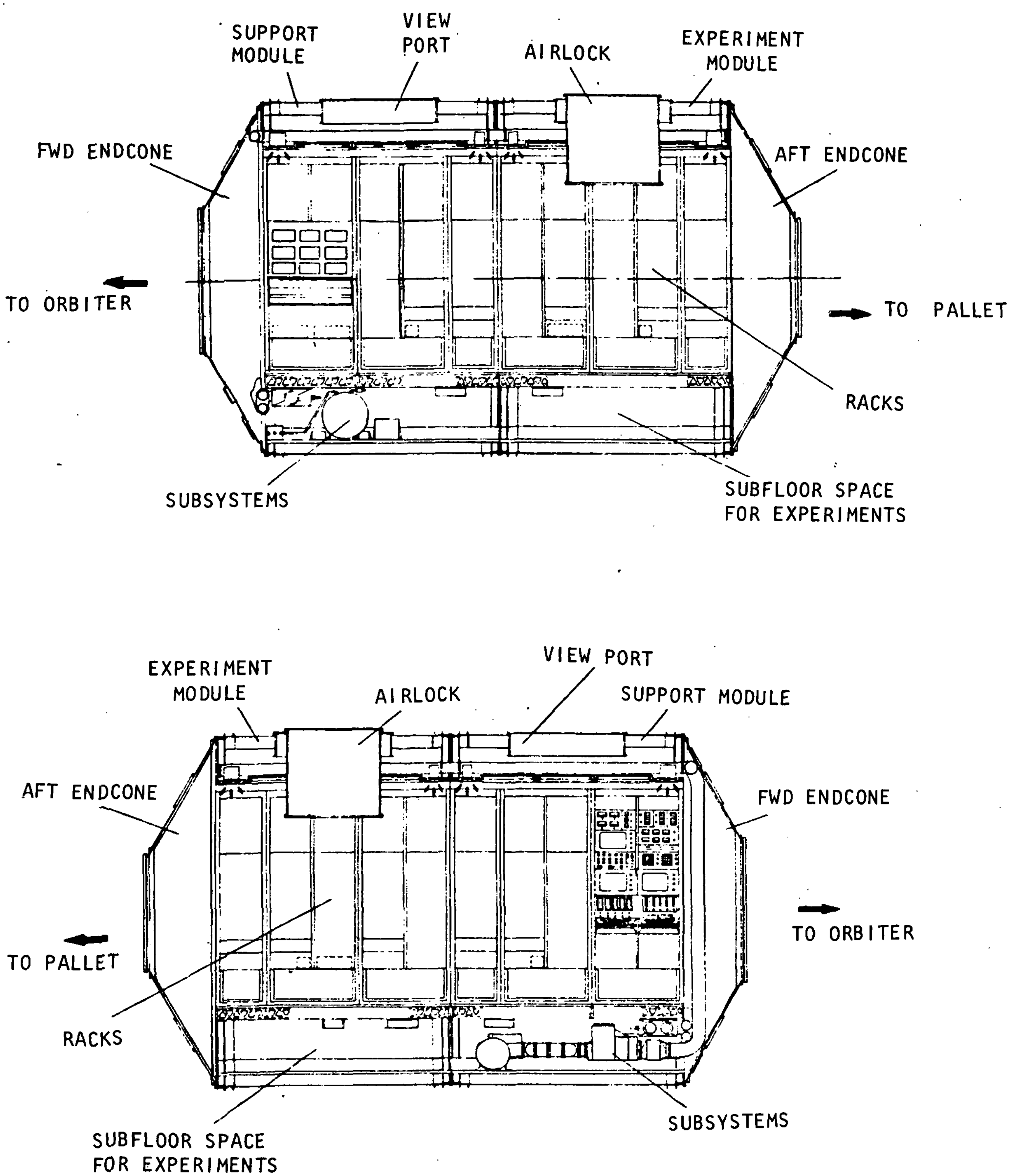
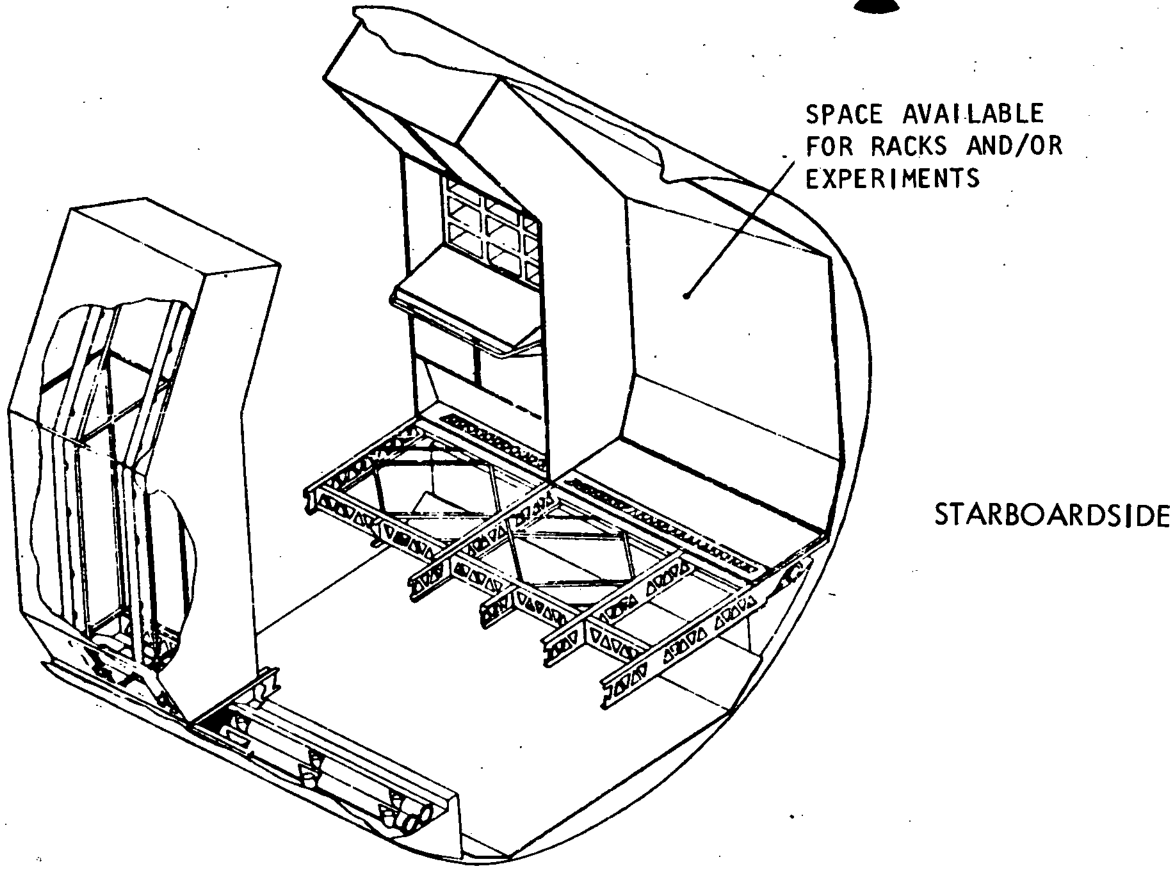


Figure 5.3-3. Sectional Views



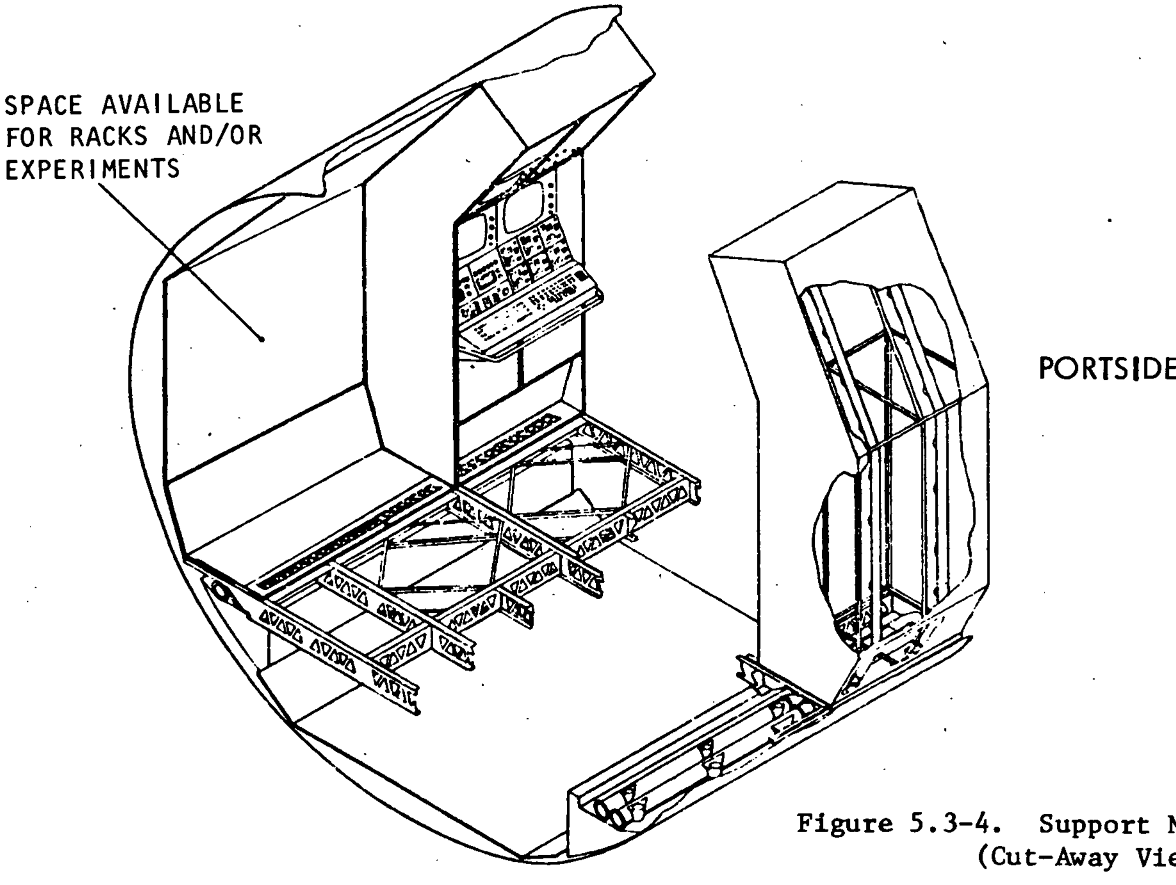


Figure 5.3-4. Support Module
(Cut-Away View)

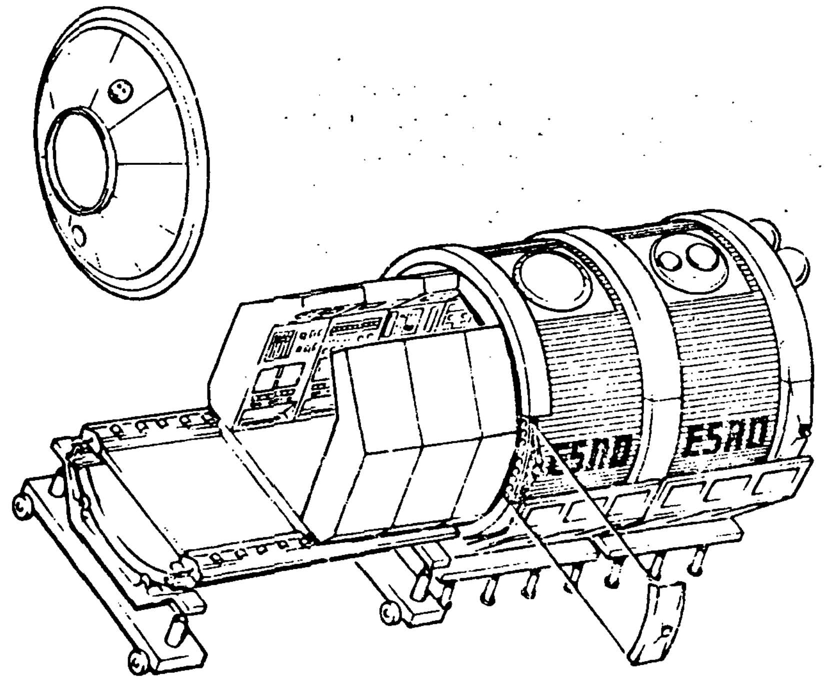


Figure 5.3-5.
Loading/Unloading Concept
of Rack Assembly

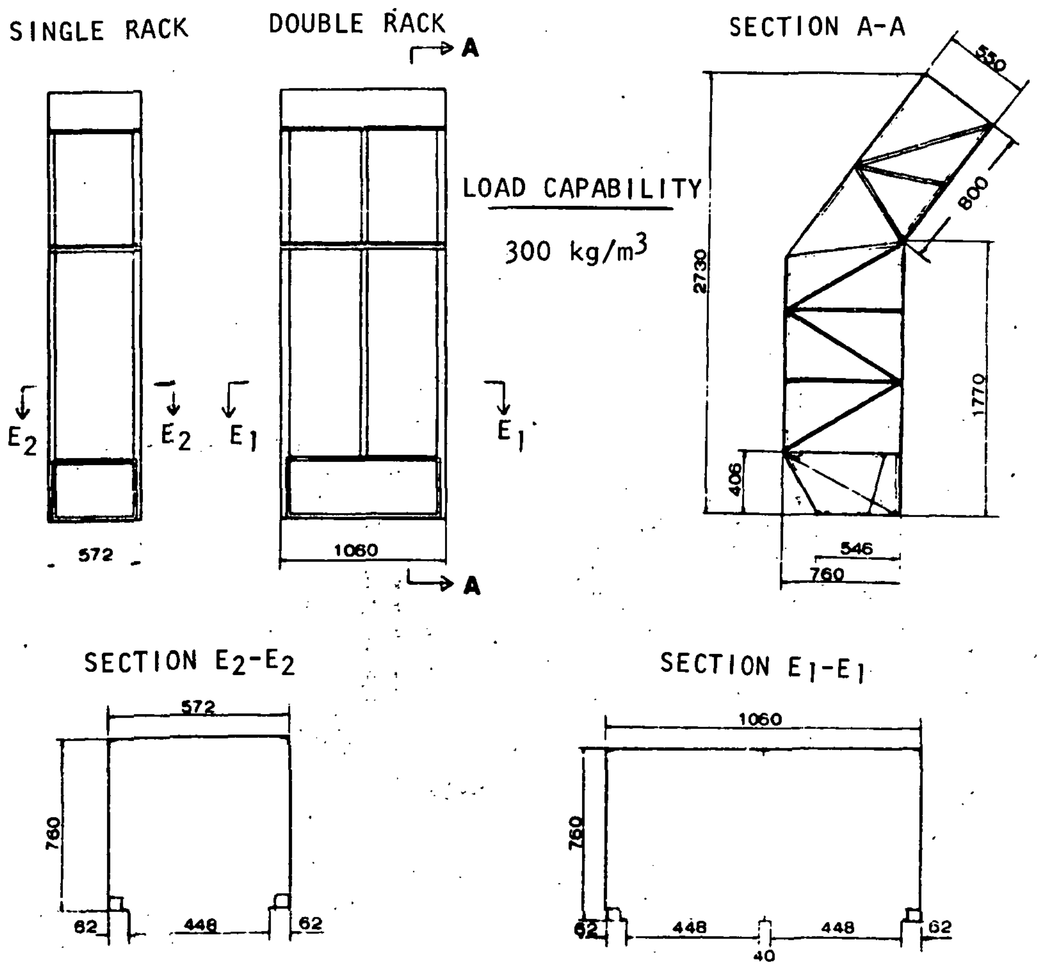


Figure 5.3-6. Standard Racks

A 406-mm removable access panel, which also acts as a foot-restraint platform, is provided at the floor level of each rack.

The rack is provided as a structure item with removable panels on three sides, open at the front, a closed panel on top, and a bottom panel with cooling system cutouts. A removable frame is also provided which, when installed, divides the 1060-mm rack into two sections. Design load for the racks is 300 kg/m^3. The panels are sealed (when installed) for thermoconditioning purposes.

The pallet structure accommodates experiments and payloads to be directly exposed to space. The pallet provides the following structural support to experiment equipment.

- Basic structure: floor panels, skin panels
- Mission-dependent structure: hard points
- Optional structure: experiment-mounting platforms

Pallet

The pallet cross-section is U-shaped and of aeronautic-type construction. It provides hard points for mounting heavy experiments and a large panel surface area to accommodate lighter payload equipment. Pallet segments are modular (3-m nominal length) and can be flown independently or interconnected. Although five pallet segments can be used in the pallet-only configuration, only a maximum of three pallets can be rigidly interconnected to form a pallet train. The physical accommodation capability of a single pallet segment is as follows.

1. The overall load-carrying capability of a single pallet segment is 1000 kg/m. However, the pallet design is such that this capability can be increased to 2000 kg/m by adding additional structural elements.

2. A single pallet segment provides 36-m^3 volume above the floor.

3. The floor panel of a single pallet segment provides about 17 m^2 of mounting area.

4. The pallet structure has provisions for attaching hard points.

It should be noted that possible pallet bending due to changing thermal conditions in orbit can present co-alignment problems for experiment equipment. The bending characteristics of the pallet are currently under investigation.

Figure 5.3-7 shows the basic pallet segment structural configuration. The basic pallet segment structure is used for all flight configurations. These pallet segments consist of the basic structure described plus additional mission-independent and mission-dependent subsystem equipment, including: electrical power distribution cables, signal distribution cables, remote acquisition units, and thermal insulation.

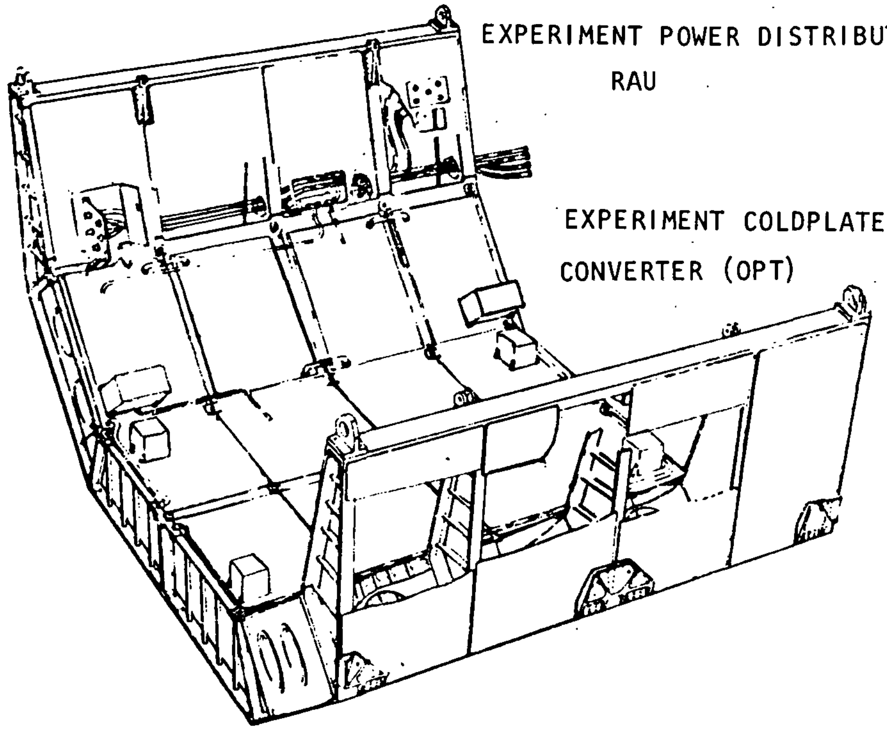


Figure 5.3-7. Pallet Integration - Standard Pallet

The electrical parts are located between the inner and outer skins of the pallet segments and thus do not reduce available experiment installation volume. Access covers are provided for installation and maintenance. Space is allocated in this same area for the addition of other subsystem equipment such as remote access units, coldplates (on the inside surface), converters, etc. Wiring assemblies are designed to accommodate these additional units, if needed.

Systems Igloo

Some Spacelab subsystem support equipment, which would be installed in the SM in the complete Spacelab configuration, is installed within the systems igloo in the pallet-only Spacelab configuration.

The igloo is a nitrogen pressurized cylinder (1.013 bars) having an internal diameter of 0.95 meter and a length of approximately 1.5 meters. It is equipped with a removable bulkhead (Marman clamp) providing full access to the interior. The internal temperature (15 to 30 C) is compatible with CAM equipment requirements and is achieved by active and passive thermal control devices.

The following subsystem equipment is mounted within the igloo in the case of the pallet-only mode.

- 3 computers
- 2 input/output units
- 1 mass memory
- 3 subsystem RAU's
- 3 experiment inverters (50, 60, and 400 Hz)
- 1 subsystem inverter
- 1 emergency battery and box
- 1 power control box
- 1 secondary power distribution box
- 1 caution and warning logic

The subsystems igloo is mounted/cantilevered to the end of the pallet segment closest to the front bulkhead of the Orbiter cargo bay, in such a way that no area or volume available on the pallet segment is used.

Transfer Tunnel

The Spacelab transfer tunnel will enable crew and equipment transfer between Spacelab modules and the Orbiter in a shirtsleeve environment. It is capable of functioning under orbital as well as ground operation conditions. It will have a minimum of about 1-m clear diameter. The same internal atmosphere as in the Spacelab module is provided. Lighting is installed in the tunnel, as well as mobility aids for internal movements.

Figure 5.3-8 shows, in simplified form, the mode of tunnel interfaces with the Orbiter bulkhead and the SM/EM.

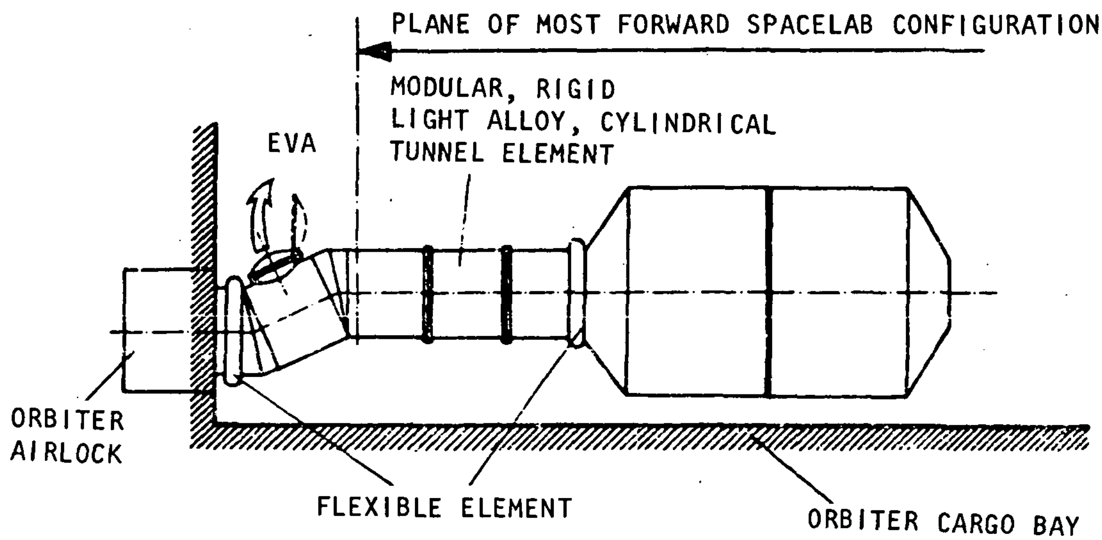


Figure 5.3-8. Transfer Tunnel

The tunnel consists of a number of cylinder segments to accommodate different flight configurations, and flexible elements for dynamic decoupling and tolerance compensation.

The tunnel can be used as an EVA airlock by virtue of the EVA hatch in the forward section and the two hatches at both ends of the tunnel (at the aft bulkhead of the Orbiter crew compartment and forward cone of the module).

SPACELAB SUPPORT SYSTEMS CAPABILITIES

The three Spacelab support systems that directly affect the integration and checkout of a Spacelab payload such as the ATL are the electrical power and distribution system (EPDS), environmental control system (ECS), and the control and data management system (CDMS). The characteristics of these systems that are pertinent to this study are summarized below.

Electrical Power and Distribution Subsystem (EPDS)

The EPDS receives its primary power from the Shuttle Orbiter. The 28 Vdc (nominal) unregulated power delivered from the Orbiter during orbital operations is 7 kW average and 12 kW peak for approximately 15 minutes every three hours. The energy available to Spacelab subsystems and payload is 890 kWh. The conditioning and distribution of electrical power is strictly separated between subsystems and payload. Activation of the Spacelab EPDS is controlled from the Orbiter crew compartment.

The services provided by the Spacelab EPDS to payloads are listed in Table 5.3-1.

Table 5.3-1. EPDS Equipment

Basic Spacelab	Mission Dependent	Optional
• Standard harnesses for power distribution within the module and on the pallet • Experiment power distribution boxes • Unregulated dc • Nominal and emergency lighting	• 400-Hz inverter • 50-Hz inverter • 60-Hz inverter • DC/DC converter for regulated dc • Experiment power switching panels	• Peaking battery • High-power harness

The principal arrangement of the EPDS with respect to experiment equipment is essentially the same for both the complete Spacelab and pallet-only configurations. The power bus system (standard harness) that is in each module and pallet segment provides the wiring for:

- Unregulated dc (28 Vdc nominal)
- Regulated dc (28 Vdc $\pm$ 2 percent)
- 115/208 Vac at 400 Hz
- 115 Vac at 60 Hz
- 115 Vac at 50 Hz

Figure 5.3-9 illustrates the power distribution network for a complete Spacelab. The power is distributed from the power buses by identical experiment power distribution boxes, one per module or pallet segment. Experiment equipment in the modules receive power through a power switching panel for each rack. Each switching panel provides connectors for internal access and intra-rack distribution by payload-provided cabling. Each output is protected against overload and can be switched ON/OFF manually from the front side of the panel. Experiment equipment must be grouped to ensure neither power consumption nor ON/OFF status requirements exceed the capabilities of the power switching panel or the experiment power distribution boxes. If regulated dc or ac is required, the necessary add-on units are installed in the rack with the power switching panel.

Experiment equipment on the pallet interfaces directly with the power distribution boxes. If regulated ac or dc is required by pallet-mounted experiment equipment, inverters/converters are mounted on the pallet segments to minimize cable runs and associated line losses. Power switching for pallet-mounted equipment is accomplished by control of the experiment power distribution boxes. In the case of the complete Spacelab, this control is accomplished in the SM. With the pallet-only configuration, power control is accomplished in the Orbiter crew compartment at the payload specialist station.

The location of the distribution boxes and the switching panels of the Spacelab EPDS is shown in Figure 5.3-10. Power distribution boxes in the module are located and mounted underneath the main floor.

Environmental Control Subsystem (ECS)

The ECS consists of the mission-dependent environmental control life support subsystem and the thermal control subsystem, which is comprises of mission-dependent and optional equipment. It provides the following services for the Spacelab and its payload: module equipment cooling, pallet equipment cooling, and a pressurized environment.

The Spacelab ECS is designed to provide a shirtsleeve earth-type environment for up to four crewmen, and provide cooling for equipment located in the pressurized module and on the pallet. The design is autonomous from the Orbiter except for heat rejection; the Orbiter provides 8.5-kW heat rejection during on-orbit operations through a fluid interface. This is the maximum possible heat rejection capability provided by the Orbiter. Additional heat rejection capability has to be provided by Spacelab payloads.

Thermal control of experiment equipment is accomplished both actively and passively. The active elements include a water and a Freon cooling loop which circulate the cooling fluids through Spacelab heat exchangers and

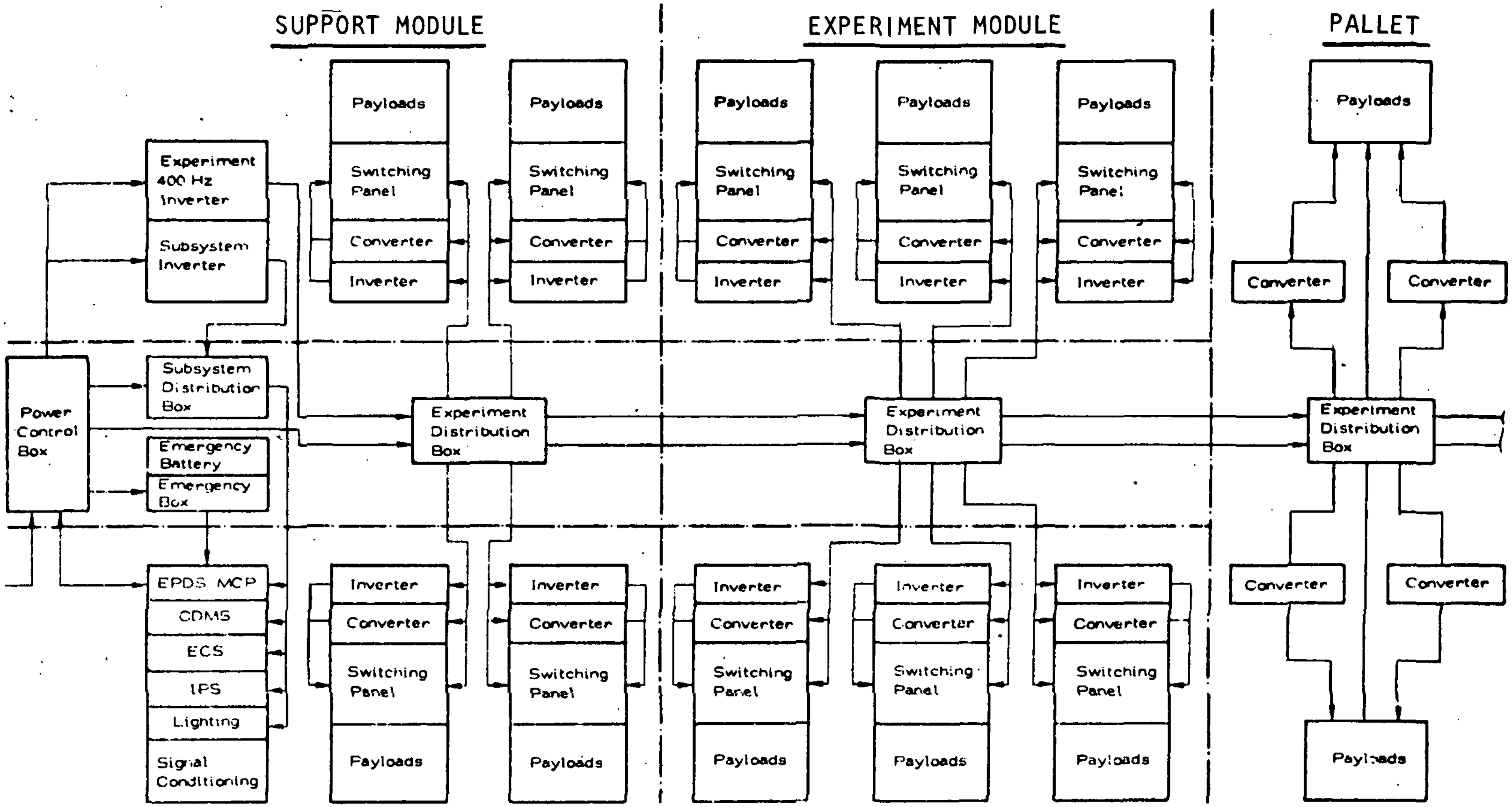
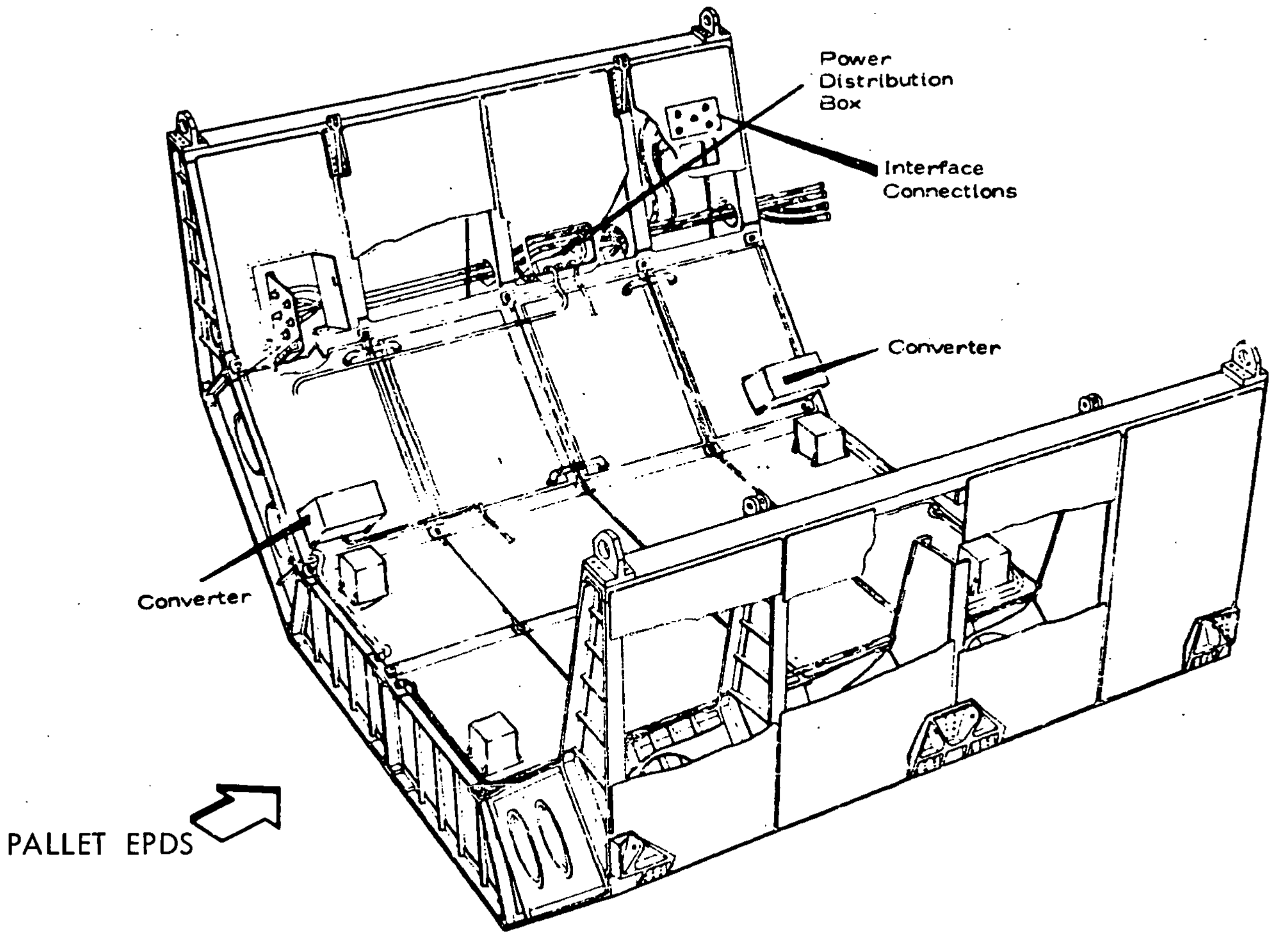


Figure 5.3-9. Distribution Schematic

Space Division
Rockwell International



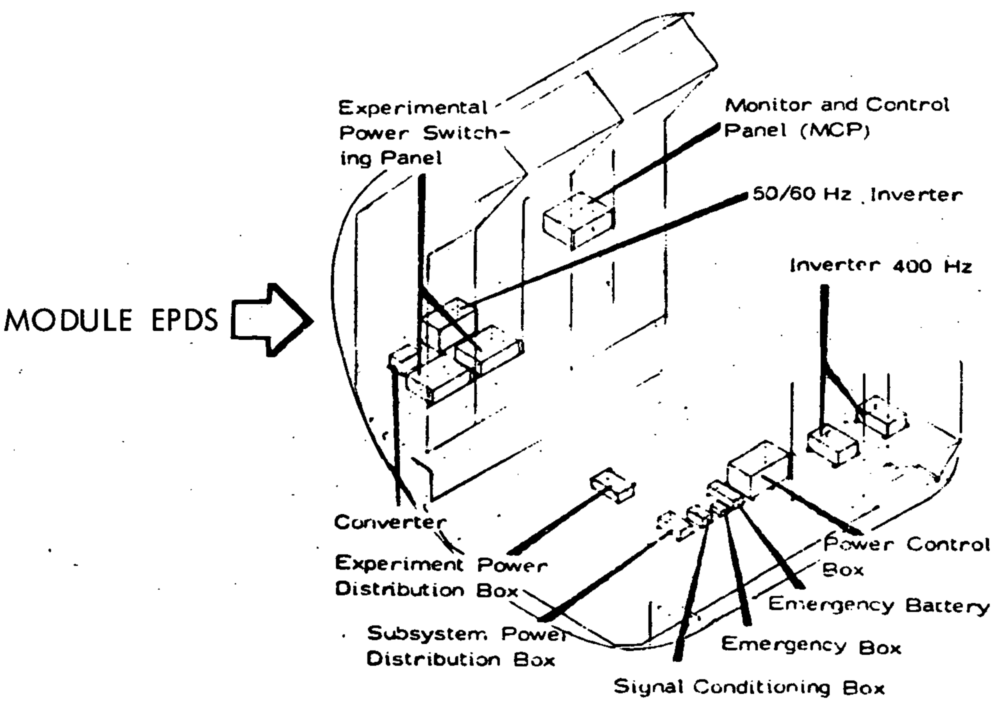


Figure 5.3-10. Location of Spacelab EPDS Equipment

experiment-dedicated coldplates. The water loop is for SM/EM cooling; the Freon loop is for cooling of pallet-mounted equipment. The heat loads are picked up and transferred via a payload heat exchanger, provided by the Orbiter, to the water loop of the Orbiter for heat rejection. There are no active means of temperature control in the cooling loop system; however, because the circulating water temperature from the payload heat exchanger is relatively constant, and with the use of thermal capacitors, the fluid temperatures do not vary greatly.

The ECS provides a separate forced air cooling loop for rack-mounted electronic equipment in the module (Figure 5.3-11). This loop is separated from the habitable volume of the module and is maintained at a lower pressure by a controlled overboard leak. This small pressure differential prevents contaminants from the electronics entering into the habitable volume; 5-micron filters are located in the loop. Air cooling for the experiment support canister is provided as an option.

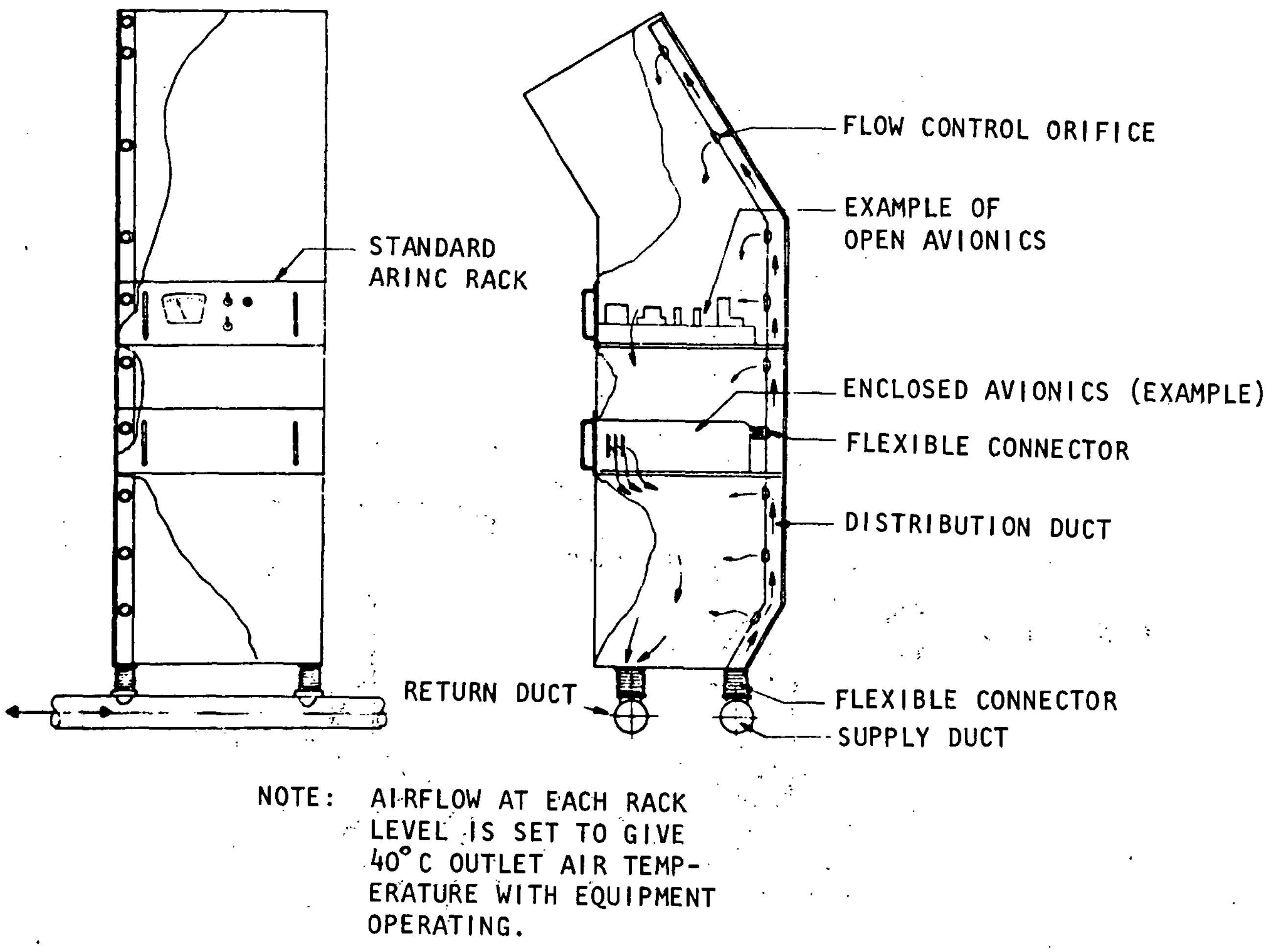


Figure 5.3-11. Consoles for Rack-Mounted Electrical Equipment

Command and Data Management Subsystem (CDMS)

In addition to the control from experiment-dedicated control panels, commands can also be provided automatically by experiment computer program control and semi-automatically by interaction of the experiment keyboard with the computer. The commands are routed serially via the experiment data bus system to the remote acquisition units (RAU's) where they are decoded and delivered as PCM signals and/or digital discretes by the RAU's (Figure 5.3-12).

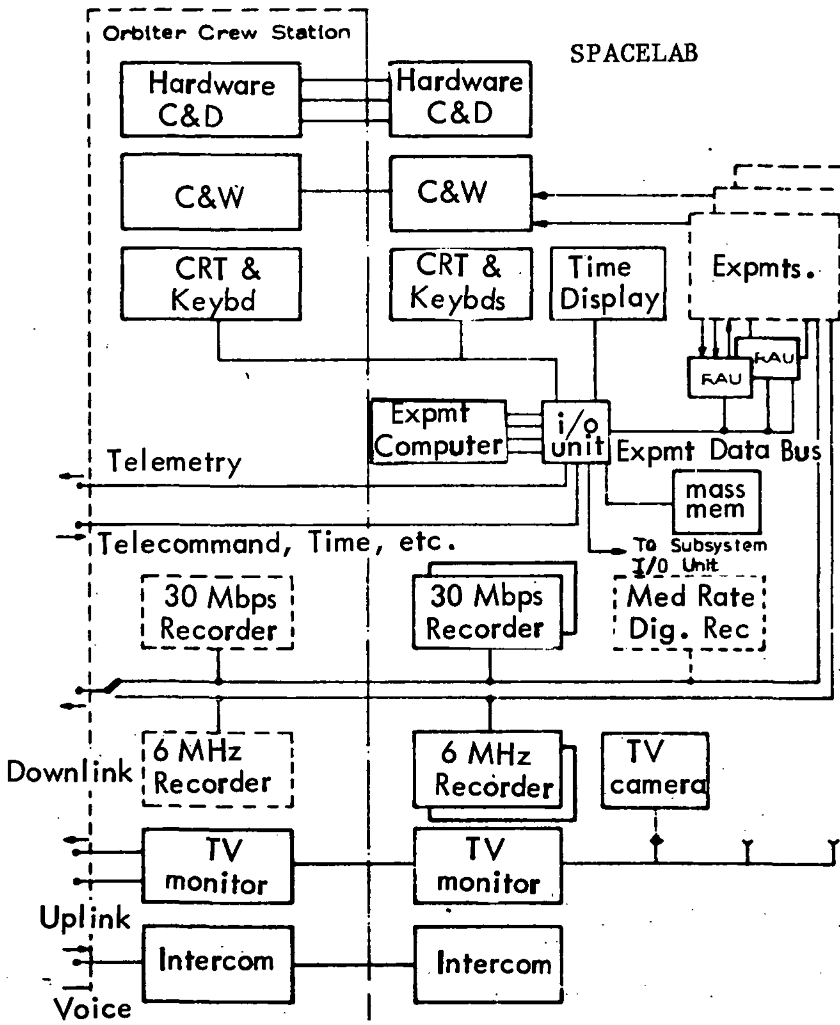


Figure 5.3-12. Command and Data Management for Experiments

A backup computer connected to the input/output (I/O) is provided in case of experiment computer failure. Programs, resident in the mass memory, must first be read into this computer's memory prior to take-over of experiment operation since the backup computer serves also as the Spacelab subsystem computer backup.

Four recorders (primary and backup) are used for the storage of video or analog data and digital data (2 x 6 MHz and 2 x 30 Mbps). Recorder selection, start/stop, record speed, track selection, and record playback are provided via hardwire from a control panel which includes a mode status and tape-remaining display. The outputs of the video/analog and digital recorders are directly hardwired to the Orbiter communication system. A video camera for general laboratory status assessment is coupled to video monitors within the Orbiter crew station and/or the operator console in the SM. Experiment-provided TV cameras can be connected to the TV system and monitored. Outputs are routed to the video recorder and/or to the Orbiter by coaxial cable. An intercom master unit at the operator console, together with remote stations at the airlock, Orbiter crew station, etc., provide the audio-communications capability within and outside of the module.

The remote acquisition units (RAU) can be connected to the data bus at several stations in order to minimize cabling between its inputs and the signal sources. The data bus is capable of communication with up to 32 RAU's, each of which can be sampled in a sequence programmed by the computer software for processing (limit check, averaging, etc.), or on request from the keyboard. A total of 8 RAU's are baseline; additional RAU's can be supplied as optional equipment.

There are provisions to accommodate up to two RAU's per rack and up to four RAU's on each pallet. The data bus clock rate is 1 Mbps. The RAU input characteristics are given in Table 5.3-2.

Table 5.3-2. RAU Input Characteristics

HIGH-VOLTAGE ANALOG INPUTS	LOW-VOLTAGE ANALOG INPUTS	DISCRETE INPUTS	SERIAL DIGITAL INPUT
Number: 32 Voltage range: 0 to 5.12 V (FS) Type: Single-ended, positive with respect to common reference (0 V RAU common neutral) Resolution: 8 bits Highest sampling frequency: 100 Hz Input impedance: >10 M ohm	Number: 32 Voltage range: ±256 mV (FS) Type: Single-ended, referred to common reference (0 V RAU common ref.) Resolution: 8 bits	Number: 64 Voltage: TTL level	This input is buffered with 1 kbit. It allows an average input rate of 100 kbps with a highest transfer rate of 1 Mbps for 1 msec.

The approximate location of the units on the pallet and within the modules are shown by Figure 5.3-13.

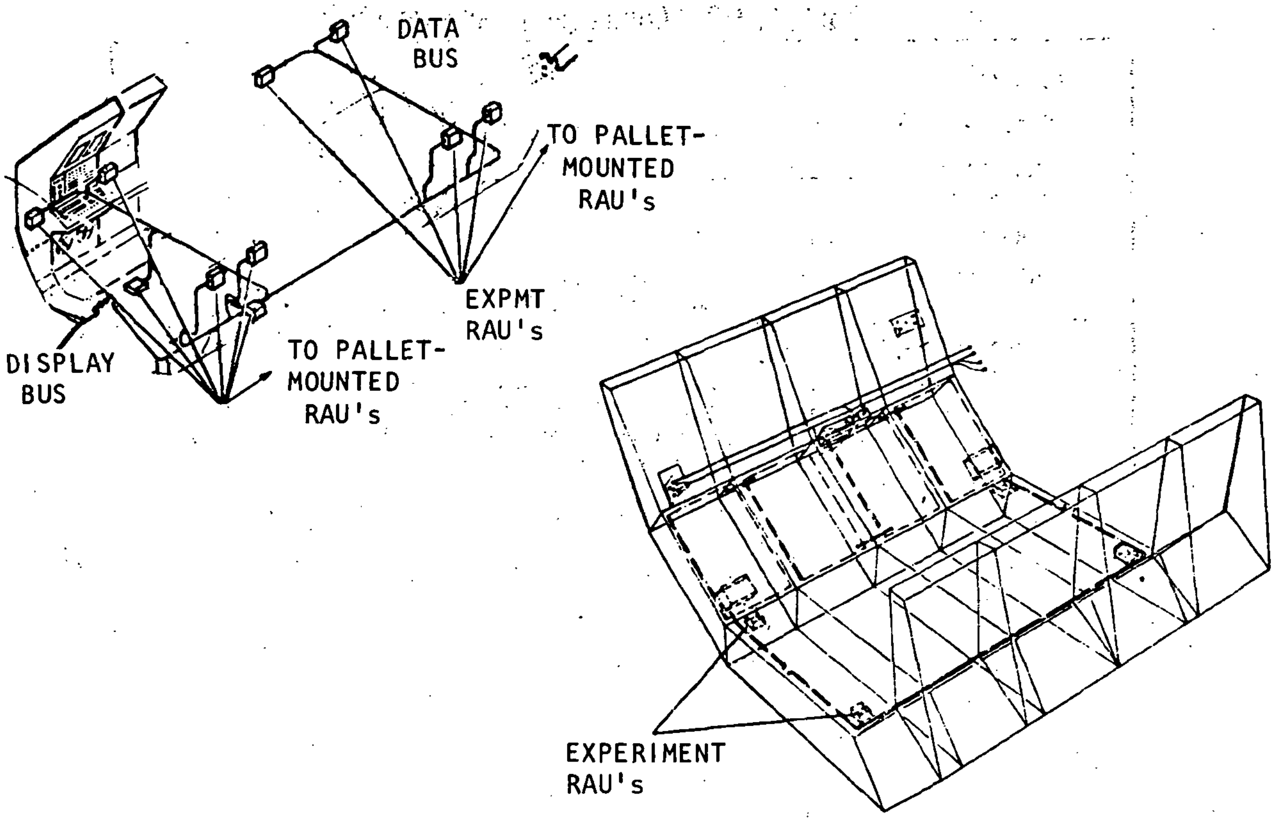


Figure 5.3-13. Location of Experiment RAU's

The CDMS provides a dedicated computer for processing data which have been acquired by the experiment data bus system. The processing outputs are displayed on CRT's and transmitted and/or delivered back to the experiments depending on the mission requirements. The computer facilities allow general-purpose processing: checkout; sequencing and control of experiments; data reduction; filtering, averaging, and histograms; computing, etc.

Application software packages performing required experiment functions shall be supplied by the Spacelab user. The basic software (I/O drivers, self-test, etc.) is supplied by the Spacelab. The basic software schedules the tasks and manages the resources of the computer system. It accommodates modular experiment application software packages. The characteristics of the currently baselined computer, dedicated to experiments, are shown in Table 5.3-3.

Table 5.3-3. Computer Characteristics

FORMATS

OPERANDS: 16, 32 and 24 + 8 (floating point) bits

INSTRUCTIONS: 16 bits

CONTROL UNIT

MICRO-PROGRAMMED CONTROL UNIT

CONTROL MEMORY CAPACITY: 1st Level, 250 40-bit words
2nd Level, 32 40-bit words

NUMBER OF INSTRUCTIONS: 100 instructions including:

- Single-word (16 bits) and double-word (32 bits) call and store
- Fixed-point arithmetical operations on 16 and 32 bits, and floating-point arithmetical operations on 32 bits (24 + 8)
- Logic and comparison operations
- Shift operations
- Fixed-to-floating and floating-to-fixed conversions
- Conditional and unconditional jumps

ADDRESSING MODES: Immediate, direct, indirect, relative to a base, indexed, relative to program counter

---

NUMBER OF ADDRESSABLE REGULATORS: 20 by micro-instructions, of which 12 can also be addressed by instructions.

COMPUTING SPEED:

Single-word length (16 bits)	
Add (register-to-register)	1.8 μsec
Add (register-to-memory)	2.4 μsec
Multiply	7.5 μsec
Divide	9.0 μsec
Double-word length (32 bits)	
Add	3.6 μsec

FLOATING POINT (32 bits = 24 + 8)

Add:	9.0 μsec minimum	
	17.1 μsec maximum	
Divide:	27.9 μsec minimum	
	28.8 μsec maximum	
Multiply:	26.4 μsec minimum	
	27.3 μsec maximum	

DIGITAL INPUT/OUTPUT: Data exchange with peripherals may be serial or parallel, depending on either of two modes of operation--programmed (controlled by the program) and channel (independent of the arithmetical unit). Data exchange takes the following times. Serial, 30.9 μsec in the programmed mode; 32.1 μsec in the channel mode, and at a maximum frequency of 31 K words/sec in the locked channel mode. Parallel, 4.0 μsec in the programmed mode; 1.8 μsec in the channel mode, and a maximum frequency of 555 K 16-bit words/sec in the locked channel mode. The maximum number of addressable channels is: 496 on the serial bus and 2,048 on the parallel bus.

MEMORY: Type, 18 mil ferrite cores, 3-D, 3-wire configuration
Capacity, 39 K 16-bit words for the basic version, extendible to 64 K 16-bit words in 8 K word modules.
Cycle Time, 1.2 sec

CRT displays, together with an associated keyboard, are used to communicate with the computer. There are two CRT/keyboard units within the Spacelab and one in the Orbiter integrated crew station, which can be used interchangeably. The CRT can display the following types of information: alphanumeric parameter lists, vector displays, and special graphics.

A Spacelab operator console contains a time display for use by experimenters. It shows: Greenwich mean time (GMT), hours/minutes/seconds; mission elapsed time (MET), hours/minutes/seconds; and event times (four times). The event timer can be set between 0 and its full range. After a start command, which can be given manually or electrically, the timer counts to zero and delivers an output signal for use by experimenters. When set to zero, it counts on a start command and stops on a manual or electrical stop command. The resolution of these timers is 0.1 second.

The integrated CDMS provides the ability to control (automatically and manually) and check out experiment equipment and provides data communication to the operator console, the Orbiter crew station, and the ground via the Orbiter communications link. All these functions are accomplished by interfacing with the RAU's. The RAU's deliver signals to the experiments for: automatic control by the computer, manual control by the operators via the keyboards, and telecommand control from the ground.

Each RAU has the following output capabilities:

On-off commands--delivered by separated lines. A line commanded ON remains at its electrical high level until an OFF command is sent to this channel.

- Number of channels: 16
- Voltage levels: 0 to 0.5 V means "low"; 3.5 to 5.5 V means "high"
- Impedance: 1 kilohm when "low"; 2 kilohms when "high"

PCM commands--delivered as 8-bit words on separate lines together with a clock line.

- Number of channels (signal and clock: 8
- Voltage levels: Same as ON/OFF
- Impedance: Same as ON/OFF

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5.4 ATL MODEL

The ATL program was baselined as a two-flight-per-year/ten-year program. It was assumed that each flight would be dedicated to ATL experiments, i.e., no other Spacelab users would share an ATL Spacelab flight. Either the complete Spacelab or the pallet-only Spacelab configuration would be used for ATL flights.

ATL requirements would reflect Langley Research Center's role as a NASA center devoted to applied research in six technology areas: (1) navigation, (2) earth observations, (3) physics and chemistry, (4) microbiology, (5) environmental effects, and (6) component/system development. Specific experiments from each of these technology areas would be combined for each mission. Experiments might be repeated on successive flights, but, in general, the experiment complement would be different for every flight.

Three representative ATL experiment groupings are listed in Table 5.4-1. Payloads 1 and 2 will utilize the complete Spacelab configuration; Payload 3 will utilize the pallet-only Spacelab configuration. All integration and checkout activities associated with experiments and experiment equipment were based on these three representative ATL payloads. Detailed descriptions of each experiment and the associated equipment are presented in Appendix C.

The following ATL program operational characteristics were baselined to this study.

1. The integrated Orbiter cargo (Spacelab and ATL experiments) will be installed in the Orbiter cargo bay in the Orbiter Processing Facility at KSC.

2. The resource requirements defined in this study are for integration and checkout activities only. Personnel equipment and facilities required to design, develop, and test individual experiment equipments are not included.

3. The NASA center assigned the coordination and interface responsibility between the principal investigators/experiment developers and the integration center (IC) and/or launch site (LS) is designated as the "user." In the case of the ATL program it is assumed that a discrete organization of Langley personnel will provide this liaison between Langley principal investigators (PI's) and the IC and LS.

4. The payload specialist members of the flight crew will be selected by the user center. In general, the payload specialists will either be PI's or Langley ATL program personnel specifically trained for ATL experiment operations in space.

Table 5.4-1. Representative Payload Groupings

PAYLOAD 1.	(SPACELAB INCLUDING PALLET)
NV-3	Multipath Measurements
EO-2	Tunable Lasers
EO-5	Laser Ranging
EO-9	RF Noise
PH-2	Barium Cloud Release
PH-3	Aerosol Properties
PH-4	Neutral Gas Parameters
PH-5	Radiation Environment
MB-1	Colony Growth
MB-3	Bio Cell Electric Field Opacity
EN-1	Micro-Organism Sampling
XST-	Contamination Monitor
PAYLOAD 2.	(SPACELAB INCLUDING PALLET)
EO-3	Multispectral Scanner
EO-6	Microwave Altimetry
PH-1	Wake Dynamics
PH-3	Aerosol Properties
MB-1	Colony Growth
MB-2	Micro-Organism Transfer
MB-4	Bio Cell Electrical Characteristics
MB-5	Bio Cell General Properties
EN-1	Micro-Organism Sampling
EN-2	Material Fatigue
EN-3	Non-Metallic Materials Degradation
CS-2	Zero-G Steam Generator
XST-	Contamination Monitor
PAYLOAD 3.	(PALLET-ONLY)
NV-1	Microwave Interferometer
NV-2	Autonomous Navigation
EO-1	Lidar Measurements
EO-4	Radiometer
EO-7	Search and Rescue Aids
EO-8	Imaging Radar
PH-2	Barium Cloud Release
PH-4	Neutral Gas Parameters
PH-6	Meteor Spectroscopy
EN-1	Micro-Organism Sampling
EN-3	Non-Metallic Materials
XST-	Contamination Monitor

6.0 CONCEPT EVALUATIONS

The eight integration and checkout concepts that were analyzed in this study are evaluated in this section. A succinct summary of the optimizations and resource requirements that are developed in detail in Volumes II and III is included.

The sensitivity of these processing concepts to the Spacelab configuration is examined. During the course of the study, the Spacelab configuration evolved from a conceptual design stage involving three versions (ERNO, MBB, and MSFC) to a preliminary design stage that reflects a singular approach based upon ESRO/ERNO and NASA/MSFC coordination. Although the details changed significantly the basic approaches, optimizations, and resources required for integration and checkout of Spacelab payloads were not affected by the configuration changes. All data associated with the eight candidate processing concepts are in accord with the Spacelab definition contained in the preliminary issue of the "Spacelab Payloads Accommodations Handbook," dated October 1974.

The integration and checkout of complete Spacelab and pallet-only payload configurations were evaluated in this study. The data indicate that, with minor additions to the GSE complement of equipment required for the processing of the complete Spacelab, pallet-only payload configurations can also be accommodated. Only negligible perturbations would result in the integration and checkout activities if an intermixing of payload configurations were to occur.

The sensitivity of Spacelab flight hardware, GSE, facilities, and staffing to various flight rates is presented. In order to accommodate the Spacelab traffic model used in this study, two SM/EM shells and one systems support igloo are required to support 15 complete Spacelab and 9 pallet-only Spacelab flights per year (based upon two-shift operations during Levels II and I integration). The rack/rack sets/pallet train and equipment canister and pallet trains required to support the flight rates of the two configurations are 7 and 4, respectively (single-shift operations during Level III integration).

The majority of the GSE end items that were defined in this study will support significantly larger flight rates than the baseline two-per-year. Those items that are utilized to maximum capacity first are all associated with Level III integration. In general, these items are associated with the experiment installation and checkout (test) station. Up to five flights a year can be accommodated with a single Level III test stand.

Plans at the IC (MSFC) and the LS (KSC) for modifications of existing facilities will accommodate the processing of the anticipated Spacelab traffic model. The facility at the user center (Langley) that was evaluated in this study will accommodate 6, 7 or 8 flights per year, depending upon the processing concept used.

In general, regardless of the flight rate, the maximum utilization of personnel could be achieved if each of the support function phases (operations analysis and requirements definition, and design and fabrication of interfacing hardware) is scheduled for the same duration of the test and operations activities. The nominal period for test and operations activities for all the concepts was six months. Therefore, the total pre-flight and post-flight cycle for the integration and checkout of a Spacelab payload would be 18 months.

Based upon mission-unique, sustaining, and non-recurring resource requirements and costs, Concepts II and VII were recommended for periodic or partial-payload Spacelab users. Concepts IV and VIII were recommended for Spacelab users with multi-flight-per-year/multi-year programs. Langley's ATL is such a program and, therefore, Concepts IV and VIII were the recommended approach. Concept I was not recommended for implementation primarily because adequate facilities to accomplish all three levels of integration did not exist either at MSFC (IC) or KSC (LS). But, existing facilities could be modified at these two sites to accommodate Level III at MSFC and Level II at KSC for the majority of the anticipated Spacelab flights. Concept III/VI was not recommended because there were no significant advantages to it when compared to II/VII and IV/VIII. Only unique proprietary/security reasons or planned flight rates of at least eight per year by a single user would justify the implementation of Concept V.

6.1 SYNOPSIS OF OPTIMIZATIONS AND RESOURCE REQUIREMENTS

Concept optimizations and resource requirements are developed in detail in Volumes II and III. A synopsis of these concept characteristics is presented in this section to facilitate concept comparisons and evaluations. The optimizations are equally applicable to all the concepts; the resource requirements are concept-dependent and were developed in three categories--mission-unique, sustaining, and non-recurring. Therefore, a general description of the optimizations is subsequently presented. Resource requirements are presented by category.

CONCEPT OPTIMIZATIONS

The composite set of tasks to integrate and check out a Spacelab payload were divided into two sets: (1) support functions, and (2) test and operations. The support function tasks pertain to mission analysis and planning, mission operations, and systems engineering. Test and operations tasks pertain to the installation and checkout of the flight hardware.

Support Functions

The first step in the optimization of the support functions was to establish the role and responsibility of the principal investigator (PI) in the checkout and integration process. Direct involvement and maintenance of experiment equipment cognizance by the PI was a baseline requirement of the study. The technique adopted to achieve the requirement was as follows.

1. The PI is responsible not only for the development of the experiment flight hardware but also a data pack (using standard formats) that includes the weight, power, volume, measurement and command list, trajectory characteristics, ground truth site requirements, payload specialist skill codes, operating procedures and time sequences, and data processing/communication requirements of his individual experiment system.

2. A software development/integration/verification approach was defined that provides the PI the flexibility of delivering a segment of the composite test and flight operations software as a hardware end item.

3. The test operator, throughout the processing of the flight hardware, is either the PI or the payload specialist trained by the PI in the PI's laboratory.

4. A cadre of experiment discipline specialists provides continuing coordination between the PI and experiment equipment development activities, and support function activities.

5. All documentation generated during support function activities that affect experiment operation or utilization is submitted to the PI for review and approval.

This approach to maintaining direct participation and control of experiments by the PI also scopes the support function activities of the integration and checkout personnel. The task of these personnel is one of integrating the requirements of multiple experiments into one cohesive/compatible Spacelab payload. Although the experiments will differ from payload to payload, the carriers (namely, the Orbiter and the Spacelab) are standardized. The capabilities, accommodations, and constraints are well defined. As the characteristics of the carriers are relatively constant from flight to flight it not only is feasible but economically practical to computerize numerous operations analyses, mission planning, and design activities. By providing standard formats to the PI's, the individual experiment system characteristics can be efficiently integrated and correlated by computer-aided operations.

The ownership and configuration management of the various levels of integration (payload, Spacelab, Orbiter) is equally significant as that of the experiments in establishing the requirements for support functions. Control of interfaces and common-usage equipment was defined to minimize responsibility transfers and documentation requirements that are associated with each level of flight hardware integration. The primary criterion was that the owner of the highest level of assembly, or element, involved in the interface controlled the implementation of that interface. But the responsibility for each lower level of assembly, or element, involved was retained by the owner of that assembly.

Test and Operations

The primary drivers in the optimization of test and operations activities was to minimize the involvement times of the Spacelab equipment, especially the support module and systems igloo. Staffing was based upon the maximum number of people that could physically work on the processing of the flight hardware at any given time.

The primary factor in minimizing involvement times is the efficiency of accomplishing the various hardware integrations. If interface compatibility rather than just interface/interconnection verification is required upon integration of two elements, the entire schedule is jeopardized. Compatibility should (and can) be demonstrated prior to actual mating of elements by proper utilization of interface simulators. In all the processing concepts definitized in this study, a Spacelab support system simulator is used during Level III integration, and an Orbiter interface simulator is used during Level II integration. The configuration of the simulators is controlled by the owner of the elements being simulated. In general, the use of simulators reduced the involvement times of the Spacelab support systems during ground operations by a factor of 2. Interface verification with an Orbiter simulator was baselined in the Shuttle program.

Summary of Optimizations

The two key factors in concept optimization were the use of computers in accomplishing support function tasks, and the use of simulators during tests and operations activities. The resource requirements in each category (mission-unique, sustaining, and non-recurring) reflect this approach. Task manpower estimates, machine (computer) time, inter-center coordination, flight hardware processing time, software and procedures development, and GSE estimates in each of the categories are based upon the inclusion of computer-aided analyses and designs, and interface simulators.

MISSION-UNIQUE RESOURCE REQUIREMENTS

Based on the staffing requirements, described in Section 3.1 of Volume III, a compilation of the man-months of effort for each center (by WBS category) is presented in Table 6.1-1. These manpower requirements represent the man-months of effort (by center) to perform the mission-unique tasks associated with one flight. Because of the interrelationship between hardware processing activities and the test procedures and reports preparation, both supporting function and test and operations efforts are included in the "Experiment Installation and Checkout," "Spacelab Integration," and "Cargo Integration" headings.

Table 6.1-1. Manpower Requirements for Mission-Unique Tasks - Per Flight (Man-Months)

WBS TASK / CONCEPT	I			II & VII			III & VI			IV & VIII		V	
CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
MISSION ANALYSIS	25	46	7	25	44	10	62	--	10	62	10	63	7
MISSION OPERATIONS	53	38	2	53	32	9	83	--	9	83	9	87	2
SYSTEMS ENGINEERING	61	176	21	61	162	44	173	52	44	209	44	223	21
EXPERIMENT INSTALL. & C/O	6	126	--	6	141	3	74	65	3	144	3	134	--
SPACELAB INTEGRATION	--	34	8	--	6	29	7	--	29	6	29	36	8
CARGO INTEGRATION	1	8	15	1	8	16	8	--	16	8	16	8	17
GSE	--	4		--	4	--	4	--		4		4	
TOTALS	146	432	53	146	397	111	411	117	111	516	111	555	55
		631			654			639		627		610	

The task requirements shown in Table 6.1-1 equate to the personnel requirements listed in Table 6.1-2. The conversion of manpower requirements of Table 6.1-1 to equivalent personnel, and their breakdown by skill code, are discussed in detail in Section 3.1 of Volume III. However, it should be noted that in some instances it was not practical to utilize all of the personnel of a particular skill code on a full-time basis with a schedule of only two flights per year. Therefore, the concept of utilizing part-time personnel was adopted.

Table 6.1-2. Mission-Unique Personnel Requirements (Two Flights Per Year)

SKILL CODE / CONCEPT	I			II & VII			III & VI			IV & VIII		V	
CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
OPERATIONS ANAL.	8	9	1	8	9	2	15	0	2	15	2	15	1
SYSTEMS ENGINEER	9	18	3	10	15	6	22	3	6	23	6	26	3
DESIGNER	5	(6) 11	(2) 0	5	(6) 10	(2) 1	(4) 8	(6) 6	(2) 1	(12) 12	(2) 1	(12) 13	(2) 0
PROGRAMMER	(2) 0	(3) 3	(1) 0	(2) 0	(3) 3	(1) 0	(3) 3	0	(1) 0	(3) 3	(1) 0	(3) 3	(1) 0
CODER	0	1	0	0	1	0	1	0	0	1	0	1	0
TEST ENGINEER	(2) 0	9	(3) 0	(2) 0	8	(3) 1	9	(3) 0	(3) 1	9	(3) 1	10	(3) 0
TEST TECHNICIAN	0	(5) 9	(8) 0	0	(5) 8	(11) 0	(12) 0	(6) 0	(11) 0	(5) 8	(11) 0	(5) 9	(8) 0
MECHANIC	0	(3) 3	0	0	(3) 3	0	1	(6) 1	0	(6) 2	0	(6) 2	0
TOTALS	(4) 22	(17) 63	(14) 4	(4) 23	(17) 57	(17) 10	(19) 59	(21) 10	(17) 10	(26) 73	(17) 10	(26) 79	(14) 4
	(35) 89			(38) 90			(57) 79			(43) 83		(40) 83	

LEGEND:
(XX) PART TIME
XX FULL TIME

It was anticipated that user part-time help could be developed from the designers, programmers and test personnel associated with the experiment hardware development. Similarly, the potential integration center and launch site part-time personnel could be shared with other Spacelab users. This sharing of personnel is advantageous in that it provides a cross-correlation of procedures, techniques and experience.

Test and Operations Processing Time

Complete Spacelab

The comparison of the basic test and operations (T&O) processing timelines for all five complete Spacelab concepts is shown in Table 6.1-3. The majority of the operations to be performed in any given concept is essentially the same. The significant differences between concepts are as follows.

- Concept III varies from Concepts II and IV by the additional 6.5 days required to ship the rack/pallet assembly to the user following post-refurbishment at the integration center. This activity is unique to Concept III.
- Concepts II and IV vary from Concepts I and V by approximately 4.5 days. The two concepts (II and IV) are longer primarily because of two operations: (1) shipment of the Spacelab to the MSOB following a mission, where the Spacelab elements are demated and the rack and pallet prepared for shipment to the integration center/user (an additional 2.6 days); and (2) shipment of racks and pallet is a 6.7-day operation, whereas Spacelab shipment is accomplished in 5.4 days.

Table 6.1-3. Complete Spacelab Summary of T&O Processing Times

Serial Processing Times	CONCEPT				
	I	II	III	IV	V
Days (8 hours/day)	111.3	115.8	122.3	115.8	111.3
Weeks (5 days/week)	22.3	23.2	24.5	23.2	22.3
Months (4 weeks/month)	5.6	5.8	6.1	5.8	5.6

Pallet-Only

The comparison of T&O processing times for the three pallet-only concepts is illustrated in Table 6.1-4. Again, as with the complete Spacelab concepts, the only principal difference between Concepts VII/VIII and VI is 5.6 days for the post-refurbishment shipment of the pallet/igloo (Functional Block 19.0).

Table 6.1-4. Pallet-Only Summary of T&O Processing Times

Serial Processing Time	CONCEPT		
	VI	VII	VIII
Days (8 hours/day)	111.7	106.1	106.1
Weeks (5 days/week)	22.3	21.2	21.2
Months (4 weeks/month)	5.6	5.3	5.3

Support Service Requirements

Supporting services that must be considered in establishing the total mission-unique resources are: personnel travel, computer facility operations, documentation, materials, shipping/transportation, and facilities.

Personnel Travel

Two categories of personnel travel were identified: supporting function liaison, and test and operations support. Since the assumptions vary for the two types, they are defined separately.

Supporting Function Liaison. Included in this category of support are personnel trips for ICD coordination, engineering liaison, ground truth site operations, mission support, and safety reviews. Each trip was identified with its associated WBS task number. The trips listed in Table 6.1-5 are identified as "User to," "IC to," or "LS to." Within each of these categories the trip is shown to either of the other two centers or to a ground truth site. Table 6.1-5 summarizes the supporting function trips for all the processing concepts. Management, PI, and payload specialist trips are not included. Trip duration estimates were: mission control operations, 10 days and ground truth site trips, periodic rotation; and all other trips, one man for two days. For the detailed allocations of trips to specific WBS task numbers, refer to Section 3.2 of Volume III.

Test and Operations Off-Site Travel Requirements. The estimates of Table 6.1-5 are for the test engineers that conducted the test and operations at one level of integration and their participation is required at the next higher level of integration, even though these integration levels occur at different sites. Table 6.1-6 summarizes the required trips and their duration.

Table 6.1-5. Support Function Travel Requirements

CONCEPT	USER TO			SUB-TOTAL	IC TO			SUB-TOTAL	LS TO			SUB-TOTAL	CONCEPT TOTAL
	LS	IC	GT		LS	U	GT		IC	U	GT		
I	7	49	20	76	25	21	20	66	11	-	-	11	155
II & VII	18	44	20	82	55	18	20	93	18	-	-	18	193
III & VI	55	9	30	94	-	4	-	4	-	19	-	19	117
IV & VIII	57	-	30	87	-	-	-	-	-	19	-	19	106
V	25	-	30	55	-	-	-	-	-	11	-	11	66

LS - LAUNCH SITE
IC - INTEGRATION CENTER
GT - GROUND TRUTH SITE

Table 6.1-6. Travel Requirements for T&O Support

<table>
<tr><td>Concept</td><td>I</td><td>V</td><td>II/VII</td><td>IV/VIII</td><td colspan="2">III/VI</td></tr>
<tr><td>Trip</td><td>IC/LS</td><td>U/LS</td><td>IC/LS</td><td>U/LS</td><td>IC/U</td><td>U/LS</td></tr>
<tr><td>Number of personnel
Duration (days)</td><td colspan="2">3
9</td><td colspan="2">2
23</td><td>2
64</td><td>3
24</td></tr>
</table>

Computer Support

Each mission is anticipated to require a significant amount of autocomputation machine time to support the preparation of flight and check out software, and the engineering analysis and design activities. Each WBS task was evaluated (see Section 3.2, Volume II) to establish the computer hours that would be required at each center for a large general-purpose computer such as the IBM 360. These estimates are summarized in Table 6.1-7. The estimates shown are for machine hours only; the engineering estimates are contained in the task estimates for the related supporting function WBS task.

Table 6.1-7. Computer Machine Time Requirements

CONCPET	I			II & VII			III & VI			IV & VIII			V		
CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	IC	LS	U	IC	LS
TOTALS (HR)	67	39.5	4.5	37	32.9	6.6	101.5	0.4	6.6	101.9	-	6.6	103.5	-	4.5
	111			111.5			108.5			108.5			108		

Documentation

The program documentation requirements were established by investigating the requirements within each WBS task element, and then analyzing the results to eliminate all possible redundancies. The effort was then directed to the establishment of the minimum quantities of formal documentation that would efficiently transfer the required coordination information between centers. Table 6.1-8 illustrates the total documentation for which each center is estimated to be responsible.

Table 6.1-8. Summary of Documentation Requirements

Type of Document	Concept	I				II/VII				III/VI				IV/VIII			V		
	Center	IC	LS	U	PI	IC	LS	U	PI	IC	LS	U	PI	LS	U	PI	LS	U	PI
OFF-LINE	Formal	7	1	1	-	8	1	1	-	1	1	7	-	1	8	-	1	7	-
	Informal	2	-	-	-	1	-	-	-	-	-	2	-	-	1	-	-	3	-
	Support	1	7	5	5	1	8	5	5	6	8	1	5	8	-	5	7	-	4
	Totals	10	8	6	5	10	9	6	5	7	9	10	5	9	9	5	8	10	4
		29				30				31				23			22		
IN-LINE	Formal	16	3	-	-	13	6	-	-	3	6	5	-	6	5	-	3	3	-
	Informal	7	1	6	-	5	3	6	-	-	3	16	-	3	19	-	1	26	-
	Support	3	9	23	18	7	10	23	18	3	10	10	18	10	7	18	9	3	18
	Totals	26	13	29	18	25	19	29	18	6	19	31	18	19	31	18	13	32	18
		86				91				74				68			63		

Materials

Each Spacelab flight will require the design and fabrication of cables, mounts, enclosures and mockups. The personnel estimates of Section 3.1 in Volume II included the design and fabrication effort. The materials involved represent a delta resource requirement.

Table 6.1-9 identifies those WBS tasks that will require mission-unique materials. The total requirements are the same for all concepts; only the cognizant center varies. The launch site is not required to furnish any mission-unique materials in any of the concepts. The material requirements of the two ATL configurations (complete Spacelab and pallet-only) are essentially the same and are indicated in the table.

Table 6.1-9. Mission-Unique Material Requirements

WBS Task	Concept	I		II & VII		III & VI		IV & VIII	V
	Center	U	IC	U	IC	U	IC	U	U
50-60	Mockups		X		X	X		X	X
60-10-10	Cables		X		X		X	X	X
60-10-20	Structures		X		X		X	X	X
60-10-30	Protective Covers		X		X	X		X	X
70-10	Special Test Equip.		X		X	X		X	X

Shipping/Transportation

The shipping/transportation requirements for the five complete Spacelab concepts vary between concepts. However, the moves of Concepts II, III and IV are equally applicable to the pallet-only configuration of Concepts VII, VI, and VIII, respectively. These moves are summarized in Figure 6.1-1.

The remaining portion of the shipping requirements are associated with the equipment of individual experiments. In Concepts I and II (VII) the individual experiments are shipped twice and only once in Concept III (VI). In the other concepts the experiments are always shipped in the integrated state. For cost accumulation purposes, the shipping accountability was assigned to the "sender" in preflight operations, and to the "recipient" in postflight operations. Table 6.1-10 summarizes the applicable shipments and the shipping responsibilities for each concept. The user is accountable for all individual experiment equipment shipments. All shipments in Concepts III, IV, V, VI and VII are accrued to the user, except for the shipment of the racks/pallet from the launch site to the integration center. The launch site is not accountable for any shipment associated with Spacelab ground processing.

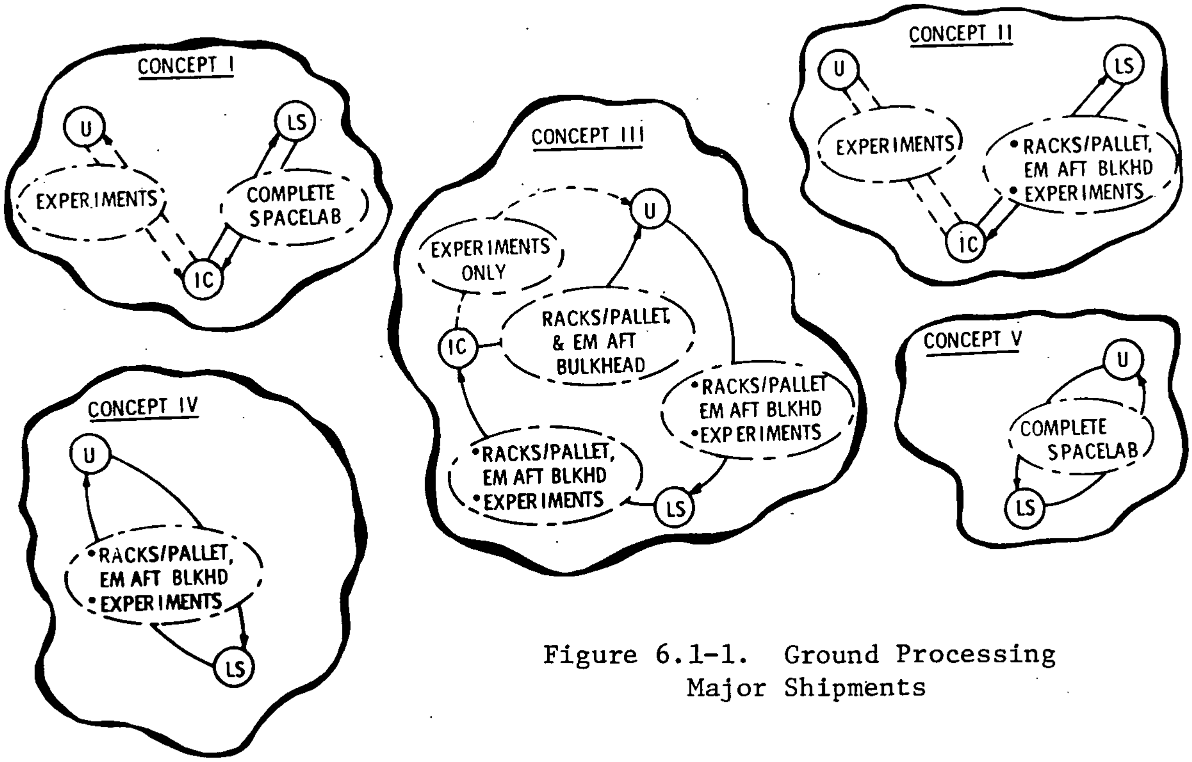

Figure 6.1-1. Ground Processing Major Shipments

Table 6.1-10. Shipment Applicability and Accountability

SHIPMENT	CONCEPT	I		II&VII		III&VI		IV&VIII	V	
	CENTER	U	IC	U	IC	U	IC	U	U	
EXPERIMENTS U TO IC		X		X						PREFLIGHT
RACKS/PALLET IC/U TO LS					X	X		X		PREFLIGHT
SPACELAB IC/U TO LS			X						X	PREFLIGHT
RACKS/PALLETS LS TO IC/U					X		X	X		POSTFLIGHT
SPACELAB LS TO IC/U			X						X	POSTFLIGHT
EXPERIMENTS IC TO U		X		X		X				POSTFLIGHT
REFURB. RACKS/PALLET IC TO U						X				POSTFLIGHT

Facilities

There is one "facility" that is classified as a mission-unique cost item. This item is the data link for real-time transfer of data during the mission. Good-quality TV (5 MHz bandwidth) was assumed to be the most stringent ATL requirement.

Mission-Unique Costs

Table 6.1-11 summarizes the mission-unique cost estimates for the integration and checkout activities associated with the ground operations of all the processing concepts. The estimates are on a per-mission basis. Personnel estimates are based upon average aerospace rates for the required skill codes. Material estimates are based upon cost estimating relationships developed on previous space programs at Rockwell. All other estimates are based on commercial rates. The cost variations are due primarily to the differences in manpower and travel/transportation requirements. From a NASA viewpoint, the more service a Spacelab user sublets, the greater the total mission-unique costs will be. The total difference between concepts, however, is on the order of 8 percent from the high to the low estimates and by itself will not establish a preferred processing concept.

SUSTAINING RESOURCE REQUIREMENTS

The yearly manpower requirements to manage and administer the integration and checkout of a two-flight-per-year Spacelab payload program are summarized in Table 6.1-12. The totals for each center were developed through the establishment of a sustaining organization at each center for each concept. Figure 6.1-2 presents the sustaining organizations for the user center (ATL program). Similar organization charts were developed for the IC and LS.

The organizations are relatively insensitive to flight rate and would manage and administer the activities of all Spacelab payloads being processed. Therefore, attributing the entire organization to the integration and checkout of one Spacelab payload would be erroneous. Pro-rations were developed to reflect that portion of the organizations that should be attributed to one payload. For example, the ATL organization of Figure 6.1-2 includes advanced mission planning and experiment development activities as well as integration and checkout activities. Thus, only a third of the resources of the program office should be attributed to integration and checkout. The resultant pro-rations of each of the center organizations for a two-flight-per-year program are reflected in the estimates of Table 6.1-12.

Sustaining Costs

A summary of the yearly sustaining costs is presented in Table 6.1-13. The sustaining cost estimates follow the same pattern as the mission-unique costs. The greater the amount of the direct involvement of the user, the less the total agency costs. But again, the difference is not exceedingly large ($100 thousand per year maximum). There is no distinct advantage to one concept over another from the standpoint of sustaining costs.

Table 6.1-11. Summary of Mission-Unique Costs (Thousands of Dollars)

COST ITEM \ CONCEPT / CENTER	I				II & VII				III & VI				IV & VIII			V		
	U	IC	LS	TOTAL	U	IC	LS	TOTAL	U	IC	LS	TOTAL	U	LS	TOTAL	U	LS	TOTAL
MATERIAL	-	69	-	69	-	69	-	69	37	32	-	69	69	-	69	69	-	69
TRAVEL	30	28	2	60	32	32	3	67	45	4	5	54	43	4	47	37	2	39
AUTO COMP	16	10	1	27	16	9	2	27	25	-	2	27	25	2	27	25	1	26
DOCUMENTATION	2	3	-	5	2	3	1.5	6.5	3	1.5	1.5	6	3	2	5	3	1	4
SHIPPING/TRANSPORT	16	24	-	40	16	24	-	40	44	12	-	56	32	-	32	32	-	32
FACILITIES	40	-	-	40	40	-	-	40	40	-	-	40	40	-	40	40	-	40
PERSONNEL	373	1005	148	1526	392	916	258	1566	1019	264	258	1541	1230	258	1488	1321	148	1469
TOTAL	477	1139	151	1767	498	1053	264.5	1815.5	1213	313.5	266.5	1793	1442	266	1708	1527	152	1679

Table 6.1-12. Pro-Rated Yearly Sustaining Manpower Requirements
(Man-Months)

CONCEPT	I			II & VII			III & VI			IV&VIII		V	
CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
TOTALS	228	49	12	228	49	17	256	7	17	256	17	256	12
	289			294			280			273		268	

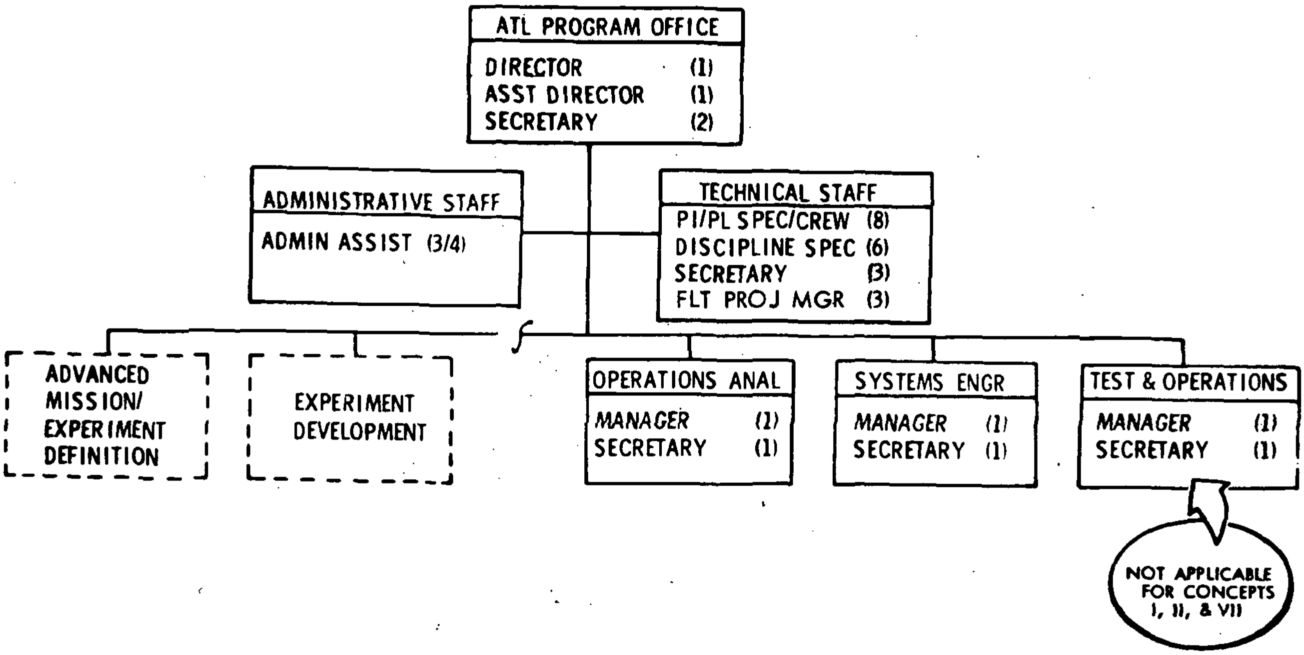

Figure 6.1-2. User Center Sustaining Organization

Table 6.1-13. Yearly Sustaining Costs (Thousands of Dollars)

COST ITEM / CONCEPT	I			II/VII			III/VI			IV/VIII		V	
CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
GSE MAINTENANCE	--	21	2	--	18	4	18	4	4	18	4	21	2
FACILITY MAINT.	--	12	1	--	12	2	12	3	2	12	2	12	1
INSTITUTIONAL BASE & OTHER ADMIN.	22	38	6	23	35	10	46	10	10	54	10	57	6
PERSONNEL	494	140	26	494	140	35	550	14	36	550	36	550	36
TOTALS	516	211	35	517	205	52	626	31	52	634	52	640	35
	762			774			709			686		675	

NON-RECURRING RESOURCE REQUIREMENTS

The non-recurring resource requirements are summarized in three categories: (1) support functions, (2) GSE requirements, and (3) facility requirements. Costs for each category are also presented.

Non-Recurring Support Functions

An appreciable effort is anticipated to adapt the generalized operations plans of the Spacelab to the unique applications of a Spacelab user. This effort was defined as non-recurring support functions. The basic data pack for utilization of the Spacelab that will be assembled by the manufacturer (ESRO/ERNO) and operations developer (MSFC) will reflect the potentially broad spectrum of users. Each user must tailor the data pack to the objectives, organization, procedures, and constraints of his program. For example, reliability requirements will vary between experiments; safety criteria and procedures will reflect user-unique fluids, specimens, radiation sources, etc.; and facility requirements must reflect the user centers involved.

As the role of the user varies between concepts, the estimates for non-recurring support functions are concept-dependent. Table 6.1-14 summarizes the estimates. The variations between concepts in the total required manpower effort are primarily due to the variations in GSE and facilities requirements definition and activation at the user's site.

Table 6.1-14. User-Unique Non-Recurring Manpower Requirements

CONCEPT	I			II & VII			III & VI			IV & VIII			V		
CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	IC	LS	U	IC	LS
TOTAL (MAN-MONTHS)	35	165	13	35	165	17	253	39	17	276	-	17	380	-	13
	213			217			309			293			393		

GSE Requirements

The GSE requirements for each of the candidate processing concepts are summarized in Table 6.1-15. There are no significant differences in the total complement of GSE for complete Spacelab Concepts I, II, IV, and V. Also, pallet-only processing concepts VII and VIII require the same GSE complement. The delta GSE requirement in the fifth complete Spacelab concept (III) and the third pallet-only concept (VI) is a result of three centers being involved in the hardware processing; only two centers are involved in all the other concepts. The difference between the GSE requirements for the processing of the two Spacelab configurations between comparable concepts (II and VII, III and VI, and IV and VIII) is primarily due to the handling and auxiliary equipment associated with the SM/EM and rack sets. An evaluation of the commonality of the GSE for the processing of the two configurations indicated that with the addition of a payload specialist station simulator at the Level III integration site, and systems igloo handling equipment at the Level II integration site, the complete Spacelab GSE can also accommodate the processing of pallet-only payloads.

Table 6.1-15. ATL Program GSE Requirements Summary

GSE \ CONCEPT	I & V	II & IV	III	VI	VII & VIII
CHECKOUT	35	42	42	44	43
HANDLING	56	55	74	56	43
AUXILIARY	46	49	60	47	37
SERVICING	20	19	24	22	17
TOTAL (END ITEMS)	157	165	200	169	140

Facility Requirements

Facility estimates were made by center for each major integration and checkout activity. These requirements are summarized in Table 6.1-16. The totals contain a 2400 ft^2 allocation at the user's facility (in all concepts) for an operations control center (see Figure 5.3-10, Volume III). This facility is required to monitor and support real-time mission activities. A dedicated building is not required. Appropriate space in an existing building is adequate. The unique requirement of the operations control center is a ground terminal for the reception of real-time mission data via a domestic communications satellite (DOMSAT). The baseline approach of this study for relay of mission data from the TDRS ground terminal to the user center is via a DOMSAT.

All other facility requirements can be accommodated by modifications to existing buildings at Langley (user), MSFC (IC), and KSC (LS). The detailed requirements, analyses, and accommodation evaluations are discussed in Section 5.3 of Volume III.

Table 6.1-16. Summary of Facility Requirements
(Square Feet)

CONCEPT	I			II & VII			III & VI			IV & VIII			V		
CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	IC	LS	U	IC	LS
	10,000	30,200	13,600	10,100	29,700	23,028	28,900	12,800	23,028	34,400	-	23,028	34,900	-	13,600
	53,800			62,828			64,728			57,428			48,500		

Non-Recurring Costs

A summary of the non-recurring costs for the eight processing concepts is presented in Table 6.1-17. The common cost estimates for Concepts II and VII, III and VI, and IV and VIII were obtained by adding two GSE items, uniquely required for pallet-only processing, to the complement of GSE required for the processing of the complete Spacelab. Adding these two items (PSS simulator at the Level III integration site, and systems igloo handling equipment at the Level II integration site) to the complete Spacelab GSE list will permit the intermixing of Spacelab configurations. Since the ATL Spacelab payload program utilizes both Spacelab configurations, all concept evaluations pertaining to non-recurring costs are based upon the data of Table 6.1-17.

User facility estimates include provisions for an operations control center and DOMSAT ground terminal in all concepts ($0.5 million) and the conversion of Building 1293A to a flight hardware processing facility in Concepts III/VI, IV/VIII, and V. The IC facility estimates are based upon preliminary plans to modify Building 4755 at MSFC. The launch site facility estimate is based upon preliminary plans to modify the MSOB at KSC.

MSFC provided the preliminary cost estimates for the majority of the GSE items (78 of 88). The estimates for the remaining 10 units were developed from utilizing comparable Apollo-Saturn equipment and updating their costs to reflect 1974 dollars.

Personnel estimates only include the effort to adapt the operational Spacelab program to the unique requirements of a Spacelab user such as Langley.

Table 6.1-17. Composite Non-Recurring Costs (Millions of Dollars)

COST ITEM / CONCEPT	I			II/VII			III/VI			IV/VIII		V	
CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
FACILITIES	0.5	3.5	0.5	0.5	3.5	0.5	2.4	3.5	0.5	2.4	0.5	2.4	0.5
GSE	--	8.9	4.9	--	6.4	8.6	6.1	2.7	8.6	6.4	8.6	8.9	4.9
SPARES	--	2.7	0.8	--	2.4	2.2	2.4	0.1	2.2	2.4	2.2	2.7	0.8
PERSONNEL	*	0.4	*	*	0.4	*	0.6	0.1	*	0.6	*	0.9	*
TOTALS	0.5	15.5	6.2	0.5	12.7	11.3	11.5	6.4	11.3	11.8	11.3	14.9	6.2
	22.2			24.5			29.2			23.1		21.1	

*LESS THAN $100K

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6.2 FLIGHT RATE SENSITIVITY

The flight rate of the Spacelab program will directly impact the resource requirements developed in this study. A two-flight-per-year ATL Spacelab program was used as the model in the derivation of previously presented resource requirements. In this section, the impact of flight rates on (1) Spacelab and interface simulator equipment, (2) GSE, (3) facilities, and (4) personnel/staffing is parametrically evaluated.

TECHNIQUE FOR DETERMINATION OF FLIGHT RATE SENSITIVITIES

The equipment requirements necessary to support a given Spacelab flight rate can be determined rigorously as indicated in Figures 6.2-1 and 6.2-2, which show example flows for two and four flights per year, respectively. This procedure for determining the parametric relationship of flight and support hardware versus flight rate is cumbersome and, for large flight rates, it becomes nearly intractable. An easier, somewhat analytical, approach for determining this parametric relationship was developed and is described below.

Several equipment items can be arranged in a schedule format as shown in Figure 6.2-3. At various points they are collectively or individually connected or mated to one main assembly. After these items have contributed to the scheduled event, they are disconnected or demated and are available to support another similar event for another flight. The problem, then, is to find the number of flights that a given equipment item can support before additional items are required.

From Figure 6.2-3, the equipment item with the longest processing or involvement time can be identified and designated as the primary element. The remaining elements can be ordered in accordance with the duration of their processing times. The processing interval of the major element can be denoted as P_1 and the other elements denoted as P_2, P_3, P_4, etc.

The number of processing cycles (flights) that can be accomplished in 52 weeks (one year) for a single unit of the primary element is

$$N_{52} = \frac{52}{P_1} \quad \text{(one unit)}$$

or

$$N_{52} = \frac{52N1}{P_1} \quad \text{(for } N_1 \text{ units)}$$

HARDWARE REQUIREMENTS		
SM SIMUL	SM/EM	RACK/ PALLET
1	1	1

2 FLTS/YEAR

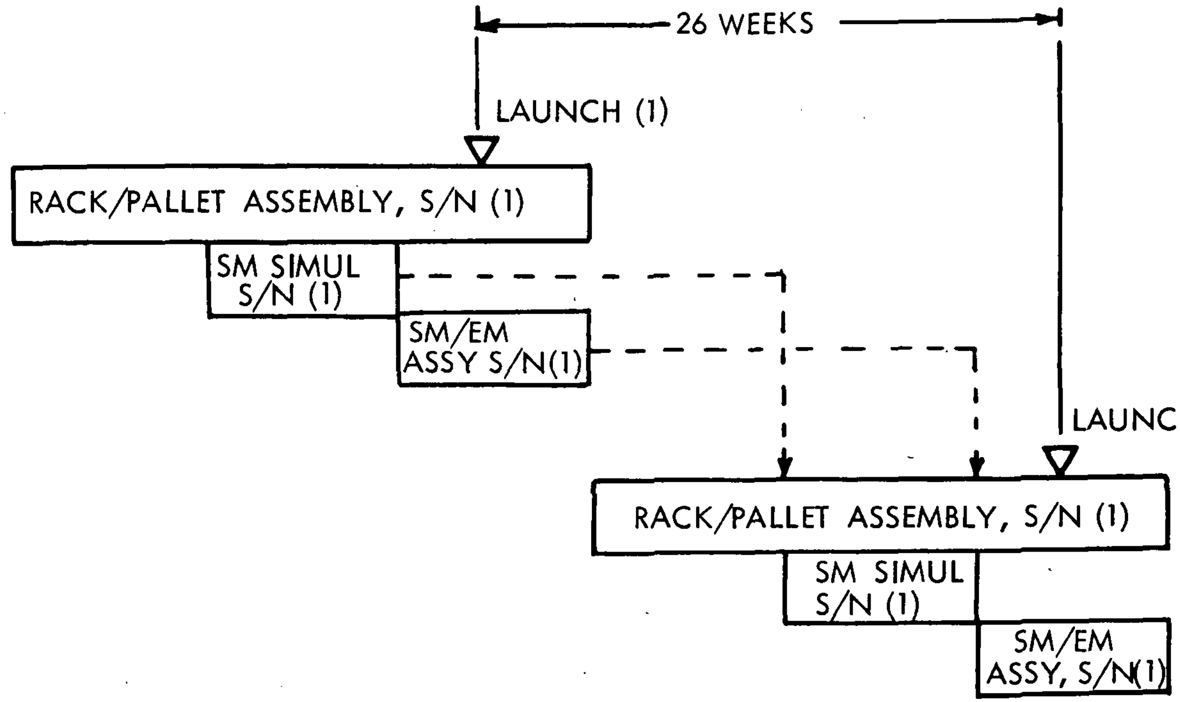


Figure 6.2-1. Typical Example of Test/Operations Flows
(2 Flights Per Year)

HARDWARE REQUIREMENTS		
SM SIMUL	SM/EM	RACK/ PALLETS
1	1	2

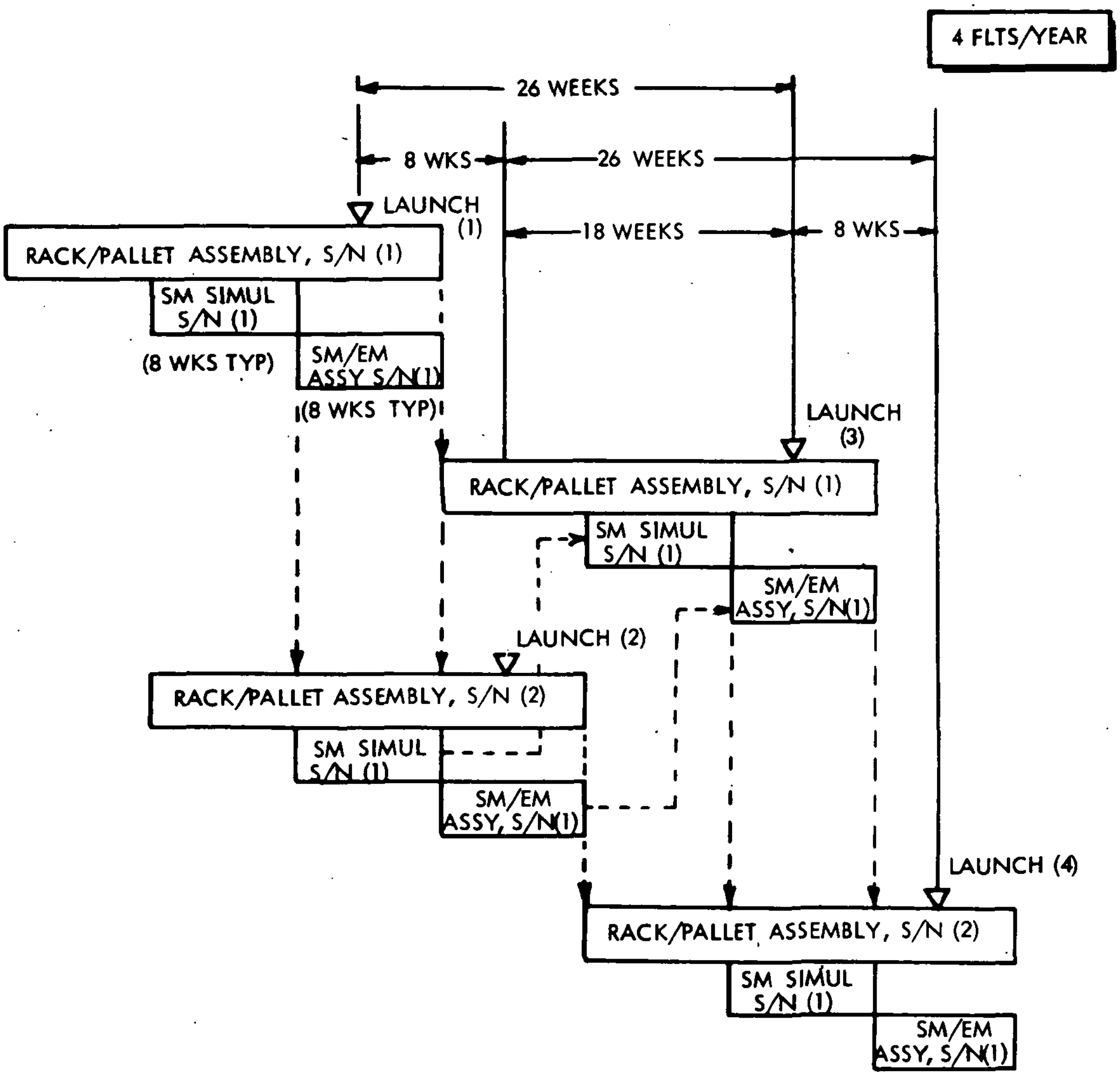


Figure 6.2-2. Typical Example of Test/Operations Flows (Four Flights Per Year)

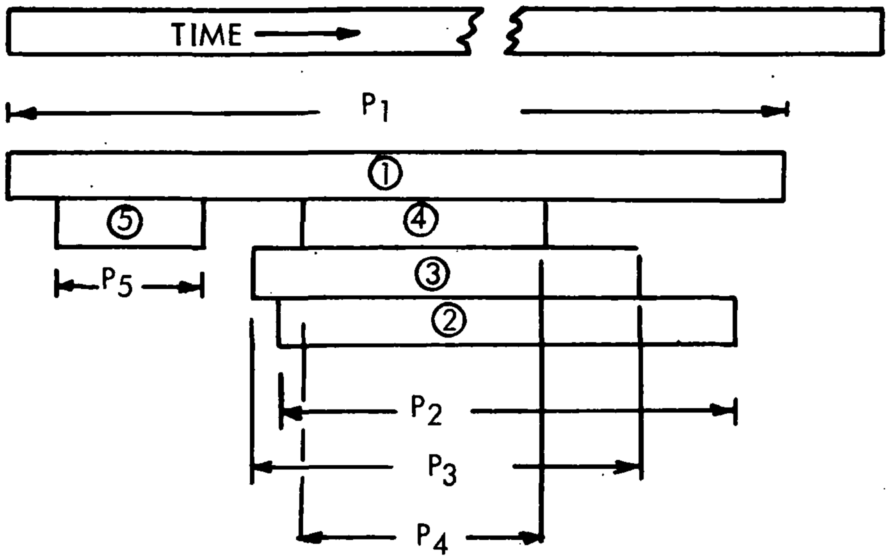


Figure 6.2-3. Typical Schedule Format

Normalizing all of the subelements by dividing their involvement times into the involvement time, P_1, of the major element, forms the ratios

$\frac{P_1}{P_2}$ = Number of units of major element (1) that subelement (2) can support.

$\frac{P_1}{P_3}$ = Number of units of (1) that (3) can support

and so forth until all ratios are formed.

It follows that the number of units of a given subelement required to support a single unit of the primary element for a period of 52 weeks is

$$\left(\frac{\cancel{P_1}}{P_2}\right)\left(\frac{52}{\cancel{P_1}}\right) = \frac{52}{P_2} \quad \text{(one unit of (2))}$$

This is equivalent to stating that a single unit of (2) can support

$$N_{52} = \frac{52}{P_2} \quad \text{(one unit of (2))}$$

processing cycles or flights per year, and N_2 units of (2) can support

$$N_{52} = \frac{52}{P_2} N_2$$

flights per year. In general, the number of flights per year for each is

$$N_{52} = \frac{52N_3}{P_3} \quad \text{(for } N_3 \text{ units of (3))}$$

$$N_{52} = \frac{52N_4}{P_4} \quad \text{(for } N_4 \text{ units of (4))}$$

and so forth.

The P_i for i = 1, 2, 3, etc., is defined in the flight rate analysis as involvement times. It is an interval that an element is actively participating in the processing flow, or awaiting its turn to participate in the flow.

When a given subelement reaches saturation, additional units will not increase the flight rate unless the number of units of the element level above it is increased by at least one unit.

This process continues up to the major element which ultimately becomes the Orbiter itself in this study.

In the case of the Orbiter, a turnaround timeline of two weeks and a typical mission of one week were assumed. The involvement time per cycle of the Orbiter is three weeks. Therefore, the number of flights/year that can be obtained utilizing a single Orbiter before saturation occurs is

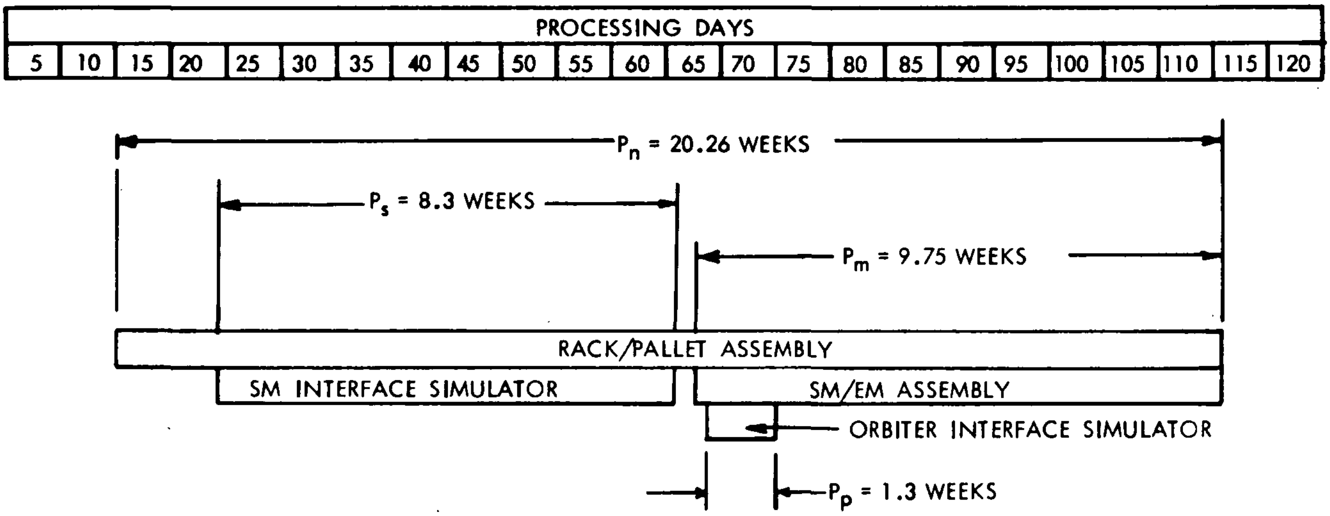
$$N_{52} = \frac{52}{3} = 17 \text{ flights (to the nearest integer flight)}$$

If additional flights are necessary, an additional Orbiter must be commited to the program.

This technique was utilized in the determination of the flight rate sensitivity of Spacelab equipment, interface simulation, GSE, and facilities. These sensitivities are presented in subsequent paragraphs.

FLIGHT RATE SENSITIVITY OF COMPLETE SPACELAB EQUIPMENT

The application of the previously described procedures to determine the involvement times of the complete Spacelab and interface simulator equipments in processing Concepts I and V is illustrated in Figure 6.2-4. The processing days are work days based upon a single-shift/five-day work week. The sequence reflects the integrated test and operations flows developed in Volume II. The involvement times for the equipments are expressed in "calendar" weeks. That is, the involvement times, in weeks, are equal to the applicable number of processing days divided by five.



	ITEM NOMENCLATURE	INVOLVEMENT TIMES (CALENDAR WEEKS)	FLIGHTS/YEAR AS FUNCTION OF E/I UNITS)
1	RACK/PALLET ASSEMBLY	$P_n = 20.26$	$N_{52} = \frac{52n}{20.26} = 2.56n$
2	SM/EM ASSEMBLY	$P_m = 9.75$	$N_{52} = \frac{52m}{9.75} = 5.33m$
3	SM I/F SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_s + 1 = 8.3 + 1 = 9.3$	$N_{52} = \frac{52s}{9.3} = 5.65s$
4	ORBITER I/F SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_p + 1 = 1.3 + 1 = 2.3$	$N_{52} = \frac{52p}{2.3} = 22.6p$

Figure 6.2-4. Complete Spacelab Involvement Times (Concepts I and V)

The involvement time of the rack/pallet assembly is shown as P_n and amounts to 20.26 calendar weeks. Therefore, the analysis indicates that one set of these end items could support a flight rate of 2.56 flights per year. Two sets of equipment could therefore support a flight rate of 5.12 flights/year, three sets could support 7.68 flights/year, etc.). The same procedure indicates that an SM/EM assembly can support a 5.33 yearly flight rate.

Determination of the annual flight rate that the two simulators can support involves not only their direct participation in the processing flows, but also an additional period for revalidation following their support of the test and operations of each flight. From Figure 6.2-4 it can be seen that the SM I/F simulator and Orbiter I/F simulator can support 5.65 and 22.6 flights per year, respectively. This revalidation includes replacement of items such as seals, filters, fluids, etc.; and calibration/verification of gauges, indicators, meters, etc. A period of one work week was allocated for revalidation of the simulators based upon previous Rockwell experience with equipment of similar complexity (Apollo-Saturn program).

A similar determination of the involvement times for complete Spacelab and interface simulator equipments for Concepts II and IV, and Concept III are illustrated in Figures 6.2-5 and 6.2-6, respectively. As in the case of the processing days for Concepts I and V, the processing days in these two figures reflect the integrated test and operations flows developed in Volume II.

Single-Shift Operation

Table 6.2-1 summarizes the involvement times for the complete Spacelab and interface simulator equipments. A single-shift/five-day work week during test and operations activities, except during common operations with the Orbiter, was assumed.

Since the Orbiter interface simulator has such a short involvement interval (it can support at least 22 flights/year), it is not considered a constraining item. Table 6.2-2 presents the required quantities of the other equipments as a function of flight rate. A flight rate of 15 per year is highlighted because that was the nominal yearly flight rate of a complete Spacelab in the traffic model used in this study.

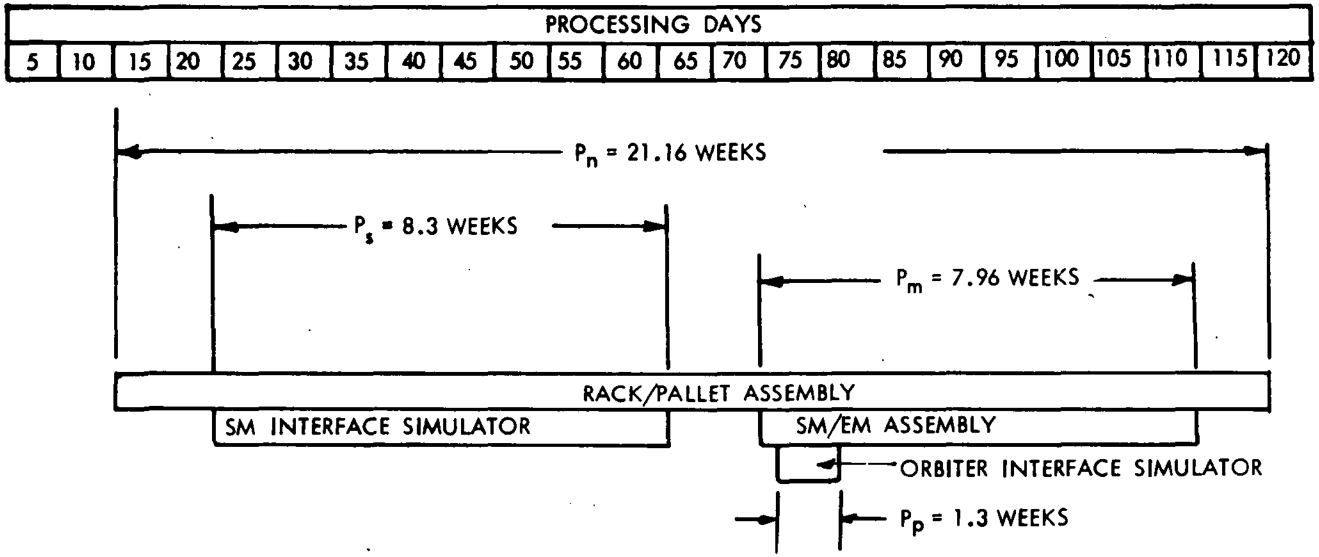
Two-Shift Operation

Table 6.2-3 presents the involvement times for complete Spacelab and interface equipment simulators if a two-shift/five-day work week is used during all test and operations activities. It is unrealistic to expect a 50-percent reduction in schedule time by adding a second shift. Rockwell experience on the Apollo-Saturn program indicated a reduction of about 45 percent was realistic. This is equivalent to dividing the single-shift scheduled times (involvement times) by a factor of 1.8.

Table 6.2-4 presents the effect of two-shift Spacelab processing on equipment end item requirements as a function of flight rate.

Two-Shift Operation at IC and LS Only

Table 6.2-5 summarizes the involvement times for two-shift operations during integration center (IC) and launch site (LS) test and operations activities. *For those concepts requiring processing of flight equipment at the* user's site, an 8-hour/day shift would still prevail at the user's site. The 1.8 factor is again employed in the areas where participation of the IC and LS occurs.



ITEM NOMENCLATURE	INVOLVEMENT TIMES (CALENDAR WEEKS)	FLIGHTS/YEAR (AS FUNCTION OF E/I UNITS)
① RACK/PALLET ASSEMBLY	$P_n = 21.16$	$N_{52} = \frac{52n}{21.16} = 2.46n$
② SM/EM ASSEMBLY	$P_m = 7.96$	$N_{52} = \frac{52m}{7.96} = 6.53m$
③ SM I/F SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_S+1 = 8.3+1 = 9.3$	$N_{52} = \frac{52s}{9.3} = 5.6s$
④ ORBITER I/F SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_p+1 = 1.3+1 = 2.3$	$N_{52} = \frac{52p}{2.3} = 22.6p$

Figure 6.2-5. Complete Spacelab Involvement Times (Concepts II and IV)

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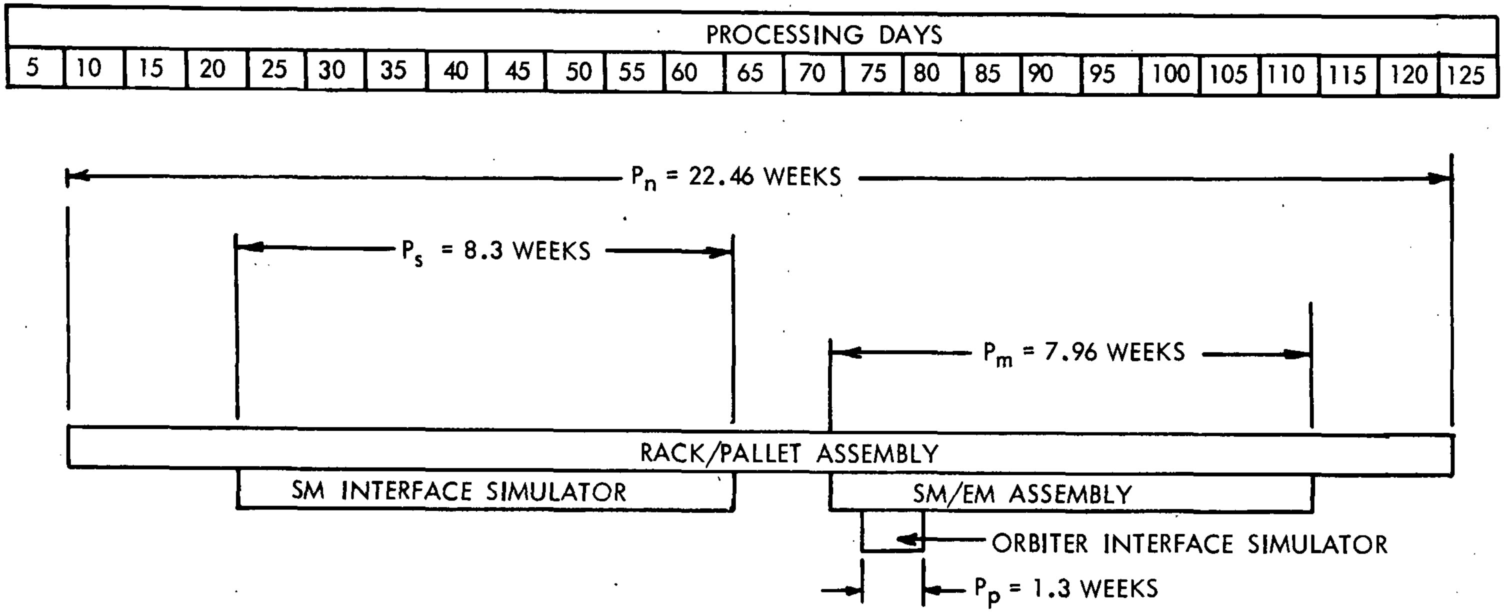
Rockwell International



	ITEM NOMENCLATURE	INVOLVEMENT TIME (CALENDAR WEEKS)	FLIGHTS/YR (AS A FUNCTION OF E/I UNITS)
①	RACK/PALLET ASSEMBLY	$P_n = 22.46$	$N_{52} = \frac{52n}{22.46} = 2.32n$
②	SM/EM ASSEMBLY	$P_m = 7.96$	$N_{52} = \frac{52m}{7.96} = 6.53m$
③	SM I/F SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_s + 1 = 8.3 + 1 = 9.3$	$N_{52} = \frac{52s}{9.3} = 5.6s$
④	ORBITER I/F SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION	$P_p + 1 = 1.3 + 1 = 2.3$	$N_{52} = \frac{52p}{2.3} = 22.6p$

Figure 6.2-6. Complete Spacelab Involvement Times (Concept III)

Space Division
Rockwell International

Table 6.2-1. Complete Spacelab Involvement Times (Calendar Weeks)
(8 hr/day)

Equipment \ Concept	I	II	III	IV	V
Racks/pallet assembly	20.26	21.16	22.46	21.16	20.26
SM interface simulator	9.3	9.3	9.3	9.3	9.3
SM/EM assembly	9.75	7.96	7.96	7.96	9.75
Orbiter interface simulator*	2.3	2.3	2.3	2.3	2.3

*Supports 22 flights/year, all concepts.

Table 6.2-2. Hardware Complement Based on 8 Hours/Day
(Except during Orbiter Involvement)

Flights Per Year	Concepts I & V			Concepts II & IV			Concept III		
	Racks/Pallet	SM/EM	SM Interface Simulator	Racks/Pallet	SM/EM	SM Interface Simulator	Racks/Pallet	SM/EM	SM Interface Simulator
1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1
3	2	1	1	2	1	1	2	1	1
4	2	1	1	2	1	1	2	1	1
5	2	1	1	3	1	1	3	1	1
6	3	2	2	3	1	1	3	1	1
7	3	2	2	3	2	2	4	2	2
8	4	2	2	4	2	2	4	2	2
9	4	2	2	4	2	2	4	2	2
10	4	2	2	5	2	2	5	2	2
11	5	3	2	5	2	3	5	2	3
12	5	3	3	5	2	3	6	2	3
13	6	3	3	6	2	3	6	2	3
14	6	3	3	6	3	3	7	3	3
15	6	3	3	7	3	3	7	3	3
16	7	4	3	7	3	3	7	3	3
17	7	4	4	7	3	4	8	3	4
18	8	4	4	8	3	4	8	3	4
19	8	4	4	8	3	4	9	3	4

Table 6.2-3. Complete Spacelab Two-Shift Operation (16 Hours Day)

Involvement Time (Calendar Weeks)					
Equipment \ Concept	I	II	III	IV	V
Racks/pallet assembly	12.3	12.8	13.5	12.8	12.3
SM interface simulator	5.2	5.2	5.2	5.2	5.2
SM/EM assembly	6.5	5.5	5.5	5.5	6.5
Orbiter interface simulator*	1.3	1.3	1.3	1.3	1.3

*Supports 40 flights/year, all concepts.

$$\frac{\text{Pre-Orbiter Integration Operations}}{1.8} + \text{Orbiter Time} + \frac{\text{Post-Orbiter Operations}}{1.8}$$

Table 6.2-4. Effect of Two-Shift Spacelab Processing

Flights Per Year	Concepts I & V			Concepts II & IV			Concept III		
	Racks/ Pallet	SM/EM	SM Interface Simulator	Racks/ Pallet	EM/SM	SM Interface Simulator	Racks/ Pallet	EM/SM	SM Interface Simulator
1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	2	1	1
5	2	1	1	2	1	1	2	1	1
6	2	1	1	2	1	1	2	1	1
7	2	1	1	2	1	1	2	1	1
8	2	1	1	2	1	1	3	1	1
9	3	2	1	3	1	1	3	1	1
10	3	2	1	3	2	1	3	2	1
11	3	2	2	3	2	2	3	2	2
12	3	2	2	3	2	2	4	2	2
13	4	2	2	4	2	2	4	2	2
14	4	2	2	4	2	2	4	2	2
15	4	2	2	4	2	2	4	2	2
16	4	2	2	4	2	2	5	2	2
17	5	3	2	5	2	2	5	2	2
18	5	3	2	5	2	2	5	2	2
19	5	3	2	5	3	2	5	3	2

The highlighted flight rate was provided from proposed ATL mission models.

Table 6.2-5. Involvement Times for Two-Shift Operation at IC and LS Only

Equipment \ Concept	I	II	III	IV	V
	Involvement Times (Weeks)				
Racks/pallet assembly	12.3	12.8	18.7	18.6	19.4
SM interface simulator	5.2	5.2	9.3	9.3	9.3
SM/EM assembly	6.5	5.5	5.5	5.5	8.9
Orbiter interface simulator*	1.3	1.3	1.3	1.3	2.3

*Supports 40 flights/year, Concepts I - IV; supports 22 flights/year, Concept V

Table 2.6-6 is the resulting relationship of equipment requirements as a function of flight rate for two-shift operations at the IC and LS only. In this table, Concepts I and II are not included since the entires are identical to those of Table 6.2-4 for these concepts.

Table 6.2-6. Hardware Complements for Two-Shift Operation at IC and LS Only

Flights Per Year	Concept III			Concept IV			Concept V		
	Racks/ Pallet	SM/EM	SM Interface Simulator	Racks/ Pallet	SM/EM	SM Interface Simulator	Racks/ Pallet	SM/EM	SM Interface Simulator
1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1
3	2	1	1	2	1	1	2	1	1
4	2	1	1	2	1	1	2	1	1
5	2	1	1	2	1	1	2	1	1
6	3	1	2	3	1	2	3	2	2
7	3	1	2	3	1	2	3	2	2
8	3	1	2	3	1	2	3	2	2
9	4	1	2	4	1	2	4	2	2
10	4	2	2	4	2	2	4	2	2
11	4	2	2	4	2	2	5	2	2
12	5	2	3	5	2	3	5	3	3
13	5	2	3	5	2	3	5	3	3
14	6	2	3	5	2	3	6	3	3
15	6	2	3	6	2	3	6	3	3
16	6	2	3	6	2	3	6	3	3
17	7	2	4	7	2	4	7	3	4
18	7	2	4	7	2	4	7	4	4
19	7	3	4	7	3	4	8	4	4

Summary

The variation between concepts in the required equipment complement for the same number of work shifts is minor. For a complete Spacelab yearly flight rate of 15, one less rack set/pallet is required in Concepts I and V.

In the case of two-shift operations at the IC and LS only, Concept V requires an additional SM/EM unit. This is an unrealistic comparison because both Level III and Level II integration are performed at the user center, which is limited to single-shift operations.

In the operational Orbiter/Spacelab era, two-shift operations during Level II and Level I integration may be practical. But advanced planning based upon two-shift operations during Level III integration is not recommended. Level III integration activities are the major mission-unique activities. It is more likely that problems and contingencies will develop during Level III integration than any other test and operations activities.

If single-shift operations are used during Level III integration and two-shift operations are used for all other test and operations activities, the equipment complement versus flight rate of Table 6.2-7 would result. The intermixing of shift schedules by integration level rather than by site is the recommended approach.

Table 6.2-7. Equipment Complement with Shift Schedules Dependent Upon the Integration Level

	I & V			II & IV			III		
FLTS	RACKS/ PALLET	EM/SM	SM INTER SIM	RACKS/ PALLET	EM/SM	SM INTER SIM	RACKS/ PALLET	EM/SM	SM INTER SIM
1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1
3	2	1	1	2	1	1	2	1	1
4	2	1	1	2	1	1	2	1	1
5	2	1	1	3	1	1	3	1	1
6	3	1	2	3	1	1	3	1	1
7	3	1	2	3	1	2	4	1	2
8	4	1	2	4	1	2	4	1	2
9	4	2	2	4	1	2	4	1	2
10	4	2	2	5	2	2	5	2	2
11	5	2	2	5	2	3	5	2	3
12	5	2	3	5	2	3	6	2	3
13	6	2	3	6	2	3	6	2	3
14	6	2	3	6	2	3	7	2	3
15	6	2	3	7	2	3	7	2	3
16	7	2	3	7	2	3	7	2	3
17	7	3	4	7	2	4	8	2	4
18	8	3	4	8	2	4	8	2	4
19	8	3	4	8	3	4	9	3	4

FLIGHT RATE SENSITIVITY OF PALLET-ONLY SPACELAB EQUIPMENT

The techniques to determine the involvement times of the Spacelab and interface simulator equipments associated with the processing of pallet-only payloads was analogous to that used for the complete Spacelab processing concepts. Figure 6.2-7 illustrates the derivation of involvement times of the equipments for processing Concept VI. Comparable data are presented in Figure 6.2-8 for Concepts VII and VIII. The processing days reflect the integrated test and operations flows developed for these concepts in Volume II. Involvement times are in "calendar" weeks. A period of one week is allocated for maintenance, calibration, and verification of interface simulator equipment. Pallet-mounted canisters for experiment equipment are also indicated.

Single-Shift Operation

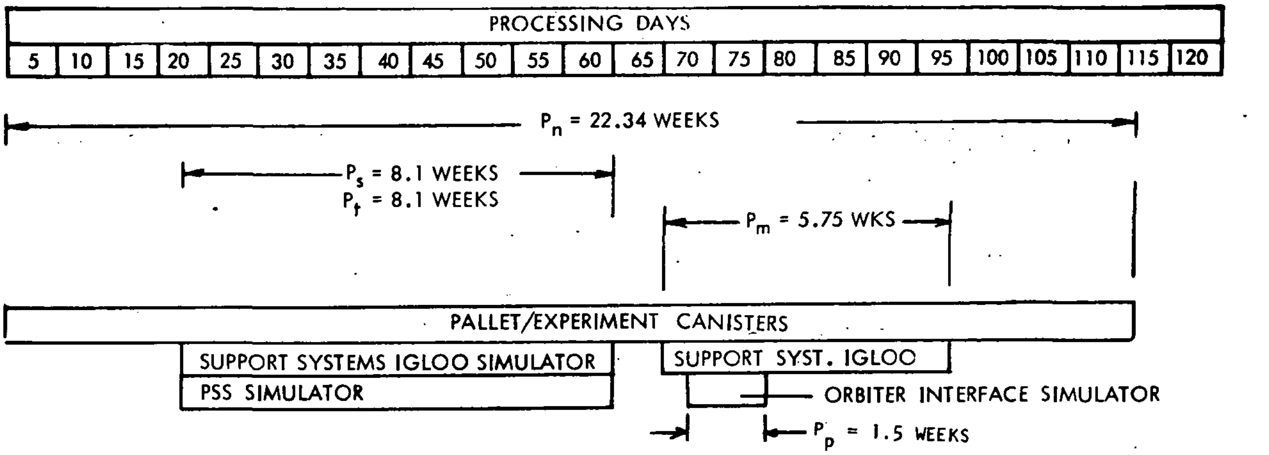
Table 6.2-8 provides a summary of the involvement times for the equipments associated with the pallet-only configuration if a single-shift operation is used during the test and operations activities except during common timeline operations with the Orbiter. In general, the Orbiter interface simulator has such a short involvement time that a single unit will support a minimum of 20 flights per year for all cases considered. Therefore, the Orbiter interface simulator is not included as an entry in any of the various site/shift combinations of the tables. For the pallet-only configuration, a payload specialist station (PSS) simulator must be provided to accomplish interface compatibility verification of payload equipment mounted in the Orbiter. The PSS simulator was considered to be an integral part of the support system simulator used during Level III integration, and an additional PSS simulator was included in the Orbiter interface simulator used during Level II integration.

Table 6.2-9 shows the quantities of equipment required as a function of flight rate for single-shift operations. The highlighted flight rate is the nominal yearly flight rate of the pallet-only Spacelab configuration in the traffic model used in this study.

Two-Shift Operation

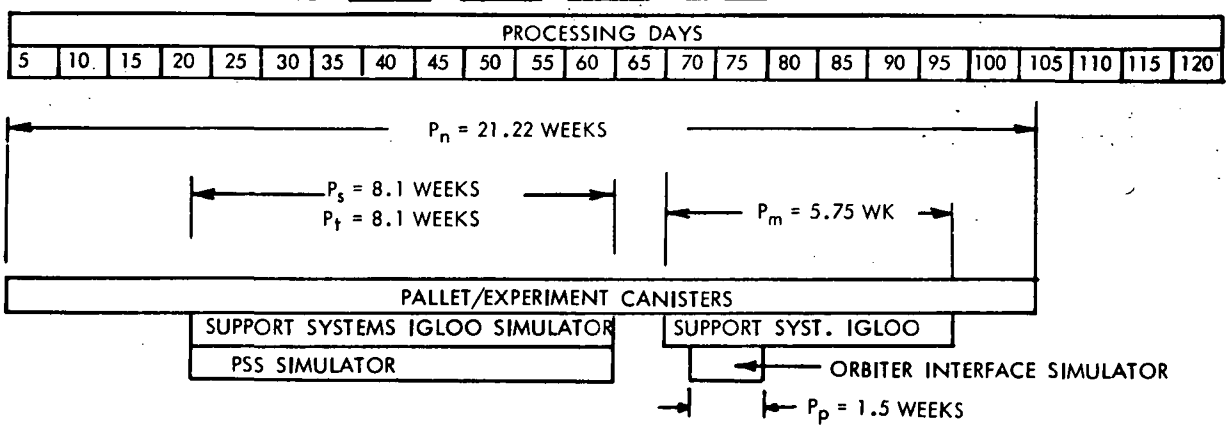
The equipment involvement times that result if two-shift operations are used during all test and operations activities are shown in Table 6.2-10. Again, the factor of 1.8 was applied (as in the complete Spacelab case) to obtain a schedule that reflects two-shift operations; that is, single-shift involvement times were divided by 1.8.

The required equipment complement versus flight rate, with two-shift operations, is shown in Table 6.2-11 for the pallet-only processing concepts.



	ITEM NOMENCLATURE	INVOLVEMENT TIME (CALENDAR WEEKS)	FLTS/YR (AS FUNCTION OF E/I UNITS)
①	PALLET/EXPERIMENT CANISTERS	$P_n = 22.34$	$N_{52} = \frac{52n}{22.34} = 2.33n$
②	SUPPORT SYSTEM IGLOO	$P_m = 5.75$	$N_{52} = \frac{52m}{5.75} = 9.04m$
③	SUPPORT SYSTEMS IGLOO SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_s + 1 = 8.1 + 1 = 9.1$	$N_{52} = \frac{52s}{9.1} = 5.71s$
④	ORBITER INTERFACE SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_p + 1 = 1.5 + 1 = 2.5$	$N_{52} = \frac{52p}{2.5} = 20.8p$
⑤	PAYLOAD SPECIALIST STATION SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION	$P_t + 1 = 8.1 + 1 = 9.1$	$N_{52} = \frac{52t}{9.1} = 5.71t$

Figure 6.2-7. Pallet-Only Involvement Times (Concept VI)



	ITEM NOMENCLATURE	INVOLVEMENT TIME (CALENDAR WEEKS)	FLIGHTS/YEAR (AS FUNCTION OF E/I UNITS)
①	PALLET/EXPERIMENT CANISTERS	$P_n = 21.22$	$N_{52} = \frac{52n}{21.22} = 2.45n$
②	SUPPORT SYSTEM IGLOO	$P_m = 5.75$	$N_{52} = \frac{52m}{5.75} = 9.04m$
③	SUPPORT SYSTEMS IGLOO SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_s + 1 = 8.1 + 1 = 9.1$	$N_{52} = \frac{52s}{9.1} = 5.71s$
④	ORBITER INTERFACE SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_p + 1 = 1.5 + 1 = 2.5$	$N_{52} = \frac{52p}{2.5} = 20.8p$
⑤	PAYLOAD SPECIALIST STATION SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_t + 1 = 8.1 + 1 = 9.1$	$N_{52} = \frac{52t}{9.1} = 5.71t$

Figure 6.2-8. Pallet-Only Involvement Times (Concepts VII and VIII)

Table 6.2-8. Single-Shift Involvement Times - Pallet-Only Configuration (Calendar Weeks)

Equipment \ Concept	VI	VII & VIII
Pallet/experiment canisters	22.3	21.2
Support system igloo simulator*	9.1	9.1
Support system igloo	5.8	5.8
Orbiter interface simulator* (one unit supports 20 flights/year)	2.5	2.5
*Includes a PSS form/fit simulator		

Table 6.2-9. Pallet-Only Equipment Complement - Single Shift (Except during Orbiter Involvement)

Flights Per Year	Concept VI			Concepts VII and VIII		
	Expmt Canister Sets	Support System Igloo	Support System Simulator	Expmt Canister Sets	Support System Igloo	Support System Simulator
1	1	1	1	1	1	1
2	1	1	1	1	1	1
3	2	1	1	2	1	1
4	2	1	1	2	1	1
5	3	1	1	3	1	1
6	3	1	2	3	1	2
7	4	1	2	3	1	2
8	4	1	2	4	1	2
9	4	2	2	4	2	2
10	5	2	2	5	2	2
11	5	2	2	5	2	2
12	6	2	3	5	2	3

Table 6.2-10. Two-Shift Operations - Pallet-Only Concepts
(Involvement Times - Calendar Weeks)

Equipment \ Concept	I	VII & VIII
Pallet/experiment canisters	13.5	12.8
Support system igloo simulator	5.1	5.1
Support system igloo	4.25	4.25
Orbiter interface simulator (One unit supports 37 flights per year--all concepts)	1.4	1.4

Pre-Orbiter Integration Ops. + Orbiter Time + Post-Orbiter Ops.
1.8 1.8

Table 6.2-11. Pallet-Only Equipment Complement
(Two-Shift Operations)

Flights Per Year	Concept VI			Concepts VII and VIII		
	Expmt Canister Set	Support System Igloo	Support System Simulator	Expmt Canister Set	Support System Igloo	Support System Simulator
1	1	1	1	1	1	1
2	1	1	1	1	1	1
3	1	1	1	1	1	1
4	2	1	1	1	1	1
5	2	1	1	2	1	1
6	2	1	1	2	1	1
7	2	1	1	2	1	1
8	3	1	1	2	1	1
9	3	1	1	3	1	1
10	3	1	1	3	1	1
11	3	1	2	3	1	2

Two-Shift Operation at IC and LS Only

The equipment involvement times that would result if test and operations activities are on a two-shift basis only at the IC and LS are shown on Table 6.2-12 for the pallet-only processing concept.

Table 6.2-12. Two-Shift Operation Involvement Times at IC and LS Only - Pallet-Only

Equipment \ Concept	Involvement Time (Calendar Weeks) VI	VII	VIII
Pallet/experiment canisters	19.2	13.0	19.7
Support system igloo simulator	9.1	5.1	9.1
Support system igloo	4.3	4.3	4.3
Orbiter interface simulator (One unit supports 73 flights per year--all concepts)	1.4	1.4	1.4

The equipment complement versus flight rate, with two shifts at the IC and LS only, is shown in Table 6.2-13 for the pallet-only processing concepts.

Summary

The variations in required equipment complements, as a function of flight rate for the pallet-only processing concepts for comparable shift schedules, is minor. At a yearly flight rate of nine (the nominal rate of the traffic model used in this study), differences occur only in the case where two-shift operations are used at the IC and LS but not at the user's center. But this constraint on the user center is not considered to be realistic.

Based upon the same rationale used in the establishment of the preferred shift schedules for processing of the complete Spacelab configuration, a set of equipment complement requirements as a function of flight rate was derived for the pallet-only concept. Table 6.2-14 reflects the equipment requirements if shift schedules are based upon the integration level involved rather than the site involved. Level III integration activities were scheduled for single-shift operations; all other test and operations activities were scheduled for two-shift operations.

Table 6.2-13. Equipment Complement - Pallet Only
(Two-Shift Operation at IC and LS Only)

Flights Per Year	Concept VI			Concept VII			Concept VIII		
	Experiment Canister Set	Support Syst. Igloo	Support Syst. Igloo Sim.	Experiment Canister Set	Support Syst. Igloo	Support Syst. Igloo Sim.	Experiment Canister Set	Support Syst. Igloo	Support Syst. Igloo Sim.
1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1
3	2	1	1	1	1	1	2	1	1
4	2	1	1	2	1	1	2	1	1
5	2	1	1	2	1	1	2	1	1
6	3	1	2	2	1	1	2	1	2
7	3	1	2	2	1	1	3	1	2
8	3	1	2	3	1	1	4	1	2
9	4	1	2	3	1	1	4	1	2
10	4	1	2	3	1	1	4	1	2
11	5	1	2	3	1	2	5	1	2

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Table 6.2-14. Pallet-Only Equipment Complement with Shift Schedules Dependent Upon Integration Level

	CONCEPT VI			CONCEPTS VII AND VIII		
FLIGHTS PER YR	EXPERIMENT CANISTER SETS	SUPPORT SYSTEM IGLOO	SUPPORT SYSTEM SIMULATOR	EXPERIMENT CANISTER SETS	SUPPORT SYSTEM IGLOO	SUPPORT SYSTEM SIMULATOR
1	1	1	1	1	1	1
2	1	1	1	1	1	1
3	2	1	1	2	1	1
4	2	1	1	2	1	1
5	3	1	1	3	1	1
6	3	1	2	3	1	2
7	4	1	2	3	1	2
8	4	1	2	4	1	2
9	4	1	2	4	1	2
10	5	1	2	5	1	2
11	5	1	2	5	1	2
12	6	1	3	5	1	3

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FLIGHT RATE SENSITIVITY OF GSE

The GSE requirements at each involved site for each of the eight processing concepts were derived in Volume III based upon a flight rate of two per year. As the test(s) that a GSE item was required to support was identified and the duration of the test(s) was also established, the involvement times of the GSE could be derived in the same manner as the involvement times of Spacelab equipment. Most of the 88 GSE items identified are used for very short durations and could support numerous flights per year. For example, slings, transporters, handling cages, and shipping canisters are used only during shipping/transportation, which is only a few days per payload processing cycle. Therefore, each GSE category (handling, checkout, auxiliary, and servicing) was analyzed to determine those GSE items within a category that would be most affected by flight rates greater than two per year.

Based upon single-shift operations, the required complement of key GSE items within each category is presented as a function of flight rate in Table 6.2-15. The processing concept used in the determination was Concept IV. Although the total number of GSE items required for a specific flight rate would vary between concepts, the flight rate at which an additional item of GSE is required is approximately the same for all concepts. For example, in Concept III a third assembly stand is required even for a flight rate of two per year. But an additional stand is still required at a flight rate of five and, again, at eight flights per year.

The line item designations refer to the GSE tabulations of Volume III. Except for the ground air-conditioning unit in the auxiliary equipment category, all the items listed were assumed to be supplied by ESRO/ERNO.

Delta spares provisioning as a function of flight rate was not included in the analyses. In general, the GSE spares complement would not be affected by the flight rates shown in the table.

Handling GSE

A review of the handling GSE indicated that the main assembly stands and access scaffoldings would be the most sensitive items in this category to increased flight rates. This sensitivity results from the near one-to-one correspondence with the rack/pallet assembly involvement. Two main assembly stand/scaffolding sets are required; one at the user center and one at the launch site. The main assembly stand/scaffolding set at the user center will support about four flights per year before a second stand is required. An additional stand would then support approximately eight flights per year. The shorter involvement times of the GSE items at the launch site allow a single main assembly stand/scaffolding set to support a minimum of nine flights per year before a second set is required at the launch site.

All of the remaining handling GSE (slings, hoists, dollies, work stands, etc.) have such low usage rates that their quantities are relative insensitive to flight rates.

Table 6.2-15. Required GSE Quantities Versus Flight Rate

LINE ITEM	GSE END ITEM	GSE QUANTITY REQUIREMENTS* FLIGHTS PER YEAR 1	2	3	4	5	6	7	8
	HANDLING								
3 18	SCAFFOLDING MAIN ASSEMBLY STAND } SET	2	2	2	2	3	3	3	4
	TOTAL	2	2	2	2	3	3	3	4
	CHECKOUT								
27	DATA PROCESSING EQUIPMENT	2	2	2	2	3	3	3	4
28	GROUND POWER SUPPLY	2	2	2	2	3	3	3	4
30	SM/IGLOO SIMULATOR SET	1	1	1	1	1	1	2	2
32	CONTROL & DATA ACQUISITION CONSOLE	2	2	2	2	3	3	3	4
33	GROUND TEST REMOTE SITE CABLE KIT	2	2	2	2	3	3	3	4
36	EXPERIMENT TEST CABLE KIT	2	2	2	2	3	3	3	4
40	GSE /FACILITY CABLE KIT	2	2	2	2	3	3	3	4
	TOTAL	13	13	13	13	19	19	20	26
	AUXILIARY								
57	INTERIOR PROTECTIVE DEVICES	1	1	1	1	1	1	2	2
58	SM/EM HATCH COVER & SEAL	1	1	1	1	2	2	2	2
24 (NASA)	GROUND AIR-CONDITIONING UNIT (PERSONNEL	2	2	2	2	3	3	3	3
	TOTAL	4	4	4	4	6	6	7	7
	SERVICING								
60	GROUND SERVICING & COOLING UNIT	2	2	2	2	3	3	3	4
63	FREON TRANSFER & SERVICING UNIT	2	2	2	2	2	2	2	3
64	VACUUM SERVICING UNIT	2	2	2	2	2	2	2	3
	TOTAL	6	6	6	6	7		7	10

*NOT INCLUDING SPARES

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Checkout GSE

The required complement of checkout equipment as a function of flight rate is approximately the same as the assembly stand/scaffolding set. It was assumed that a main assembly stand would be an integral part of a checkout station, which would include appropriate checkout equipment. Thus, a one-to-one correspondence between checkout equipment and main assembly stands would occur.

The one exception to the commonality of utilization of checkout station equipment was the Spacelab support systems simulator. Because of the complexity and cost of this item of GSE, it was assumed that provisions would be made for interconnection of multiple checkout stations with the simulator.

The utilization rates of those items of checkout GSE that are not included in Table 6.1-15 were such that no additional quantities were required for flight rates of up to eight per year.

Auxiliary GSE

Table 6.2-15 indicates that three items of auxiliary GSE are affected by flight rates of less than eight per year. Based upon the total number of auxiliary end items required to support hardware processing ($\approx$50), Table 6.2-15 indicates a very low percentage increase in the auxiliary GSE end items for flight rates of up to eight per year. The auxiliary end items not shown in this table have low usage rates and, therefore, are not affected by flight rates up to eight per year.

Servicing GSE

Only three units of servicing GSE are sensitive to flight rates of eight or less per year. The ground servicing and cooling unit, which is used for flight equipment cooling, is an integral part of the checkout station and, thus, the required number of units directly correspond to the previously listed checkout station equipment.

The Freon transfer and servicing unit and the vacuum servicing unit are both associated with the checkout station. But their operational duty cycles are such that, with proper manifolding between these units and multiple checkout stations, one set at the Level III integration site will accommodate seven flights per year. Servicing equipment not listed in Table 6.2-15 has low usage rates and is relatively insensitive to flight rates.

Summary

The GSE end items that are sensitive to flight rate are all related to Level III integration. In general, a Level III checkout station can support four flights per year based upon the recommended single-shift operations.

FLIGHT RATE SENSITIVITY OF FACILITIES

The facility requirements to process two ATL Spacelab payloads per year with each candidate processing concept were derived in Volume III. These requirements were compared with planned and existing facility capabilities at MSFC (IC), KSC (LS), and Langley (user).

MSFC Accommodations

Current modification plans for Building 4755 at MSFC indicate that this facility will accommodate the Level III integration activities of up to 24 Spacelab payloads per year (with appropriate quantities of GSE and two-shift operations). Capability for Level II integration is also planned, but would reduce the Level III integration capability. For example, if 7 Level II integrations are conducted, then approximately 20 Level III integrations can be accommodated. The basic facility at MSFC could accommodated the anticipated flight rates.

KSC Accommodations

The proposed modifications to the MSOB at KSC would accommodate up to 24 Level II integrations per year. In addition, a Level III integration capability that will accommodate approximately five payloads per year is also planned. Two-shift operations are assumed. These KSC accommodations are compatible with the anticipated Spacelab flight rate.

Langley Accommodations

Building 1293A at Langley was evaluated as a potential facility for test and operations activities. Modifications were defined that included separate disassembly/refurbishment and buildup/checkout areas. If both areas were equipped to conduct all the test and operations associated with a single flight (pre-flight and post-flight), then Building 1293A could accommodate the flight rates indicated in Table 6.2-16. The data are based on single-shift operations for all activities. Maximum flight rate support occurs with Concepts III and VI because all post-flight refurbishment is accomplished at the IC in these two concepts. Therefore, each area in Building 1293A would be dedicated to buildup and checkout of the flight hardware. The differences between Concepts IV and VIII, and V are attributed to the delta involvement times associated with Level II integration activities in Concept V.

Table 6.2-16. Building 1293A Flight Rate Support Capabilities

CONCEPT	FLIGHT RATE (YEARLY AVERAGE)
III	8
IV	7
V	6
VI	8
VIII	7

PERSONNEL/STAFFING FLIGHT-RATE SENSITIVITY

In addition to evaluating the impact of various flight rates on the Spacelab hardware end items and the GSE/facilities, an analysis was made of the impact to the personnel requirements for varying flight rates. The baseline staffing approach and requirements developed in the study were derived from manpower estimates for the integration and checkout tasks to support a flight rate of two Spacelab payloads per year. Increasing the flight rate beyond two flights per year will proportionately increase the required manpower/man-months of effort per calendar year, but the personnel or staffing requirements could be significantly impacted by flight rate. In order to determine parametrically what this impact would be, an evaluation of the structure of the integration and checkout cycle was made.

Figure 6.2-9 illustrates the 18-month cycle for the integration and checkout of a Spacelab payload that was derived in Volume III to support a flight rate of two per year. This cycle is comprised of two phases: the test operations phase (6 months) that is relatively fixed, and the 12-month support function phase that is somewhat variable in that the application of additional personnel can complete this effort in a shorter time span.

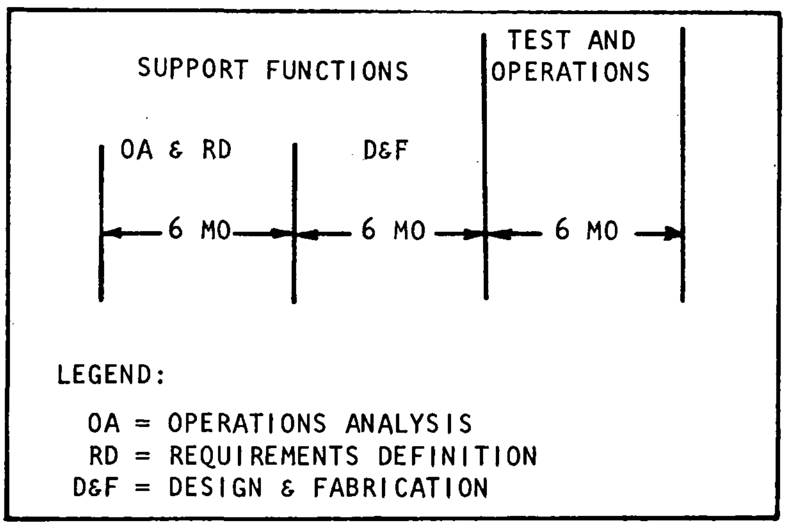
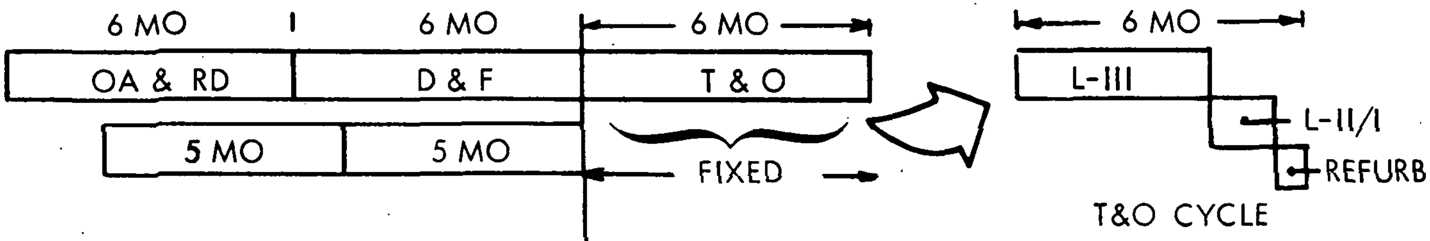
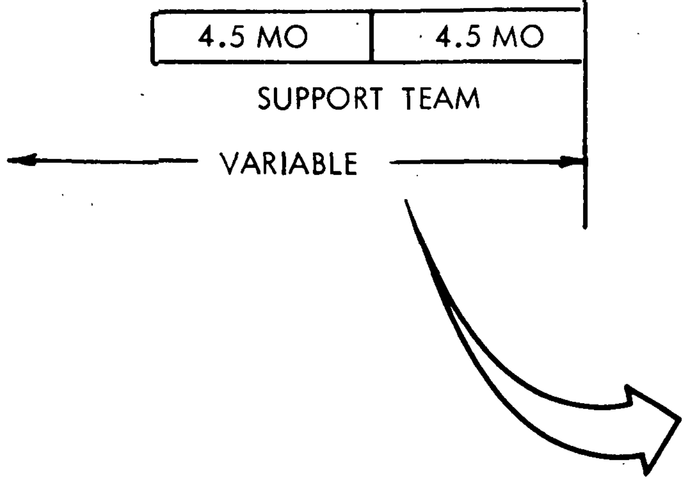


Figure 6.2-9. Typical Payload Integration and Checkout Cycle

Support Function Staffing

To determine the impact on support function personnel requirements as a function of flight rate, the duration of the support function tasks was varied. The total man-months of effort required to accomplish the support function tasks was held constant; the required personnel was proportionately varied. Figure 6.2-10 illustrates how the support function phase or rate of accomplishment was varied from two 6-month periods to two 5-month periods and also two 4.5-month periods. Therefore, the total variation in time for the completion of the support function tasks was from 9 to 12 months. As previously mentioned,





FLIGHT RATE	SUPPORT TEAM ACTIVITY DURATION 4.5 MO		5.0 MO		6.0 MO		T&O TEAM * L-III (3/YR)	L-II/I (8/YR)	REFURB (24/YR)
1	0.37	1	0.42	1	0.5	1	1	1	1
2	0.75	1	0.83	1	1.0	1	1	1	1
3	1.12	2	1.25	2	1.5	2	1	1	1
4	1.50	2	1.67	2	2.0	2	2	1	1
5	1.87	2	2.08	3	2.5	3	2	1	1
6	2.25	3	2.50	3	3.0	3	2	1	1
7	2.62	3	2.92	3	3.5	4	3	1	1
8	2.99	3	3.33	4	4.0	4	3	1	1
9	3.37	4	3.75	4	4.5	5	3	2	1
10	3.75	4	4.17	5	5.0	5	4	2	1
11	4.12	5	4.58	5	5.5	6	4	2	1
12	4.50	5	5.00	5	6.0	6	4	2	1
13	4.87	5	5.42	6	6.5	7	5	2	1
14	5.25	6	5.83	6	7.0	7	5	2	1
15	5.62	6	6.25	7	7.5	8	5	2	1
16	5.99	6	6.67	7	8.0	8	6	2	1

*DURATION FIXED AT 6 MONTHS

LEGEND
(X) PREFERRED STAFFING APPROACH
L-III LEVEL III INTEGRATION
L-II/I LEVELS II AND I INTEGRATION

Figure 6.2-10. Personnel Flight-Rate Sensitivity

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the test and operations duration was relatively fixed at six months by the physical limitations associated with the processing of flight hardware.

The accompanying tabulation in Figure 6.2-10 lists the numbers of 4.5-month, 5.0-month, and 6.0-month support function teams that would be required to support flight rates of 1 to 16 per year. The number of teams (in fractions) required for each support function rate are indicated in this tabulation. The fraction is derived as follows:

$$\text{Support team requirements} = \frac{(\text{flight rate}) \times (\text{activity duration})}{12}$$

For example, at a flight rate of four per year, the support team requirements (STR) for each rate are:

$$STR_{(4.5)} = \frac{(4 \text{ flts/yr}) \times (4.5 \text{ mo/flt})}{12 \text{ mo/yr}} = 1.50$$

$$STR_{(5.0)} = \frac{(4 \text{ flts/yr}) \times (5.0 \text{ mo/flt})}{12 \text{ mo/yr}} = 1.67$$

$$STR_{(6.0)} = \frac{(4 \text{ flts/yr}) \times (6.0 \text{ mo/flt})}{12 \text{ mo/yr}} = 2.00$$

Since it is not possible to put together fractional teams, the next higher integer number is the team size that would be required to support that given flight rate (i.e., at 4 flights per year, two 5-month support function teams would be required).

Efficiency of operation (personnel utilization) was the criterion for selection of the preferred scheduling of activities. The baseline staffing approach of this study was established for a two-flight-per-year rate. The support function teamsto conduct the operations analysis/requirements definition and the design/fabrication activities were scheduled in approximately 6-month increments to match the test and operations activity time duration. From the table in Figure 6.2-10, it can be seen that this is an optimum arrangement since 6-month support function teams are completely utilized to support a two-flight-per-year rate. Only fractional teams are required in the other two approaches. These fractional entries are indicative of the idle time that would result from a mismatch between support team size and capability, and flight rate. For example, at a flight rate of two per year, only 75 percent of the capability of a 4.5-month team is required. Therefore, this team would be idle 25 percent of the time.

It was indicated previously that the man-months required to accomplish the support function tasks were assumed to be a constant regardless of the staffing approach; the required number of personnel would vary proportionately with the duration of the effort. That is, if 100 personnel are required to accomplish the support function tasks in 12 months, then 133+ personnel are required to accomplish the same tasks in nine months. A 33-percent increase in personnel is required to reduce the duration of the tasks by 33 percent. Evaluation of the team requirements for a flight rate of 10 per year will demonstrate the significance of this assumption.

At a flight rate of 10 per year, five 6-month teams are required; only four 4.5-month teams are required. The five 6-month teams are the preferred approach because each team is fully utilized. There is a 25-percent inefficiency with the 4.5-month team approach. Each 4.5-month team is idle 6.25 percent of the time. If the teams were of equal size, then the 4.5-month approach would be preferred even with the inefficiencies (e.g., 400 personnel on the 4.5-month teams versus 500 personnel on the 6-month teams). But the 4.5-month teams are 33-percent larger than the 6-month teams. In the example used there would be a staff of 532 people with the 4.5-month approach, all of which would be idle 6.25 percent of the time.

The predominantly preferred staffing approach for flight rates up to 16 per year is the 6-month team. In only four cases is a better efficiency/utilization of manpower achieved with a different staffing approach.

Test and Operations Staffing

The impact of flight rate on the staffing of the test and operations activities is relatively minor. The basic approach derived in Volume III for a two-flight-per-year rate utilized part-time personnel that were shared with related/other Spacelab activities. A transition from part-time support to dedicated test teams can be achieved as flight rates increase. The sequential and discrete activities associated with the integration levels and refurbishment operations would permit the dedicated assignment of personnel to each of the major activities of flight hardware processing. For example, at a flight rate of eight per year, three teams dedicated just to Level III integration and one team dedicated to Level II/I integration could be formed. A part-time team would still be required for refurbishment activities.

6.3 CONFIGURATION SENSITIVITY

At the initiation of this study, the configuration of the Spacelab was not established. At that time the ESRO Spacelab development competition was not completed. There were three versions of the Spacelab: one from ERNO, one from MBB, and one from MSFC. As it was necessary to assume a model configuration to conduct the study, the MSFC version was used as the baseline. During the study the Spacelab development contract was awarded to ERNO. Comparison of the study baseline model with the preliminary design of the ERNO Spacelab (as of October 1974) is presented in this section. Data pertaining to both the complete Spacelab and pallet-only configurations are presented.

During the course of the study, the scope of the processing concepts was expanded to include the pallet-only Spacelab configuration. Analyses comparable to those performed in the candidate complete Spacelab processing concepts were also performed on three pallet-only processing concepts. Comparison of the results of comparable analyses on the processing of the two configurations are presented, by topic, throughout the volumes of this report. In this section, a succinct summary of these comparisons is presented.

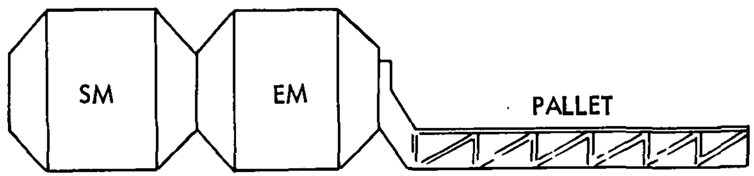
IMPACT OF SPACELAB DESIGN EVOLUTION

The evolution of the design of the Spacelab during the course of this study has perturbed interim results/data. Wherever possible, the study data have been updated to reflect the Spacelab design of October 1974 as indicated in the Spacelab Payload Accommodation Handbook (preliminary issue). The more significant changes to both the complete Spacelab and pallet-only configurations that affected this study are discussed subsequently.

Complete Spacelab Configuration

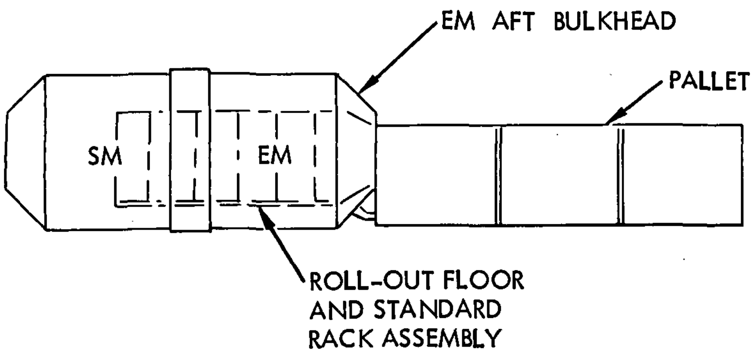
The "initial" and "final" complete Spacelab configurations that were used in this study are illustrated in Figure 6.3-1. The support module (SM) was dedicated to support systems, and the experiment module (EM) was dedicated to experiment equipment in the initial model. Also, the pallet train was rigidly connected to the EM. Although the rack and floor structure was removable from the EM shell, it was assumed that the shell, or equivalent, was required for shipment. Thus, with the initial configuration the SM and the EM were considered as separate entities, and the EM and complete pallet train were required for Level III integration. With the 15-foot-diameter of the EM, it was imperative that a "Guppy" or 747 piggyback approach be used for transportation of a Level III integrated payload. The cargo door of the C-5A has a cargo door height limitation of 11.5 feet.

In the final configuration, experiment equipment rack space is also available in the SM. A rack/floor set of 16 (8 racks on a side) can be assembled, tested, and transported independent of either the SM or EM. This entire



"INITIAL" CONFIGURATION

- SM AND EM SEPARATED AND INDEPENDENT
- EXPERIMENT RACKS IN EM ONLY
- RIGID EM/PALLET INTERCONNECTION
- EM AND RACKS HANDLED AS INTEGRAL UNIT
- SINGLE COMPUTER



"FINAL" CONFIGURATION

- EXPERIMENT EQUIPMENT SPACE IN SM
- RACK/FLOOR SET HANDLED INDEPENDENTLY
- FLEXIBLE EM/PALLET INTERCONNECT
- THREE COMPUTERS

Figure 6.3-1. Complete Spacelab Configuration rack/floor set can be installed in a mated SM and EM. Six racks will be positioned in the SM and ten in the EM. The interface between the rack/floor set and the pallet train is accommodated through an aft end cone of the EM via a flexible utility bridge. By providing a special transport fixture, which tilts the end cone, the overall height of a Level III integrated payload is reduced to less than the height constraint of the C-5A cargo door for most payloads. It is anticipated that there will be only a few payloads that will have a combined pallet structure-sensor height greater than 11.5 feet.

This significant Spacelab configuration change impacted the concept definitions, the details of the test and operations activities, and the required GSE. Whereas the SM was originally considered an entity and the EM/pallet was considered an entity, with the final configuration the logical ownership division between Spacelab elements was: SM with support systems and EM shell only, and 16 rack/floor sets and pallet train. The entire sequence of assembly and test operations was revised to reflect the final configuration. Although the details were significantly different, the serial processing times were very similar. GSE requirements also changed significantly. With the initial configuration module handling, stowage, repair, and transport GSE requirements were significantly larger than with the final configuration.

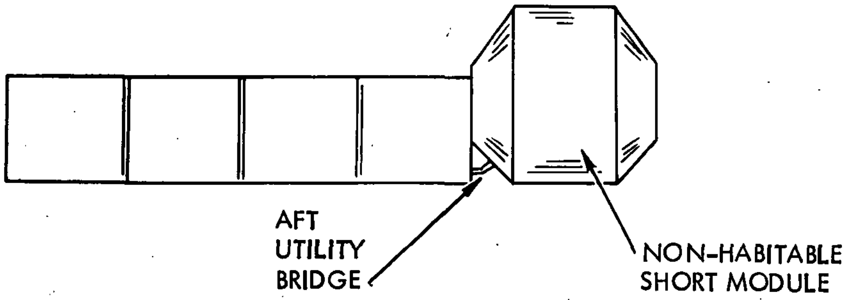
The most significant change in the support systems of the Spacelab that perturbed the integration and checkout definitization was the establishment of the computer system of the control and data management system. The CDMS of the MSFC baseline was patterned after the Orbiter capabilities. The baseline CDMS was a large capacity, interactive system. The checkout operations were based upon the utilization of this capability.

The final Spacelab CDMS included three computers--one each dedicated to support systems and experiment operations, and one spare. But the capacity of each computer was significantly less and intercommunication of computers was not provided for. A re-evaluation of the use of the on-board system was conducted. It was concluded that one computer, even with the reduced capacity, could accommodate both the pre-flight and flight operations, which had been derived with the MSFC baseline with appropriate executive, operating system, and data base management software employing the software architecture planned for the Orbiter data management system.

The complete Spacelab configuration significantly changed during the course of the study. But the impact on the study data was primarily one of semantics/nomenclature. The approach, tasks, organizations, and study results have been relatively insensitive to the configuration changes experienced thus far. Although the final complete Spacelab configuration was not definitized until approximately two thirds of the study were completed, all data presented in the reports of this study reflect the final configuration.

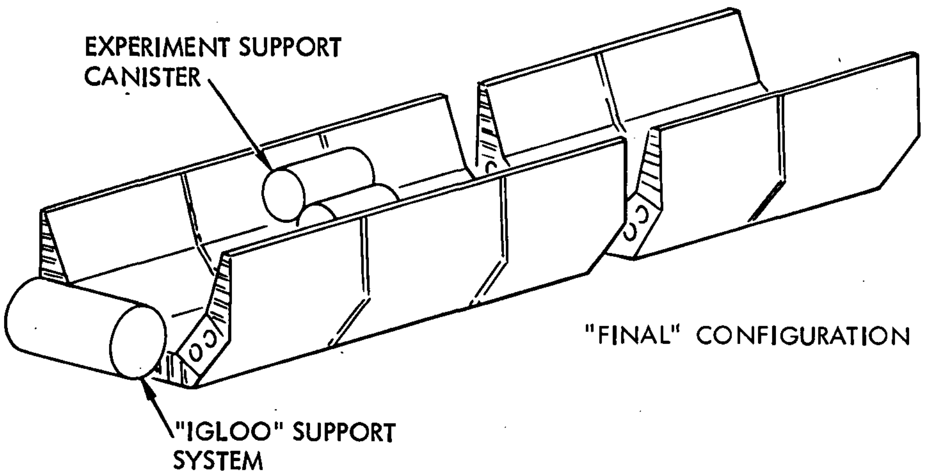
Pallet-Only Spacelab Configuration

Figure 6.3-2 illustrates the "initial" and "final" pallet-only configurations used in this study. The initial configuration was synthesized as part of this study.



"INITIAL" CONFIGURATION

- FOUR-SEGMENT PALLET TRAIN
- NO MULTI-MISSION SUPPORT EQUIPMENT IN THE ORBITER PAYLOAD SPECIALIST STATION (PSS) OR MISSION SPECIALIST STATION (MSS)



"FINAL" CONFIGURATION

- THREE-SEGMENT/TWO-SEGMENT PALLET TRAIN
- CENTRALIZED CONTROLS AND DISPLAYS
- IGLOO PRESSURIZED VOLUME FOR SUPPORT SYSTEMS
- EXPERIMENT SUPPORT CANISTERS, ADDITIONAL PRESSURIZABLE VOLUME

Figure 6.3-2. Pallet-Only Configuration

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The initial pallet-only configuration did not include provisions for support systems equipment. Therefore, a non-habitable short module (SM or EM with standard racks) was included at the aft end of the Orbiter cargo bay to house support system equipment and experiment support equipment that could not be accommodated in the Orbiter crew compartment but did require a pressurized environment. Four pallet segments between the short module and the forward bulkhead of the Orbiter cargo bay were required to accommodate the sensor equipment of the baseline pallet-only ATL payload. The short module was placed at the aft end of the cargo bay in order to be within the center-of-mass constraints of the Orbiter. It was assumed that all equipment installed in the mission specialist station (MSS) and payload specialist station (PSS) of the Orbiter would be mission-unique. This configuration, or a similar configuration based upon the same accommodation assumptions, would have resulted in integration and checkout procedures significantly different from those of the complete Spacelab especially with respect to design and fabrication of interface hardware, and test and operations activities.

The final pallet-only configuration (Figure 6.3-2) includes a support systems igloo and provisions for mounting pressurizable experiment equipment canisters. Common payload support equipment in the MSS and PSS is included. The support capability of the igloo equipment, coupled with the control panel in the PSS, is comparable to that of the SM of the complete Spacelab.

The final pallet-only Spacelab configuration resulted in a major simplification of the integration and checkout activities that were based upon the initial configuration. However, the final pallet-only configuration did require two additional items of GSE: igloo handling equipment, and spreader bars/slings to handle a three-segment/two-segment pallet train. But these two deltas are considered minor compared to the overall decrease in complexity that results with the use of the final configuration. All data presented in the reports of this study reflect the final pallet-only configuration.

COMPARISON OF COMPLETE SPACELAB AND PALLET-ONLY PROCESSING CONCEPTS

A comparison of the integration and checkout activities associated with the two Spacelab configurations indicated very minor differences. Initially, large differences were anticipated. But, with the inclusion of a support systems igloo in the final pallet-only configuration, the variations in the supporting functions and tests and operations of comparable processing concepts were such that intermixing of configurations within a payload program was feasible and practical.

Support Function Comparisons

The comparison of the support functions for both the pallet-only and the complete Spacelab configurations resulted in similarities across almost all activities. The composite support function tasks, manpower estimating techniques, and optimization approaches for the pallet-only configuration are the same as for the complete Spacelab.

Test Requirements and Procedures

The two configurations have almost identical experiment and "Spacelab" integration (Levels III and II) tasks because the functions to be verified at these levels of integration are almost identical. However, Orbiter integration (Level I) is significantly different for the two configurations. With the complete Spacelab configuration, the interfaces that must be connected and verified after installation in the Orbiter cargo bay are relatively minor. Standardized interconnection of the transfer tunnel, utilities (power, cooling, communications) and activation/monitor controls of the Spacelab can be readily accomplished as they are repeat functions with each flight. The only truly mission-unique functions with the complete Spacelab configuration are the direct display/control functions from the experiment equipment to the Orbiter crew compartment that are required, primarily for safety reasons. With the pallet-only configuration, the composite controls and displays equipment for both the support systems and the experiment equipment must be installed and verified in the MSS/PSS. The impact on the support functions of these installation and verification tasks is that procedures/techniques, equipment design guidelines, and simulation requirements must be developed and demonstrated prior to the actual Level I integration. A high degree of confidence that these pallet-only Level I integration activities will not jeopardize the Shuttle turnaround schedule must be achieved.

An opposite effect results when lower levels of integration are considered. Because of the limitations of the MSS/PSS, experiment operations must be more automated with the pallet-only configuration than with the complete Spacelab configuration. Thus, less manual and more automatic checkout will occur with pallet-only payloads. As the development of individual experiment automation and associated software is the responsibility of the PI's, the support function activities associated with the development of the test requirements and procedures at Level III (and somewhat at Level II) integration are less. This decrease in support function task effort for Level III/II integration activities for the pallet-only configuration tends to offset the increased task effort associated with Level I integration activities for the same Spacelab configuration.

Mission Operations/Systems Engineering

Although there are no fundamental differences in the support system capabilities of the two Spacelab configurations, there is a potential difference in mission operations and associated systems engineering activities. Only one payload specialist can be accommodated at the PSS, and pallet-only experiments require a higher level of automaticity. Thus, the payload specialist crew for a pallet-only flight would be less; the mission duration could be extended. This approach would increase the task effort associated with operations analysis and mission planning. Conversely, crew task timelines would be significantly simplified because of the decreased crew size and, more importantly, the automaticity of the experiment equipment. As in the case of the test requirements and procedures, the effects are offsetting.

A second aspect of increased automaticity is a decrease in the need for real-time ground communications and associated real-time mission support. Automaticity and adaptability are reciprocal functions; an automatic mechanism has a rigorously logical response, and does not readily adapt its configuration or processes to altered conditions or objectives. Therefore, the "objectives of opportunity" at least partially available in the complete Spacelab configuration are reduced in the pallet-only configuration. The impact is two-fold: (1) less real-time control and mission support would be required, but (2) more acquired data would be recorded on board. Only minimum on-board data handling would be implemented, as the PI would not be present in the control loop, and the rawest form of experiment data would be required. To regain some of the operational flexibility, more selectable modes of operation would be desired. Thus, each experiment subsystem would become more complex; it might even be desirable to develop an on-line rescheduling/reprogramming capability (i.e., new software transmitted to the Orbiter every day). The reduction in real-time mission support and on-board data processing that would result with a pallet-only configuration is offset by the increased systems engineering effort that would be required to define and implement alternative/selectable modes of operation. Expansion of the reprogramming capability of Skylab would minimize the effort required to incorporate the alternate/available modes of operation in flight plan updates.

In addition to the generalized comparisons of support functions for the two configurations, a task-by-task analysis of the entire WBS was conducted. Although there were minor differences in some tasks, the composite requirements were almost identical. Also, with the inclusion of the support systems igloo in the final pallet-only configuration, the similarity between the three pallet-only processing concepts and three of the five complete Spacelab processing concepts permitted common evaluations of comparable concepts. Table 6.3-1 indicates the comparable pallet-only and complete Spacelab processing concepts, and the support function manpower estimates for each set of concepts.

Table 6.3-1. Support Function Manpower Estimates

CONFIGURATION		MANPOWER ESTIMATES (MAN-MONTHS PER MISSION)			
PALLET-ONLY	COMPLETE SPACELAB	USER	IC	LS	TOTAL
VI	III	368	97	73	538
VII	II	146	337	73	549
VIII	IV	446	-	73	519

From a support function standpoint, the similarities between tasks, personnel requirements, and scheduling for the two configurations will permit intermixing both complete Spacelab and pallet-only payloads in a continuing operational program.

Test and Operations Comparison

Utilizing the final study configuration of both the complete Spacelab and pallet-only configurations, an evaluation of the test requirements and the processing time estimates for each of the functional flow blocks involved in the various levels of integration was made. The establishment of an igloo for the housing of the support systems equipment and the identification of mission-dependent control and displays and support equipment to be installed in the PSS and/or MSS for operation and control of the support systems and experiments eliminated significant differences in the test and operations tasks for the two configurations.

It is recognized that this similarity is strictly related to the integration and checkout of a Spacelab payload. Individual experiment equipment packaging and design will probably be significantly different for the two Spacelab configurations. In the pallet-only configuration the control, activation, and setup of the experiments cannot be aided by crew support. With the Spacelab, dedicated space for mission-dependent equipment was available in both the support and experiment modules. Without this space available in the SM and EM, the physical constraints of the PSS and MSS impose additional remote control/automation requirements on the hardware design of pallet-only experiments.

Comparison of Processing Times

The processing time estimates of comparable concepts are shown in Table 6.3-2. There were no major differences in any of the functional blocks of the test and operations flows. The differences were minor deltas of from a half to one day in such areas as pallet and experiment support canister refurbishment (8.0 days) compared to pallet/rack refurbishment (8.2 days); and the time

Table 6.3-2. Comparison of Processing Times

PROCESSING TIME (WORK DAYS)			
COMPLETE SPACELAB CONCEPT		COMPARABLE PALLET-ONLY CONCEPT	
CONCEPT	TIME	TIME	CONCEPT
II	115.8	106.1	VII
III	122.3	111.7	VI
IV	115.8	106.1	VIII

estimates for Spacelab demate and shipment of racks/pallet (7.9 days) when compared to 6.9 days for pallet and experiment support canisters. In summary, these small deltas, resulting in approximately a two-week shorter pallet-only schedule, can be attributed to both a more simple test element to handle, and check out. Again, it should be noted that the simplicity that is stated for pallet-only testing is a result of the requirement imposed upon the PI's to either self-contain or automate the individual experiment systems. This will impact the experiment design and development phase, but the result in the checkout and integration cycle is an experiment system that includes control software and integrated/shared displays and controls that have direct applicability in the integration and checkout processing cycle.

Comparison of GSE and Facility Requirements

The facility requirements for both the complete Spacelab and the pallet-only configurations, in comparable processing concepts, are identical. Table 6.3-3 presents a comparison of the GSE requirements for the comparable processing concepts. The delta requirements for processing the complete Spacelab are primarily a result of the handling and auxiliary equipment associated with the SM and EM. Except for two items, the complement of GSE required for the processing of complete Spacelabs can also accommodate the processing of pallet-only configurations. The two items are a PSS simulator at the Level III integration site, and systems igloo handling equipment at the Level II integration site. Inclusion of these two GSE items in the complete Spacelab complement would permit the intermixing of Spacelab configurations in a continuing program such as the ATL.

Table 6.3-3. Comparison of GSE Requirements

GSE END ITEMS			
COMPLETE SPACELAB CONCEPT		COMPARABLE PALLET-ONLY CONCEPT	
CONCEPT	ITEMS	ITEMS	CONCEPT
II	165	140	VII
III	200	169	VI
IV	165	140	VIII

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6.4 CONCEPT APPLICABILITY

The potential users of Spacelab cover a wide spectrum of requirements and applications. In this section, the applicability of each concept to various classes of users is discussed. Also, the development of a complete integration capability at a launch site is evaluated. Consideration of Spacelab processing/launch from the Western Test Range is included. In all cases, the key parameter is the expected flight rate.

GENERAL APPLICABILITY

One of the primary reasons for the selection of the five candidate complete Spacelab and the three pallet-only concepts was to maximize the spectrum of feasible/practical concepts that would be definitized. The objective was to develop a data bank with sufficient detail (including resource and cost requirements) that potential Spacelab users could evaluate each concept with respect to the requirements of their particular program. Three major factors were considered in the determination of concept applicability: experiment complement, flight rate, and proprietary payloads.

Experiment Complement

Potential Spacelab users that do not require the full capabilities/resources of the Spacelab (partial payloads) would utilize Concepts I, II, or VII. The capital investment for flight hardware (Spacelab modules) and GSE plus the staffing and non-recurring costs associated with all the other processing concepts would be prohibitive for a part-time/partial-load user. These three concepts provide this class of user considerable flexibility. "Piggybacking" on other payloads is feasible and could significantly reduce the costs of the operation to a user. Concept I or Concept II/VII is equally applicable to the part-time Spacelab user.

Flight Rate

Potential users that will require the total capability of the Spacelab must evaluate the amortization of the capital investments required by some of the concepts before selection of a preferred concept. Users of this class that anticipate flight rates of less than two per year would be hard pressed to justify capital investments for GSE and facilities of approximately $20 million. Concepts I or II/VII would be applicable.

Users that anticipate long-range programs of 2, 3 or 4 flights per year could justify not only the capital investments required, but also the development of the required engineering staff of Concepts III/VI and IV/VIII. The user-owned flight hardware is limited to racks and pallets; and therefore, maximum utilization of the support module/system igloo can be maintained by the launch site.

Anticipated user flight rates of 4 per year would tend to support the selection of Concept V. The flight rate sensitivity analyses presented in Section 6.2 indicated that the involvement times for both Spacelab hardware and GSE become continuous at about 4 flights per year for single-shift test and operations. But the recommendation was made to schedule two-shift operations during Levels II and I integration because of the repeatable/standardized nature of the tasks. This recommendation was based primarily upon the objective of minimizing the required inventory of the single most-expensive end item of the Spacelab program, the SM. Therefore, Concept V would be applicable only if a user planned a flight rate of eight complete Spacelabs per year.

<u>Proprietary Payloads</u>

Flight rate and the associated capital investments are not the sole criteria for concept applicability. Some Spacelab users may have the requirement for a high degree of security. For example, DOD payloads may have a security classification that will preclude the use of any concept except Concept V regardless of flight rate. Proprietary payloads of industry could also be of this nature. A more reasonable assumption would be that only Level III integration activities would require secured operations and thus Concepts III/VI and IV/VIII would be applicable. Obviously, only the user can establish the level of security required, but the delta capital investment costs associated with ownership of the support module/systems igloo will be difficult to justify if the anticipated flight rates of secured payloads are less than four or five per year (approximate equipment saturation level).

SUPPORT MODULE/SYSTEMS IGLOO OWNERSHIP

Ownership of support module/systems igloos (SM/SI) by three different centers has been considered: integration center, launch site, and user. User ownership is recommended only in those cases where a user has a planned long-range program averaging about 8 flights per year or, because proprietary/security requirements are so stringent, all activities through Level II integration must be rigidly controlled.

Whether an integration center or a launch site should own the SM/SI is primarily dependent upon SM/SI standardization. During the course of the study the configurations of the SM/SI have evolved to be highly standardized. The proposed flight rates of Spacelabs suggest Shuttles dedicated to Spacelab operations. It would appear that the SM/SI could evolve to the status of being an Orbiter "kit" in which case it would be more appropriate for the Shuttle operator, the launch site, to maintain cognizance of the SM/SI also. This centralized ownership would greatly enhance the maintenance of the Shuttle turnaround schedule. The responsibility for installation and interface compatibility of the Spacelab with the Orbiter would reside within one NASA center.

CO-LOCATION OF INTEGRATION CENTER AND LAUNCH SITE

In Concept I, the responsibility for and accomplishment of Levels III and II integration was assigned to a centralized integration center (IC) that was geographically separated from the Shuttle launch site (LS). An evaluation of the impact on the required resources if the IC and LS were geographically co-located is presented in subsequent paragraphs.

Personnel

The magnitudes of the Spacelab integration task and the Shuttle integration tasks preclude the combining of these into one task set. It would be equivalent to combining the individual CSM and LM integration of the Apollo program into one task with the integration of the Saturn V launch vehicle. Separate, independent organizations are required up to the point of integration between program elements.

The separate activities do not preclude co-location. One activity would be for Spacelab integration and the other for Shuttle integration. The analysis, requirements definition, design, fabrication, tests, and operations tasks would remain the same for all levels of integration as they are currently defined in Concept I. The manpower estimates would remain the same because the coordination and documentation would be the same.

Travel

Estimates of trips for coordination between integration center personnel and launch site personnel were on a man-day, per-diem basis. With co-location this line item would disappear. Thirty-six 2-day trips would be eliminated. Although the cost savings is only of the order of $6000, the actual benefits of co-location are probably greater. Co-location would foster more frequent and informal coordination.

Transportation

Co-location of the two activities would negate the pre-flight and post-flight shipment of the Spacelab which requires the use of the 747/piggyback configuration. Intra-site moves would be required but would cost significantly less than an air ferry operation. Net savings would be of the order of $20,000 per mission.

GSE/Facilities

Regardless of the location of the integration activities, adequate GSE must be acquired to support Spacelab flight rates of the order of 24 per year. The difficulty is the facility to house the equipment, installation, checkout, integration, and refurbishment stands. Preliminary plans at KSC call for the renovation of the MSOB (O&C) to a Spacelab processing facility. The proposed changes could accommodate Level II integration activities for some 24 flights per year, but the space allocation for Level III integration would be saturated at flight levels of the order of 5 per year. MSFC Plans for conversion of Building 4755 at MSFC to a Spacelab payload processing facility will accommodate about 24 Level III integrations per year. The renovation of this building would be significantly less costly than the erection of a comparable building at the launch site.

User Impact

Co-location of integration center and launch site activities will have a negligible effect on the Spacelab user. As stated above, two separate organizations would still be required at the launch site, and the user must coordinate with both. Documentation requirements would not change. A minor reduction in travel could be achieved by coordinating trips to the co-located activities.

Composite Evaluation

Some minor cost savings per mission could be achieved (travel and transportation) by co-locating the integration center and the launch site. But the cost of erecting an integration facility capable of accommodating the processing of up to 24 Spacelabs per year, including Level III integration, at the launch site (KSC) does not appear to be practical in light of the existence and availability of a suitable structure at MSFC. It is not recommended that integration center activities and launch site activities be co-located. This should not be interpreted to mean Level III integration at the launch site is always precluded. If only for contingencies, Level III integration capability should be incorporated at the launch site. It is inevitable that some payloads that have completed Level III integration off site will arrive at the launch site and require repair, revision and/or equipment changeout. The test stands are required for handling purposes and all equipment, except the interface simulator, must be available for servicing and operations verification.

WESTERN TEST RANGE IMPLICATIONS

In all the analyses conducted in this study, only one launch site (KSC) was considered. However, an appreciable number of Shuttle launches and, particularly, Spacelab payloads will be launched from the Western Test Range (WTR), Vandenberg Air Force Base. Detailed studies of facilities and accommodations at WTR are currently being conducted by the Martin Company. Preliminary results indicate that almost an entirely new set of facilities is required for the Shuttle era. Although the Air Force baseline is vertical installation of Shuttle payloads, facilities for horizontal installation will be developed.

The three primary concepts for processing Spacelabs through WTR are (1) only Level I integration at WTR, (2) Level II integration at WTR with a "transient" KSC crew, and (3) Level II integration at WTR with resident personnel.

The first option, Level I only at WTR, would be essentially a "ship and shoot" concept. Spacelab integration, Level II, would be completed at KSC, the Spacelab loaded in a 747/piggyback, shipped to WTR and taken directly to the Shuttle for installation. The second option would provide for complete Spacelab integration on site at WTR with WTR GSE but with a trained crew from KSC. This approach would be applicable to Concepts II, III, IV, VI, VII, and VIII. The payload would be shipped directly from the integration center or user to WTR for integration with the SM/SI. The third option, in essence, duplicates the KSC accommodations and support of the six applicable concepts listed in Option 2.

Evaluation of these "options" indicates that they are more characteristic of a buildup or activation of a second processing center. It would appear that the key factor is the flight rate for Spacelabs at WTR. The traffic model used in this study indicates that initially only one or two Spacelab flights per year are required. Because all new facilities are required at WTR, it is a reasonable approach to defer Spacelab processing facilities and GSE until the flight rates warrant such a large capital investment. Option 1, the "ship and shoot" approach, is preferred for the initial Spacelab flights from VAFB.

Option 2 is considered to be only an interim step in the activation of Spacelab processing at WTR. The concept of a transient crew should only be utilized to accelerate the learning curve of a new, resident, WTR crew. The large investment of facilities and GSE is the predominant consideration in activation of WTR Spacelab processing. In comparison, the test and operations crew is a minor cost item. Also, although the test engineers and test conductors can perform in an advisory or consulting capacity, transient technician help is not recommended because of basic differences in local procedures, equipment, and regulations. It would be more practical to utilize resident technician help in all cases.

The third option is the operational stage of WTR Spacelab operations. It is merely an extension of Option 2. The planned Spacelab flight rate at WTR should be at least 4, and probably 5, per year before even Option 2 is implemented. The capital investment including the ownership of an SM/SI must be justified based upon flight rate.

The user's role during the activation of WTR would not change until initiation of independent WTR Spacelab operations. At such time, the user would conduct his coordination activities with the appropriate launch site. All activities of all concepts would be the same; only the launch site (KSC or WTR) would vary.

SUMMARY

The applicability of a processing concept is primarily determined by the planned flight rate of the user. Standardization of the SM/SI tends to downgrade the desirability of Concept I (all modules owned by the integration center and Levels III and II integration performed at the integration center). Unless a user plans on eight flights per year, it is not recommended that the user own the SM/SI. Thus, in the general case, it is recommended that the SM/SI remain at the launch site (KSC) and, when the flight rate warrants it, an SM/SI at WTR.

It is anticipated that the majority of users will either make up only part of a payload or, infrequently, a full Spacelab payload. Concept II/VII (IC owns and integrates racks/pallet) is the preferred processing concept for this class of users. Capital investment is minimized and a large engineering staff for integration functions is precluded for the user in this concept. The IC can provide common facilities and support functions that are shared by multiple users simultaneously. Duplications of GSE, facilities and personnel are minimal.

Users that plan 2 to 4 flights per year could efficiently use either Concepts III/VI or IV/VIII (IC owns racks/pallet, user integrates racks/pallet, or user owns and integrates racks/pallet). The variation in capital investment for the user is minor for the two concepts. The primary differences between the two concepts is that in Concept III/VI the user does not maintain the inventory of Spacelab flight hardware, nor does the user require the design and fabrication skills and shop equipment for the development of experiment equipment layouts and interfacing hardware; the IC provides these services. In Concept IV/VIII the user must provide all functions through Level III integration. The choice should be based upon the specific charter, objectives, and staffing of the user. It may be advantageous to adopt a mixture of these concepts. The user could provide all the services through Level III integration except for the ownership, inventory, and refurbishment of racks/pallets. This would enable the user to have maximum and direct control of the layout of experiment equipment and the design of interfacing hardware without the capital investment, inventory, and renovation of flight hardware.

As stated previously, Concept V would be applicable only if the users planned eight flights per year. The costs associated with the ownership of the SM/SI are not warranted unless almost continuous usage is planned.

6.5 CONCEPT SELECTION

Based upon the currently planned multi-flight-per-year, multi-year Spacelab ATL program, Concept IV/VIII is the recommended Spacelab processing concept for Langley. The anticipated flight rate of 2 to 4 per year, including both complete Spacelab and pallet-only configurations, does not warrant Langley ownership of the support module/systems igloo. The flight rate is adequate to justify the capital investment for GSE and facilities, especially since the program is projected to have a duration of approximately 10 years.

SUBJECTIVE CONSIDERATIONS

The flight rate and program duration are not compatible with concepts that require the majority of functions to be performed off site. Duplicating organizations on and off site would be inevitable. Also, the diversified scientific endeavors proposed for the ATL program would significantly complicate the on-site/off-site coordination efforts.

The broad spectrum of scientific investigations/applications of the ATL program is also a primary reason for selection of Concept IV/VIII over Concept III/VI. The ATL Spacelab payload averages greater than 10 experiments per mission. Some experiments will be reflown several times with only minor modifications. In fact, in some cases the only modification required is a different trajectory. Since both complete Spacelab and pallet-only configurations will be used in the program, it is highly probable that pallet sections and/or rack assemblies can be maintained in a flight configuration while awaiting the next applicable mission. It is believed that maximum efficiency of reconfiguration/refurbishment operations can be achieved with repeat flight hardware if Langley maintains complete cognizance of the racks/pallet sets.

The diversity and continuing nature of the ATL program also increases the likelihood of data from one mission affecting the design/accommodations of at least one of the experiments on the next mission. In order to achieve the required quick-turnaround, it is essential that the design/fabrication of the interface hardware also be under the direct cognizance of Langley.

Concept IV/VIII is also more adaptable to cope with contingencies during Level III integration. If both the skills and equipment for design and fabrication are off site (as in Concept III/VI), a significant schedule problem could be encountered if incompatibilities or changes occurred during Level III integration. With the design and fabrication of interface hardware on site, these same contingencies would be met with minimum schedule impact.

OBJECTIVE CONCLUSIONS

A comparison of alternate concept costs must include individual consideration of non-recurring, sustaining, and mission-unique costs for both Langley and the composite NASA. Comparing only the dollar amounts is insufficient; the utilization of these capital investments must also be considered.

Mission-Unique Costs

Comparison of the costs for the alternate concepts, summarized in Section 6.1, indicates that while Concept V is the least expensive for the agency, it is the most expensive for Langley. Variations between concepts for composite costs are due primarily to personnel requirements and travel expenses. In all concepts, just personnel costs comprise approximately 80 percent of the totals. The maximum differences between Concepts III/VI and V is $136 thousand, which is less than 9 percent of the total costs for any concept. Although this difference is significant, it does not warrant a selection of a particular concept based upon composite costs only.

The Langley costs for Concepts I and II/VII are less than half of what the costs are in the other concepts. Either of these concepts would be preferred if an individual center's budget was severely restricted. But the "advantage" is misleading: to conduct the ATL program with these concepts (I, II/VII), the total agency funds required would actually be greater. The allocation to the support/service centers would have to be proportionately larger in Concepts I and II/VII as compared to the other processing concepts. Therefore, for the ATL program there is no distinct advantage to the agency to adopt either of these concepts. The NASA will fund the entire effort based upon Langley's definition and demonstration of the usefulness and effectiveness of the ATL, not upon the magnitude of the budget for one center.

The general characteristics of the cost data for the mission-unique functions indicate that for a given program the more a user does in the performance of a Spacelab payload program, the more cost-effective the process will become on a recurring basis. In general, purchased labor and services for various tasks are more expensive than if the tasks are performed "in-house." But the trend is only applicable to the recurring mission-unique costs. Startup and capital investment costs must also be considered. The mission-unique costs developed in this study indicate a slight preference for Concepts IV/VIII and/or V, but are inconclusive in the identification of a preferred Langley approach.

Sustaining Costs

Sustaining costs, summarized in Section 6.1, exhibit the same general characteristics as mission-unique costs. Personnel costs account for approximately 85 percent of the totals. The yearly costs (based upon a flight rate of 2 per year) vary $99 thousand across the concepts. This composite cost difference would not warrant a selection of a specific concept. User or Langley costs are less for Concepts I and II/VII but composite totals for these concepts are greater than for the other concepts. Thus, there is no distinct advantage to Langley to select a given concept based upon sustaining costs. It is strictly a matter of program budget allocations to various centers. Also, if only personnel sustaining costs are considered, then the differences in Langley costs are only $56 thousand per year which would not justify the preference of one concept over another.

Non-Recurring Costs

Direct comparison of the non-recurring cost figures is not advisable. It must be recognized that an integration center (MSFC) and a launch site (KSC) will be established and facilities/GSE will be activated for processing of both a complete Spacelab and a pallet-only payload. Facilities will be sized for processing the general Spacelab program--not just the ATL. Multiple sets of GSE will be required. The non-recurring cost estimates, summarized in Section 6.1, reflect the preliminary estimates for general-use facilities and a set of GSE equipment at the IC and LS. Also, current planning includes consideration of two-shift operation at these sites. All evaluations conducted in this study have been based upon one-shift operations throughout the processing cycle.

A more meaningful comparison and evaluation of the non-recurring costs for the alternate processing concepts would be based upon utilization of that equipment/facilities that would be required at Langley. This can be accomplished by using the flight-rate sensitivity data developed in Section 6.2 in conjunction with the anticipated flight rates of the ATL program and the total Spacelab program.

In Concepts I and II/VII, Langley non-recurring costs are minimal but most of the analyses and design and all of the hardware processing is off site. If only a few flights or a couple of years were all that were planned for the ATL program, one of these two concepts would be the preferred approach. But the currently planned ATL program is 2 to 4 flights per year for about 10 years. Therefore, large capital investments at Langley should be considered. In Concepts III/VI and IV/VIII, the total Langley non-recurring investment is about $11.5 million. Even at only 2 flights per year, this investment would pro-rate to about $570 thousand each flight. Concept V also pro-rates to less than $1 million per flight.

The flight-rate sensitivity analyses of Section 6.2 indicated that the saturation point of an installation and checkout facility and most major items of GSE (simulator, assembly stand, checkout equipment, cable sets, etc.) was about 5 flights per year. Thus, the ATL program would result in the utilization of the GSE and facilities at Langley from 40 to 80 percent of the time. Based upon past space programs, this utilization factor for a 10-year span is excellent.

Duplication of provisions presently planned for the LS and IC at Langley is warranted in light of the projected Spacelab traffic model. Current planning at MSFC will accommodate 24 Spacelab payload integrations a year, based upon two-shift operations. The present traffic model nominally has 24 Spacelab flights per year with several peaks of 27 and 29 flights per year. Installation and checkout facilities for at least Level III integration must be developed in addition to those planned at MSFC. KSC is planning a Level III integration station, but it is presumed that it would primarily be used for contingencies, piggyback modes, and so-called "quick reaction" types of payloads. It would be inadvisable to dedicate this KSC station to the ATL program.

The ATL is an established and approved long-range Spacelab payload program. As additional integration accommodations will be required, and Langley will maintain a very high utilization rate, it is recommended that these provisions be developed at Langley. The differences in the Langley non-recurring costs for Concepts III/VI and IV/VIII are insufficient to clearly discriminate between the two sets. Langley's non-recurring costs for Concept V are an additional $3.1 to $3.4 millions. Justification of the additional capital investment must also consider the implied ownership of an SM/SI by Langley.

SUMMARY

Subjective factors indicate a preference for Concept IV/VIII because of the diversified nature of the investigations/applications of the ATL program and the necessity for direct control and cognizance of all activities through Level III integration. Ranking of the concepts by agency costs for both mission-unique and sustaining cost categories results in a preference (in descending order) of V, IV/VIII, III/VI, I, and II/VII. Non-recurring cost evaluations indicated that for the ATL program, the preferred concepts (in descending order) were III/VI, IV/VIII, and V.

The anticipated costs for an SM and an SI almost preclude Langley ownership of these two items of flight hardware (Concept V). To be cost-effective, both units must be utilized almost continuously. Langley would probably utilize the SM only 30 to 60 percent of the time, and the SI only 10 to 20 percent of the time. It would not be cost-effective from a programmatic standpoint for Langley to adopt Concept V.

As the yearly recurring costs (mission-unique and sustaining) for even a 2-flight-per-year flight rate are approximately $200 thousand less for Concept IV/VII than Concept III/VI, and the total difference in non-recurring costs between the two sets of concepts is only about $400 thousand, the preferred concept from an objective evaluation is Concept IV/VIII. This selection is in accord with the subjective evaluation.