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DEFINITION OF LIFE SCIENCES LABORATORIES FOR SHUTTLE/SPACELAB

VOLUME II • LIFE SCIENCES LABORATORY CONCEPT DEFINITIONS

GENERAL DYNAMICS
Convair Division

FOREWORD

The Skylab program provided for the first systematic investigation of physiological problems associated with manned spaceflight. While the Skylab medical experiments resolved many of these problems, several remain unanswered – for example, the etiology of space nausea and bone mineral losses. The Shuttle/Spacelab program of the 1980s will permit life sciences to continue extensive research in the biomedical areas. Besides providing data needed to understand the effects of the space environment on man, these studies have a high potential to produce new basic knowledge for application to earth medicine.

In addition to missions with biomedical emphasis, the Shuttle/Spacelab will support in-depth space biology investigations. Such missions will employ a spectrum of research organisms including primates, small vertebrates, invertebrates, plants and cells/tissues to study basic biological processes in the space environment. These organisms will be used to study such factors as the effects of space on aging, growth, cell division and differentiation and biorhythms as well as supportive studies in the biomedical area.

The Shuttle/Spacelab era also permits the development of the advanced technologies needed to support future space efforts such as orbiting space stations or long-term exploratory missions. These advanced technologies include life support systems, space suits, maneuvering units, and man-machine interactions.

This report documents a study conducted by General Dynamics Convair Division for NASA/MSFC concerning the definition of research requirements and the laboratories needed to support that research during the Shuttle/Spacelab era. A basic approach taken in this study was the development of a common operational research equipment inventory to support a comprehensive but flexible life sciences program. Candidate laboratories and operational schedules were defined and evaluated in terms of accommodation with the Spacelab and the overall program planning. The study results provide a firm foundation for the initiation of a life sciences program for the Shuttle era.

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MAJOR ACRONYMS AND ABBREVIATIONS

ARC	Ames Research Center
BEST	Bioexperiment Support & Transfer
CER	Cost Estimating Relationship
CDMS	Command and Data Management Subsystem
CIS	Central Integration Site
COL	Carry-On Laboratory
CORE	Common Operational Research Equipment
CRT	Cathode Ray Tube
CVT	Concept Verification Test
EC/LSS	Environmental Control/Life Support Subsystem
ECS	Environmental Control System
EDC	Experiment Development Center
EI	Equipment Item
ESA	European Space Agency
G&A	General & Administrative
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
HQTRS	Headquarters (NASA)
IMBLMS	Integrated Medical & Behavioral Laboratory Measurement System
JSC	Johnson Space Center
K	One Thousand (e.g., $K or Kbits)
KSC	Kennedy Space Center
LSPS	Life Support & Protective Systems
M	One Million
ML	Mini-Lab
MSFC	Marshall Space Flight Center
MSI	Man Systems Integration
MSOB	Manned Space Operation Building
NR	Non-Recurring
OPF	Orbiter Processing Facility
PCR	Payload Changeout Room
POC	Payload Operations Center
RAM	Research and Application Module
RAU	Remote Acquisition Unit
R-O	Recurring Operations (Cost)
R-P	Recurring Production (Cost)
S/L or SL	Spacelab
SRT	Supporting Research & Technology
SPDA	STS Payload Data & Analysis
STDN	Space Tracking & Data Network
STS	Space Transportation System
TDRS	Tracking and Data Relay Satellite
WBS	Work Breakdown Structure

SECTION 1

INTRODUCTION

The Life Sciences Payload Definition and Integration studies are an integral part of current NASA planning activity to define potential research laboratories for the Shuttle/Spacelab. This report documents the last in a series of four closely related studies which together describe requirements, analytical work, and design concepts for a family of life sciences laboratories. Total program history from its initiation through the current study is shown in Figure 1-1.

1.1 BACKGROUND

The first of these four studies (Reference 1), performed under Contract NAS8-26468 during 1970-1972, drew heavily on guidance from NASA and consulting scientists. The scientists were surveyed to aid in selecting an inventory of life sciences research functions and related equipment necessary to accomplish space research goals. In compiling the inventories of functions and equipment, mission parameters and other constraints were purposely not imposed so that comprehensive baseline inventories could be obtained. Research requirements, as defined by the scientific community, were broad in scope to encompass research in medicine, biology, life support and protective systems, and man/systems integration. The research was grouped by categories, rather than by specific experiments, to provide planning flexibility. A general philosophy of the laboratory "facility" approach was used in the conceptual designs generated. This was the beginning of the common operational research equipment (CORE) approach that was developed and matured in the subsequent payload studies. The four preliminary conceptual designs selected from this effort were characterized as:

a. Maximum Laboratory. A reference baseline providing full life sciences research capability.

b. Maximum Nominal Laboratory. Foreseen as the most comprehensive laboratory that could be flown with the space station complex.

c. Minimum-30 Payload. Applicable to an initial space station mission as well as to a 30-day Shuttle Sortie* flight.

d. Minimum-7 Payload. To operate in a 7-day Shuttle Sortie flight.

These payloads encompass a range of capabilities from full capability to respond to all research goals down to lesser capability payloads with defined reductions in facility weight, volume, power, and cost for reduced scientific responsiveness.

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*Sortie module used prior to Spacelab definition

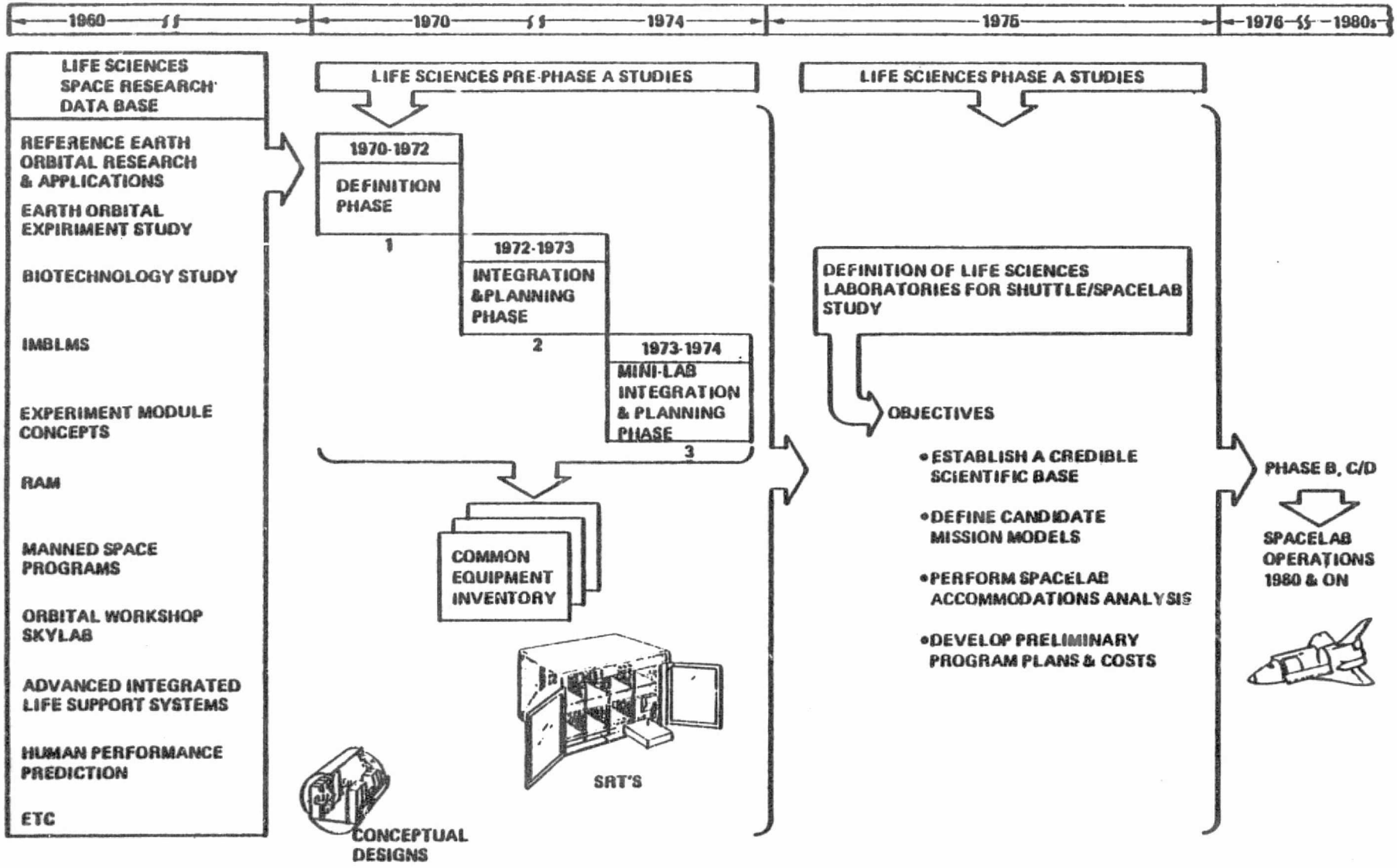


Figure 1-1. Life Science Payload Definition & Integration Studies Chronology

The second study (Reference 2) was performed under Contract NAS8-29150 during 1972-1973. This study employed several of the smaller laboratories from the previous study to determine compatibility with the Shuttle Sortie module concept. Initial activity involved updating functional capabilities and related equipment items of the laboratories as directed by the NASA Life Sciences Payload Integration Team. The second task established size and characteristics of the various Sortie module subsystems (e.g., electrical power, environmental control/life support) required to support the defined research capability of the baseline laboratories. Additional activity included determination of equipment costs, development schedules, and significant supporting research and technology requirements associated with the laboratory development. This study also generated conceptual designs of smaller, portable, essentially self-contained carry-on laboratories (COLs) that could be employed in a multiple-purpose Sortie laboratory or in the crew compartment of the Shuttle Orbiter.

The third study (Reference 3) was performed under Contract NAS8-30288 from mid-1973 through mid-1974. This study was primarily directed toward the definition of various carry-on and mini-laboratories. Research guidelines were provided by the NASA Life Sciences Steering Committee and the spacecraft interface guidelines were updated to reflect new information obtained from the European Space Agency Spacelab program. Design concepts were defined for several categories of COL and mini-laboratory payloads ranging from 23 to 318 kg (50 to 700 lb). The data defining these designs, development schedules, and costs were taken to the same level of detail as for the larger shared and dedicated laboratories.

The recently completed Phase A study was primarily directed to defining life sciences research programs for the early Shuttle/Spacelab time period. Important elements in the study were providing concepts which were compatible with the presently defined Shuttle/Spacelab characteristics and the post-Skylab research requirements. The CORE approach was a significant concept used throughout the study to provide scientific and programmatic flexibility.

1.2 STUDY OBJECTIVES AND TASKS

The study objectives as shown in Figure 1-2 fall into two categories: scientific and engineering/programmatic. The scientific objective stresses biomedical investigations relevant to man's well being and performance in space. In addition, the capability to do fundamental studies in medicine, biology, man-systems integration, and life support and protective systems are also to be accomplished. The engineering/programmatic objective deals with the attainment of laboratory development and operational options that are compatible with the scientific requirements and Spacelab capabilities. These options must span the potential scientific and programmatic considerations imposed by funding limitations and hardware development schedule alterations. The basic output of this study is laboratory concepts, mission models, and program plans.

This data will serve as building blocks for attaining the life sciences program objective of providing a flexible laboratory capability for a long-term space research program, starting in the 1980's.

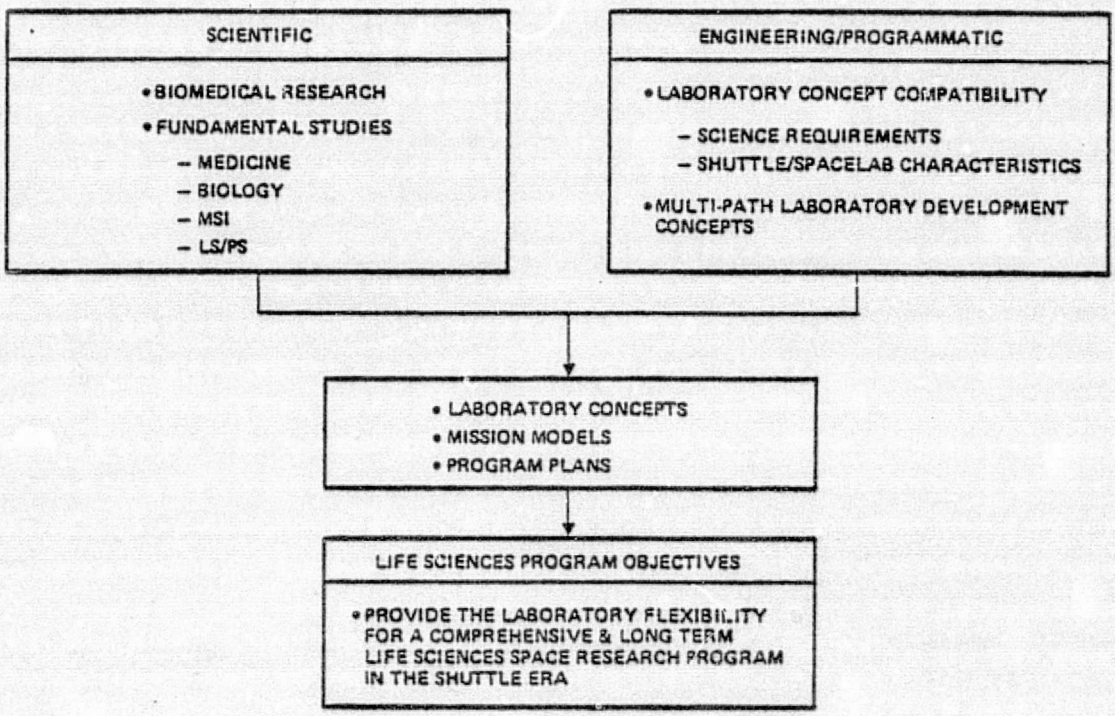


Figure 1-2. Study Objectives

The study as shown in Figure 1-3 was composed of three major tasks. Task 1 established candidate mission models; Task 2 accomplished the systems analysis and integration of the laboratories with the Spacelab; and Task 3 provided the program plans, costs, and scheduling details.

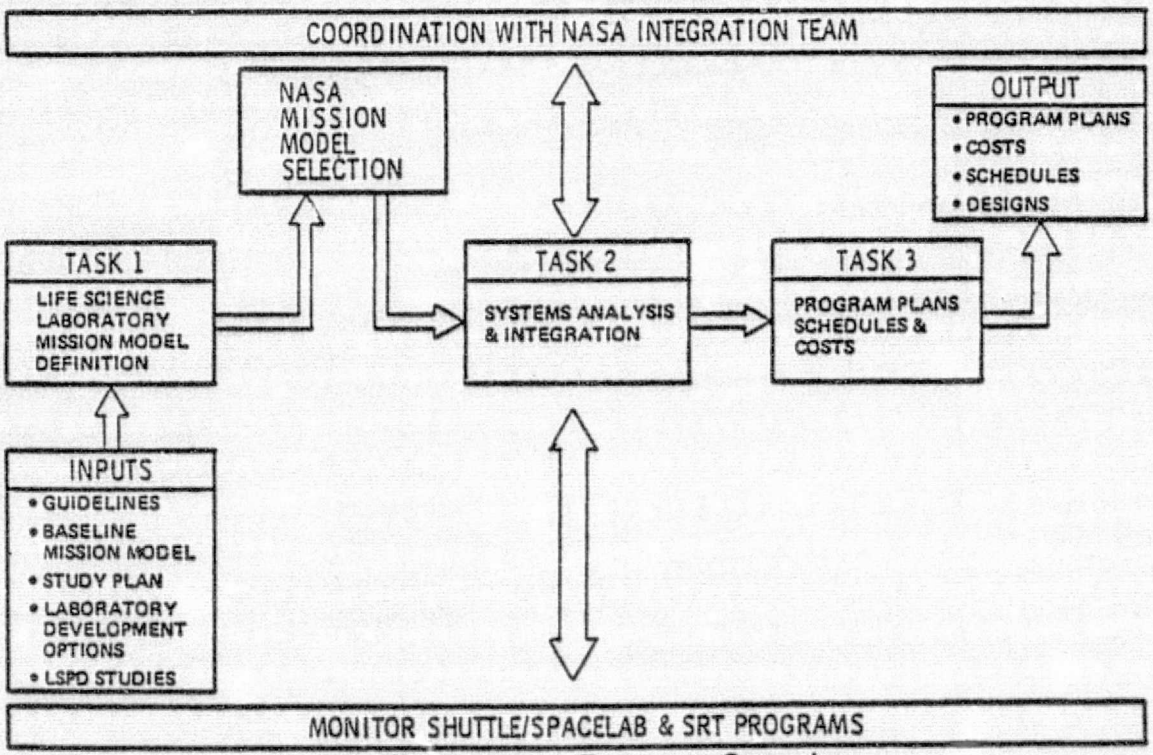


Figure 1-3. Program Overview

Task 1

The goal of the Task 1 effort was to provide a recommendation of the mission models to be used during Tasks 2 and 3. These mission models were to be as responsive as possible to the scientific community requirements for prioritized research while staying within the constraints of the Shuttle/Spacelab concept. The common operational research equipment (CORE) inventory played an important role in providing a flexible base of laboratory concepts for this science planning activity. (See Sections 2 and 3.)

Task 2

The primary objective of Task 2 was to ensure that the hardware and laboratories concepts represented by the selected mission models could be properly accommodated by the Shuttle/Spacelab. The basic tasks centered on the Bioresearch Centrifuge, design analysis and integration, and the ground support analysis. Task 2 is described in detail in Section 4.

Task 3

The Task 3 effort paralleled the systems analysis and integration of Task 2 and defined preliminary program plans, master program development schedules, and cost outputs of the study. (See Section 5.)

1.3 GENERAL GUIDELINES

The guidelines used during the performance of this study (Table 1-1) were those fundamental to the basic goal of defining and recommending candidate mission models, laboratory concepts, and preliminary program costs. The baseline mission model

Table 1-1. Study Guidelines

BASELINE MISSION MODEL	1st FLIGHT 1980 THEN 2 DEDICATED & 2 MINI-LABS PER YEAR
LIFE SCIENCE DATA BASE	PRIOR PAYLOAD STUDIES – RESEARCH AREAS & EQUIPMENT/FUNCTION INVENTORIES
LABORATORY CONCEPTS	DEDICATED, MINI-LABS, CARRY-ON LABS
LABORATORY DEVELOPMENT OPTIONS	PARALLEL – SERIES
LABORATORY EQUIPMENT	CORE APPROACH TO SERVE ALL LAB & RESEARCH OPTIONS
MISSION MODEL OPTIONS	BIOMEDICAL EMPHASIS & BIOLOGY EMPHASIS
SHUTTLE/SPACELAB	ACCOMMODATIONS, INTEGRATION, OPERATIONS

was developed by integrating data from several sources, including the OMSF/MMS payload descriptors (August 1974, Reference 4), and the Yardley Flight model (November 1974, Reference 5). The prior study results provided an important starting base, which included valuable sources for defining research areas, functions, and equipment inventories, as well as conceptual designs of dedicated, mini, and carry-on laboratories. The application of selected Shuttle/Spacelab operational characteristics provided a significant guideline in determining the equipment makeup and time sequencing of the various laboratory options. The "Spacelab Payload Accommodations Handbook" provided the details required to properly do the system analysis and integration tasks.

The common operational research equipment (CORE) approach was used to provide science planning flexibility. The mission models were to include a biomedical and biology emphasis option.

SECTION 2

LIFE SCIENCES RESEARCH REQUIREMENTS FOR SPACELAB

The major objectives of this task were to generate a comprehensive plan for time sequenced life sciences research for Shuttle/Spacelab missions and then determine laboratory functions and measurements commonly employed to carry out each research activity in the plan. The functions and measurements requirements in turn dictated the laboratory equipment needs and the research time sequencing which determined the equipment need dates.

The research plan and related functions comprise a major driver for this entire study since subsequent tasks which specify laboratory hardware and development schedules are based upon results of this first task. Accordingly, it is imperative that the research plan be defined and sequenced to accurately reflect the combined best interests of the manned space program and life sciences research community. At this point in time, specific life sciences research protocols for Spacelab missions are not available. The approach followed in this task has therefore emphasized a thorough analysis of existing, more generally defined research requirements for future space missions. This information is then used to develop a plan broad in scope so as to provide capabilities to perform essentially all routine, commonly employed research functions anticipated to be required by future principal investigators. This approach enables realistic science, schedule, cost and technical requirements for a comprehensive and flexible research capability to be analyzed and defined now while deferring hardware development commitments until specific research requirements are subsequently defined. Figure 2-1 traces the work flow employed to reach the objectives of this task. Results of previously completed NASA studies provided a baseline set of data defining life sciences research requirements for Spacelab. These data were analyzed and updated to incorporate inputs from recent U.S. and foreign life sciences space research results and other inputs obtained during working sessions with NASA biological scientists. The new inputs were synthesized with applicable baseline data into a set of research requirements, related function and measurements requirements, and a proposed time sequencing of research activities.

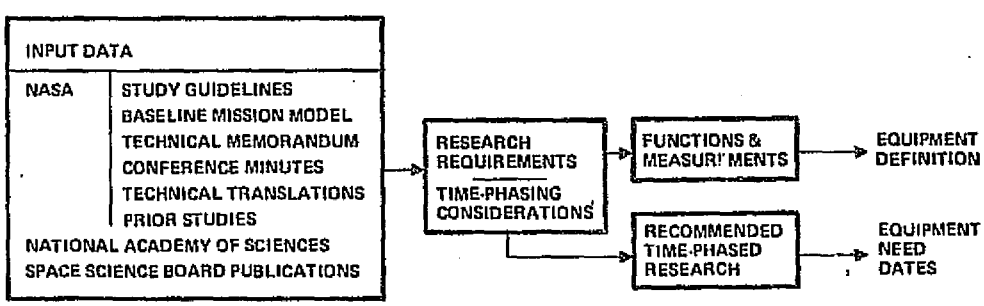


Figure 2-1. Life Sciences Research Requirements Study Flow

These data were documented in a manner to guide subsequent definition of research equipment and equipment need dates for Spacelab missions.

2.1 ORGANIZATION OF LIFE SCIENCES RESEARCH

This activity was initiated by a thorough review of pertinent data defining life sciences space research requirements. The data elements extracted from the multiple input sources were synthesized into a set of requirements for each life sciences research discipline.

2.1.1 LITERATURE REVIEW. A series of NASA life sciences payload studies (References 1-3) performed during the 1970-1974 time period produced a comprehensive data base defining space research requirements for Shuttle/Spacelab operations. During the 1974-1975 time period, several planning documents were published by in-house NASA groups and the Space Science Board, National Research Council of the National Academy of Sciences. Additional highly applicable data was published during this same period which summarized the space life sciences research activities and results of Skylab and unmanned Soviet research missions. The present study drew upon all of these data sources. The approach was to utilize existing baseline research requirements information as a starting point and to update the baseline data as necessary to apply the new insight obtained from recent space operations and in-house NASA planning studies. Table 2-1 lists the sources for the background information and Table 2-2 lists the major sources of input data utilized for the present study. Table 2-3 tabulates data obtained from a NASA working group.

The principal information elements sought throughout the literature review were: recommended research, time required to perform the research, test organisms required, data acquisition needs, bioresearch centrifuge requirements, and application potential of experiment results to the space program or to control of life processes on earth. Data elements obtained from these analyses were in most cases extracted verbatim from source documents and tabulated under the appropriate research discipline, i.e., biomedicine, biology, etc. The many tables of data produced by the literature review are documented in Volume V, Book 2, Appendix A of this report.

The total set of research requirements data assembled by this approach is responsive to the composite interests of the space program planners and science community. These raw data elements were then synthesized into an integrated research requirement document as discussed in the next section.

2.1.2 CLASSIFICATION OF RESEARCH REQUIREMENTS. The studies of life sciences payload definition and integration requirements accomplished prior to initiation of the present study had produced a preliminary definition of research requirements. These were classified under four major research disciplines — Biomedicine, Biology, Man-Systems Integration, and Life Support and Protective Systems. A wealth of data was documented for each research discipline which related research requirements

TABLE 2-1

GUIDELINE DOCUMENTS FOR DETERMINING RESEARCH REQUIREMENTS

1.	Memo to NASA Centers Life Sciences Payload Integration Study Steering Committee from Robert W. Dunning, Subj: Discipline Priority Guidance for Current Life Sciences Payload Integration Study (MSFC/NAS8-29150), July 25, 1972.
2.	"Planning Guidance for Identification and Layout of Life Sciences 'Carry-On' Payloads for Shuttle Sortie Missions," August 9, 1972.
3.	Memo to Robert W. Dunning from S. P. Vinograd, M.D., Subj: Candidate Research Functions for "Carry-On Mini-Lab", July 25, 1973.
4.	Memo to Robert W. Dunning from S. Tom Taketa, Subj: Candidate Research Functions for Shuttle Carry-On Mini Lab Configuration," August 23, 1973.
5.	"Skylab and the Life Sciences," NASA-Manned Spacecraft Center, February 1973.
6.	"Biomedical Experiments and Systems in Skylab," NASA-Manned Spacecraft Center, April 1971.
7.	"Survey of Techniques Used to Preserve Biological Materials," E. J. Feinler & R. W. Hubbard, Stanford Research Institute (Contract NAS2-6201), January 1972.
8.	Final Report, "Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions - Phase II, Volume I: Description of Requirements," McDonnell Douglas Astronautics Company-West, Report MDC G0620 (Contract NAS1-9248), July 1970.
9.	IMBLMS Phase B-4 Reports, Both General Electric & Lockheed Missiles & Space Co.
10.	Task A&B, Final Reports, General Dynamics Convair Aerospace Div., NAS8-26468, March 1972.
11.	Task C&D, Final Reports, General Dynamics Convair Aerospace Div., NAS8-29150, August 1973.
12.	Life Sciences Payload Definition & Integration Study, Final Report, General Dynamics Convair Division, NAS8-30288, August 1974.

TABLE 2-2

PRINCIPAL DATA SOURCES FOR LIFE SCIENCES RESEARCH REQUIREMENTS

STUDY GUIDELINES

- Life Sciences Payload Definition & Integration Studies 1970-74
- Baseline Mission Model
- Baseline Life Sciences Research Objectives
- Baseline Life Sciences Research Functions

CONFERENCE MINUTES — "Non-Human Primates in Space," 1974

TECHNICAL REPORT — "Maintenance Requirements for Biological Specimens in Spacecraft"

WORKING SESSIONS WITH NASA COR & BIOLOGICAL SCIENTISTS, 1975

NASA TECHNICAL PUBLICATIONS

- "The Proceedings of the Skylab Life Sciences Symposium," Vol. I & II, 1974
- "The Effects of Cosmic Particle Radiation on Pocket Mice Aboard Apollo XVII"

NASA TECHNICAL TRANSLATIONS

- NASA TT F-15210 - "A Biologist's Questions on Space," 1973
- NASA TT F-15863 - "The Biosatellite: Results of the Experiment," 1974
- NASA TT F-16851 - "Life in Weightlessness. Biological Laboratories in Orbit," 1974

NATIONAL ACADEMY OF SCIENCE

- "Physiology in the Space Environment"
- "HZE-particle Effects in Manned Spaceflight"
- "Infectious Disease in Manned Spaceflight"
- "Scientific Uses of the Space Shuttle"

REQUIREMENTS & RECOMMENDATIONS FOR SPACELAB CENTRIFUGE — J. Oyama, NASA/ARC, 1975.

TABLE 2-3

TYPICAL SPACELAB EXPERIMENTS PROVIDED BY NASA/ARC

HUMAN VESTIBULAR EXPERIMENTS	BIOMEDICAL/PRIMATE EXPERIMENT AREAS	SMALL ANIMAL EXPERIMENT AREAS
Otolith Function Experiments	Cardiovascular	Bone Metabolism
Vestibulo-spinal Reflex	Blood Distribution	Bone Parameters
Linear Acceleration Threshold	Enzyme Changes	Hormonal Studies
H-Reflex	Biorhythms	Hemolysis & RB Life Span
Visuo-Vestibular Experiments	Metabolic Balance	Cell-Mediated Immunity
Visual Accommodation	Bone Metabolism	Drosophilia Aging
Tilt Illusion	Gastrointestinal	Eye Ultrastructure
Linear Vection Threshold	Vestibular Function	Cardiac Norepinephrine
	Pharmacological	Endocrine Glands
	Organs & Vessels Contours	Gastric Ulceration
		Liver Regeneration
		Metabolic Rate & Deep Body Temp.
		Birth & Postnatal Survival
		Muscle Atrophy

with priorities, functions, measurements, and equipment needs. Table 2-4 contains baseline information previously produced to define research requirements and priorities for biomedical research in Spacelab missions. It should be noted that a column was provided for insertion of then-nonexistent Skylab inputs for the purpose of subsequent updating of research requirements as is being accomplished by this present study.

The literature review described in the preceding section indicated that the new research requirements could be arranged within the four major research disciplines utilized in the past studies. Since this method of research classification provided direct traceability to the extensive and applicable data previously developed under these research disciplines, the classification method was retained. The updated set of research requirements obtained from the laterature review was compressed to remove redundant requirements, and classified as research areas under one of the four research disciplines as shown in Figure 2-2.

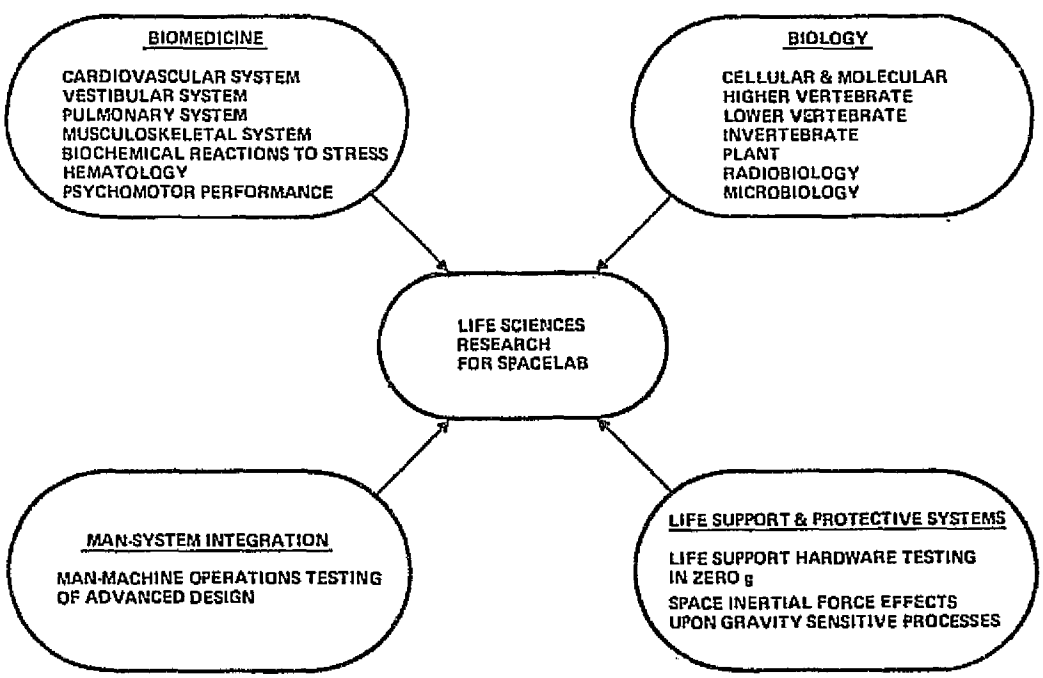


Figure 2-2. Life Sciences Research Disciplines.

Each of the research areas was then further subdivided into research topics selected to enable numerous specific experiments to be subsequently arranged under each topic. For example, vestibular system responses to zero-g figured heavily in the referenced source documents due to the occurrence of space nausea in the early period after transition into zero-g in a significant number of instances during Skylab operations. Recommendations for both non-invasive research on humans and invasive research on animals to determine basic causes and techniques for control of space nausea guided the subdivision of the vestibular system research area into four research topics. These

TABLE 2-4. RESEARCH AREA PRIORITIES FOR BIOMEDICAL (MAN AND MAN-SURROGATE) MISSIONS

RESEARCH AREAS	PAYLOAD INTEGRATION TEAM-AUG. '72	STEERING COMMITTEE-JULY 72	HDQTS., JULY 1973	ARC, SEPT. 1973	SKYLAB	*VERTEBRATE	*CELLS & TISSUES
CARDIAC FUNCTION	1	1	2	1		CARDIAC FUNCTION	BIOCHEMICAL PROPERTIES
PULMONARY FUNCTION	2	2	3	2		PULMONARY FUNCTION	BIOPHYSICAL PROPERTIES
HEMODYNAMICS	3	3	4	3		HEMODYNAMICS	RADIATION EFFECTS
BLOOD MORPHOLOGY ELECTROLYTES ENZYMES ENDOCRINES GASES ORGANISMS IMMUNOGLOBINS PROTEINS CHEMISTRIES						BLOOD MORPHOLOGY ELECTROLYTES ENZYMES ENDOCRINES GASES ORGANISMS IMMUNOGLOBINS PROTEINS CHEMISTRIES	MORPHOLOGY
G.I. FUNCTIONS	4	6	-	5		G.I. FUNCTIONS	
EXCRETORY FUNCTIONS	5	7	4	4		EXCRETORY FUNCTIONS	
METABOLIC STUDIES	6	5	4	6		METABOLIC STUDIES	
MICROBIOLOGY STUDIES	6	-	5	6		MICROBIOLOGY STUDIES	
NEUROLOGICAL FUNCTIONS	7	8	1	7		NEUROLOGICAL FUNCTIONS	
VESTIBULAR FUNCTIONS	7	4	6	6		VESTIBULAR FUNCTIONS	

PRIORITY: HI ↓ LO

TO BE DETERMINED

*PARALLEL BIOMEDICAL RESEARCH OBJECTIVES TO STUDY BASIC MECHANISMS OF MAN'S ADAPTATION TO THE SPACE ENVIRONMENT.

were: mechanical neural responses of otolith organs to stimuli in space; role of visual cues in space nausea; pharmacological prevention and treatment of space nausea; and role of altered body fluid, volume, pressure and distribution in space nausea.

The cardiovascular system was shown by previous manned space operations to exhibit adaptive changes soon after entry into the zero-g environment, which reduced normal tolerance for re-entry and landing stresses. The referenced source documents contained numerous recommendations for both non-invasive human studies and invasive studies on animals to generate basic understanding of mechanisms of cardiovascular adaption to zero-g and techniques to prevent unwanted responses.

Recommended cardiovascular system research was tabulated as three research topics under this system. These were:

1. Altered vascular flow, volume, pressure relationships in zero-g.

2. Demonstrate the presence or absence of the Gauer-Henry reflex, a compensatory body fluid redistribution mechanism.

3. Cardiovascular regulatory responses to exercise in zero-g.

Many specific experiments can be assembled within each of these research topics when specific experiments are subsequently defined by principal investigators.

This method of tabulating research requirements was applied to the medicine, biology, man-system integration, and life support/protective systems research disciplines and their subareas to assemble the total life sciences research requirements. These data, which are shown in Appendix A, (Vol. V, Book 2), are utilized to define correlated research functions and measurements requirements as described in Section 2.2.

2.1.3 BIORESEARCH CENTRIFUGE SCIENCE REQUIREMENTS. A NASA guideline, which limits the experiments selected for space research to those that cannot be performed on earth, in essence dictates that space life sciences experiments be designed to measure biological effects of exposure to weightlessness, altered circadian rhythms or HZE-particle radiations (Reference 6). These three space environment characteristics, which to date cannot be duplicated in earth-based laboratories, may be encountered simultaneously in space missions unless special measures are implemented. An example might be the use of a synchronous orbit to retain a near normal circadian period. Considerations of means of isolating these experimental variables point to the use of an onboard bioresearch centrifuge in Spacelab. This centrifuge could maintain space experimental organisms at one-g to serve as controls for the identical experiment conducted simultaneously in the same space vehicle environment but at zero-g.

The Space Sciences Board of the National Academy of Sciences established a scientific basis for employing a bioresearch centrifuge on Spacelab (Reference 6). Requirements were discussed for conducting inflight g controls for test organisms exposed to zero-g conditions, defining effects of fractional g on experimental organisms and for assessing the validity of the clinostat as a ground-based zero-g simulation device for certain types of research. The Space Sciences Board also recommended that the bioresearch centrifuge provide variable g in the range from 0 - 1.5 g, avoid stopping the centrifuge during the course of the space experiment, handle test organisms of weights up to 0.5 kg and provide at least a 1.5 meter radius but as large a radius as possible to reduce coriolis and g-gradient effects. A NASA Ames Research Center report (Reference 7) provided additional science requirements data which emphasized requirements for small vertebrate animals. The group of researchers involved in this work expressed no firm requirements for continuous rotation throughout the experiment duration. Biweekly stops of 0.5-hour duration for maintenance, etc., had not been found to evoke any significant effect upon growth patterns or other physiological functions measured on rats exposed to long duration centrifugation. This latter report recommended providing variable g in the range up to 3 g, a g-onset rate as low as 0.01 g/sec, and use of the maximum centrifuge radius compatible with vehicle constraints. The above described requirements were compressed and tabulated (see Table 2-5) to guide subsequent centrifuge design studies.

Additional laboratory work is required to determine subthreshold coriolis and g-gradient forces for test organisms that would be housed on a bioresearch centrifuge in order to firm up the science requirements. The requirements tabulated in Table 2-5 are viewed as preliminary working data for purposes of this study. The data should be updated after a more in-depth analysis of science requirements before being applied to guide hardware design decisions.

It is anticipated that experiment control specimens will be maintained on the bioresearch centrifuge in a manner as identical to the maintenance, control and monitoring in zero-g of experimental animals as is practical. Accordingly, the research functions and measurements determined for the research requirements described in the preceding section of this report will encompass most, if not all, such requirements for experiment controls on the centrifuge. The design guides for the centrifuge will dictate major function/measurement requirements for operating and maintaining the centrifuge, per se. The application of these research and biocentrifuge requirements to drive out function and measurement requirements is discussed in the next section.

2.2 RESEARCH FUNCTIONS/MEASUREMENTS REQUIREMENTS

The definition and organization of research requirements described in Section 2.1 produced a detailed breakdown of research topics for each life sciences research area.

TABLE 2-5

BIORESEARCH CENTRIFUGE SCIENCE REQUIREMENTS

OBJECTIVES

Conduct inflight 1 g control experiments for test organisms being maintained under zero-g conditions.

Define effects of fractional-g and hypergravity on tissue cultures, plants & small animals.

Assess validity of ground-based zero-g simulation devices; e.g., clinostats.

BIOLOGICAL RESEARCH AREAS

Cellular/molecular biology — chromosome replication, mitosis, wound repair, membrane transport.

Plant biology — geotropism, cellular growth and development.

Animal biology — musculoskeletal development, life cycle studies, cardiovascular deconditioning.

DESIGN GUIDES

Use maximum possible radius.

Minimum acceptable radius approx. 1.5 meter.

Accommodate test organisms up to 0.5 kg weight.

Provide gravity range of 0-3 g.

Can employ low onset g rate of 0.01 g/sec.

Minimize number and duration of stops.

Each of these research requirements was analyzed to determine functions and measurements required to accomplish that element of the research plan. Those determined to be necessary for non-invasive studies of altered vascular flow/volume/pressure relationships in human subjects are shown in Table 2-6. These functions enable determination of equipment; e.g., blood pressure cuff for measuring pressures, cardiopulmonary analyzer for capillary blood volume and pressure, and centrifuge blood sample processor and freezer for obtaining and storing blood plasma, etc.

TABLE 2-6. FUNCTIONS/MEASUREMENTS - EXAMPLE: CARDIOVASCULAR SYSTEM

SUBTOPIC: ALTERED VASCULAR FLOW/VOLUME/PRESSURE RELATIONSHIPS IN ZERO-G

NONINVASIVE STUDIES ON MAN	INVASIVE STUDIES ON HIGHER VERTEBRATES
BLOOD PRESSURE - SYSTOLIC/DIASTOLIC	INTRACARDIAC CATHETERIZATION
PULMONARY CAPILLARY BLOOD VOLUME	RECORD CHAMBER PRESSURES
PULMONARY CAPILLARY BLOOD FLOW	DETERMINE CHAMBER VOLUMES
VENOUS CAPACITANCE	DERIVE VENTRICULAR COMPLIANCE
ARTERIAL FLOW IN LIMBS	IMPLANT DEPTH CELLS
RENAL BLOOD FLOW	MEASURE ORGAN BLOOD FLOW
COLLECT BLOOD SAMPLES	RECORD ECG/VCG/PULSE
SEPARATE PLASMA	DERIVE STROKE VOLUME
COLLECT 24-HOUR URINES	DERIVE CARDIAC OUTPUT
MEASURE URINE VOLUME	COLLECT BLOOD SAMPLES
FREEZE & STORE BLOOD & URINE	SEPARATE PLASMA
DERIVE BODY FLUID COMPARTMENT VOLUMES	COLLECT 24-HOUR URINES
DETERMINE HEART CHAMBER VOLUMES	MEASURE URINE VOLUMES
RECORD ECG/VCG/PULSE	FREEZE & STORE BLOOD & URINE SAMPLES
DERIVE STROKE VOLUME	DERIVE BODY FLUID COMPARTMENT VOLUMES
DERIVE CARDIAC OUTPUT	MAINTAIN ANIMALS
ENVIRONMENTAL MONITORING	RECORD FOOD & FLUID INTAKE
PERFORM BIOCHEMICAL ANALYSES	HISTOLOGICAL & BIOPSY PREP.
	ENVIRONMENTAL MONITORING
	PERFORM BIOCHEMICAL ANALYSIS

Also shown in Table 2-6 are the function and measurement determination for the case of invasive studies on animals. Many, of course, are similar to those of the human studies. The functions and measurements required for invasive studies of altered hemodynamics in zero g are intended to support a series of related research operations. The acceptable number of implanted devices and body sensors to be employed in any one experiment is strictly limited and will be determined by the principal investigator. A specific experiment protocol could employ alternative methods for measuring pressure and flow. In the absence of specific experiment protocols, the non-implanted instrument (e.g., doppler flow meter and echocardiogram) are recommended. Indwelling sensors are expected to be implanted in experimental and control animals in the preflight period. A weight allowance has been provided in each payload to accommodate experiment-specific items that cannot be predetermined.

A major guideline of this study was to emphasize reduction of costs in such cases where cost reductions do not degrade research quality. This guideline directed attention to selection, where appropriate, of functions and measurements employed in previous space missions for which flight-rated equipment may be available for Spacelab. The Skylab program was reviewed and functions and measurements employed there were utilized to fulfill similar requirements for Spacelab missions (Reference 8). For example, Skylab developed special equipment for on-board collection of blood samples, separation of cellular elements from plasma, and storage of samples for comprehensive ground analysis. It was determined that the Skylab requirements for blood and urine collection and chemical analysis would satisfy anticipated requirements for Spacelab. Typical measurements are shown in Table 2-7.

The characteristics of space research equipment developed after Skylab were similarly reviewed to determine compatible Spacelab function and measurement requirements. An example is provided in Table 2-8 in which case the functions and measurements requested for in-flight biomedical studies of the pulmonary system were made compatible with the specified capability of the Cardiopulmonary Analyzer currently being developed by the Ames Research Center. Other major sources of data used to define Spacelab function/measurement requirements were the comprehensive lists of common-purpose research functions and measurements and related hardware specifications developed and documented in final reports of contracts NAS8-29150 and NAS8-30288 (References 1 and 3). Applicable excerpts from these reports are in Appendix A, (Volume V, Book 2).

As an example of the blood and urine analysis capability, Table 2-9 tabulates the analytical function and measurement capabilities of candidate Spacelab equipment items 7, 7A, 85, 52 and 70. The five equipment items shown on this table are capable of in-flight biochemical analyses which were not available for Skylab missions. The literature review disclosed that certain research recommended for future Spacelab missions would necessitate a few selected on-board chemical analyses in addition to the delayed ground analysis. These items from the existing baseline data bank provide candidate measurement sources to satisfy these new requirements.

It may be noted that routine functions such as collecting a blood sample are not defined to the detail level in the research requirements. The reason for this is that the baseline data defined kits, e.g., hematology kit - which contains tourniquets, alcohol disinfectant, cotton swabs, stylus, hemaglobinometer, needles and syringes, etc., to handle blood sample collection and blood smear preparation. When the functions requirements indicate need for blood collection, the hematology kit would be provided as a necessary equipment item chosen from the equipment inventory.

The functions and measurements list defined for each research topic serves two purposes: it denotes what procedures you can do, as well as providing the means to define equipment needs. This method was employed to define functions and measurements for all research proposed in the four life sciences disciplines. These results

TABLE 2-7. BODY FLUID MEASUREMENT REQUIREMENTS

RESEARCH DISCIPLINE	FUNCTIONS/MEASUREMENTS REQUIRED	
BIOMEDICINE Basis and Control of Biochemical Reactions to Stresses in Space Environment Fluid & electrolyte balance Calcium regulation Adrenal function Food utilization	Time related record of crew nutrition and exposure to stress and exercise. Radionuclide body compartment studies: - total body water - extracellular volume - plasma volume Obtain fractionated urine samples and plasma and serum samples for on-board and/or delayed analysis: Urine Analyses: Volume Sodium Potassium Chloride Osmolality Calcium Phosphate-(PO_4) Magnesium Creatinine Antidiuretic hormone Aldosterone Cortisol Epinephrine Norepinephrine Total 17-Hydroxycorticosteroids Total 17-Ketosteroids Uric Acid	Plasma & Serum Analyses: Sodium Potassium Calcium Magnesium Chloride Phosphorus Osmolality Carbon dioxide Cholesterol Triglycerides Adrenocorticotrophic hormone Cortisol Angiotensin I Aldosterone Insulin Blood urea nitrogen Uric acid Creatinine Total protein Alkaline phosphatase Serum glutamic oxaloacetic transaminase (aspartate aminotransferase) Creatine phosphokinase Lactic dehydrogenase Glucose Total bilirubin Growth hormone Thyroxine Thyroid stimulating hormone Testosterone Parathormone Calcitonin Vitamin D

are documented on work sheets in the format shown in Table 2-6 to provide the data base from which to determine payload equipment needs. The total list of function and measurement requirements for life sciences research in Spacelab is documented in Appendix A, (Vol. V, Book 2 of this report).

The function and measurement requirements selected to satisfy the research requirements provide the necessary data to guide the definition and selection of research equipment for Spacelab.

TABLE 2-8. PULMONARY MEASUREMENT REQUIREMENTS

RESEARCH DISCIPLINE	FUNCTIONS/MEASUREMENTS REQUIRED
BIOMEDICINE Pulmonary System Altered pulmonary volume/flow relationships in zero-g	Performed by Cardiopulmonary Analyzer VC Vital capacity FVC Forced vital capacity FEV-1 Forced expiratory volume - one second CV Closing volume MEFR Maximum expiratory flow rate MMRF Maximum midexpiratory flow rate TLC Total lung capacity RV Residual volume Pulmonary capillary blood volume Pulmonary capillary blood flow

2.3 TIME-PHASED LIFE SCIENCES RESEARCH

The literature review of Skylab operations demonstrated capability of trained crews for effective research during space missions of up to 84 days duration with no evidence of irreversible effects (Reference 8). These findings minimized the need for further research to qualify man for 7- and 30-day Spacelab missions. However, a few specific medically oriented studies were recommended in early Spacelab missions to obtain first-day on-orbit measurements of the acute alterations in plasma and urine concentrations and/or excretion rates of certain enzymes, hormones, proteins, electrolytes and fluids in order to provide better understanding of basic mechanisms of cardiovascular and fluid volume adaptations to zero-g. These data were not obtained during the first days of previous Skylab missions due to scheduling problems and/or inability to obtain and preserve specimens in the early mission periods. Another recommendation was to perform experiments to better understand basic factors related to space nausea. The justification for these selected studies of causes and control of orthostatic intolerance and space nausea resulting from space adaptations is based

TABLE 2-9. CANDIDATE EQUIPMENT ITEM IN-FLIGHT MEASUREMENT CAPABILITY

CONSTITUENT	7 GEMSAEC	7A A.P.E.A.	85 GAS ANAL.* AUTO. PHY.	52 COULTER* COUNTER	70 ELECTRO-PHORESIS
Properties					
RBC				X	
WBC				X	
Hemoglobin				X	
Hematocrit				X	
MCV				X	
MCH				X	
MCH Concentration				X	
pH		X	X		
pO_2		X	X		
pCO_2		X	X		
Constituents					
Organics					
BUN	X				
Bilirubin	X				
Glucose	X	X			
Triglycerides	X				
Albumin					X
Phosphatides					X
Fibrinogen					X
Inorganics					
Ca^{++}	X	X			
Na^{+}		X			
K^{+}		X			
Chloride		X			
Total Ca		X			
Enzymes					
SGOT	X				
SGPT	X				
Alkaline Phosphatase	X				
Acid Phosphatase	X				
CPK	X				
LDH-L	X				

*NOT IN PRESENT COMMON EQUIPMENT INVENTORY

upon the anticipated altered stresses in the seated, erect and active crew mode of reentry in Spacelab as compared to the supine passive crew mode of reentry in previous operations. Further justification for these biomedical studies is the likelihood of flying passengers in Spacelab with less tolerance for dynamic loading than the crews of previous space missions. Spacelab 7- and 30-day missions can, therefore, emphasize research to further improve crew and passenger effectivity and well-being during on-orbit and earth return under altered re-entry modes from those previously employed.

Spacelab life sciences research can also emphasize basic research which, by augmenting fundamental knowledge of the factors controlling physiological and biochemical processes, could contribute in a high degree to management of living processes on earth.

Scheduling priorities for the required research were accordingly guided by the potential of a recommended research activity to resolve a signficant problem related to the well-being and efficiency of man in space or the potential for uncovering basic knowledge regarding management of life processes on earth. Another scheduling consideration was the flight duration required to accomplish a proposed research task. Statements related to the scheduling considerations, as obtained from input sources, were tabulated on the work sheets of Appendix A, (Volume V, Book 2) opposite the related research item.

The acute response of the cardiovascular system to zero g qualifies this research for scheduling on seven-day flights. The potential for determining basic mechanisms of cardiovascular system response to zero g and applying this knowledge to prevent or reduce orthostatic intolerance during Shuttle mode re-entry and flyback gives this research a high scheduling priority, the potential for increased understanding of basic enzyme, endocrine, and renal mechanisms controlling fluid volume, distribution, and pressure could have important applications in management of surgical and other nonambulatory patients on earth; e.g.,

Zero g is similar to bed rest
Zero g evokes plasma volume reduction
Zero g causes vascular pressure and flow alterations
Zero g depresses hematopoietic stimulus
Zero g causes protein and electrolyte losses
Zero g causes endocrine and enzyme changes

Scheduling considerations for vestibular system research include the acute onset of space nausea in a significant percentage of Skylab crew members after transition into zero g and the relatively short adaptation period required. This finding gives this research area a high priority due to the potential for reducing or preventing the impaired crew efficiency encountered in the early on-orbit period, and qualifies this research area for scheduling on seven-day flights. The potential for obtaining increased understanding of basic mechanisms of mechanical and neural responses of otolith organs

and the possible application of this knowledge to increase crew tolerance during re-application of constant g during re-entry and flyback also argue for giving this research area a high priority.

In the manner illustrated by the two above examples, research priority determinants obtained from source documents were tabulated for each research topic. The results are presented in Table 2-10. The following comments deal with some of the research time-phasing considerations employed in arriving at the recommended order:

- Vestibular and cardiovascular system responses to zero-g degrade crew well-being and performance during early on-orbit and re-entry periods, respectively. These problems are unresolved and research is required for solutions. Research in these two systems has potential for application to earth medicine.

- Pulmonary system response is integrally associated with cardiovascular responses so these systems should be studied together. Spacelab provides a first opportunity for pulmonary measurements in zero-g with sea-level pressures.

- Biochemical reactions are involved with cardiovascular, pulmonary, and musculoskeletal research topics and must be studied in concert with these related research areas.

- Human and higher vertebrate research on acute adaptive responses to zero-g are given equal priority since the ability to perform invasive studies and maintain critical control of experimental parameters using animal subjects balances the disadvantage of extrapolation of animal data to man.

- Musculoskeletal system adaptation was continuing unabated throughout Skylab missions of durations up to 84 days, and research on small vertebrates with rapid bone turnover times may demonstrate long-range adaptive end points.

- Red blood cell mass decrease was not directly related to increased length of zero-g exposure. Red blood cell life span (about four months) limits the value of hemapoietic studies with man in 30-day missions.

- Behavioral performance continued to improve from beginning to end of all Skylab missions. Although crew performance measurements should be obtained and related to pre-mission training on all flights, psychomotor performance research per se does not appear to pose an urgent requirement for study in the 7- and 30-day missions.

- Growth, development, reproduction, genetic changes, and cell response research employing experimental subjects with brief reproductive and growth times can disclose basic mechanisms of physical adaptation to long-duration zero-g applicable to man but not readily studied in man in 30-day missions.

TABLE 2-10. RECOMMENDED TIME-PHASED LIFE SCIENCES RESEARCH

RESEARCH AREAS	RESEARCH ORGANISM							NOMINAL DURATION (DAYS)
	HUMAN	VERTEBRATES		CELL CULTURE	INVERT.	PLANTS	MICRO-ORGANISM	
		HIGHER (MONKEY)	LOWER (RAT)					
VESTIBULAR SYSTEM	▲	▲	●					7
CARDIOVASCULAR SYSTEM	▲	▲	●					7
PULMONARY SYSTEM	▲	▲	●					7
BIOCHEMICAL REACTIONS	▲	▲	●					7
MUSCULOSKELETAL SYSTEM	●	●	▲					7+
HEMATOLOGY	●	●	▲					7+
PSYCHOMOTOR PERFORMANCE	▲	●	●					7
GROWTH			▲	●	●	●		7+
DEVELOPMENT			▲	●	●	●		7+
REPRODUCTION			▲	●	●	●		7+
LONGEVITY				●	▲	●		7+
GENETIC CHANGES				●	▲	●	●	7+
SINGLE CELL TYPE RESPONSE				▲			●	7+
GEOTROPISM						▲	●	7+
RADIOBIOLOGY (HZE)		●	▲	●	●	●		7+
MICROBIOLOGY							▲	7+
CIRCADIAN CYCLES	●	●	▲	●	●	●	●	7+
MAN-MACHINE TESTING	▲							7
LIFE SUPPORT HARDWARE TESTS	▲							7
g SENSITIVE PROCESSES	▲							7

● CANDIDATES RESEARCH ORGANISM
▲ PREFERRED RESEARCH ORGANISM

- Low orbital inclination and short-duration missions do not provide good conditions for HZE particle studies.

- MSI and LS/PS research priority will be determined to a large extent by the criticality and need date of the hardware or process being tested and so could have high priority in many cases.

- The priorities and preferred test organism assigned to the research areas are judgment factors that will undergo constant revision as research topics are completed, others are added, and new insight into requirements is developed and applied.

The format for documenting these data is illustrated by Table 2-11. Each priority determinant notation bears a reference number which traces it to its source document and page. The total life sciences research requirements for Spacelab are documented on 20 pages of data tabulated in the format shown in Table 2-11. These are found in Appendix A, Volume V, Book 2 of this report.

The requirements document in Appendix A comprises the major output of the work described in Section 2. The research functions and measurement and time-phasing requirements identified in this document for each research topic comprised a firm basis for defining Spacelab research equipment, candidate payloads, and mission models.

TABLE 2-11. EXAMPLE REQUIREMENTS DOCUMENTATION
(Reference Appendix A, Volume V, Book 2)

RESEARCH DISCIPLINE	FUNCTIONS/MEASUREMENTS REQUIRED	PRIORITY DETERMINANTS
BIOMEDICINE		
Cardiovascular System		
Altered vascular flow, volume & pressure relationships in zero-gravity.	Pulmonary capillary blood volume Pulmonary capillary blood flow Venous capacitance Venous compliance Arterial flow in limbs Body fluid component volumes - total body water volume - extracellular volume - plasma volume Renal blood flow	Space flight furnishes an environment for cardiovascular study which can be produced in no other way. It is difficult to imagine that increased understanding of cardiovascular function and control mechanisms, as they are altered in weightlessness, will not in the future become relevant to the cardiovascular problems that face us on earth.[1] Skylab studies have clearly shown that changes in fluid volume distribution during the first few hours of flight creates profound alterations in cardiovascular functions which in turn, impair orthostatic mechanisms to a marked degree as early as four or five days after entering the weightless environment.[2] It should be noted in all crewmen there was an increase in compliance that required 10 days or more to reach a maximum.[3]
Demonstrate presence or absence of Gauer-Henry-Reflex.	Intrathoracic blood volume ADH Renin Angiotensin Aldosterone Catecholamines Water excretion Sodium excretion Plasma volume	The Gauer-Henry reflex has yet to be demonstrated. This will not be easy to demonstrate in man, since the critical time-period to be investigated is thought to coincide with the early operationally exacting first day of the mission.[4] The first two to three days of each mission were spent in the activation of the orbital workshop.[5]
Cardiovascular regulatory responses to exercise in zero gravity. (Man)	Electrocardiogram/vectorcardiogram - pulse rate and rhythm - cardiac axis Echocardiogram - stroke volume - cardiac output - cardiac compliance Systolic blood pressure Diastolic blood pressure - pulse pressure - mean arterial pressure Calibrated exercise level	The increased quantity and quality of exercise available to the crew was important in maintaining crew health of Skylab 4.[6] Future research efforts should focus on optimum methods of exercise with respect to crew time and crew acceptance, interrelationship of musculoskeletal fitness with cardiovascular fitness, and design of practical, efficient, total body exercisers.[7]

SECTION 3

LABORATORY DEFINITION AND MISSION MODEL DEVELOPMENT

Task 1 of this study defined mission models or alternative ways of accomplishing a life sciences research program in space. The steps leading to the recommended mission models as shown in Figure 3-1 included the definition of the time-phased research, the development of several laboratory concepts, and finally the development and evaluation of candidate mission models.

The time-phased research requirements have been discussed in Section 2. The hardware required to perform the research functions and measurements was defined. A comprehensive common equipment inventory that satisfies the research requirements was established. This inventory of hardware was then reviewed and selection made from it to support various research specific laboratory payloads. The payloads ranged from the small carry-on laboratories to the mini-lab and, finally, the fully dedicated laboratories. These laboratories, when properly time-phased, became the development and operational options that were used in defining candidate mission models. The final output of the task was the mission model recommendations based upon an evaluation of the scientific capability, programmatic aspects, and potential problem areas.

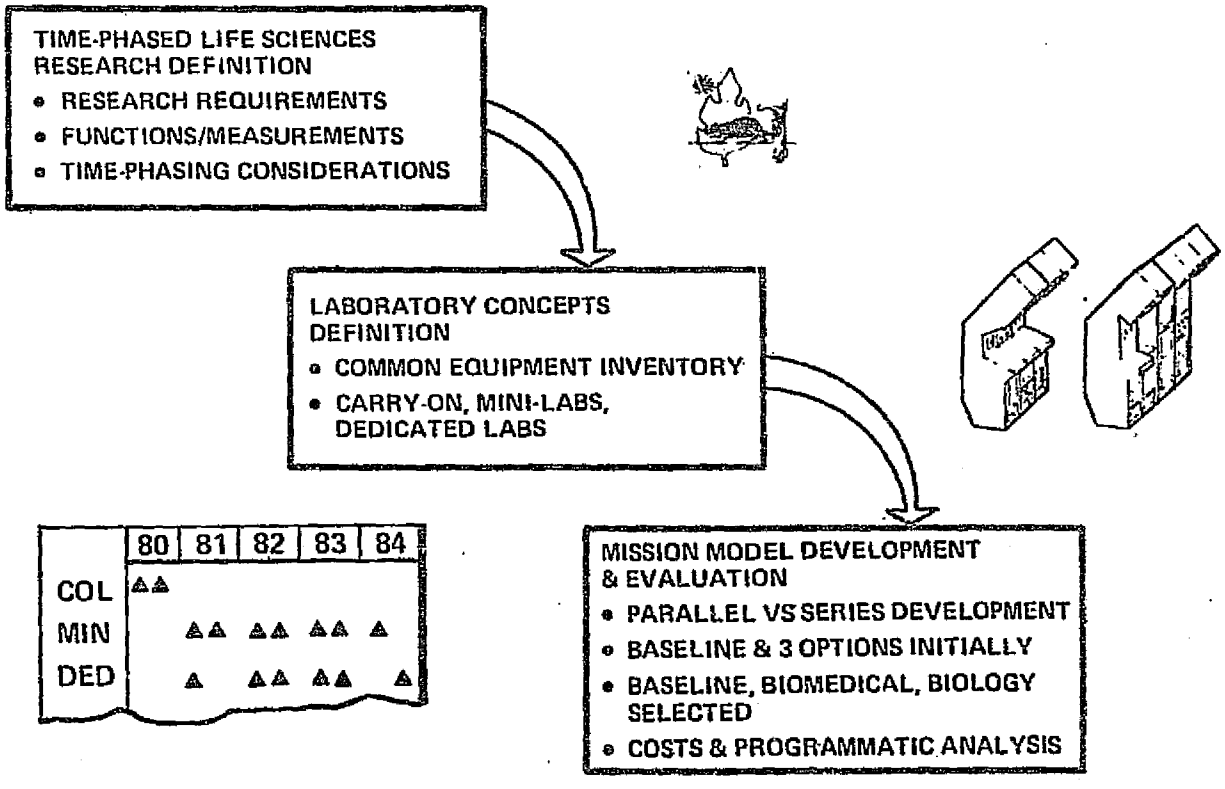


Figure 3-1. Life Sciences Mission Model Development

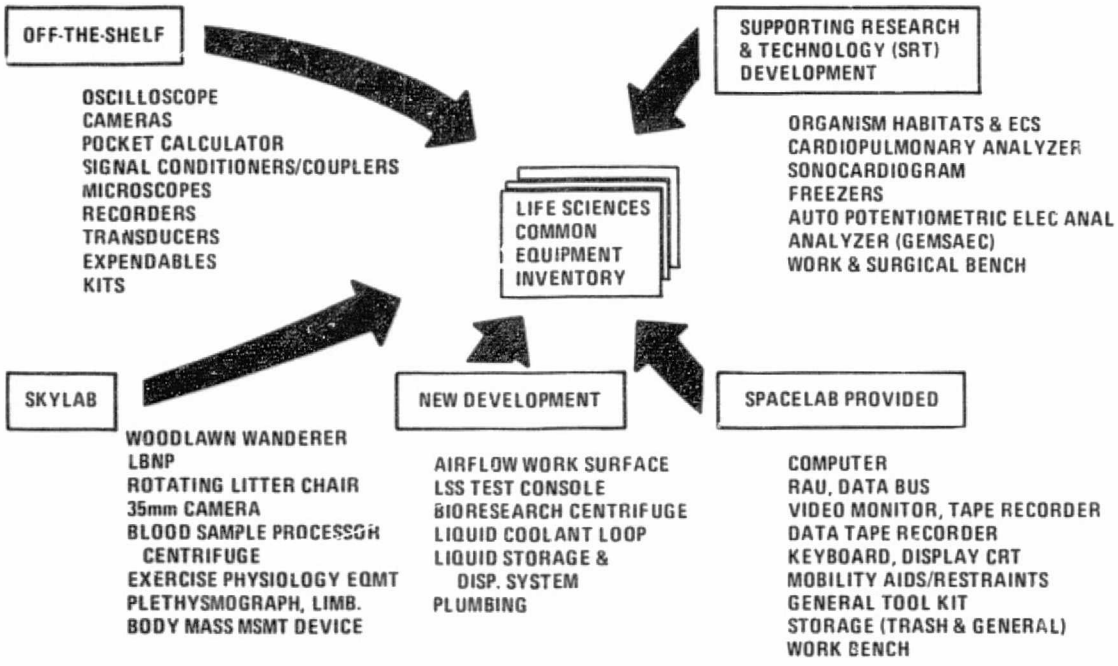
3.1 COMMON EQUIPMENT INVENTORY

Fundamental to the development of the life sciences manned laboratories is the concept of a common operations research equipment (CORE) inventory, or simply, the common equipment inventory. This body of equipment has been defined, reviewed, altered and updated by industry, NASA and outside consultants over the past few years and currently represents a consensus of researchers as to what constitutes the basic hardware complement of a general life sciences laboratory. The current inventory contains those equipment items needed to support the functions and measurements driven out by the research requirements discussed in Section 2. To be sure, all of the hardware needed for a particular flight mission is not contained in the inventory. There are allowances for principal investigator (PI) equipment to be added to the laboratory when specific missions are determined. However, the common equipment inventory does provide for those common functions such as organism holding, environmental control and monitoring; sample collection, preparation, analysis and/or preservation; signal sensing, amplification/conditioning and recording; microscopic analysis, photography, chemical analysis among others.

3.1.1 COMMON EQUIPMENT INVENTORY DEVELOPMENT. The analysis and update of the life sciences equipment inventory began with consideration of the two inventories referenced in the Statement of Work. The CORE inventory originally developed by Convair has been extensively reviewed by the Life Sciences Working Group in the past and represented a consensus equipment complement for a dedicated laboratory (Reference 9). The carry-on laboratory inventory was a more recent inventory developed to support the smaller carry-on or mini-labs. Many of the items in the two lists were identical or similar. These inventories were combined into one by eliminating redundancies, redefining some items (such as kits), and modularizing other items, such as freezers. Generally, the more detailed and current information for the selected equipment item (EI) was retained. Additions to the inventory were made by including Skylab items, equipment currently undergoing development, and new items defined where deficiencies occurred. The functional grouping of items into equipment units was continued since it has meaning when defining dedicated laboratories.

A major effort relative to the refinement of the equipment inventory was the review and analysis of some 55 selected equipment items with a team of University of California (San Diego) consultants. The UCSD consultants and their research areas of interest are: Dr. Paul Saltman, plant physiology and biochemistry; Dr. Maarten Chrispeels, plants; Dr. Ted Hammel, vertebrate physiologist; Dr. Nick Spitzer, cell and tissue physiology; and Dr. Al Selverston, neurophysiology and bioinstrumentation. Many excellent suggestions and comments were received from the consultant team. Their recommendations were included in the updating of the EI definition sheets.

The equipment items in the life sciences common equipment inventory derive from a variety of sources. Figure 3-2 shows the principal ones. The EIs listed are representative and are not inclusive. A large number of items (approximately 40 percent)



Preliminary quantity breakdown:

Off-the-shelf	73	SRT	30
Skylab	15	New Development	40
Spacelab-provided	18		

Figure 3-2. Common Equipment Inventory Makeup

are presently available commercially and require little or no modification. Typical modification would include vibration tolerance improvement and zero-g operability assurance. Items in this category are referred to as "off-the-shelf" items. All of the various kits in the inventory fall into this category as their contents are generally commercially available. Electronic equipment, recorders, cameras, microscopes and transducers are other examples.

Several items were developed and flown aboard Skylab. Some Skylab flight articles (or backups) exist in bonded storage and can be used for Spacelab. Fabrication of additional units would be relatively inexpensive because the development costs have been paid.

The Spacelab-provided EIs have been retained in the inventory but are presently baselined into the Spacelab program and do not require life sciences development. Their inclusion in the inventory indicates capability available to life scientists.

Items whose development is presently being funded by NASA are denoted supporting research and technology (SRT). Major items in this category that are in initial phases of development are the organism habitats, habitat ECS, freezers, refrigerators, and

the work and surgery bench. Analytical or diagnostic instrumentation such as the automatic potentiometric electrolyte analyzer, the GEMSAEC autoanalyzer, and the cardiopulmonary analyzer are in more advanced stages of development and are intended to form the significant analytical capability of the life sciences laboratories.

Finally, EIs defined as needed in the laboratory but not presently existing nor under development are denoted as "new development". This category includes many items whose components may be available off-the-shelf, but whose assembly into flight articles is not complete. Interface items such as liquid handling equipment, plumbing, vacuum manifolds, etc., are typical. Major items such as the Bioresearch Centrifuge and the life support systems test console are not yet program line items. These items along with those in the SRT category, while representing but 40 percent of the total number of equipment items, probably account for close to 90 percent of the inventory development costs. This aspect of the inventory is discussed more fully in Section 5.

The quantity breakdown shown in Figure 3-2 is an estimate for the five categories. However, flight payloads (laboratories) will consist of equipment items taken from the common inventory plus that hardware supplied by principal investigators (PIs). These latter items, estimated to form 10 to 20 percent by weight of the total payload, are not included in the inventory.

3.1.2 COMMON EQUIPMENT INVENTORY DESCRIPTION. The entire common equipment inventory of 176 items is listed in Table 3-1. This list was categorized into regular, intermittent, Spacelab, and principal investigator (PI) equipment items. Regular and intermittent items are those deemed essential for laboratory development. Spacelab items have already been discussed. PI items are exemplary of the research-specific equipment provided by the experiment. Complete definition of these terms and listings for each category are provided in Volume V, Book 3.

Each equipment item in the regular and intermittent categories was defined to a level of detail sufficient for accomplishment of this Phase A study. Figure 3-3 shows an example of the EI definition package. Descriptive data is presented in one to several specification sheets relative to purpose, requirements, and current hardware status. Estimated flight parameters of weight, volume, and power (type and level) are made. Development times and schedules are estimated by vendor or other source contacts. As an aid to designers, sketches, catalog data sheets, photographs, etc., are included, if available. A detailed cost data backup sheet was developed to assist in determining program costs and schedules.

Since the entire inventory was reviewed and many changes made, an EI Disposition Record is provided. This record accounts the action taken with respect to each EI and provides traceability for the inventory as of its last review by the Life Sciences Working Group in January 1975. This review was documented in the MSFC report, "Life Sciences Working Group Payload Evolution Working Papers for Shuttle Payload Planning," July 1975 (Reference 10).

TABLE 3-1. COMMON EQUIPMENT INVENTORY

E.I. No.	Equipment Item Name	Unit Weight kg	Unit Power w	Unit Volume dm^3
1	ACCELEROMETER	0.1	0	0.03
1A	ACCELEROMETER COUPLER	0.05	1	0.01
3B	AIRLOCK	SHUTTLE		
6	AIR PARTICLE SAMPLER	2.7	50	0.85
6A	AIRFLOW WORK SURFACE	5	75	6
7	AUTOANALYZER (GEMSAEC)	26	200	40
7A	AUTO POTENTIO. ELEC. ANAL.	12.7	100	57
11	ANALYZER, GENL. SPECTROPHOT.	30	240	90
14	ANESTHETIZER, INVERT.	0.2	0	1
14B	ANTENNAS, ASSORTED	0.1	0	0.03
15	ANTHROPOMETRIC GRID	1.8	0	2.8
15A	ATMOS. SAMPLING SYSTEM	10	20	28
15D	AUDIO STEREO HEADSET	0.7	0	5.7
16B	AUDIOMETER	4.5	25	4.3
16L	BADGES, RADIATION	0.2	0	0.1
16F	BALLISTOCARDIOGRAM COUPLER	0.1	1	1
18D	CUSTOM BITE BOARDS	0.23	0	0.03
19D	BODY MASS MEAS. DEVICE	36.5	15	675
25	CAGE, INVERTEBRATES	0.3	0	0.2
25B	COLONY CHAMBER, SEALABLE	0.2	0	0.1
26A	CAGE, METABOLIC, C/T	0.8	5	0.9
26B	CAGE, METABOLIC, PLANT	7	30	74.6
28	CAGE, METABOLIC, RATS	8	20	28.3
29	CAGE, PLANT	4.5	0	56.6
30A	CAGE, RAT, HAMSTER, STANDARD	2.3	9	11
31	CALCULATOR, POCKET	0.47	0	0.4
32	CAMERA, CINE	5	13	5
32A	CAMERA CONTROLLER	13.6	100	28.3
33	CAMERA, POLAROID	3.3	0	5.6
36	CAMERA, 35 MM AND STROBE	2	0	.2
37	CAMERA, VIDEO, B/W	4.4	15	3
38	CAMERA, VIDEO, COLOR	7.7	69	6.2
38B	CAMERA MOUNTS	3	0	3
38D	CAMERA TIMER, VIDEO	4	10	3
38F	CARDIOPULMONARY ANALYZER	90.7	200	172
40A	CENTRIFUGE, BLD SMPL PROCESSOR	12.7	100	25
43A	CENTRIFUGE, BIORESEARCH	250	354	6800
44	CHEMICALS	0.5	0	1.0
44A	CHEMICALS, RADIOISOT. TRACERS	0.3	0	0.5
45	CHEMICAL STORAGE CABINET	4.0	0	14.1
48	CLEANER, VACUUM	2.3	100	10
50	CLINOSTAT (FOR PLANTS)	3	10	20
50A	CLINOSTAT (FOR C/T)	2	10	4
50B	COMPACTOR, SOLIDS	18	100	113
51	COMPUTER, DIGITAL	SPACELAB		
51D	CONTROL CONSOLE, EXPERIMENTER	22.7	100	113.3
51F	COOLANT LOOP, LIQUID	30	50	25
54	COUNTER, COLONY, MANUAL	1.5	50	1.5
55A	CREW MOBILITY AIDS	SPACELAB		

TABLE 3-1. COMMON EQUIPMENT INVENTORY (Cont'd)

E.I. No.	Equipment Item Name	Unit Weight kg	Unit Power w	Unit Volume dm^3
55B	CREW RESTRAINTS	SPACELAB		
55C	CREW WORK STATION	SPACELAB		
56A	DATA MGMT SYST BUSES	SPACELAB		
58A	DMS CONTROL AND DISPLAY STA.	SPACELAB		
58B	DMS REMOTE ACQUISITION UNIT	SPACELAB		
63B	DISPLAY KEYBOARD, PORTABLE	13.6	60	42.5
63C	DISPLAY, NUMERIC	2	2	4
64	ECG COUPLER	0.2	2	0.5
65	EEG COUPLER	0.2	2	0.5
65B	ELECTROPHYS. BACKPACK	0.3	0	0.25
65C	ELECTROPHYS. RECEIVER	2.7	25	5.0
66	EMG COUPLER	0.2	2	0.5
69A	ELECTROMETER	3.7	3	7.3
70	ELECTROPHORESIS APPARATUS	9.1	85	25.5
70C	EQUIPMENT RESTRAINT DEVICE	0.5	0	1
70E	EXERCISE EQUIP., PHYSIOL.	96	18	992
75C	FILM, CINE	0.54	0	0.54
75F	FILM, POLAROID	0.16	0	0.13
76C	FILM, 35 MM	0.13	0	0.05
76D	FLOWMETERS	0.5	1	0.5
76L	FIBROMETER, BLOOD CLOT	4.5	40	19.8
77B	FREEZER, CRYOGENIC	21.6	10	74.1
80	FREEZER, GENERAL	15	200	61.4
81	FREEZER, LOW TEMP.	8	10	30.5
83	FRIG. (REFRIGERATOR)	18	50	120
87	GAS ANALYZER, INFRARED	11.3	50	42.6
91	GAS ANALYZER, MASS SPEC.	25	50	20
93	GAS ANALYZER, RH	5.2	6	13
93A	GAS SUPPLIES	5.75	0	18
96	GLOVE BOX, PORTABLE	4.5	0	25
96C	GLOVE BOX LINERS	0.5	0	1
97C	HANDWIPES, BETADYNE	0.3	0	0.3
98A	HOLDING UNIT, CELLS/TISSUES	23	30	188
98C	HOLD. UNIT, INVERTEBRATES	23	50	188
99	HOLDING UNIT, COMMON	20.4	50	188
101	HOLDING UNIT, PLANT	25	500	188
101B	HOLDING UNIT, MONKEY POD	53	100	425
101C	HOLDING UNIT, PRIMATE	113	100	340
103	HOLDING UNIT, SM. VERT.	13.6	0	188
103B	INCUBATOR	5	5	8
105	KIT, CHEMICAL	1.5	0	5
106	KIT, HEMATOLOGY AND UROLOGY	5	0	9
106A	KIT, CLEANUP	1.5	0	4
108	KIT, HISTOLOGY	1	0	1
109	KIT, LINEAR MEAS.	1	0	1
110	KIT, MICROBIOLOGY	2	0	3
110C	KIT, HUMAN PHYSIOLOGY	3	0	8
111	KIT, PLANT MANAGEMENT	1	0	1
113	KIT, GENERAL TOOL	SPACELAB		

TABLE 3-1. COMMON EQUIPMENT INVENTORY (Cont'd)

E.I. No.	Equipment Item Name	Unit Weight kg	Unit Power w	Unit Volume dm^3
113A	KIT, INVERT. MANAGEMENT	1	0	2
114A	KIT, DISSECTION	1	0	2
114B	KIT, VERTEBRATE MANAGEMENT	3	0	6
114C	KIT, VERTEBRATE PHYSIOLOGY	3	0	6
114E	LAMP, PORTABLE HI INT. PHOTO	6.3	150	6
114G	LIQUID STOR. AND DISPENS. SYS.	13	0	18
115F	LSS TEST CONSOLE	15	0	560
116	LOG BOOKS	0.5	0	0.4
117	LOWER BODY NEG. PRESS. DEVICE	78.7	26	2375
118	LYOPHILIZER	23	300	143
118I	MANIFOLD, VACUUM	9.1	0	28.3
119	MSI TASK SIMULATOR	22.7	5	200
121	MASS MEAS. DEVICE, MACRO	11.8	15	32.8
122	MASS MEAS. DEVICE, MICRO	12	15	25
122A	MASS, TEST, VARIABLE SIZE	0	0	0
124	MEDIA, PREPARED	0.45	0	0.5
126	MICROSCOPE, COMPOUND	11	15	27.4
126A	MICROSCOPE, DISSECTING	9	100	28
126G	MONITOR, VIDEO	SPACELAB		
126I	MOBILITY UNIT, PROT. CORRIDOR	22.7	0	56.6
126J	MICR. ACCESS. KIT, COMPND	10	15	25
131D	MOTORIZED PLANT GROWTH MONITOR	0.5	5	0.6
131E	NON-VISUAL DIRECTION INDICATOR	4.1	0	2.8
131H	OPTISCAN - FIELD AND FIXED	2.3	5	8.5
131J	ORB. FROG OTOL. EXPER. PACKAGE	45	20	80
132	OSCILLOSCOPE AND CAMERA	11.7	75	28.9
133	OTOLITH TEST GOGGLES	0.2	0	2.8
134B	PAPER, RECORDING	0.6	0	1.2
138	PH METER	1.8	20	5.2
138B	PHOTOCELL COUPLER	0.2	2	0.5
138E	PHYSIOL. MULTICHAN. SENS SYS.	0.2	0	1.4
139	PLETHYSMOGRAPH, LIMB	2.4	5	6
140	PHONOVIBRACARDIOGRAM COUPLER	0.2	1	0.3
141A	PLUMBING	20	2	15
142	PORTABLE LSS	30.4	0	79
142B	POWER COND. EQUIP.	SPACELAB		
143G	PRESSURE COUPLER	0.2	2	0.5
144	PSYCHOMOTOR PERFORM. CONSOLE	8.2	15	10.3
144D	PSYCHOGALVANOMETER, GSR	0.5	1	0.3
144C	RADIATION DETECTOR, DOSIM.	0.3	0	0.5
147	RADIATION COUNTER	15	50	20
149G	RAD. SOURCE, SHIELDED	65	5	28.3
150A	RECORDER, STRIP CHART	11.8	0	16.9
150B	RECEIVER, BIOTELEMETRY	0.5	10	1
153	RECORDER, VOICE	1	0	1
153A	ROTATING LITTER CHAIR/CONSOLE	100.2	127	239
153B	SENSORS, ASSORTED	0.5	0	0.3
156	SIGNAL CONDITIONERS (COUPLERS)	0.2	2	0.5

TABLE 3-1. COMMON EQUIPMENT INVENTORY (Cont'd)

E.I. No.	Equipment Item Name	Unit Weight kg	Unit Power w	Unit Volume dm^3
156F	SONOCARDIOGRAM	19	32	59
157	SOUND LEVEL METER	13.6	0	33.4
158C	SPACESUIT TEST CONSOLE	35	50	50
159	STAINING SYSTEM	2.2	0	3.5
162	STERILIZER, AUTOCLAVE	11	300	34.7
165	STERILIZER, TOOL	1	110	1
167B	STORAGE, GENERAL	SPACELAB		
167C	STORAGE, FILM	SPACELAB		
172	SPACESUIT	36.3	1	198.2
174	TANK, VERTEBRATE WATER	8.5	5	28.3
175	TANK, PLANT/INVERT. WATER	1.7	0	3
176	TAPE, VIDEO	SPACELAB		
176H	TASKBOARD, FORCE/TORQUE	22.7	5	56.6
178B	THERMOCOUPLE INDICATOR	6	8	9.4
179	TEMPERATURE BLOCK	4.5	200	1.7
179A	THERMOCOUPLES	0.5	0	0.3
179D	THERMOMETER, ELECTRONIC	5.4	14	8.7
180	TIMER, EVENT	0.2	0	0.2
181D	TRANSDUCER, PRESSURE	0.2	1	0.4
181G	TRASH CAN	SPACELAB		
182E	URINE VOLUME MEAS. SYST.	SHUTTLE		
182J	VCG COUPLER	0.2	2	0.5
182K	VISION TESTER	22.7	100	113.3
182P	VENTILATION UNIT, VERT.	19	40	32.7
182R	VERTEBRATE ECS	38	320	121
182T	VIDEO TAPE RECORDER	SPACELAB		
185	MULTIMETER	2	0	2.4
187A	WASTE STORAGE DEVICE	SPACELAB		
187C	WOODLAWN WANDERER	10	15	12.9
188	WORK AND SURGICAL BENCH	136	1000	.420

COST DATA BACK-UP SHEET

SPECIFICATION SHEETS
Ex: Cardiopulmonary Analyzer

EI DISPOSITION RECORD

EI & EU NAME & NUMBER		
EU #5 - Biochemical & Biophysical Analysis Unit		
6	Air Particle Sample Collector	In
7	GEMSAEC	In
13	Ion Specific Analyzer	Out
15A	Atmospheric Sampling Mnfld	In
50A	Commutator, Gas Manifold	Out
85	Gas Analyzer, Auto Physiological	Out
91	Gas Analyzer, Mass Spec.	In
125B	Meters, Asst.	Out
-	Mass Measurement Device	Out

Function provided by Automated Pot
Name changed to Atmospheric Samp
Included in Atmospheric Sampling S
Provided by Autoanalyzer (GEMSAEC) (5/7) and Automated Potentiometric Electrolyte Analyzer (5/7A).
Provided by various other EIs or experiment-specific meters; e.g., Multimeter (6/185), Oscilloscope (2/132), Numeric Display (2/131C), Spacelab CDMS, etc.
Provided by Mass Measurement Device (Micro) (4/122).

Figure 3-3. Example Equipment Item Definition Package.

The specification sheets and disposition record are published as a separate volume of this report — Volume V, Book 3. The cost back-up data sheets are collectively documented in Volume IV, Appendix A.

3.1.3 USE OF COMMONALITY IN PAYLOAD DEVELOPMENT. The commonality of the equipment from one laboratory to another is a significant factor in providing the scientific and programmatic flexibility required for life sciences missions of the Spacelab era. An example of this commonality is shown in Figure 3-4. This example shows a portion of the common equipment inventory which was listed in Table 3-1. The equipment items (EI) circled are those that partially make up the laboratory capability for a biology emphasis mini-lab (ML-2D) and a biomedical emphasis mini-lab (ML-3A). These two laboratories have 19 EIs that are common to each other out of the 57 and 24, respectively, total common equipment inventory items. This example shows that two laboratories, although supporting different aspects of life sciences research, require similar common equipment. Of course, the PI-specific equipment would determine the research emphasis of a particular laboratory. The flexibility of the common equipment inventory allows this duality of biology or biomedical emphasis.

A similar commonality exists for all of the defined payloads of this study. Table 3-2 is a matrix of all the defined mini and dedicated laboratories with the number of common equipment items noted. The meaning of the laboratory designation, ML-1A, MOD IA, etc., will be covered in Section 3.2. The numbers in bold type are the numbers of EIs required for each laboratory. The degree of commonality between laboratories can be determined by reading down the vertical column until reaching the boldfaced number and then reading across the horizontal row to the end.

TABLE 3-2. EQUIPMENT ITEM COMMONALITY BETWEEN LABORATORIES

	Defined Laboratories													
Labs	ML-1A	ML-2A	ML-3A	ML-4A	ML-5A	ML-2B	ML-2C	ML-2D	MOD-IA	MOD-IIA	MOD-IIIA	MOD-IIB	MOD-IIC	MOD-IIIB
ML-1A	**26**	20	18	9	6	21	22	21	24	24	24	22	22	22
ML-2A		**42**	20	12	8	34	42	41	42	42	42	41	41	40
ML-3A			**24**	10	7	20	20	19	24	24	24	22	22	22
ML-4A				**28**	6	12	11	12	26	28	28	26	26	26
ML-5A					**10**	8	8	8	10	10	10	10	10	10
ML-2B						**37**	34	33	36	36	37	35	35	33
ML-2C							**49**	47	48	48	48	47	43	42
ML-2D								**57**	49	56	56	56	45	44
MOD-IA									**118**	118	118	103	95	94
MOD-IIA										**143**	143	102	95	94
MOD-IIIA											**154**	112	95	94
MOD-IIB												**113**	95	93
MOD-IIC													**96**	93
MOD-IIIB														**95**

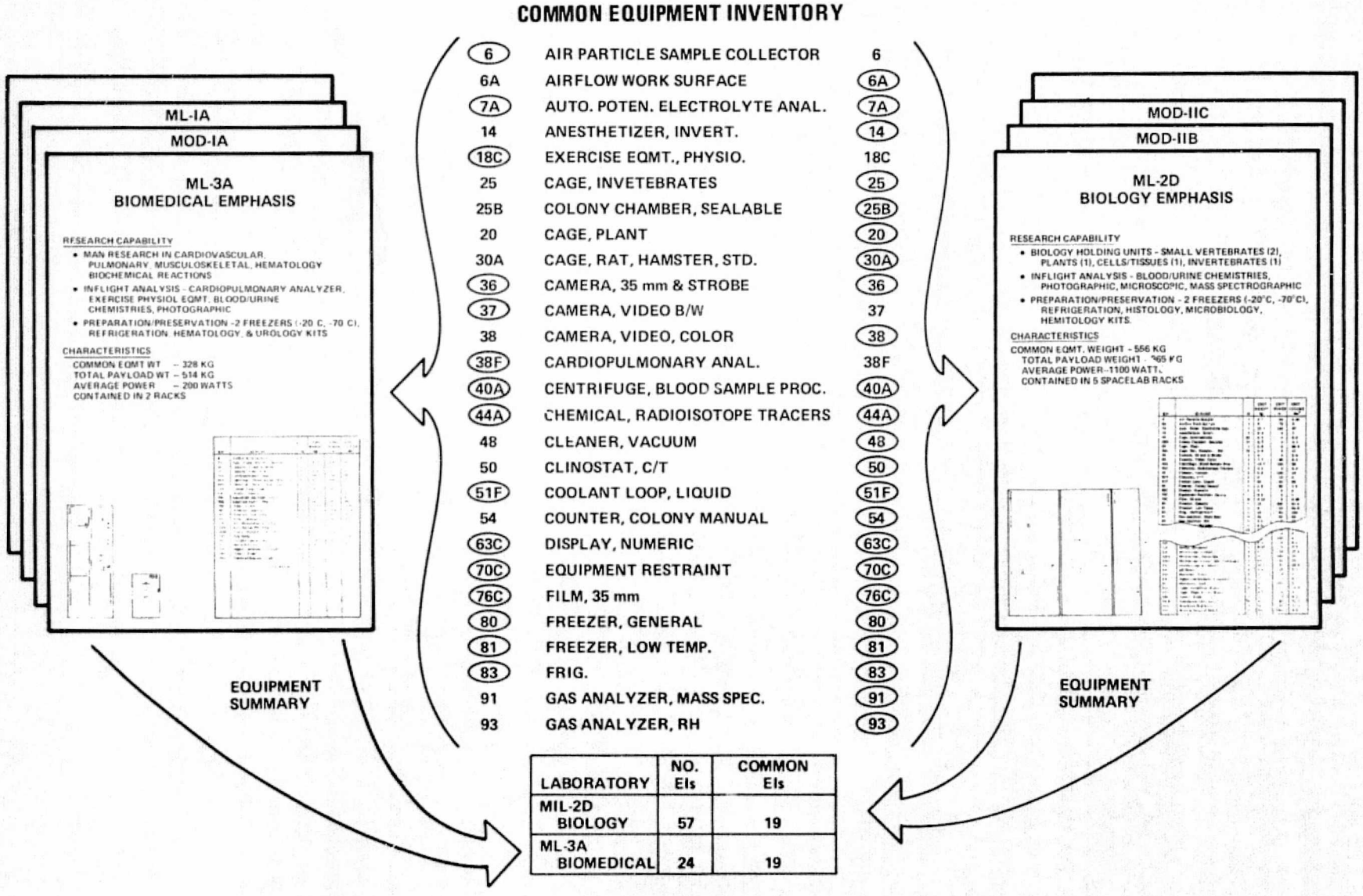


Figure 3-4. Example of Equipment Commonality.

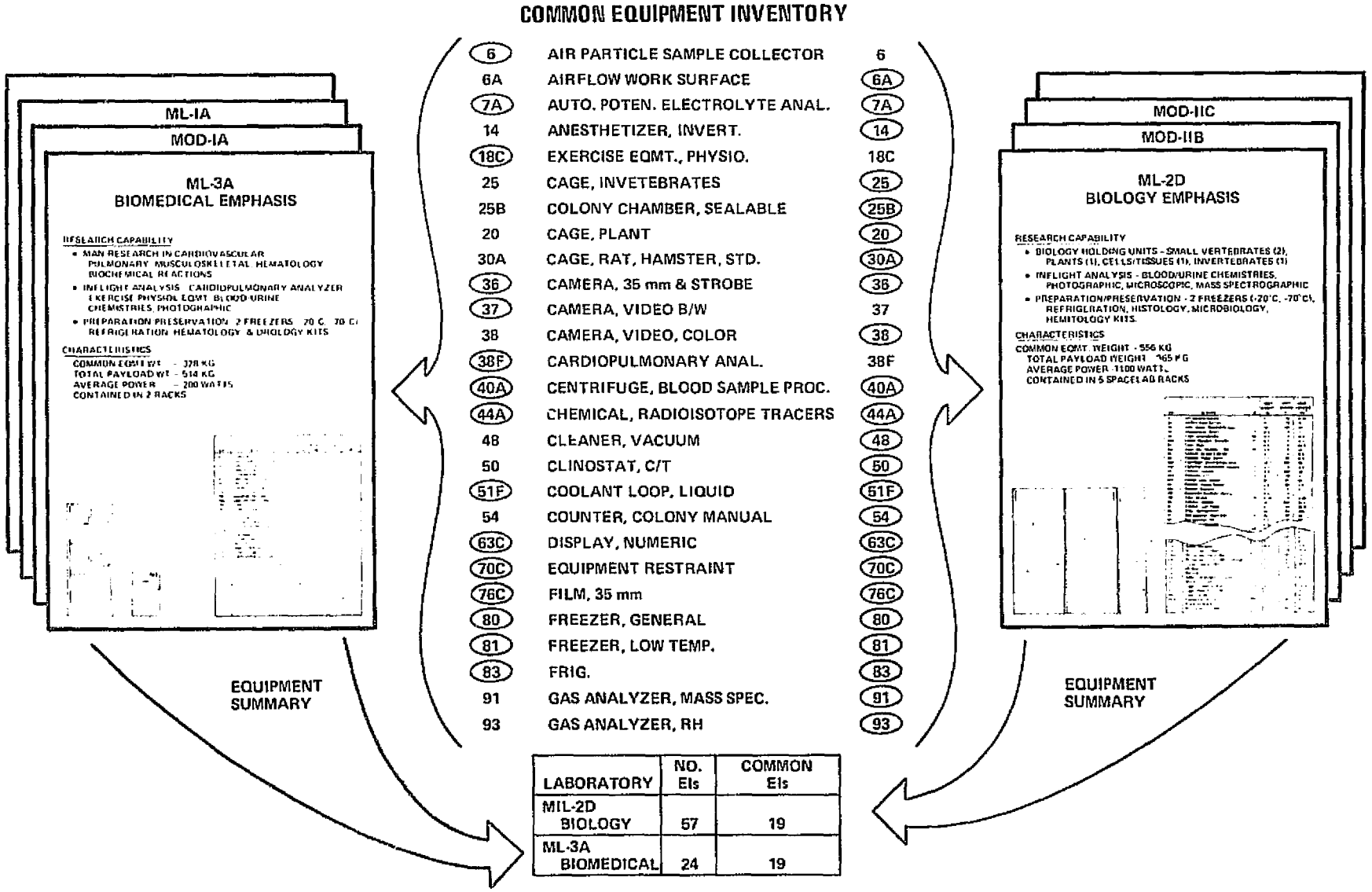


Figure 3-4. Example of Equipment Commonality.

3.2 LIFE SCIENCES LABORATORIES DEFINITION

Several life sciences laboratories (or payloads) in various classes have been defined in this study. Some laboratories were provided at the beginning of the study from prior GDC and MSFC studies (see References 3 and 9). These are called the baseline payloads. In addition, several alternative payloads were defined in response to new or additional science requirements as discussed in Section 2.

3.2.1 LABORATORY CLASSES. All payloads, whether baseline or alternative, are of one of three classes - carry-on laboratories, mini-laboratories, or dedicated laboratories. The carry-on laboratories are true "suitcase" experiments - small, lightweight, with a minimum of interfaces with the supporting spacecraft. Often serving a specific experiment, they are designed to fit within one or more of the stowage containers in the mid-deck area of the Orbiter crew compartment. An approximate limit of 23 kg (50 lb) was arbitrarily placed on carry-on labs and they were packaged to fit into compartments measuring 43 cm wide by 36 cm high by 51 cm deep (17 x 14 x 20 in). While basically intended to be flown early in the Shuttle program, particularly during the proof-test missions, they can be taken aboard any flight of opportunity. This is especially true when the manned Spacelab is not available for the more extensive life sciences laboratories. The interfaces with the Orbiter are expected to be minimal and consist primarily of power and thermal control. A typical example of a carry-on payload is the Woodlawn Wanderer, the S015 single-cell experiment taken aboard the Apollo command module during the Skylab program. A completely automated experiment, it required power and a minimal crew interface. It and three other candidate carry-on laboratories were initially defined and two were selected for the baseline flight schedule.

Mini-labs are more comprehensive life sciences laboratories and are intended to be flown on shared Spacelab missions. Generally, they support several experiments in a single life sciences sub-discipline such as biomedicine, life support/protective systems, etc. They range in size from tens to several hundreds of kilograms of common equipment and occupy from one to several Spacelab racks. The largest of the mini-labs defined occupied approximately one third of the Spacelab long module. There will be significant interfaces of the mini-labs with the Spacelab. Primary ones will be power, data management, thermal, environmental and crew. Due to the multi-discipline nature of the flight not all of the payload specialists will be life scientists. Crew skills and available manhours for life sciences research will be somewhat limited by the sharing payloads. Consequently, mini-labs emphasize sampling for ground analysis rather than extensive on-board analysis. They are primarily intended for 7-day missions but 30 days are desirable, particularly for chronic biological studies.

Dedicated laboratories are the most comprehensive payloads for life sciences. Covering all aspects of life sciences research, they occupy the entire Spacelab pressurized module, generally the long module. Consequently, the payloads range up to several thousand kilograms of weight, occupy up to 16 standard racks and fully utilize Spacelab stowage and aisleway areas. Interfaces with Spacelab sub-systems will be extensive, with the payload totally integrated with the carrier vehicle.

Seven and 30-day missions are anticipated and, with an estimated crew of three life sciences payload specialists, both in-depth on-board analyses and return for ground analysis are provided. Figure 3-5 shows example sketches of the three types of life sciences labs defined in this study.

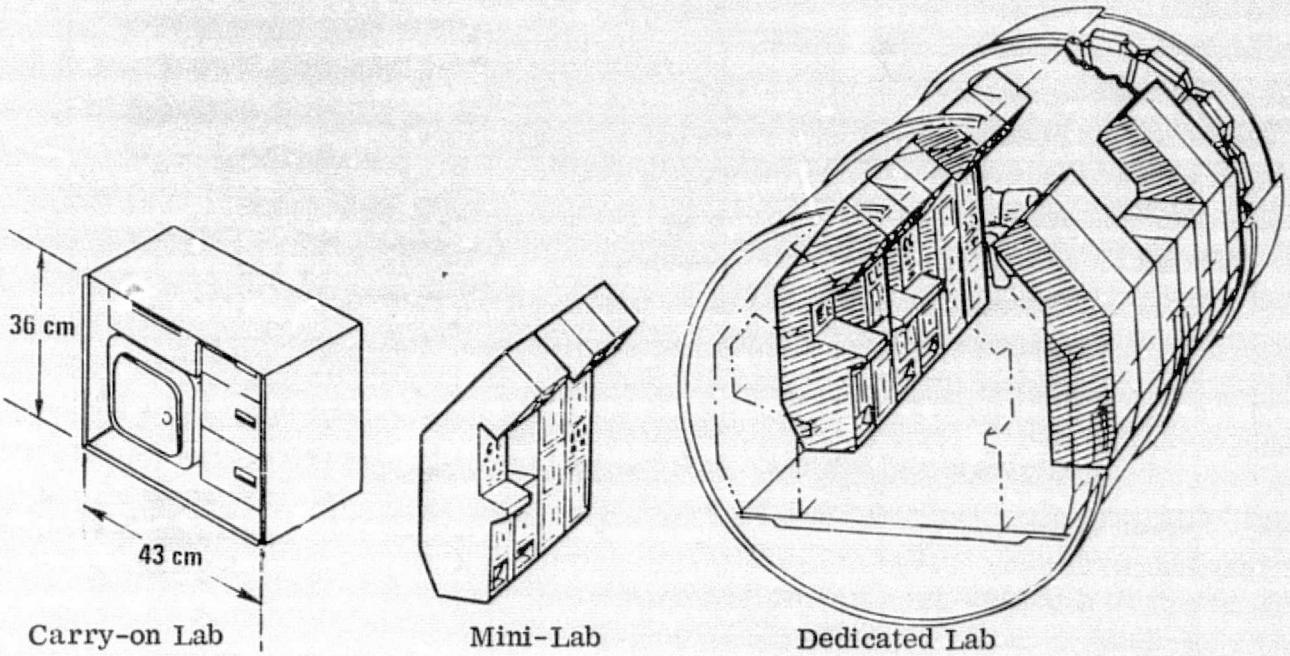


Figure 3-5. Life Sciences Laboratory Concepts

3.2.2 LABORATORY DEFINITION AND CAPABILITY. Early in the study some 20 baseline and alternative payloads were defined. These consisted of 4 carry-on, 8 mini-labs and 8 dedicated labs. Subsequent to the study mid-term review, two carry-ons, one mini-lab and two dedicated labs were dropped from further consideration and one mini-lab was added. The total complement of 16 laboratories used for the remaining tasks of the study, along with their major research emphasis, is shown in Table 3-3. Payload nomenclature is arabic numerals for carry-on and mini-labs; roman numerals for dedicated laboratories; letter A for baseline payloads, B, C and D for alternative payloads.

The column labeled "Research Emphasis" in Table 3-3 gives a very general description tion of the laboratory's research capability. A more detailed description for each laboratory was developed. An example of the research requirements and specific capability for the US/ESA First Spacelab mission (Mini-lab ML-1A) is shown in Table 3-4. Shown also are some of the major equipment items in the laboratory. A complete listing of the equipment drawn from the common equipment inventory (Section 3.1) is shown in Table 3-5. Tables containing research capability and equipment listings for all of the 16 defined laboratories are given in Volume V, Book 2, Appendix B.

TABLE 3-3. LIFE SCIENCES CANDIDATE LABORATORIES

Type	Designation	Research Emphasis
Carry-On	COL-2A	Biomedicine - Blood Sampling
	COL-3A	Biomedicine - Urine, Electrolytes
Mini-Lab	ML-1A (first S/L mission)	Biomedicine - OFO, Vestibular, Urine, Single Cell Studies
	ML-2A	Biomedicine/Biology - Small Vertebrates
	ML-3A	Biomedicine - Man
	ML-4A	Life Support/Protective Systems
	ML-5A	Man Systems Integration
	ML-2B	Biomedicine/Biology - Primates
	ML-2C	Biomedicine/Biology - Small Vertebrates/Cells & Tissues
	ML-2D	Biology - Small Verts, Plants, C&T, Invertebrates
Dedicated	MOD IA	Biomedicine - Man, Vertebrates, Cells & Tissues
	MOD IIA	Biomedicine/Biology/Adv. Technology
	MOD IIIA *	Biomedicine/Biology/Adv. Technology - Centrifuge
	MOD IIB	Biology/Biomedicine
	MOD IIC *	Biology/Biomedicine
	MOD IIIB *	Biology/Biomedicine - Centrifuge

*30-day Laboratories

TABLE 3-4. LABORATORY RESEARCH CAPABILITY
Example: Mini-Lab ML-1A

Research Requirements	Specific Capability	Major Equipment: OFO Packages (2)	Rotating Litter Chair	Hem./Urology Kits	Freezers	Centrifuge Proc.	Human Phys. Kit	Auto. Poten. Elec. Anal	Woodlawn Wanderer
Biomedicine									
Vestibular	Mechanical & neural responses of otolith organs to zero-g.	x							
	Role of visual cues to space nausea.		x						
	Role of altered body fluid volume, pressure & distribution to space nausea.			x	x	x			
Cardiovascular	Gauer-Henry reflex.			x	x	x			
	ECG, VCG						x		
	Anthropomorphic measurements of fluid shifts.						x		
	Altered vascular flow, volume & pressure relationships.			x	x		x		
Biochemical Reactions	Measure stress hormone, enzyme, fluid/electrolye & fluid volume changes.							x	
Cellular Physiology	Single-cell type culture responses to zero-g — bone marrow.								x

TABLE 3-5. COMMON EQUIPMENT LIST
Example: Mini-Lab ML-1A

EI#	EI NAME	Q	UNIT WEIGHT kg	UNIT POWER w	UNIT VOLUME dm^3
6A	Airflow Work Surface	1	5	75	6
7A	Auto. Poten. Elec. Analyzer	1	12.7	100	57
31	Calculator, Pocket	1	0.47	0	0.4
36	Camera, 35 mm & Strobe	1	2	0	2
37	Camera, Video, B/W	1	4.4	15	3
40A	Centrifuge, Blood Sample	1	12.7	100	25
51F	Coolant Loop, Liquid	1	30	50	25
63C	Display, Numeric	1	2	2	4
70C	Equipment Restraint Device	1	0.5	0	1
76C	Film, 35 mm	3	0.13	0	0.05
80	Freezer	1	15	200	61.4
81	Freezer, Low Temp.	1	8	10	30.5
106	Kit, Hematology & Urology	1	5	0	9
106A	Kit, Cleanup	1	1.5	0	4
110	Kit, Microbiology	1	2	0	3
110C	Kit, Human Physiology	1	3	0	8
114E	Lamp, Portable Hi Int. Photo	1	6.3	150	6
116	Log Books	1	0.5	0	0.4
126	Microscope, Compound	1	11	15	27.4
126J	Microscope Accessory Kit, Compd.	1	10	15	25
131J	OFO Experiment Packages	2	45	20	80
132	Oscilloscope & Camera	1	11.7	75	28.9
153	Recorder, Voice	1	1	0	1
153A	Rotating Litter Chair/Console	1	100.2	127	239
156	Signal Conditioners (Couplers)	6	0.2	2	0.5
182E	Urine Volume Measurement System		In Orbiter		
187C	Woodlawn Wanderer	1	10	15	12.9
	TOTAL WEIGHT		347		

Carry-on laboratories COL-2A and COL-3A are single-experiment payloads supporting respectively blood and urine collection, sampling and preservation for ground analysis. They are used to investigate the Gauer-Henry reflex and fluid redistribution mechanisms associated with the transition from 1-g and hypergravity to zero-g. Mini-lab ML-1A, scheduled for the first Spacelab mission, supports four or five different experiment areas ranging from a repeat of the Skylab M131 human vestibular experiment to the orbiting frog otolith (OFO) experiment previously flown as an automated satellite. Mini-lab ML-2A supports 16 small vertebrates (rats, hamsters, etc.) and permits in-depth research including surgery on these organisms. ML-3A permits detailed investigations in the biomedical area and uses man as the experimental subject. Mini-labs 4A and 5A are dedicated to life support/protective systems and man systems integration respectively.

Alternate mini-lab payloads were defined in order to broaden the research coverage of the baseline payloads. ML-2B supports two restrained primates placed in the University of California, Berkeley "monkey-pods". This laboratory permits in-depth man-surrogate biomedical experimentation similar to that of the Biosatellite primate experiments. Invasive monitoring and metabolic measurements will support experiments on the acute effects of zero-g. ML-2C is an extension of ML-2A in that the capability for cells and tissues growth, maintenance and study is added to the small vertebrate research capability. ML-2D adds plant and invertebrate capability to ML-2C and consequently permits research in all biology areas of interest except higher vertebrates.

The dedicated laboratories offer broad research capability both in the number of areas covered and the depth of analysis within each. The baseline laboratory MOD IA is a biomedical emphasis mission and supports in-depth research on man, man-surrogates (primates, small vertebrates) and cell/tissues. Both on-board analysis and preparation for ground analysis is provided. MOD IIA adds capability for plant and invertebrate research along with the LS/PS and MSI areas. MOD IIIA, a 30-day payload, adds the Bioresearch Centrifuge for studies of the chronic effects of weightlessness. Alternative dedicated labs MODs IIB, IIC and IIIB are primarily biology laboratories, which however, by the selection of experiments, can also cover biomedical areas as well. MOD IIB has the complete biology capability from primates to plants while MOD IIC supports both large and small vertebrates. MOD IIIB contains small vertebrates only but adds the Bioresearch Centrifuge. It and MOD IIC are 30-day missions.

Table 3-6 illustrates the spectrum of research capability of the 16 laboratories across the life sciences research requirements areas. This matrix shows the primary research emphasis to be in biomedicine using man and man-surrogates (i.e., vertebrates). Fundamental biological research is performed mostly by dedicated laboratories with the exception of biology mini-lab ML-2D. However, as stated before, the research emphasis of a particular mini-lab or dedicated lab can be directed toward either biomedicine or biology by selection of the specific experiments.

It was noted at the beginning of this section that initially five other payloads were defined but subsequently dropped from further consideration. These are listed in Table 3-7 for completeness.

TABLE 3-6. SPECTRUM OF LABORATORY PAYLOAD CAPABILITY

RESEARCH REQUIREMENT	CANDIDATE LABORATORIES													
	CARRY-ON		MINI-LAB							DEDICATED LABS					
	2A	3A	1A	2A	3A	4A	5A	2B	2C	2D	1A	IIA	IIIA	IIB	IIC	IIIB
BIOMEDICINE																
VESTIBULAR		√	√	√	√			√	√		√	√	√	√	√	√
CARDIOVASCULAR	√	√	√	√	√			√	√		√	√	√	√	√	√
PULMONARY								√	√		√	√	√	√	√	√
BIOCHEMICAL REACTIONS	√		√	√	√			√	√		√	√	√	√	√	√
MUSCULOSKELETAL		√	√	√	√			√	√		√	√	√	√	√	√
HEMATOLOGY	√		√	√	√			√	√		√	√	√	√	√	√
PSYCHOMOTOR PERF.			√	√	√		√	√	√		√	√	√	√	√	√
BIOLOGY																
HIGHER VERTEBRATE								√			√	√	√	√	√	
LOWER VERTEBRATE				√					√	√	√	√	√	√	√	√
CELLULAR & MOLECULAR			√						√	√	√	√	√	√		
INVERTEBRATE										√		√	√	√		
PLANT										√		√	√	√		
RADIOBIOLOGY										√		√	√	√		
MICROBIOLOGY										√		√	√	√		
MAN-SYSTEM INTEGRATION																
MSI TESTING							√				√	√				
LS/PS																
LS HARDWARE TESTING						√					√	√				
ZERO-g EFFECTS						√					√	√				

TABLE 3-7. ADDITIONAL PAYLOADS

Type	Designation	Wt.	Research Emphasis
Carry-On	COL-1A	22.9	Biomedicine - Electrolytes
Carry-On	COL-4A	10	Single-cell studies. Woodlawn Wanderer
Mini-Lab	ML-3B	83.5	Biomedicine - Man
Dedicated	MOD IB	556	Biomedicine - Man
Dedicated	MOD IC	1242	Biomedicine - Man, Vertebrates

3.2.3 LABORATORY/EXPERIMENT ACCOMMODATION. In order to determine whether some of the initial payload concepts were compatible with proposed experiments, a set of typical experiments in three categories supplied by Ames Research Center principal investigators (Reference 11) were evaluated in terms of accommodation. Three mini-labs, ML-1A, -2B, and -2D, were compared to the research requirements. These comparisons are given in Tables 3-8, 9 and 10. Each shows the referenced experiments or experiment areas and the major equipment provided by the mini-lab. In most cases, the addition of PI specific items to the existing

TABLE 3-8. HUMAN VESTIBULAR EXPERIMENT ACCOMMODATION

Equipment	Human Vestibular Experiments								
	Otolith Function Experiments			Visuo-Vestibular Experiments			M131 Vestibular Experiments		
	Vestibulo-spinal Reflex	Linear Acceleration Threshold	H-Reflex	Visual Accommodation	Tilt Illusion	Linear Vection Threshold	Repeat of M131 Experiment with Eyes Open		
Mini-Lab 1A									
Orbiting Frog Otolith Exp.									
EMG Electrodes	×		×						
Rotating Litter Chair							×		
ERNO Space Sled	×	×	×	×					
PI Equipment									
Hartunger Refractometer				×					
Viewing Box/Peripheral Visual Fields						×			
Frontal Display Field					×				
Electric Stimulator			×						

TABLE 3-9. BIOMEDICAL/PRIMATE MINI-LAB ACCOMMODATION

Mini-Lab 2B Equipment		Typical Spacelab Experiment Areas									
		Cardiovascular	Blood Distribution	Enzyme Changes	Biorhythms	Metabolic Balance	Bone Metabolism	Gastrointestinal	Vestibular Function	Pharmacological	Organs & Vessels Contours
101B	Holding Unit, Monkey										
101B	Holding Unit, Monkey Pod	x	x	x	x	x	x	x	x	x	x
91	Gas Analyzer, Mass Spec.								x		
7A	Auto. Poten. Electrolyte Analyzer	x		x		x				x	
40A	Centrifuge, Blood Sample Proces.	x		x		x				x	
106	Kit, Hematology & Urology	x	x	x		x	x	x		x	
80,81,83	Freezers, Frig.	x		x		x	x	x		x	
156	Signal Conditioners - E G, EOG, EEG	x			x				x		
138E	Physiol. Multichannel Sensor Sys.	x	x		x			x	x		
150B	Receiver	x	x		x			x	x		
Equipment to be added as PI specific:											
	X-ray/Video Equipment										x
	Linear Acceleration Track								x		
	Threshold Response Lever								x		

TABLE 3-10. SMALL ANIMAL RESEARCH MINI-LAB ACCOMMODATION

Mini-Lab 2D Equipment		Typical Spacelab Experiment Areas													
		Bone Metabolism	Bone Parameters	Hormonal Studies	Hemolysis & RB Life Span	Cell-Mediated Immunity	Drosophilia Aging	Eye Ultrastructure	Cardiac Norephephrine	Endocrine Glandes	Gastric Ulceration	Liver Regeneration	Metabolic Rate & Deep Body Temp.	Birth & Postnatal Survival	Muscle Atrophy
103	Holding Unit, Small Vert.	x	x	x	x	x		x	x	x	x	x	x	x	x
98C	Holding Unit, Invertebrates						x								
188	Work & Surgery Bench	x	x	x				x	x	x	x	x			x
80,81,83	Freezers, Frig.	x	x	x	x				x	x		x	x		x
103B,110	Incubator, Microbio. Kit					x									
114A	Dissection Kit														
126,126J	Microscope & Access. Kit	x	x			x	x	x	x	x	x	x	x	x	x
44A	Chemicals, Radio. Tracers	x	x		x	x						x			x
36	Camera, 35mm	x	x	x			x				x			x	x
38	Camera, Video/Monitor			x			x				x			x	x
40A	Centrifuge, Blood Sample			x		x			x						
Eqmt. to be added as PI Specific:															
	X-ray or Bone Densitometry	x	x												
	Isotope Counting			x	x	x									
	Tissue Embedding, Microtome		x	x											
	Electron Microscope		x	x				x	x	x	x	x		x	x
	Spectroscopy			x					x			x	x		

common inventories will allow accomplishment of the specific research goals. In one case, human vestibular research, the addition of the ESA "Space Sled" (or a similar device to provide a definitive acceleration profile) is required. It was therefore assumed that the ESA device would be available for this set of experiments. Specific comments in the three experiment areas are:

a. Human Vestibular Function - ML-1A together with the ESA "Space Sled" will accommodate 5 of the 6 experiments. The addition 4 small PI equipment items will handle all 6. In addition, ML-1A permits invasive otolith determination (OFO experiment) and repeat of Skylab M 131 experiment.

b. Biomedical Research - Primates - 8 of the 10 experiment areas can be accommodated to some extent by the defined ML-2B. The addition of x-ray/video equipment, a linear acceleration track and a threshold response lever permits coverage of all 10.

c. Small Animal Research - All 14 experiments areas can be accommodated to some extent by the defined ML-2D. Addition of PI specific equipment such as x-ray, radioisotope counting, microtome, electron microscope will allow in-depth coverage in all areas.

Generally, this analysis reaffirmed that the CORE development approach for the life sciences program will satisfy specific experiments and will provide the flexibility needed to be responsive to changing scientific requirements.

3.3 MISSION MODEL DEVELOPMENT

A prime objective of this study was to determine the readiness status of the life sciences hardware needed for the intended laboratory flight schedule. As a first step in this task, various development and operational options were synthesized and assessed. These options combined the payloads defined by the time-phased research priorities with a baseline flight schedule to produce alternative ways of accomplishing the research program. From these mission model options, or simply mission models, several programmatic elements were determined in support of the Task 3 effort. These included: hardware development requirements including supporting research and technology (SRT), hardware development schedules, program hardware development and procurement costs, and total program costs. Development of the mission models considered such factors as scientific responsiveness (priority of research), equipment inventory buildup and funding spreads. Two fundamental modes of development were considered: parallel and series. Parallel development means simultaneous development and operation of mini-labs and dedicated labs while series development refers to first mini-lab, then dedicated laboratory development and operation. Obviously each mode has advantages and disadvantages relative to early research opportunities, use of life sciences vs general payload specialists, learning and growth from one laboratory type to another and the like. The defined mission models are exemplary and were used to examine the full breadth of programmatic considerations. The actual flight schedule probably would be some combination of all the mission models defined in this study.

3.3.1 BASELINE FLIGHT SCHEDULE. A baseline flight schedule (NASA mission model) was used to create the various mission models. This schedule is shown in Figure 3-6. This baseline schedule was derived from several sources of background guideline data:

1. Appendix D of the Statement of Work.
2. OMSF/MMS Life Sciences Payload Schedule, 15 August 1974 (Reference 4).
3. Life Sciences Mission Model, MSFC, PS02, October 1974 (Reference 12).
4. Updated Flight Model, Associate Administrator for Manned Space Flight, 2 October 1974 (Reference 5).

Thi baseline flight schedule shows two carry-on laboratories, tentatively on Shuttle fl[illegible]ts 4 and 6; nine mini-labs beginning with the First Spacelab Mission (Mission 8) in July 1980; and eight dedicated missions beginning with Mission 12 in January of 1981. The baseline generally shows two flights per year for both mini-labs and dedicated labs. The baseline was not extended beyond 1984 and the 19 flights formed the common costing basis for all of the mission models.

3.3.2 MISSION MODEL DEFINITION. Initially during the Task 1 effort four candidate mission model options were defined. These are shown in Figure 3-7. Each mission model including the baseline was based upon a flight schedule containing 16 laboratories and 16 flights. The common research equipment inventory containing

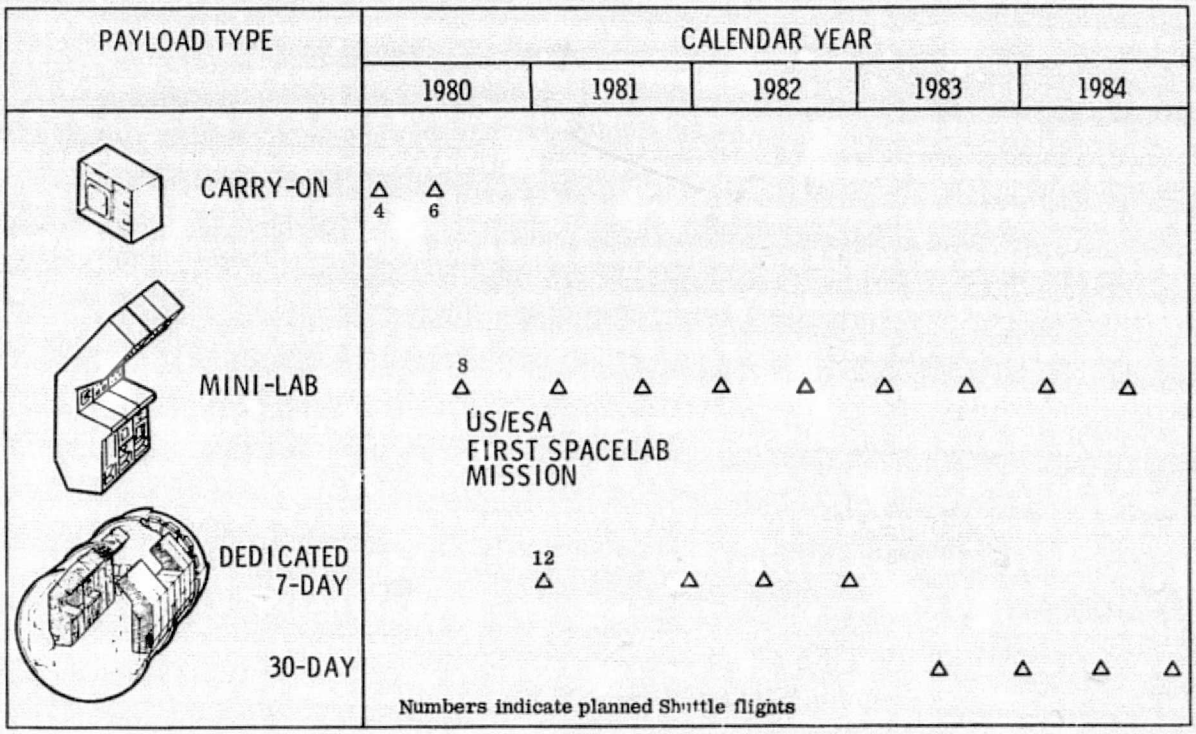


Figure 3-6. Baseline Mission Model Flight Schedule

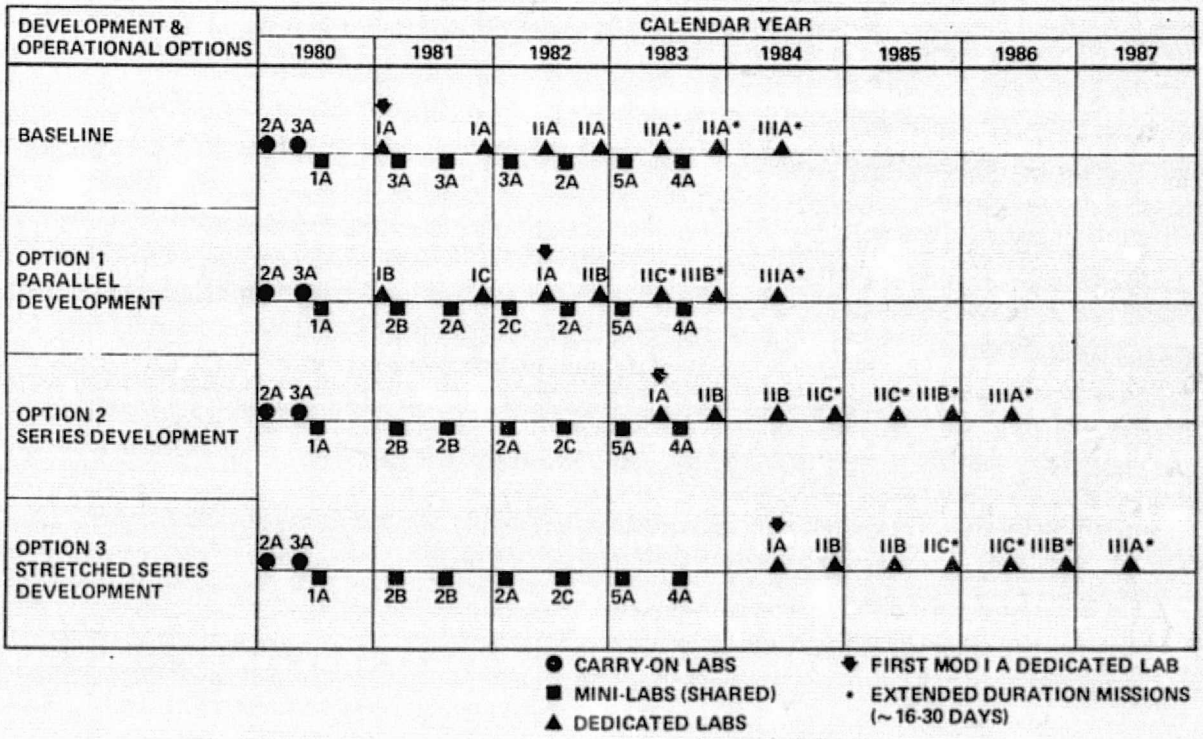


Figure 3-7. Candidate Life Sciences Mission Models

approximately 175 items is the same in each mission model; only the scheduling of development or the number of equipment items required for each payload is varied. The payloads have previously been identified in Tables 3-3 and 3-7.

During 1980, all mission models have the same flight schedule composed of three laboratories; namely, two carry-on laboratories (COL 2A and COL 3A) planned for installation in the crew compartment of the Shuttle Orbiter, and mini-lab ML 1A for the first Spacelab mission.

The baseline mission model is based upon the parallel development of the mini-labs and dedicated laboratories and covers a $4\frac{1}{2}$-year period. The breakdown of the laboratory types includes the three mentioned above during 1980 plus six more mini-labs and seven dedicated laboratories. Option 1, a parallel development of mini-labs and dedicated laboratories, covers the same time span as the baseline; however, a reduced dedicated laboratory capability is included that coincides with the baseline (MOD IA) flight date. This reduced-capability, dedicated laboratory was included to decrease early and total funding.

Option 2 is a series development, starting with the mini-labs and finally working into the dedicated laboratories in a $6\frac{1}{2}$-year period. This approach delays the peak funding required to about two years later than the baseline. Option 3 is a series development similar to Option 2. The basic difference is the stretch out in time to $7\frac{1}{2}$ years and the absence of any overlap in mini-lab and dedicated laboratory operations. The peak funding rate for this option is the lowest of all considered.

The four candidate mission models shown in Figure 3-7 were reviewed by the NASA Life Sciences Working Group in June 1975 following the contract mid-term review. Two of these models were selected for Task 2 analysis: the baseline and Option 3 or the stretched series development, subsequently renamed the biomedical emphasis mission model. After a review at NASA Headquarters on July 1, a third mission model, emphasizing biology research, also a series development, was added. These three selected mission models are shown in Figure 3-8 and the specific flight dates are indicated in Table 3-11. Note that the baseline has 19 flights while the other two have 16.

The major difference between the biomedical emphasis and biology emphasis models is the use of the mini-lab ML-2D, which supports all biological organisms. It should be noted that all of these mission models and their payloads can emphasize either pure biological or biomedical research, dependent on the experiment complement selected for a particular flight. The flexibility of the payload's common equipment allows this duality of research emphasis.

Figure 3-9 shows the cumulative equipment item total needed for each flight date of each mission model. The philosophy of developing an item for its first scheduled flight and not before was used throughout. The data shows that the baseline requires approximately 75% of the equipment inventory being developed by January 1981, with

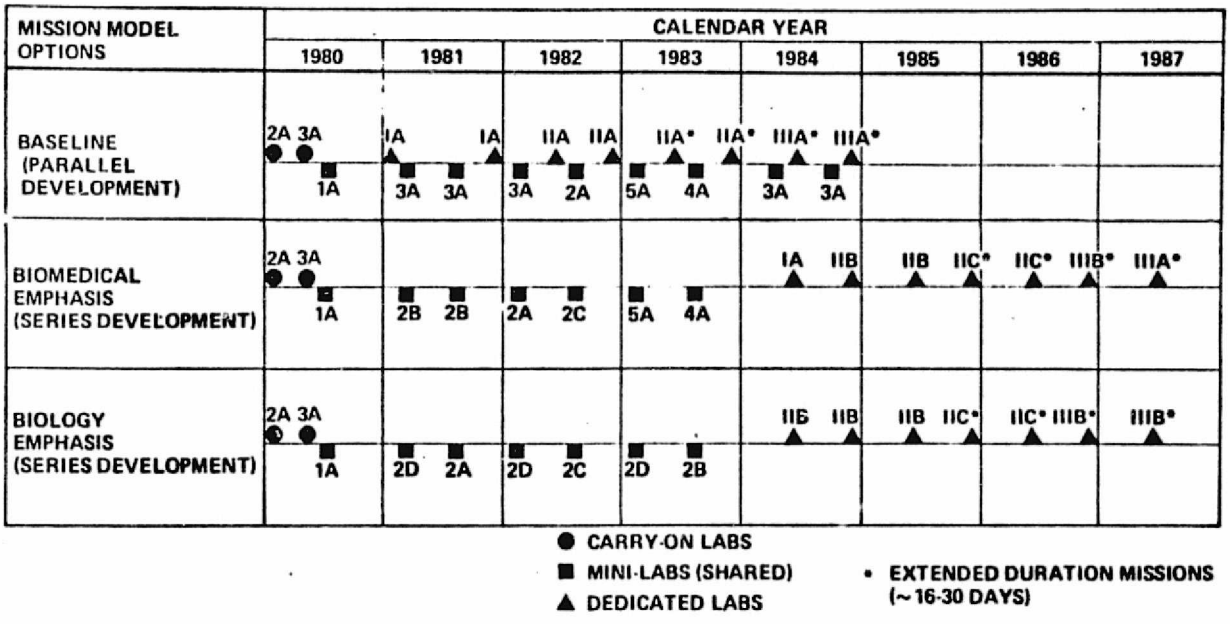


Figure 3-8. Selected Life Sciences Mission Models

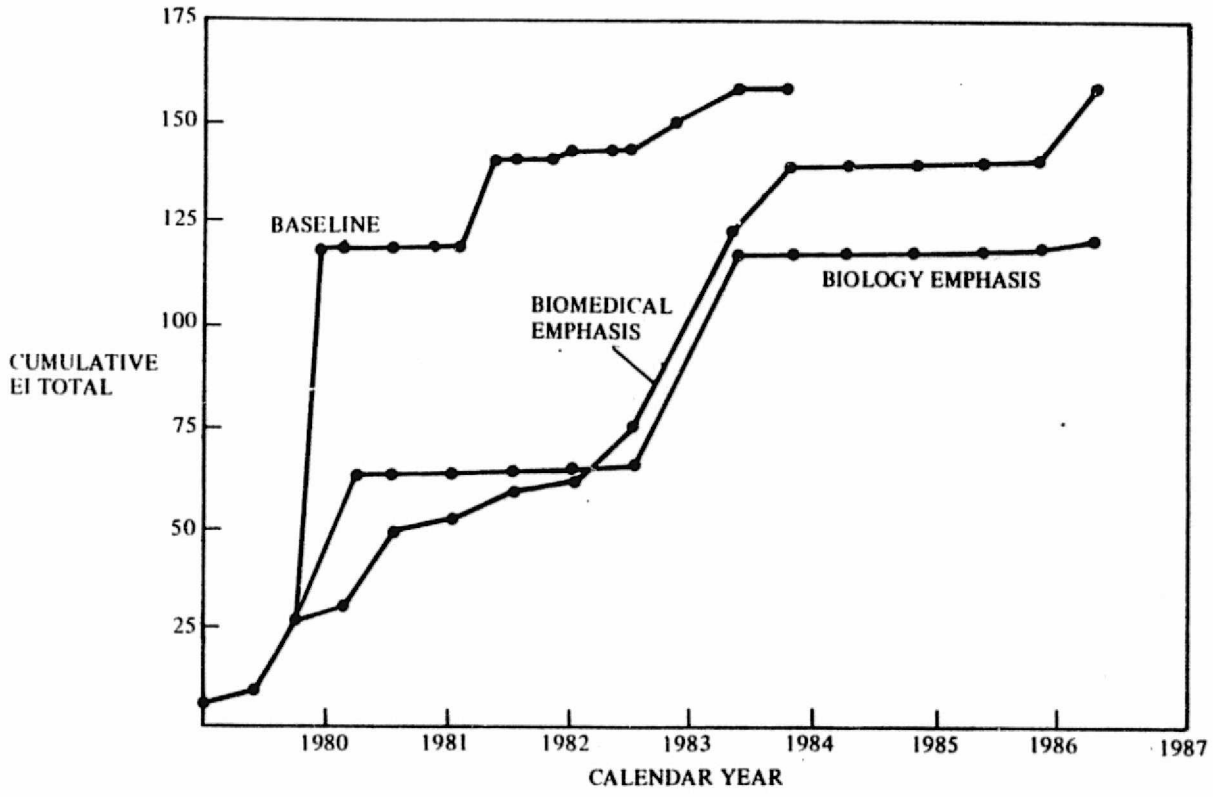


Figure 3-9. EI Development Vs Need Date

TABLE 3-11. FLIGHT SCHEDULES OF SELECTED MISSION MODELS

Baseline		Biomedical Emphasis		Biology Emphasis	
Flight Date	Payload	Flight Date	Payload	Flight Date	Payload
Jan 1980	COL-2A	Jan 1980	COL-2A	Jan 1980	COL-2A
May 1980	COL-3A	May 1980	COL-3A	May 1980	COL-3A
July 1980	ML-1A	July 1980	ML-1A	July 1980	ML-1A
Jan 1981	MOD IA	Mar 1981	ML-2B	Mar 1981	ML-2D
Mar 1981	ML-3A	Aug 1981	ML-2B	Aug 1981	ML-2A
Aug 1981	ML-3A	Feb 1982	ML-2A	Feb 1982	ML-2D
Dec 1981	MOD IA	Aug 1982	ML-2C	Aug 1982	ML-2C
Feb 1982	ML-3A	Feb 1983	ML-5A	Feb 1983	ML-2D
June 1982	MOD IIA	Aug 1983	ML-4A	Aug 1983	ML-2B
Aug 1982	ML-2A	June 1984	MOD IA	June 1984	MOD IIB
Dec 1982	MOD IIA	Dec 1984	MOD IIB	Dec 1984	MOD IIB
Feb 1983	ML-5A	June 1985	MOD IIB	June 1985	MOD IIB
June 1983	MOD IIA	Dec 1985	MOD IIC	Dec 1985	MOD IIC
Aug 1983	ML-4A	June 1986	MOD IIC	June 1986	MOD IIC
Dec 1983	MOD IIA	Dec 1986	MOD IIIB	Dec 1986	MOD IIIB
April 1984	ML-3A	June 1987	MOD IIIA	June 1987	MOD IIIB
July 1984	MOD IIIA				
Oct 1984	ML-3A				
Dec 1984	MOD IIIA				

considerable reuse in subsequent flights. The other two options reduce this rapid EI buildup by substituting alternative payloads (mini-lab and dedicated) that require less new development early in the program. This approach results in reduced research capability in the early stages of the program, but not in end total capability, particularly for the biomedical emphasis option. The lower end point for the biology emphasis mission reflects the absence of biomedical equipment in this option.

3.3.3 MISSION MODEL RESEARCH CAPABILITY. Figure 3-10 summarizes the research capability of the three selected mission models. The time-phased research areas are compared to the time that they are first scheuled for study in the various options. Since each option contains the same three biomedical emphasis payloads in 1980 - two carry-on laboratories and the U.S./ESA mini-lab ML-1A - initiation of biomedical research is identical. The solid bars indicate when the research capability is available, but do not reflect continuous activity throughout the period.

BASELINE

DISCIPLINE AREA	TIME-PHASED RESEARCH PRIORITY	YEAR 1980	1981	1982	1983	1984	1985	1986	1987
BIOMEDICINE	VESTIBULAR								
	CARDIOVASCULAR								
	PULMONARY								
	BIOCHEMICAL								
	MUSCULOSKELETAL								
	HEMATOLOGY								
	PSYCHOMOTOR PERF								
BIOLOGY	HIGHER VERTEBRATES								
	LOWER VERTEBRATES								
	CELLULAR & MOLECULAR								
	INVERTEBRATE								
	PLANT								
	RADIOBIOLOGY								
	MICROBIOLOGY								
MAN-SYSTEMS INTEGRATION	MSI TESTING								
LS/PS	LS HARDWARE TEST								
	ZERO-g EFFECTS								

BIOMEDICAL EMPHASIS

DISCIPLINE AREA	TIME-PHASED RESEARCH PRIORITY	YEAR 1980	1981	1982	1983	1984	1985	1986	1987
BIOMEDICINE	VESTIBULAR								
	CARDIOVASCULAR								
	PULMONARY								
	BIOCHEMICAL								
	MUSCULOSKELETAL								
	HEMATOLOGY								
	PSYCHOMOTOR PERF								
BIOLOGY	HIGHER VERTEBRATES								
	LOWER VERTEBRATES								
	CELLULAR & MOLECULAR								
	INVERTEBRATE								
	PLANT								
	RADIOBIOLOGY								
	MICROBIOLOGY								
MAN-SYSTEMS INTEGRATION	MSI TESTING								
LS/PS	LS HARDWARE TEST								
	ZERO-g EFFEC'S								

BIOLOGY EMPHASIS

DISCIPLINE AREA	TIME-PHASED RESEARCH PRIORITY	YEAR 1980	1981	1982	1983	1984	1985	1986	1987
BIOMEDICINE	VESTIBULAR								
	CARDIOVASCULAR								
	PULMONARY								
	BIOCHEMICAL								
	MUSCULOSKELETAL								
	HEMATOLOGY								
	PSYCHOMOTOR PERF								
BIOLOGY	HIGHER VERTEBRATES								
	LOWER VERTEBRATES								
	CELLULAR & MOLECULAR								
	INVERTEBRATE								
	PLANT								
	RADIOBIOLOGY								
	MICROBIOLOGY								
MAN-SYSTEMS INTEGRATION	MSI TESTING								
LS/PS	LS HARDWARE TEST								
	ZERO-g EFFECTS								

Figure 3-10. Research Capability of Selected Mission Models

The baseline mission model, with its dedicated (MOD IA) laboratory scheduled for flight in January 1981, is the first to include all recommended biomedicine time-phased research areas. In this model, man, using ML-3A and the dedicated labs, and higher and lower vertebrates are available in 1981 to accomplish the biomedical research. The higher vertebrates are used for invasive studies investigating the acute medical problems associated with the early portions of the space flight. The lower vertebrate studies support the investigations of chronic effects and are more appropriate for later, longer-duration missions. In all biomedical cases, the baseline provides for the earliest initiation of the recommended biomedical time-phased research.

The biomedical emphasis (series development) mission model delays the start of biomedical research from 3 to 15 months. The delay time for a portion of biology research is 30 months. The schedule of research organisms for this option shows a delay of about three months for man and higher vertebrates. Restrained primates are studied using ML-2B. The lower vertebrates are delayed 15 months compared to the baseline.

The biology emphasis mission model provides the earliest laboratory (ML-2D) devoted to pure biology research. This option naturally shows early emphasis in biology and decreased (but not total absence of) biomedical research. Except for some cardiovascular and musculoskeletal research using the human physiology kit and exercise physiology equipment, biomedical research on man is reduced in 1981. The capability for blood and urine collection and analysis still exists, however, but is not presented in this chart. In addition, there is no LS/PS or MSI capability in this option.

SECTION 4

SYSTEMS DESIGN AND ANALYSIS

This section covers the work performed under Task 2 which was the major engineering analysis task of the study. The effort in this task was to determine the major system impacts of accommodating the life sciences program within the proposed Space Transportation System. Specific subtasks indicated in Figure 4-1 were to:

1. Accommodate the defined payloads within the Shuttle/System.

2. Define the interface and subsystems requirements (power, thermal, data, etc.) of the payloads.

3. Evaluate the impact of having a Bioresearch Centrifuge in the life sciences program, specifically with respect to costs and integration with the Spacelab.

4. Identify the ground support requirements associated with the complete development and operations of the life sciences payloads.

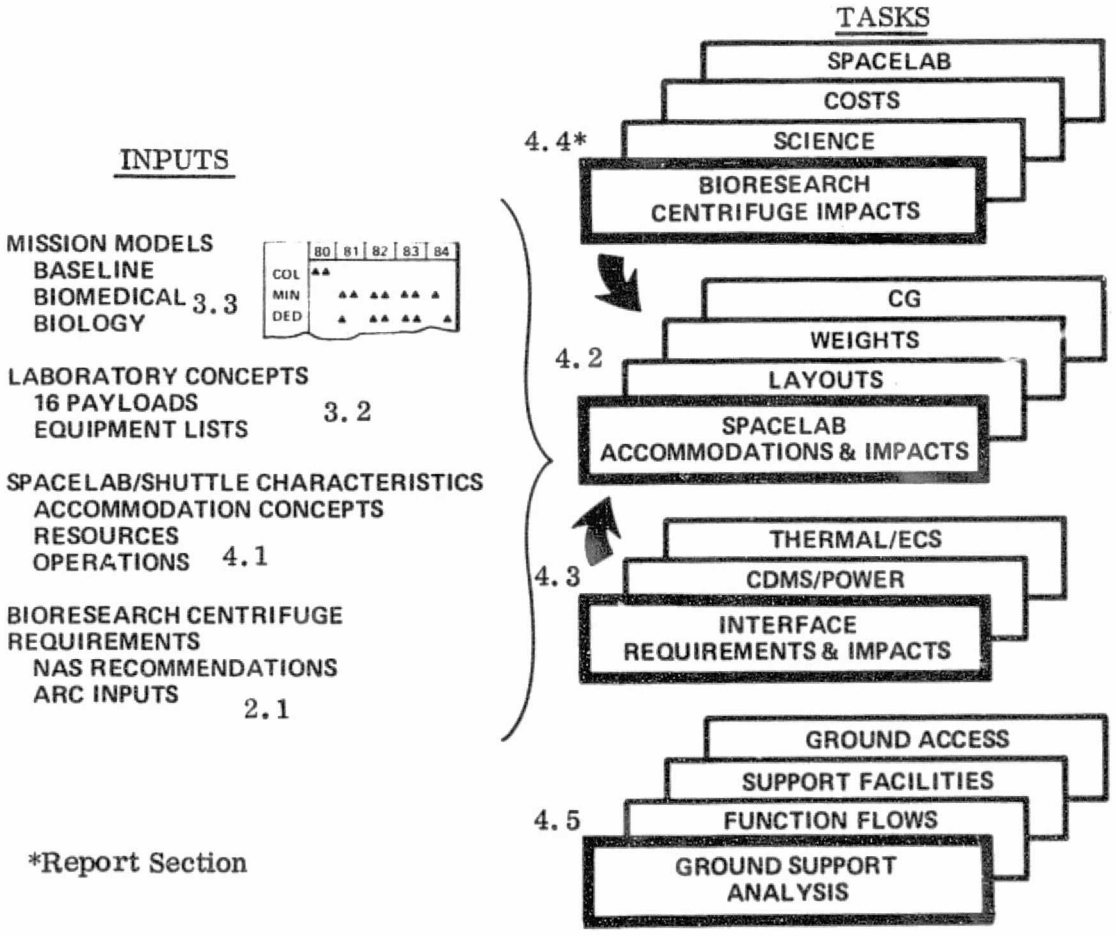


Figure 4.1. Systems Design & Analysis Overview

Significant inputs to this task were the 16 laboratory concepts defined in Section 3.2 and the three mission models (baseline, biomedical, and biology) linking payloads to flight schedules discussed in Section 3.3. Applicable Shuttle and Spacelab characteristics regarding payload accommodation were used for payload design, compatibility analysis and impact determination. The scientific requirements for the Bioresearch Centrifuge were acquired from recommendations stated in a National Academy of Sciences report and a working document provided by NASA Ames Research Center. (References 6 and 7).

4.1 SHUTTLE/SPACELAB ACCOMMODATION

The Space Transportation System will be NASA's space launch, recovery and ground system for the 1980's. Elements of that system which are important to the Life Sciences Manned Laboratory development are the Space Shuttle, Spacelab, Communication/Data Systems and the Launch Site Facilities. These are shown in Figure 4-2. Applicable characteristics of each of these elements will be discussed in the following paragraphs. Additional detailed descriptions can be found in References 13 to 16.

4.1.1 SPACE SHUTTLE. The Space Shuttle flight system is composed of the Orbiter, an external propellant tank and two solid rocket boosters. The Orbiter provides cargo carrying capability in its payload bay to and from low earth orbit. It is designed to carry into orbit a crew of seven including up to four scientific and technical personnel. On a standard mission, the Orbiter is boosted into orbit by the external tank and solid rockets. It can remain in orbit for up to 30 days, return to Earth with the payload and personnel, land like an airplane and be readied for another flight. The Shuttle system can deliver payloads up to 29,500 kg to orbit and land with maximum payloads of 14,500 kg.

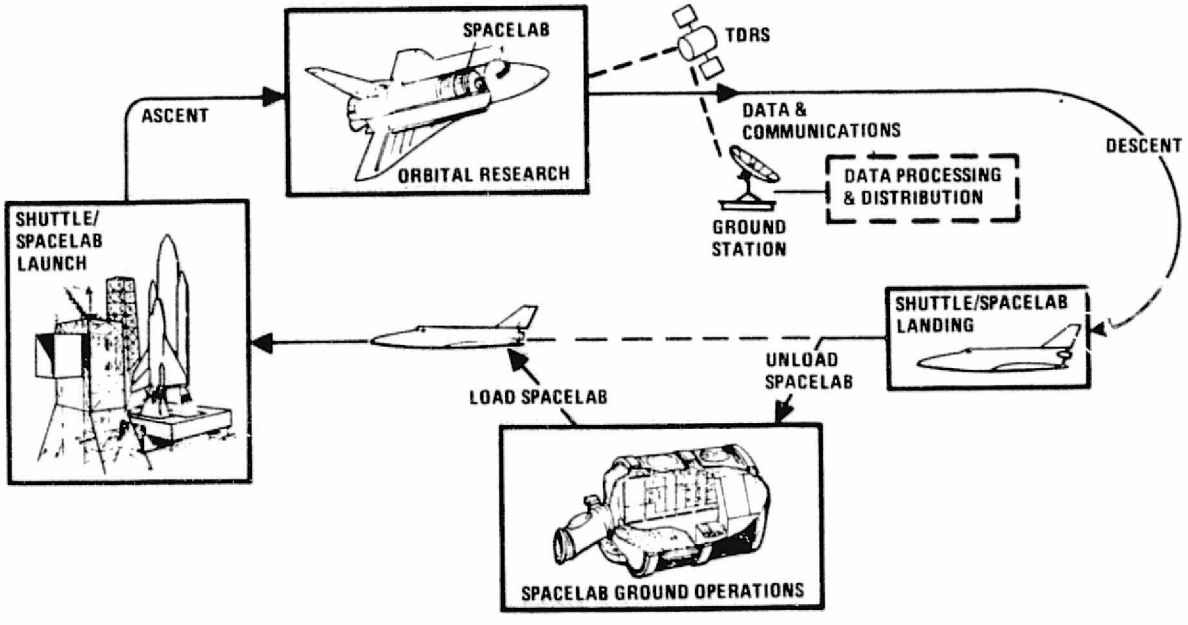


Figure 4-2. Space Transportation System Elements

The Space Shuttle provides capability for a variety of space program missions - deliver and retrieve payloads, service or refurbish satellites and operate space laboratories in orbit. It is in this last mode, also called the sortie mission, that the Space Shuttle in conjunction with the Spacelab will carry out the life sciences manned laboratory program. Loitering in a near-earth circular orbit (typically 170-550 km, inclination 28-57°) the Shuttle will support Spacelab operations and personnel for the mission duration. Baseline habitability provisions are for 28 man-days. Additional provisions for crew and Shuttle expendables are payload chargeable. This severely compromises the desired extended-duration missions in terms of the laboratory size that can be launched. Detailed discussion of this limitation is in Section 4.2.4. The Orbiter provides additional support services to the sortie mission besides the crew habitability accommodations. These include payload checkout, controls and displays; orientation and pointing; various subsystem services like power, heat rejection and data management; and the communication link with the ground data system. These subsystem services will be discussed in detail in the appropriate subsections under 4.3.

4.1.2 SPACELAB. Spacelab is an international program being developed by the European Space Agency (ESA). A large pressurized module and an external equipment pallet will provide an extension of the experimenters' ground-based laboratories in the weightless environment of space. Several Spacelab system configurations can be flown; generally, life sciences will utilize the pressurized module. This configuration consists of two 4 m diameter, 2.7 m long cylindrical, pressure shell segments and two cone-shaped endcaps. A transfer tunnel from the Orbiter properly locates the Spacelab within the Orbiter payload bay for center of gravity requirements. Experiment equipment will be located primarily within standard Spacelab racks which are arranged eight to each side in the single floor module. Four racks of Spacelab subsystem equipment are located at the front of the module. The rack volume along with aisleway and storage volume allows up to 22.2 m^3 and 5500 kg of experiment equipment to be placed within the module.

The Spacelab in addition to the Shuttle Orbiter provides several support services to the experiment payload. Table 4-1 summarizes some of these resources. Details of these plus the data management system are covered in Section 4.3. When payload requirements exceed these resources, energy, power conversion and heat rejection kits can be added to the Orbiter or Spacelab to provide the increments required.

The environment within the Spacelab module will be very similar to that of the experimentor's ground based laboratory. The environmental conditions within the habitable Spacelab volume are listed in Table 4-2. A controlled temperature and composition atmosphere is maintained within the module by the Spacelab environmental control system (ECS). The module atmosphere is a controlled nitrogen/oxygen atmosphere at sea level pressure. An atmosphere revitalization system controls humidity, carbon dioxide level, trace contaminants and particulate matter. Except for the launch/ascent phase, the acoustic, vibration and acceleration environments will have minimal impact on life sciences equipment or experiments. The ascent acoustic environment, however, is a serious factor and is discussed more fully in Section 4.3.4.

Table 4-1. Shuttle/Spacelab Resources

Resource	Available from Orbiter				Available to Payload from Spacelab
	Thrusting		On-Orbit		
	Cabin	Orbiter Bay	Cabin	Orbiter Bay	On-Orbit Module Only Configuration
Power					
Average (kW)	0.35	1.0	0.75	7.0	4.0
Peak (kW)	0.42	1.5	1.0	12.0	9.0
Peak Duty Cycle	2 min	2 min	2 min	15 min/ 3 hr	
Energy (kW-hr)	50 Total				422
Voltage Bus					
DC Voltage (vdc)	24-32	27-32	24-32	27-32	24-32
AC Voltage (kVA)					400 Hz, 115/200 Vac - 2.25 50 Hz, 220 VAC - 1.0 60 Hz, 115 VAC - 1.0
Heat Rejection					
Quantity (kW)	0.35	1.5	0.35	8.5	4.0
Coolant Temp (^{o}K)	TBD	283-311		283-313	280-313
P/L Personnel (Specialists)	0	0	1	1	4
EVA (Planned)	N/A				N/A
No. Msn.			2		
No. pers.			2 Max		
Duration (hr)			6 Max		

Table 4-2. Spacelab Environmental Conditions

Parameter	Capability
Habitable Volume Air Temp	291-300°K controlled to ±1°K.
Humidity	279° K Dew Point. 25-70% RH not controllable.
Total Pressure	1.013×10^5 N/m^2 (1 atmosphere) $N_2/O_2/CO_2$ composition
O_2 Pressure	2.14×10^4 N/m^2 (21% by volume)
CO_2 Pressure	666 N/m^2 (5 mm Hg)
Cleanliness Class	<100,000 Cabin Air, 5μ filters
Equipment Cooling	Air inlet Temp: 295-297°K, Outlet Temp: 323°K.
Acoustic Vibration	During Ascent ref. 20μN/m^2 P/L Bay: 145 db Module: 138 db
Vibration	During Launch/Ascent. For rack mounted eqmt Sinusoidal: ±0.25g (5-35 Hz) Random: 20-200 Hz +8 db/oct 200-700 Hz 0.1 g^2/Hz 700-900 Hz -18 db/oct 900-200 Hz 0.02 g^2/Hz
Acceleration X; Y; Z(1)	Max levels to Spacelab equipment Ascent: -3.0, ±0.3, ±0.4 g On-Orbit Drift: ~10^{-6}g >10^{-5}g RCS on Descent: +1.0, ±0.4, +3.0g

1) Orbiter directions, +X aft, +Y right, +Z up

The present operational concept indicates that Spacelab will be inactive during launch, ascent and descent (except for caution/warning monitoring) and hence the experiments are not provided with power, heat rejection, ECS, etc. However, the provision of limited resources and services by the payloads during these phases has been considered in this study. In addition, this aspect is presently under investigation by Spacelab.

4.1.3 COMMUNICATION/DATA SYSTEMS. Communications, data, and tracking support are provided to sortie payloads by the Shuttle Orbiter avionics.

Figure 4-3 summarizes payload communication capability through the Shuttle to the Space Tracking and Data Network (STDN) and the Tracking and Data Relay Satellite (TDRS) system. Data transmission to and from STDN and TDRS ground terminal stations is through the NASA Communications Network (NASCOM), a global network providing operational ground communications support. Real-time operational control and scheduling of the networks are provided by the Goddard Space Flight Center (GSFC).

The figure shows several orbit ground tracks over a typical 13-station STDN network and an example of an eight-station network that may be retained concurrent with the TDRS. The STDN is a worldwide complex of stations used to provide primary communications support to spacecraft above 5,000 km altitude.

Communication coverage to the ground is a function of the altitude and inclination of the operating orbit as shown. Data transmission coverage with STDN ranges from 7 to 15% (185 to km altitude), while TDRS contact occurs 90 to 95% of the time for the same altitude range. At altitudes above 5,000 km, coverage by STDN is about 90%.

The TDRS system consists of two satellites at geosynchronous orbit 130 degrees apart in longitude, operating to a single CONUS ground terminal station at White Sands, New Mexico. The satellites act as relays for telemetry, command, and tracking information. Full TDRS capability at White Sands is available to any investigator. Ground stations within CONUS are limited to 1.344 Mbps rates. The use of NASCOM ground links for transmission of data from remote (56 kbps) ground stations to a payload ground station may constrain meeting some real-time data needs.

Specific data handling that is available to the payload through both STDN and TDRS is indicated in Table 4-3. The values shown for payload down and uplink are mission phase dependent since they are shared with Orbiter data transmission requirements.

4.1.4 LAUNCH SITE FACILITIES. The Space Shuttle will be launched from two locations, the NASA Kennedy Space Center (KSC) in Florida and the Vandenberg Air Force Base in California. Each launch site offers various orbital altitude and inclination options to the payload - low inclination orbits from KSC and higher inclination, including polar orbits, from Vandenberg. It was assumed in this study that all life sciences payloads would be launched from KSC.

A wide variety of facilities exist or will exist at KSC that support the payload processing, preparation, checkout, launch and postflight payload removal from the Orbiter.

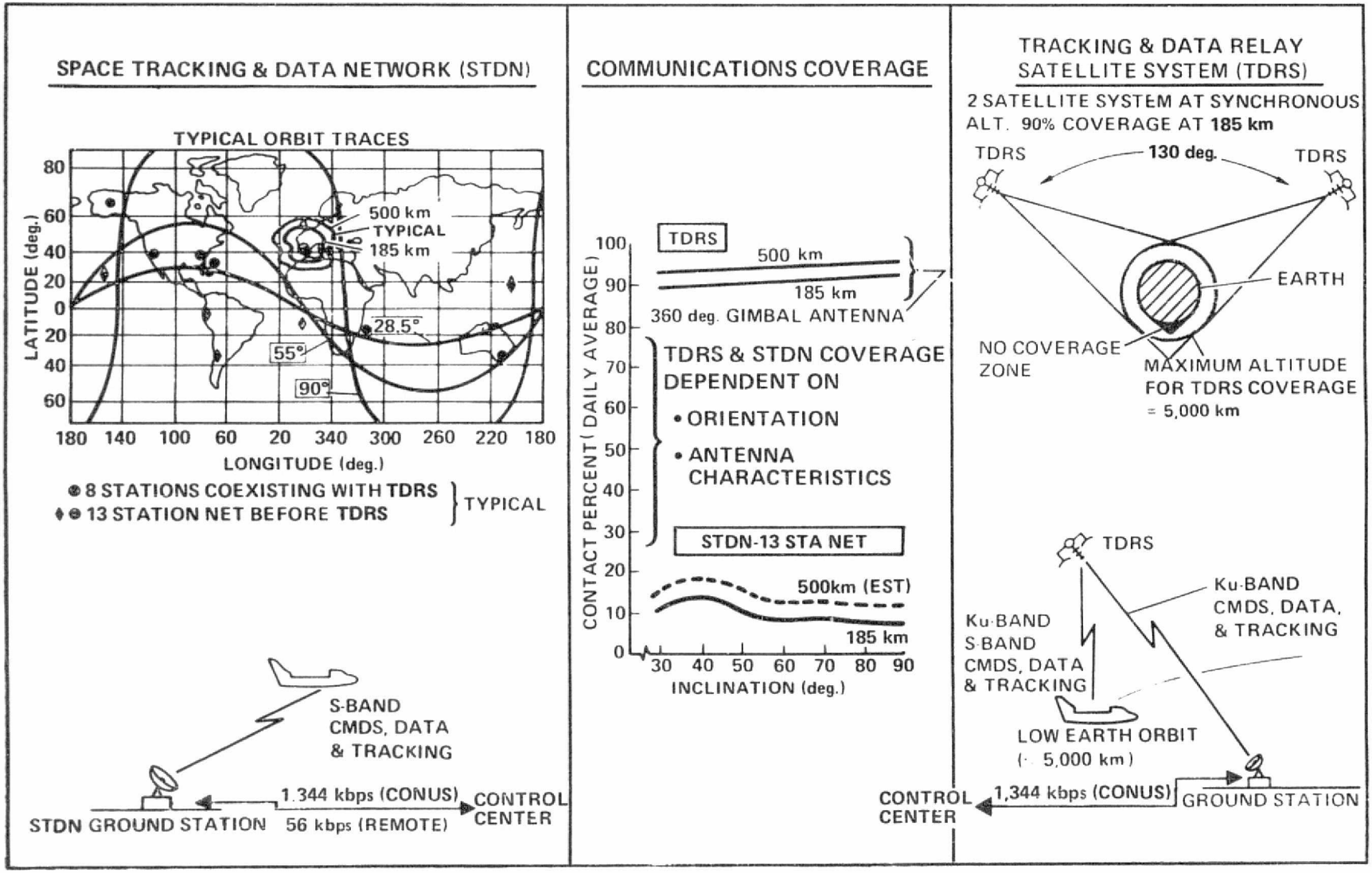


Figure 4-3. STDN and TDRS Data Networks

Table 4-3. Shuttle Communication/Data Capability

Shuttle Provided Comm/Data Resource		Max. Available to Payload	
		STDN	TDRS
Downlink	S-Band (PM)	64 kbps	64 kbps
	(FM)	4MHz or 5 Mbps(1)	-
	Ku-Band Mode 1	-	2 Mbps(1), 50 Mbps
	Mode 2		2 Mbps, 4 Mbps or 4.2 MHz, 64 kbps
Uplink	S-Band	2 kbps(1)	2 kbps(1)
	Ku-Band	-	2 kbps(1), 1 Mbps
Voice		1 Duplex Chl	1 Duplex Chl
Computer	Shuttle	10k 32-Bit Words	
	Spacelab	64k 16-Bit Words Extendable to 512k	
Record	Shuttle	1.024 Mbps, 2 Hzs Shuttle MSS PCM Recorder (No reel change)	
	Spacelab	30 Mbps Digital Recorder (Reel change)	
		6 MHz 2 Channel Analog/Video Recorder (Reel change)	

(1) Time Share with Orbiter

It is here that the life sciences laboratory equipment will be installed into the Spacelab, the Spacelab installed in the Orbiter, launched, returned and refurbished for other flights. Many of the details of the KSC operations are discussed in Section 4.5

4.2 LABORATORY DESIGNS AND PHYSICAL ACCOMMODATION

The objective of the Spacelab accommodation and interface subtask was to determine the support requirements imposed upon the Shuttle/Spacelab carrier system by the 16 candidate life sciences laboratories. Working to the volumetric, weight and configuration constraints of the Spacelab baseline, conceptual layouts were produced for each laboratory. The total weight penalty was determined for each concept. Total weight and center-of-gravity analyses were performed for dedicated laboratories with emphasis on extended-duration missions. An in-house mockup activity assisted in the design and evaluation of Spacelab racks and life sciences mini-labs.

4.2.1 SPACELAB ACCOMMODATION. The overall volume available for payload equipment for the long-module Spacelab configuration is 22.2 m^3. This value is the maximum volume available when all the mission-dependent racks, ceiling storage containers, and subflooring areas are used and when reasonable allowances are made for unrestricted crew movement and working conditions. The volume allocations of the

various available areas are shown in Figure 4-4. Along each side of the Spacelab, there are three double and two single racks. The available volume inside each double rack is 1.75 m^3, and 0.9 m^3 for single racks. Overhead storage is available in eight storage containers, each 0.34 x 0.58 x 0.6m for a total volume of 1.6 m^3. A subfloor volume of 2.58 m^3 is available for payload use only in the experiment segment of the module. A center aisleway volume of 3.92 m^3 is also available for equipment mounted to the floor if there are no impacts with crew habitability and safety. All of these available volumes total 22.? m^3.

The mass available for Spacelab payloads is dependent on several factors, the principal ones being the configuration of Spacelab, the launch/landing capabilities of Shuttle, and the specific load carrying capability of Spacelab. For the Spacelab long module and a total Shuttle payload landing limit of 14,500 kg, the total scientific payload available is 5500 kg. This value is obtained after allowances are made for each of the following major equipment categories:

Mission-Independent Spacelab Equipment — All structure, floors, endcaps, pressure shells, etc.; power, thermal, ECS subsystems, etc.; cable, ducting.

Mission-Dependent Spacelab Equipment — Racks, RAUs, power modules, computer, CRT, recorders, stowage, airlocks, film vaults, etc.; all those items that are added to the basic Spacelab to satisfy mission hardware requirements.

Transfer Tunnel — Provides access to and egress from Spacelab. Length and therefore weight is dependent on Shuttle payload center-of-gravity constraint.

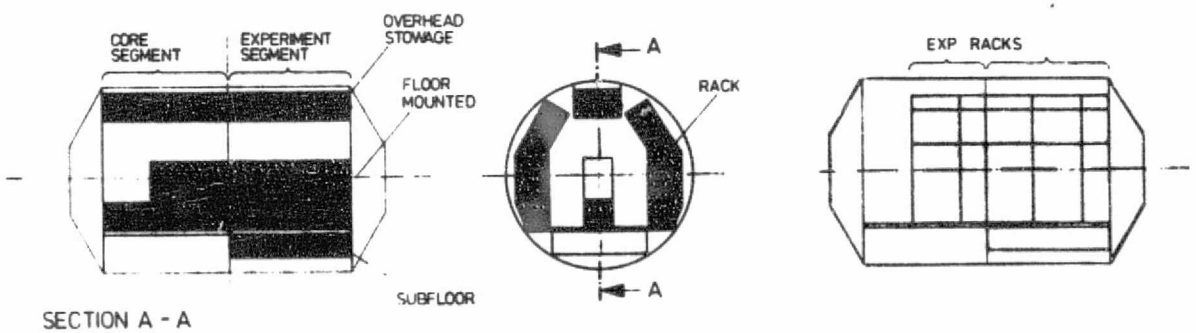


Figure 4-4. Long Module Payload Volume Allocation

Mission-Independent Orbiter Support Equipment — Orbiter-supplied equipment necessary for Spacelab operation and mass chargeable to the Orbiter payload. Includes heat rejection components above Orbiter baseline, tankage and fuel cell consummables in excess of 50 kWh, etc.

Details of the allowances for each of these categories are given in Reference 13.

Experiment equipment within the Spacelab is primarily placed within the standard 483 mm (19-inch) racks, 16 of which (6 doubles and 4 singles) are available. The dimensional aspects of these racks are indicated in Figure 4-5. Ducting for air cooling of rack equipment and space allowances for electric power switch panels, RAUs, power converters, etc., decrease the usable volume for equipment. The usable volume for experiment equipment is estimated to be 0.63 m^3 for a single rack and 1.28 m^3 for a double rack.

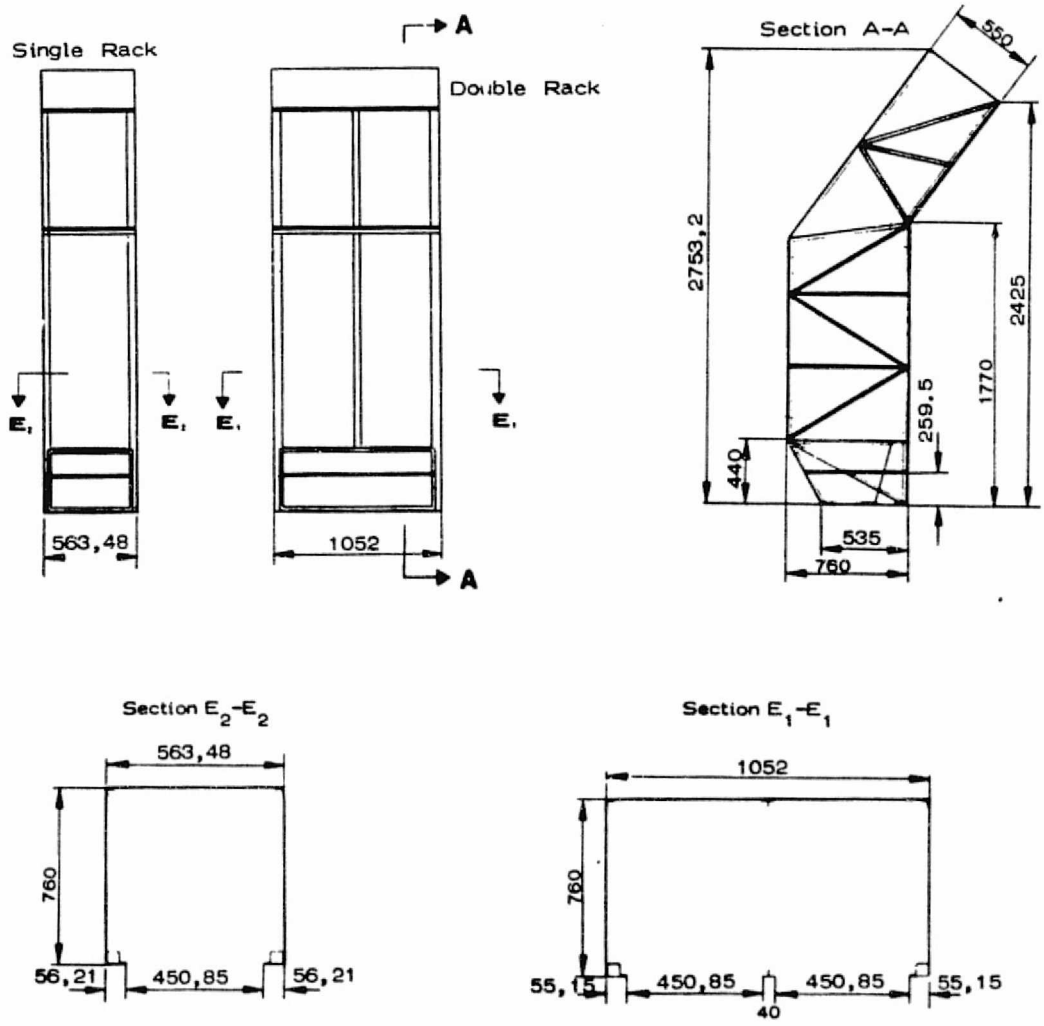


Figure 4-5. Standard Spacelab Racks

4.2.2 LABORATORY LAYOUTS. Preliminary plan view layouts were made for the 16 payloads defined in the study. These payloads and their common equipment listings appear in Volume V, Book 2, Appendix B. The layouts were made by locating the equipment in the standard Spacelab racks. The equipment definition sheets (Volume V, Book 3) were used to determine size and location preference with respect to other interfaces. Basic human engineering principles were used in placing the equipment within the racks. Functionally similar equipment, such as photographic and microscopic analysis, were grouped together. Equipment requiring crew access, such as analysis equipment, was located near the middle of the rack. Minimum-access equipment (tanks, plumbing, storage areas) tended to be placed near the bottom, rear or top of the rack. Kits, which generally contain a large number of small items, were placed in pullout trays or drawers near where they would commonly be used. For example, the vertebrate management kit, EI 114B, would be placed near either the small vertebrate holding unit, EI 103, or the primate holding facilities, EI 101B or 101C. Several equipment items needing more access than the confines of the 19-inch rack were mounted on pullout or swingout trays. Examples are microscopes, restrained monkey pods, and work surfaces.

Not all of the common equipment will be located in the payload racks. Some items like log books are stored in the Spacelab subsystems workbench rack. Film was assumed to be stored in the Spacelab film vaults. Waste is stored in Spacelab trash disposal bags. Some distributed interface equipment, such as coolant loops, vacuum manifolds and plumbing, were placed in the subfloor space. Finally, some of the larger equipment items were placed in the center aisleway. Typical items in this category were the Work and Surgical Bench (188), Rotating Litter Chair (153A), part of the Exercise Physiology Equipment (70E), and the Body Mass Measurement Device (19D). These and other deployable equipment will extend into the habitable Spacelab volume and may temporarily restrict crew movement and equipment access during use.

Figures 4-6 through 4-8 show examples of various laboratory layouts. Layouts for all mini-labs and dedicated labs are provided in Volume V, Book 2, Appendix C. Mini-lab ML-1A, the life sciences contribution to the first US/ESA Spacelab mission, a multidiscipline mission, is shown in Figure 4-6. The common equipment for this payload is listed in Table 3-5. Of the 27 total items, 27 are contained within one and one-half Spacelab racks. Major items are the Orbiting Frog Otolith (OFO) canisters, the Automatic Potentiometric Electrolyte Analyzer, the freezers, and the microscope. The Rotating Litter Chair (153A) is located in the center aisleway. Five other items are distributed elsewhere in the laboratory. The weight of the common equipment is 347 kg. Total payload weight is 497 kg. Mission-dependent equipment, interface equipment and allowances for PI equipment account for the difference. These items are defined more fully in the next section.

MINI-LAB ML-1A

DISTRIBUTED EQUIPMENT:

EI	NAME	LOCATION
31	CALCULATOR, POCKET	S/L WORKBENCH
51F	COOLANT LOOP, LIQUID	S/L SUBFLOOR
76C	FILM, 35mm	S/L FILM VAULT
116	LOG BOOKS	S/L WORKBENCH
182E	URINE VOLUME MEASUREMENT SYSTEM	ORBITER MID-DECK

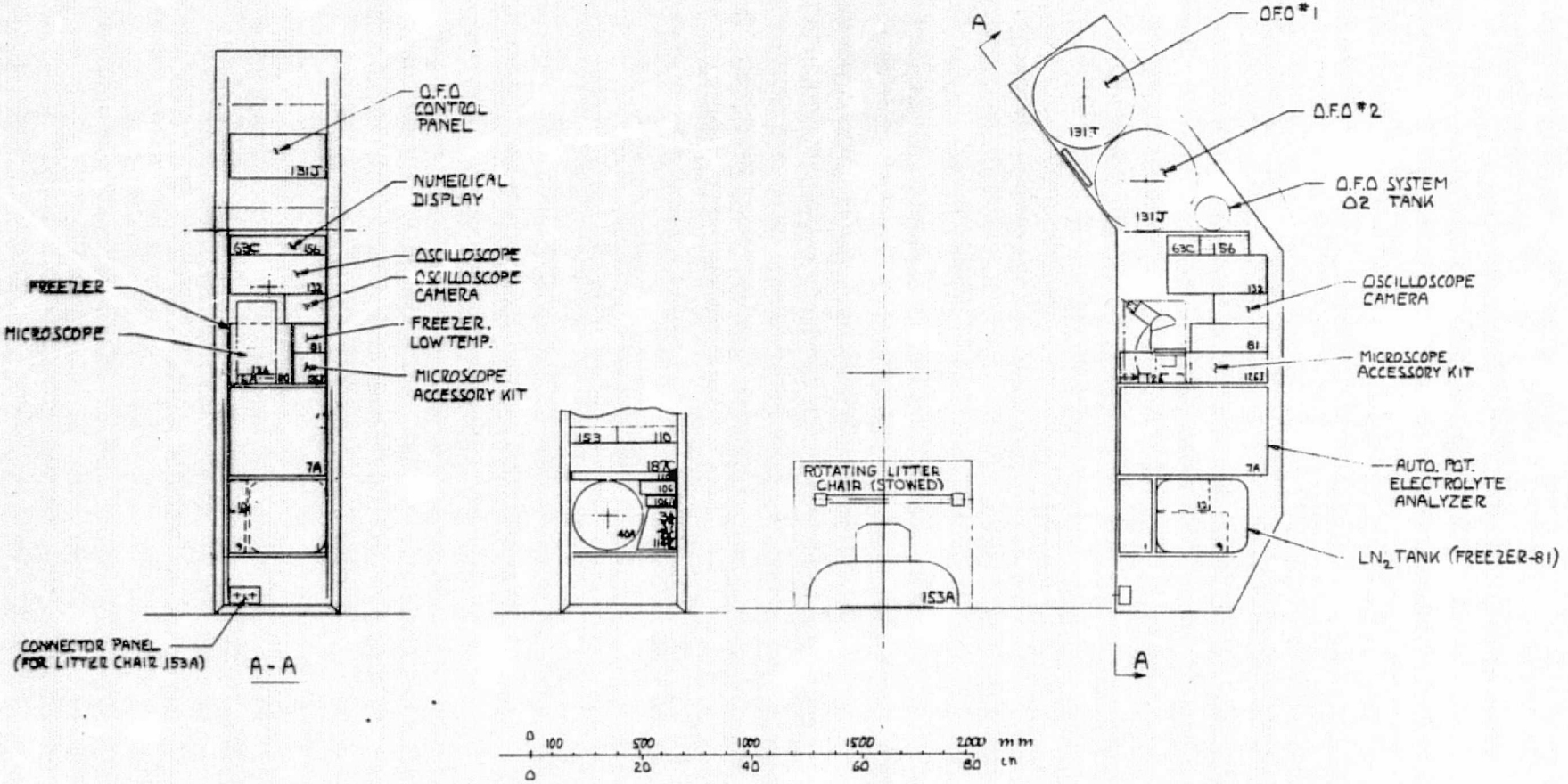


Figure 4-6. Example Mini-lab Layout — ML-1A, First Spacelab Mission

Another mini-lab example, ML-2B, a biomedical/restrained primate laboratory, is illustrated in Figure 4-7. The equipment complement for this laboratory is presented in Table 4-4. The main feature of this laboratory is the University of California, Berkeley, monkey pods (EI 101B) located in the lower portion of the double rack. Support equipment is located in the upper portion, while the single rack contains analysis and preservation hardware. A few items are distributed elsewhere in the laboratory. The common equipment, listed in Table 4-4, weighs 364 kg and the total payload weight is 611 kg. A unique feature of this layout is that the double rack must be located on the starboard side of the Spacelab in order to have the proper launch and reentry orientation of the restrained primates.

A typical layout for the dedicated laboratories is shown in Figure 4-8. This laboratory, Mod IA, is for a seven-day, biomedical emphasis, dedicated mission. The laboratory supports in-depth biomedical research using man and man-surrogate organisms. Capability for both inflight and preparation-for-ground analysis exists. The layout shows the laboratory equipment (Table 4-5) filling the entire 16 racks of the Spacelab. Some equipment is placed in the center aisleway, overhead stowage areas, and Spacelab support systems racks in the core segment. This equipment totals 1,904 kg. With allowances for mission-dependent, interface, and PI specific equipment, the total payload chargeable weight is 3,315 kg.

4.2.3 PAYLOAD WEIGHT ANALYSIS. Based on the equipment inventories and layouts, detailed weight estimates were made for each of the 16 payloads. As a first step, estimates for mission-dependent, interface and principal investigator (PI) specific equipment were made as shown in Table 4-6. The common equipment inventory weight was computed from the quantity and unit weight for each item in the list of common equipment. Mission-dependent equipment consists of such items as racks, RAUs, power switch panels, converters, experiment computer, I/O, handrails, etc. Allowances for a fully dedicated laboratory in a long module were based on a 991 kg figure given in the Spacelab System Requirements (Level II) document, dated 11 November 1974 (Reference 14). Allowances for mini-labs and dedicated labs of less than full size were factored from the 991 kg according to the number of racks used.

Interface equipment includes brackets, electrical harnessing, ducting — all those items necessary to integrate the equipment items together into a functional unit. Their weight was also computed by factoring according to rack usage. The factor is based on a detail estimate of 230 kg needed to integrate the fully dedicated lab MOD IA.

The PI equipment allowance was computed as 10% of the common inventory total. This allowance accounts for those research-specific items which cannot be described at this time but will undoubtedly be needed for the flight. The arbitrary 10% figure is based on past NASA Life Sciences Working Group estimates, although an estimate of 20-30% may be more accurate for dedicated laboratories.

DISTRIBUTED EQUIPMENT:

EI	NAME	LOCATION
51F	COOLANT LOOP, LIQUID	S/L SUBFLOOR
76C	FILM, 35mm	S/L FILM VAULT
116	LOG BOOKS	S/L WORK BENCH

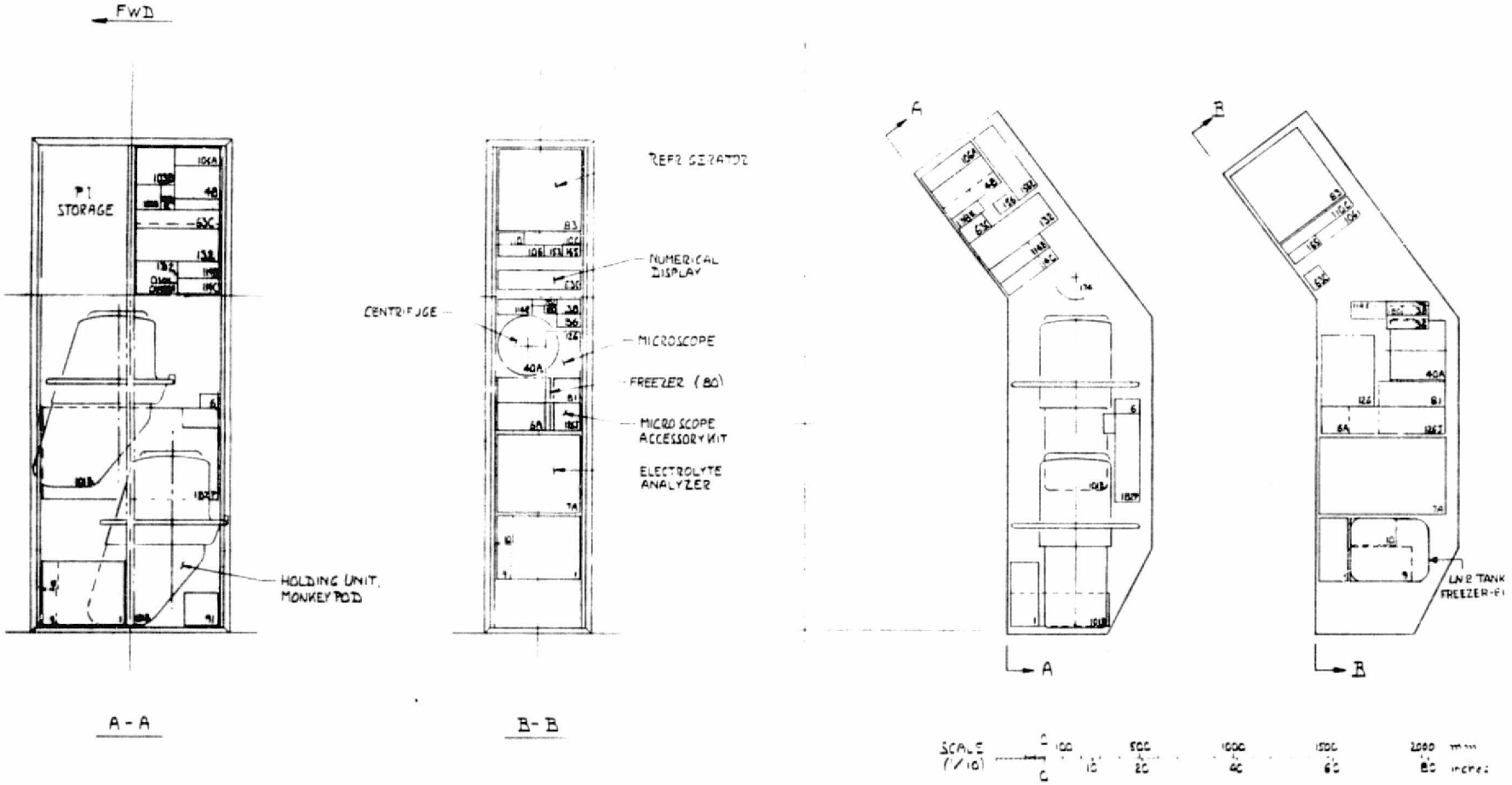


Figure 4-7. Example Mini-Lab Layout — Restrained Primate ML-2B

Table 4-4. Common Equipment List for ML-2B

EI#	EI NAME	Q	UNIT WEIGHT kg	UNIT POWER w	UNIT VOLUME dm^3
6	Air Particle Sampler	1	2.7	50	0.85
6A	Airflow, Work Surface	1	5	75	6
7A	Auto. Poten. Electrolyte Anal.	1	12.7	100	57
36	Camera, 35 mm & Strobe	1	2	0	2.0
38	Camera, Video, Color	1	7.7	69	6.2
40A	Centrifuge, Blood Sample Proc.	1	12.7	100	25
44A	Chemicals, Radioisotope Tracers	1	0.3	0	0.5
48	Cleaner, Vacuum	1	2.3	100	10
51F	Coolant Loop, Liquid	1	30	50	25
63C	Display, Numeric	1	2	2	4
70C	Equipment Restraint Device	1	0.5	0	1
76C	Film, 35 mm	5	0.13	0	0.05
80	Freezer, General	1	15	200	61.4
81	Freezer, Low Temp.	1	8	10	30.5
83	Frig. (Refrigerator)	1	18	50	120
91	Gas Analyzer, Mass Spec.	1	25	50	20
101B	Holding Unit, Monkey Pod	2	53	100	425
103B	Incubator	1	5	5	8
106	Kit, Hematology & Urology	1	5	0	9
106A	Kit, Cleanup	1	1.5	0	4
110	Kit, Microbiology	1	2	0	3
110C	Kit, Human Physiology	1	3	0	8
114B	Kit, Vertebrate Mgmt.	1	3	0	6
114C	Kit, Vertebrate Physiology	1	3	0	6
114E	Lamp, Portable Hi Int. Photo	1	6.3	150	6
116	Log Books	2	0.5	0	0.4
126	Microscope, Compd.	1	11	15	27.4
126J	Microscope Access Kit, Compd.	1	10	15	25
132	Oscilloscope & Camera	1	11.7	75	28.9
138E	Physiol. Multichannel Sens. Sys.	1	0.2	0	1.4
150B	Receiver	1	0.5	10	1
153	Recorder, Voice	1	1	0	1
156	Signal Conditioners	6	0.2	2	0.5
165	Sterilizer, Tool	1	1	110	1
174	Tank, Vertebrate Water	1	8.5	5	28.3
180	Timer, Event	1	0.2	0	0.2
182P	Ventilation Unit, Vert.	2	19	40	32.7
	TOTAL WEIGHT:		364		

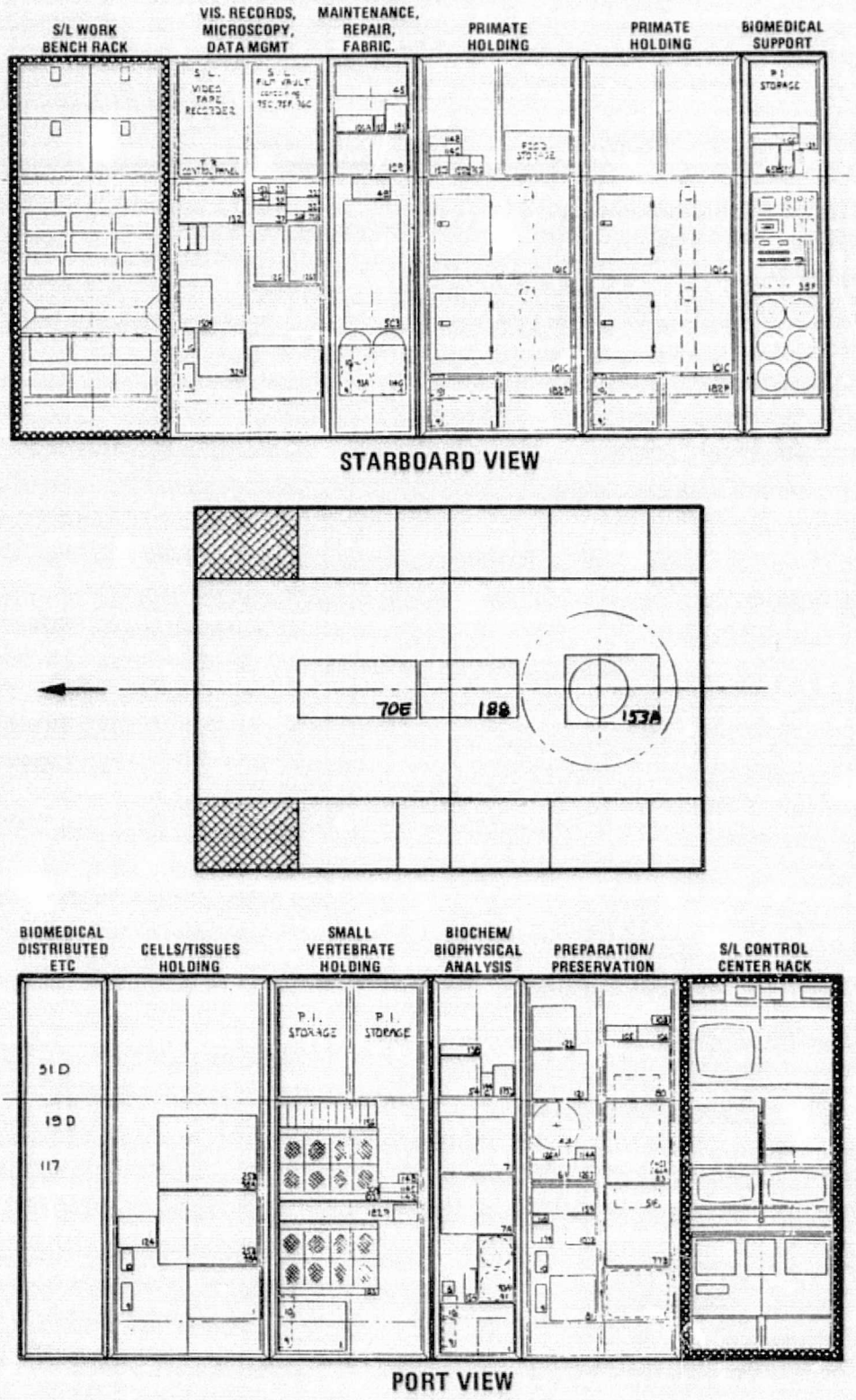


Figure 4-8. Example Dedicated Laboratory Layout — MOD IA

Table 4-5. Common Equipment List for MOD IA

EI	Name	Q	Weight (kg)	Power (watts)	Unit Volume (dm^3)
1	ACCELEROMETER	3	0.1	0	0.03
1A	ACCELEROMETER COUPLER	3	0.05	1	0.01
5	ATD PARTICLE SAMPLER	1	2.7	50	0.95
6A	AIRFLOW WORK SURFACE	1	5	75	6
7	AUTOANALYZER (GEMSAEC)	1	26	200	40
7A	AUTO POTENTIO. ELEC. ANAL.	1	12.7	100	57
14B	ANTENNAS,ASSORTED	1	0.1	0	0.03
15A	ATMOS. SAMPLING SYSTEM	1	10	20	28
16B	AUDIOMETER	1	4.5	25	4.3
16D	BADGES, RADIATION	2	0.2	0	0.1
16E	BALLISTOCARDIOGRAM COUPLER	1	0.1	1	1
18D	CUSTOM BITE BOARDS	1	0.23	0	0.03
19D	BODY MASS MEAS. DEVICE	1	36.5	15	675
25B	COLONY CHAMBER, SEALABLE	20	0.2	0	0.1
30A	CAGE, RAT, HAMSTER, STANDARD	16	2.3	9	11
31	CALCULATOR, POCKET	1	0.47	0	0.4
32	CAMERA, CINE	1	5	13	5
32A	CAMERA CONTROLLER	1	13.6	100	28.3
33	CAMERA, POLAROID	1	3.3	0	5.6
36	CAMERA, 35 MM AND STROBE	1	2	0	2
37	CAMERA, VIDEO, B/W	2	4.4	15	3
38	CAMERA, VIDEO, COLOR	1	7.7	69	6.2
38B	CAMERA MOUNTS	1	3	0	3
39D	CAMERA TIMER, VIDEO	1	4	10	3
38E	CARDIOPULMONARY ANALYZER	1	90.7	200	172
40A	CENTRIFUGE, BLD SMPL PROCESSOR	1	12.7	100	25
44	CHEMICALS	1	0.5	0	1.0
44A	CHEMICALS, RADIOISOT. TRACERS	1	0.3	0	0.5
45	CHEMICAL STORAGE CABINET	1	4.0	0	14.1
49	CLEANER, VACUUM	1	2.3	106	10
50A	CLINOSTAT (FOR C/T)	1	2	10	4
50B	COMPACTOR, SOLIDS	1	18	190	113
51D	CONTROL CONSOLE, EXPERIMENTER	1	22.7	100	113.3
51E	COOLANT LOOP, LIQUID	1	30	50	25
54	COUNTER, COLONY, MANUAL	1	1.5	50	1.5
63B	DISPLAY KEYBOARD, PORTABLE	1	13.6	60	42.5
63C	DISPLAY, NUMERIC	2	2	2	4
64	ECG COUPLER	12	0.2	2	0.5
65	EEG COUPLER	4	0.2	2	0.5
65B	ELECTROPHYS. BACKPACK	1	0.3	0	0.23
65C	ELECTROPHYS. RECEIVER	1	2.7	25	5.0
66	EMG COUPLER	6	0.2	2	0.5
70C	EQUIPMENT RESTRAINT DEVICE	1	0.5	0	1
70E	EXERCISE EQUIP., PHYSIOL.	1	96	18	992
75C	FILM, CINE	4	0.54	0	0.54
75E	FILM, POLAROID	5	0.16	0	0.13
76C	FILM, 35 MM	10	0.13	0	0.05
76J	FLOWMETERS	4	0.5	1	0.5
77B	FREEZER, CRYOGENIC	1	21.6	10	74.1
80	FREEZER, GENERAL	1	15	200	61.4
81	FREEZER, LOW TEMP.	1	8	10	30.5
83	FRIG. (REFRIGERATOR)	1	18	50	120
91	GAS ANALYZER, MASS SPEC.	2	25	50	20
93	GAS ANALYZER, PH	1	5.2	6	13
93A	GAS SUPPLIES	6	5.75	0	18
96	GLOVE BOX, PORTABLE	1	4.5	0	25
96C	GLOVE BOX LINERS	10	0.5	0	1
97C	HANDWIPES, BETADYNE	10	0.3	0	0.3
98A	HOLDING UNIT, CELLS/TISSUES	2	23	30	188
101C	HOLDING UNIT, PRIMATE	4	113	100	340

Table 4-5. Common Equipment List for MOD IA, Contd

EI	Name	Q	Weight (kg)	Power (watts)	Unit Volume (dm^3)
103	HOLDING UNIT, SM. VERT.	2	13.6	0	188
103B	INCUBATOR	1	5	5	8
105	KIT, CHEMICAL	1	1.5	0	5
106	KIT, HEMATOLOGY AND UROLOGY	1	5	0	9
106A	KIT, CLEANUP	1	1.5	0	4
108	KIT, HISTOLOGY	1	1	0	1
109	KIT, LINEAR MEAS.	1	1	0	1
110	KIT, MICROBIOLOGY	1	2	0	3
110C	KIT, HUMAN PHYSIOLOGY	1	3	0	8
114A	KIT, DISSECTION	1	1	0	2
114B	KIT, VERTEBRATE MANAGEMENT	1	3	0	6
114C	KIT, VERTEBRATE PHYSIOLOGY	1	3	0	6
114E	LAMP, PORTABLE HI INT. PHOTO	1	6.3	150	6
114G	LIQUID STOR. AND DISPENS. SYS.	1	13	0	18
116	LOG BOOKS	3	0.5	0	0.4
117	LOWER BODY NEG. PRESS. DEVICE	1	78.7	26	2373
118T	MANIFOLD, VACUUM	1	9.1	0	26.3
121	MASS MEAS. DEVICE, MACRO	1	11.8	15	32.8
122	MASS MEAS. DEVICE, MICRO	1	12	15	25
124	MEDIA, PREPARED	2	0.45	0	0.5
126	MICROSCOPE, COMPOUND	1	11	15	27.4
126A	MICROSCOPE, DISSECTING	1	9	100	28
126J	MICR. ACCESS. KIT, COMPND	1	10	15	25
131E	NON-VISUAL DIRECTION INDICATOR	1	4.1	0	2.8
132	OSCILLOSCOPE AND CAMERA	1	11.7	75	28.9
137	OTOLITH TEST GOGGLES	1	0.2	0	2.8
134B	PAPER, RECORDING	1	0.6	0	1.2
138	PH METER	1	1.8	20	5.2
138B	PHOTOCELL COUPLER	12	0.2	2	0.5
138E	PHYSIOL. MULTICHAN. SENS SYS.	1	0.2	0	1.4
139	PLETHYSMOGRAPH, LIMB	1	2.4	5	6
140	PHONOVIBRACARDIOGRAM COUPLER	1	0.2	1	0.3
141A	PLUMBING	1	20	2	15
143G	PRESSURE COUPLER	4	0.2	2	0.5
144C	RADIATION DETECTOR, PORTM.	1	0.3	0	0.5
147	RADIATION COUNTER	1	15	50	20
150A	RECORDER, STRIP CHART	1	11.8	0	16.9
150B	RECEIVER, BIOTELEMETRY	1	0.5	10	1
153	RECORDER, VOICE	1	1	0	1
153A	ROTATING LITTER CHAIR/CONSOLE	1	100.2	127	239
153B	SENSORS, ASSORTED	1	0.5	0	0.3
156	SIGNAL CONDITIONERS (COUPLERS)	12	0.2	2	0.5
156E	SONOCARDIOGRAM	1	19	32	59
157	SOUND LEVEL METER	1	13.6	0	33.4
159	STAINING SYSTEM	1	2.2	0	3.5
162	STERILIZER, AUTOCLAVE	1	11	700	34.7
165	STERILIZER, TOOL	1	1	110	1
174	TANK, VERTEBRATE WATER	5	8.5	5	28.3
176B	THERMOCOUPLE INDICATOR	1	6	8	9.4
179	TEMPERATURE BLOCK	1	4.5	200	1.7
179A	THERMOCOUPLES	1	0.5	0	0.3
179D	THERMOMETER, ELECTRONIC	1	5.4	14	8.7
180	TIMER, EVENT	2	0.2	0	0.2
181D	TRANSDUCER, PRESSURE	4	0.2	1	0.4
182J	VCG COUPLER	1	0.2	2	0.5
182E	VENTILATION UNIT, VERT.	5	19	40	32.7
185	MULTIMETER	1	2	0	2.4
188	WORK AND SURGICAL BENCH	1	136	1000	420

Table 4-6. Mission-Dependent, Interface, PI Equipment

Payload	Common Inventory (kg)	Mission Dependent Equipment (kg)	Interface Equipment (kg)	PI Equipment (kg)	Total MD, I, & PI Equipment (kg)
COL-2A	25.2	0	2	0	2
COL-3A	16.8	0	2	0	2
ML-1A	347	93	22	35	150
ML-2A	460	186	43	46	275
ML-3A	328	124	29	33	186
ML-4A	185	124	29	18	171
ML-5A	25.5	31	7	3	41
ML-2B	364	186	43	18	247
ML-2C	500	186	43	25	254
ML-2D	556	309	72	28	409
MOD IA	1904	991	230	190	1411
MOD IIA	2431	991	230	243	1464
MOD IIIA	2504	991	230	250	1471
MOD IIB	1409	929	215	141	1285
MOD IIC	1128	557	158	113	828
MOD IIIB	1229	681	129	123	933

The data in Table 4-6 was then incorporated in the summary chart, Table 4-7. The number of Spacelab racks required was determined from the layouts. The boxed figures for dedicated MOD IIA and MOD IIIA indicate that the rack and volume capability (equivalent to 16 racks) of the Spacelab long module are exceeded. The total life sciences payload is the sum of the common equipment and the allowances for mission dependent, interface and PI equipment.

The total Shuttle landing weight was calculated by including all elements carried by the Shuttle: Spacelab, mission-independent equipment, transfer tunnel, experiment payload and, for extended duration missions, the required energy kits and expendables. The next section discusses this aspect. This total Shuttle payload calculation for mini-labs cannot be made until other sharing payload elements are determined. It is seen

Table 4-7. Summary of Physical Accommodations

PAYLOAD	NO. OF SPACELAB RACKS REQUIRED	COMMON INVENTORY EQUIPMENT WEIGHT, KG	S/L MISSION DEPENDENT, INTERFACE & 10% PI EQUIPMENT ALLOWANCES, KG	TOTAL L/S PAYLOAD KG	TOTAL SHUTTLE PAYLOAD LANDING WEIGHT KG	ACCOMMODATION IMPACTS
COL-2A	ORBITER STORAGE	25.2	2	27.2		SHARING PAYLOADS MUST BE EXAMINED FOR ACCOMMODATION IMPACTS
COL-3A	ORBITER STORAGE	16.8	2	18.8		
M L-1A	1 1/2	347	150	497		
M L-2A	3	460	275	735		
M L-3A	2	328	186	514		
M L-4A	2	185	171	356		
M L-5A	1/2	25.5	41	66.5		
M L-2B	3	364	247	611		
M L-2C	3	500	254	754		
M L-2D	5	556	409	965		
MOD-IA	16	1904	1411	3315	9918	
MOD-IIA	20	2431	1464	3895	10498	TOO LARGE FOR LONG MODULE
MOD-IIIA*	18 + CENTRIF	2504	1471	3975	15795	TOO LARGE FOR LONG MODULE & EXCEEDS LANDING WEIGHT LIMIT
MOD-IIB	15	1409	1285	2694	9297	
MOD-IIC*	11	1128	828	1956	13776	
MOD-IIIB*	9 + CENTRIF	1229	933	2162	13982	

*30-DAY MISSIONS

that dedicated lab MOD IIIA exceeds the Shuttle landing weight limit. In addition, it and MOD IIA volumetrically exceed the long module rack accommodations. As mentioned above it was recommended that these laboratories be dropped from further consideration and be replaced with more compatible dedicated labs such as IIB, IIC, or IIIB.

4.2.4 WEIGHT/C.G. ANALYSIS. The analysis of total Shuttle payload weight and center of gravity (cg) location showed that all seven-day dedicated laboratories were well within the landing limits and cg envelopes. However, 30-day payloads are another matter. The 30-day mission MOD IIIA, for instance, exceeded the maximum landing limit of 14,500 kg. Alternative payloads were consequently considered.

The current Shuttle/Spacelab definition indicates a significant payload weight penalty for extended-duration missions. Figure 4-9 shows the available payload weight as a function of on-orbit stay time. It indicates the large penalty needed to account for Orbiter energy requirements (8.5 kW, average) and Spacelab long-module energy requirements (3 kW, average). The top and bottom curves show the available payload weight for minimum and maximum payloads. "Crew" is the total number on board, including three persons in the Orbiter plus payload specialists. The center curve is for a typical life sciences laboratory of three payload specialists and an average power of 2.8 kW — similar to MOD IIIA. It is seen that less than 1000 kg can be accommodated. The analysis shown does not include the payload-chargeable weight for structure to mount energy kits or additional EC/LS tankage, or weight reserves (approximately 20% of allocation).

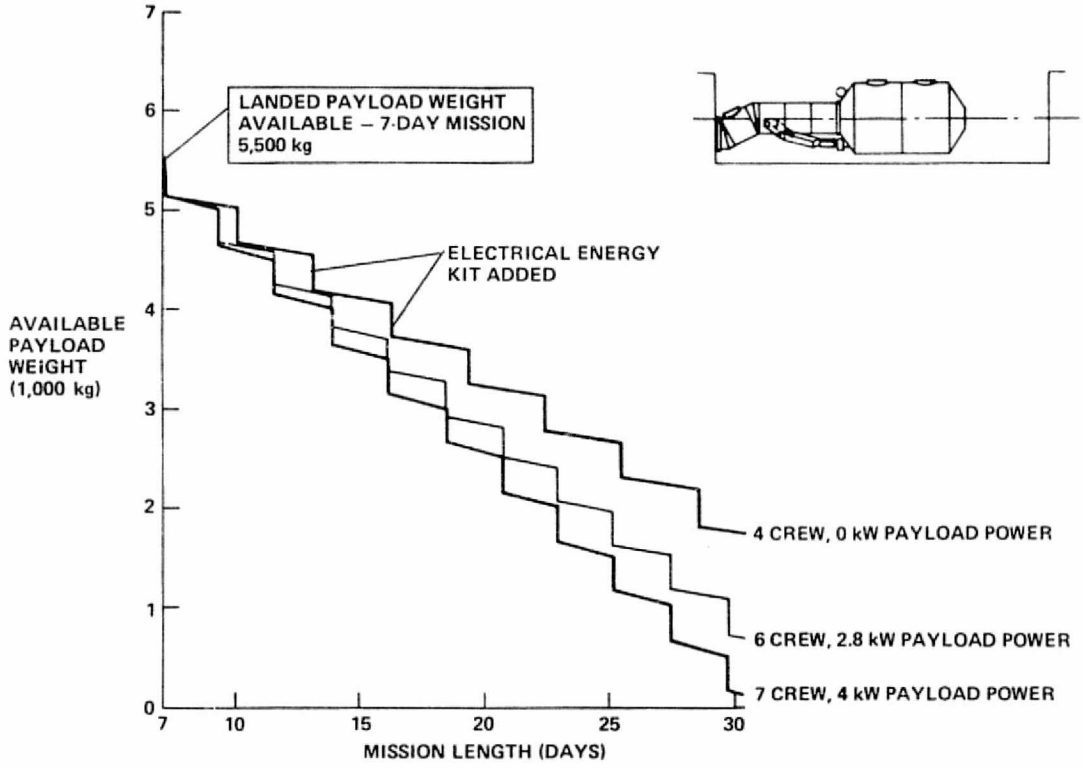


Figure 4-9. Payload Weight for Extended Duration Mission — Long Module Configuration

Alternative power system approaches are currently under investigation by NASA. They might include solar panels and/or throw-away tankage. Until such alternatives are introduced into the program, however, our approach is to develop alternative payloads that will provide valid research on 30-day missions and operate within the weight penalties shown.

One such alternative 30-day payload was the reduced-capability payload MOD IIIB. The analysis shown in Table 4-8 and Figure 4-10 confirmed its compatibility with the Shuttle system. The common inventory weight of MOD IIIB totals 1229 kg. To this must be added the various elements shown in Table 4-8: Spacelab structure, mission-dependent equipment, the tunnel, Orbiter mission-independent equipment, payload-chargeable mission-extension hardware and extendables. The total launch weight is 19,236 kg while the landing weight is 14,088 kg, within the 14,500 kg limit. These weights and the cg locations are indicated in Figure 4-10. Even through the payload has been minimized by reducing common equipment to little over 1000 kg, and crew requirements reduced to one payload specialist, the total Shuttle landing weight is near its limit. Extended-duration missions have a drastic effect on Shuttle payload carrying capability.

Table 4-8. Shuttle Payload Weight and Cg — MOD IIIB

	ITEM	SIZE	UNIT VALUES: UNIT WEIGHT (kg)	UNIT VALUES: BAY LENGTH (m)	UNIT VALUES: CG STATION (m)	REQTS OF PAYLOAD: NO. OF UNITS	REQTS OF PAYLOAD: WEIGHT (kg)	REQTS OF PAYLOAD: BAY LENGTH (m)
SPACELAB — BASIC	SHORT MODULE - LANDED		3134	4.20				
	LONG MODULE - LANDED		4210	6.90	27.46	1	4210	
	PALLET							
	PSS (SPACELAB SUBSYSTEMS):							
	MOD OR MOD/PAL		68	—	13.80	1	68	
	PALLET ONLY		76	—	13.80			
	UTILITY BRIDGE: SHTL/PAL, MOD/PAL (FREON)		192					
	SHTL/MOD		156	—	21.41	1	156	
	MOD/PAL, PAL/PAL (NO FREON))		56					
	IGLOO (PALLET SUBSYSTEMS)							
SPACELAB — MISSION DEPENDENT	STRUCTURE, ECS, EPDS, CPSE, CDMS, HABITABILITY, OTHER	LEVEL II SYS. REQTS. ALLOCATION	991	--	28.40	1	991	--
	TRANSFER TUNNEL		610		20.61	1	610	
ORBITER MISSION INDEP.	HEAT REJECTION KIT		88	—	30.89	1	[illegible]	
	EPS ENERGY KIT (1st) - LANDED	840 kW-hr	313.4	—	34.88		[illegible]	
	SPACELAB ATTACH. FITTING	After 1st Four	25					
	TUNNEL ADAPT, DUCT, A/L KITS		486	1.98	15.60	1	486	
SPACELAB PAYLOAD	EXPERIMENT (LESS EXPENDABLES)		1229		28.30	1	1229	
	INSTRUMENT POINTING SYSTEM	(Inside-Out Gimbal)	780					
	P/L SPECIALIST, SEAT/RESTRAINTS FOOD & LiOH FLT. OPER., CREW EQ. & STORAGE		771	—	12.00	1	771	
	N_2/O_2 TANKAGE		221	—	28.50	1	221	
	OMS KIT - LANDED	500 fps	1443	2.92	31.57			
	EPS ENERGY KIT - LANDED	After First	313.4		29.05	12	3761	
	ENERGY KIT MOUNT	After Fifth Kit	142		30.11	8	1136	
EXPENDABLES	SPACELAB (O_2 & N_2) EXPERIMENT EPS REACTANTS OMS KIT PROPELLANT RCS PROPELLANT	Per Kit	386			13	5148	

PAYLOAD NAME: Life Science Mod IIIB

DELIVERY ORBIT ALT. (km): _____ PAYLOAD NO.: _____

INCLINATION (deg): _____ MISSION DURATION (days): 30

CABIN VOLUME (m^3): _____ MODULE VOLUME (m^3): _____

PAYLOAD SPECIALISTS: 1 TOTAL CREW: 4

	USER PAYLOAD	SPACELAB	TOTAL
AVERAGE ELECTRICAL POWER (kW)			
MISSION ELECTRICAL ENERGY (kW-hr)			

NOTES:

	Average Power (kW)	Energy (kW-hr)
ORBITER	12.5	7215
HEAT REJECTION	0.34	245
SPACELAB	3.00	2160
EXPERIMENT	1.28	921
TOTAL	17.12	10541

$\frac{10541 - 50}{840}$ = 13 KITS

(2 KITS OVER TUNNEL)

TOTAL SHUTTLE PAYLOAD LENGTH (m): _____

WEIGHT SUMMARY — ITEM	WEIGHT (lb)	WEIGHT (kg)	CG STATION (m)
BASIC SPACELAB	9775	4434	27.04
SPACELAB MISSION DEPENDENT	2185	991	28.40
TRANSFER TUNNEL	1345	10	20.61
ORBITER MISSION INDEPENDENT	1955	887	20.39
SPACELAB PAYLOAD	15498	7166	27.23
SHUTTLE PAYLOAD AT LANDING	31058	14088	26.54
EXPENDABLES	11350	5148	29.36
SHUTTLE PAYLOAD AT LAUNCH	42408	19236	27.29

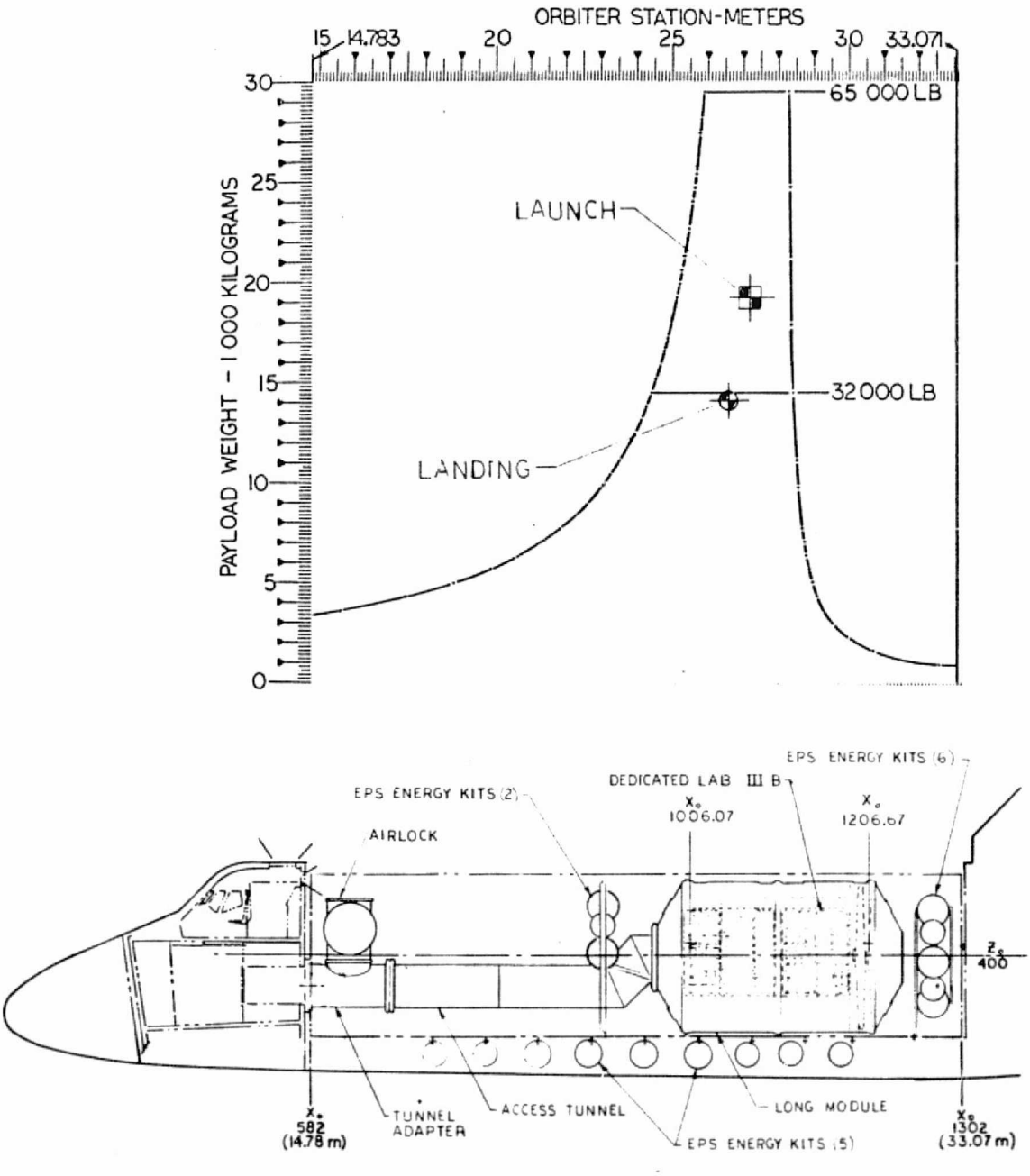


Figure 4-10. Example Weight/CG Analysis for Dedicated Lab MOD IIIB

4.2.5 MOCKUP ACTIVITY. In conjunction with an in-house human engineering study, Convair produced full-sized soft mockups of the Spacelab single and double racks, the latter of which is shown in Figure 4-11. The layouts of two mini-laboratories, ML-1A and ML-2B, were then incorporated into the rack mockups to provide both the pictorial representation of the laboratories and a basis for a human factors analysis of the integrated designs. Both of these are shown in Figure 4-12.

Mini-lab ML-1A, shown previously in layout form in Figure 4-6, is shown as a single rack. Another half rack and aisle space for the rotating litter chair are also required. ML-2B, the biomedical mini-lab using restrained primates, consists of a double rack (containing two restrained-monkey pods) and a rack of analysis equipment. Also, each mini-lab requires support equipment which is distributed elsewhere in the Spacelab.

Reviews of "Lessons Learned in Skylab" (References 17 and 18) and other Skylab documents published by JSC and MSFC show that astronauts prefer working in zero-g, foot-restrained, in their neutral body positions, see Figure 4-13. They would also like to have work stations arranged to permit use of the greatly expanded zero-g functional reach capability. Incorporating these preferences in designs of future spacecraft work stations will take a considerable amount of effort for such reasons as:

a. Major alterations of conventional sit/stand console designs will be required to meet these needs. Eye positions, leg room, reach envelopes, and equipment arrangements will have to be changed from conventional to zero-g.

b. Zero-g designs will have to remain compatible with 1-g operations such as equipment installation, checkout, and astronaut training.

A preliminary human factors analysis of the mini-lab mockups revealed some interesting information. The general conclusion is that the standard 19-inch Spacelab racks are fine for electronics equipment but not ideally suited for a life sciences laboratory. The single rack is too narrow for comfortable maneuvering within the rack, as required for microscopic analysis. Also, the Spacelab foot restraint, designed for vertical positioning using rail guides, interferes with deployed L/S equipment like shelves, work surfaces, microscope trays and kit drawers. Finally, the front of the rack, vertical and tilted outward at the top, is not compatible with the crewperson neutral body position in zero-g discussed above. Even the erect 90th percentile stature shown in Figure 4-14 indicates reach-envelope problems to all parts of the rack. All of these factors should be considered in the detail design of the life sciences laboratory and the placement of equipment within the standard racks.

4.3 SUBSYSTEM REQUIREMENTS

This section describes the subsystem requirements of the candidate payloads. The Spacelab subsystems that have major interfaces with the payloads are: electrical power, thermal/ECS, and data management. The requirements in these areas are

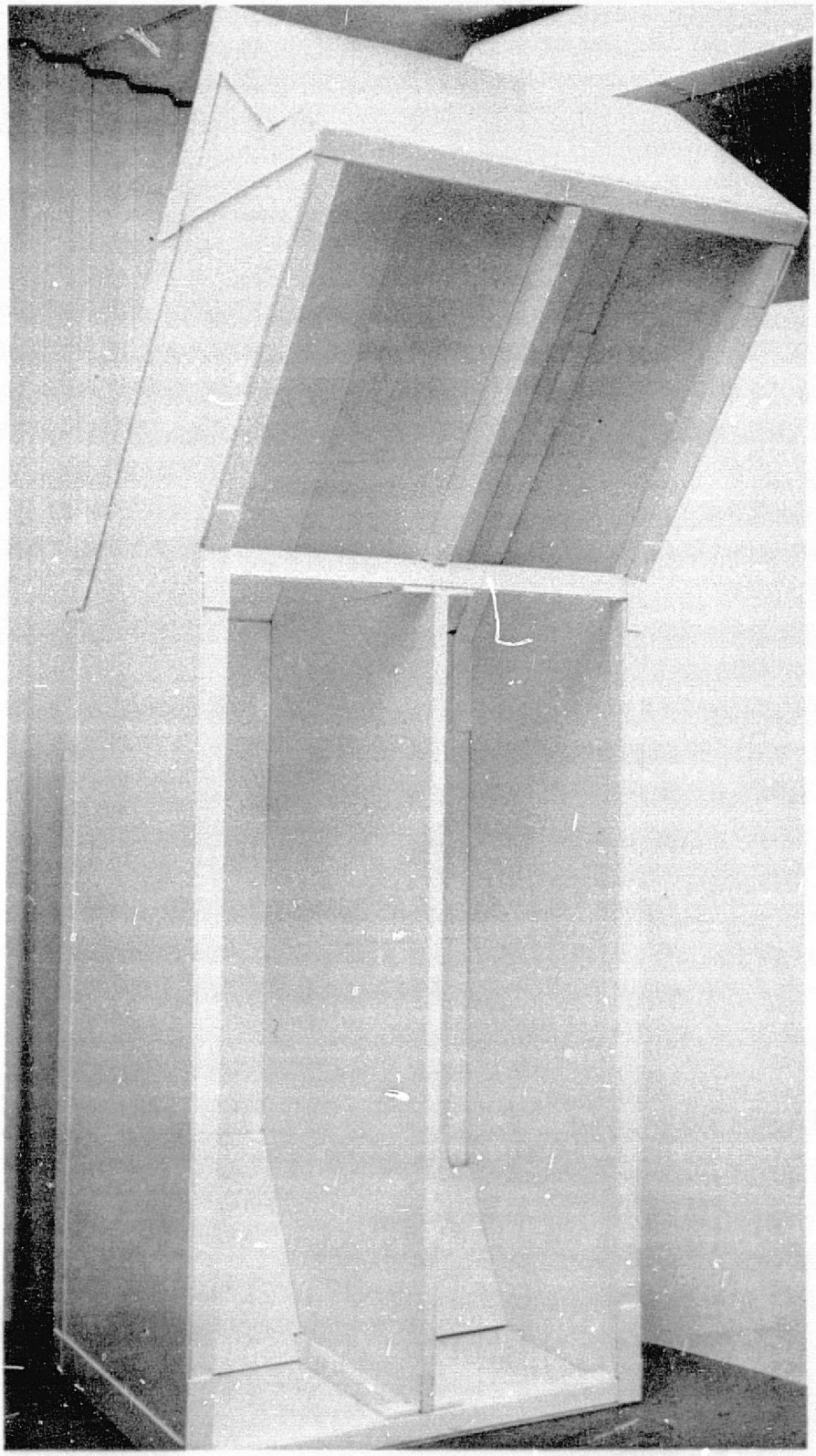
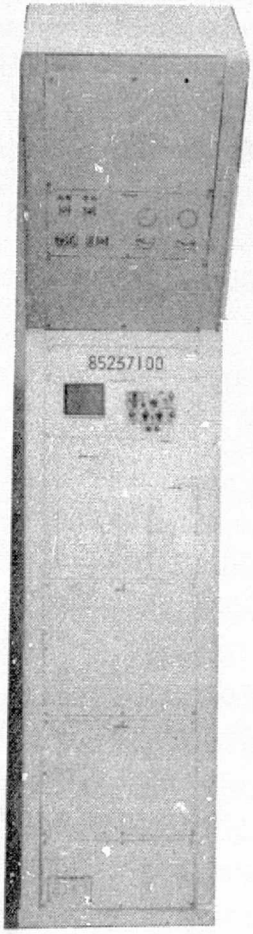
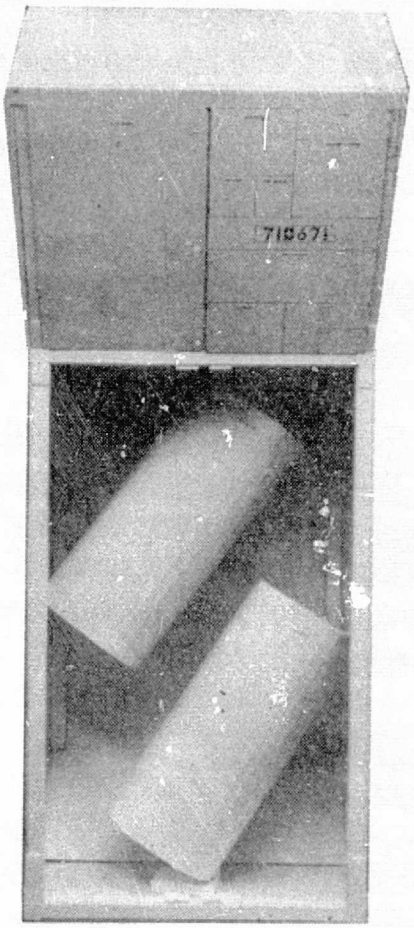


Figure 4-11. Double Rack Mockup





ML-1A FIRST SPACELAB MISSION

ML-2B RESTRAINED PRIMATE

Figure 4-12. Mini-Lab Mockups

	5th		95th	
	CM	IN	CM	IN
A	11.9	4.7	13.5	5.3
B	26.4	10.4	28.9	11.4
C	58.9	23.2	65.8	25.9
D	27.2	10.7	31.2	12.3
E	12.2	4.8	14.5	5.7
F	72.6	28.6	84.3	33.2
G	84.1	33.1	92.9	36.6
H	81.8	32.2	90.2	35.5
I	45.2	17.8	53.8	21.2
J	152.6	60.1	172.7	68.0
1-2	46.7	18.4	55.6	21.9
2-3	65.0	25.6	72.6	28.6
3-4	62.5	24.6	68.6	27.0
4-5	27.2	10.7	31.2	12.3
5-6	28.4	11.2	31.7	12.5

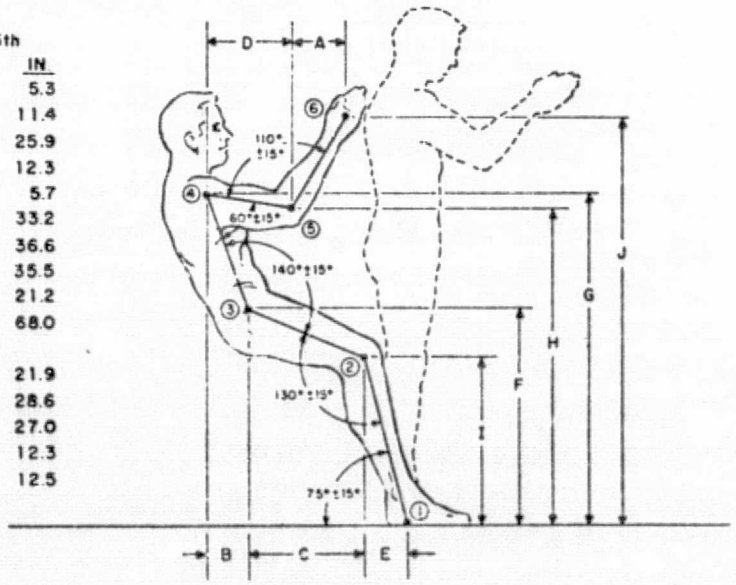


Figure 4-13. Neutral Body Position

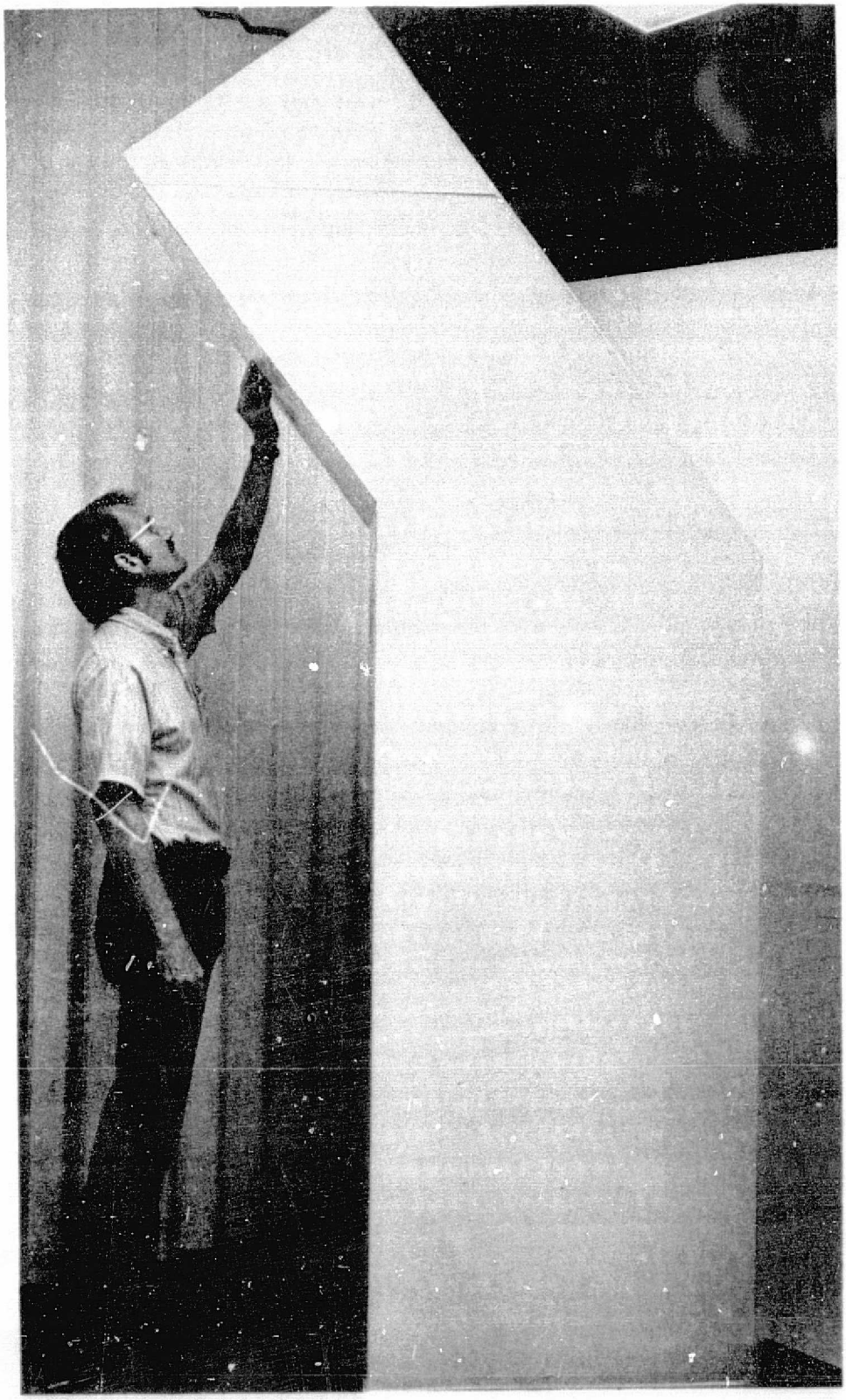


Figure 4-14. 90th Percentile Stature and Spacelab Double Rack — Side View

discussed in sections 4.3.1, 4.3.2 and 4.3.3, respectively. An additional section, 4.3.4, covers collectively the interfaces associated with the environmental factors such as acoustics, vibration, electrical and magnetic emissions, radiation, contamination, etc.

4.3.1 POWER SYSTEM. The power system was analyzed to determine the compatibility of the life sciences payload requirements with the Spacelab power resources available. The intent of the analysis was not to define the in-depth integration factors but to define the major impact and accommodation characteristics of the various payloads. Consequently, only those Spacelab power parameters relevant to the analysis are presented in this report. For a more complete description of the Spacelab power system, the latest version of the Spacelab Payload Accommodation Handbook (Reference 13) should be reviewed.

The following paragraphs describe the appropriate Spacelab power system capabilities, the life sciences payload power requirements, and finally the life sciences payload/Spacelab power impacts and accommodations.

4.3.1.1 Spacelab Power System Capability. Spacelab power is provided by the Shuttle Orbiter. The primary power delivered from the Orbiter during orbital operations is 7 kW average, and 12 kW peak for nominally 15 minutes every 3 hours at a nominal voltage of 28 Vdc. The energy available to the Spacelab subsystems and experiments is 890 kWh.

During the prelaunch and post-landing phases, power is provided to Spacelab either by Orbiter ground support equipment (GSE) or by the Orbiter power supply system itself. In the case of GSE support, the power supplied to Spacelab is 1.0 kW average and 1.5 kW peak with the Orbiter subsystems powered up and 7.0 kW average and 12.0 kW peak with the Orbiter subsystems powered down. For periods during which no GSE support is available (e.g. during transportation of the Space Shuttle to the launch pad), 1.0 kW average and 1.5 kW peak are available to Spacelab only at certain periods. The allocation of these amounts between Spacelab subsystems and payload has not been determined.

The primary power available to Sapcelab subsystems and payload from the Orbiter during ascent and descent is 1.0 kW average and 1.5 kW peak. The peaks are limited to 2 minutes maximum duration. In the present operational concept Spacelab will be inactive during ascent and descent, and hence the experiments are not provided with power, heat rejection, etc. However, the provision of limited resources and services to experiments during these phases is presently under investigation by ESA. In the event that Spacelab power is not available to the life sciences payloads, batteries will be required to support various power demands during these mission phases.

The power available to experiments during orbit operations depends on the power consumption of the mission-independent Spacelab subsystems and is also a function of the use of mission-dependent equipment. A maximum amount of power is available to the

payload if no mission-dependent equipment is used, and a minimum amount if a maximum arrangement of power-consuming support equipment has been selected.

The Spacelab power and energy budget values used during this study are shown in Table 4-8.

Table 4-9. Spacelab and Payload Power Values

Available to Spacelab			S/L Mission Equipment Allocations		Available to Payload		
Avg	Peak	Energy	Independent	Dependent	Avg	Peak	Energy
7 kW	12 kW	890 kWh	3 kW	0.7 kW	3.3 kW	9 kW	422* kWh

*Available to the payload and mission dependent equipment

4.3.1.2 Life Sciences Payload Power Requirements. The power requirements were estimated for each of the 16 proposed payloads by analyzing each power consuming equipment item in the payload, assuming typical operational protocols, determining the average power peak power, total energy consumption, and the ascent and descent requirements. Tables 4-10 and 4-11 describe the requirements for a mini-lab, ML-1A, and the most comprehensive dedicated lab, MOD IIIA. A complete set of tables for all payloads appears in Volume V, Book 2, Appendix D.

The power-on periods for the equipment items were defined using the Equipment Operations Analysis Model developed during Contract NAS 8-29150 (Reference 2, Volume VIII). This basic operations information was modified to reflect changes in equipment items as well as in research emphasis to define the estimated power-on times.

The daily average on-duty power was based on the equipment item operating power, the equipment item on-time, and a nominal laboratory operating period of 12 hours per day. This laboratory operating period corresponds with the results of previous manning studies for life sciences laboratories described in the operations model of the above-referenced document.

The peak power estimate was composed of the high-use items which are on 8 hours or longer plus the combination of various instruments and support items that could be used simultaneously during the 12-hour duty cycle. Time-lining of this example power data can be accomplished using the power summary tables in Appendix D plus a set of defined experiment protocols. The timelines would obviously only be examplary and would vary with changing experiments and protocols. Time lining was not necessary at this stage in the Phase A study to define Spacelab power accommodation factors; therefore, only tabular power summary data is presented.

Table 4-10. Mini-Lab Power Requirement Summary

LAB CODE: ML-1A		ORBIT OPERATIONS				ASCENT	DESCENT
Equipment Items Using Power	Operating Power (Watts)	On Time Hrs/Day	Average On Duty Power	Peak Power Contribution	Energy Consumption Watt-hrs/Day	Watts	Watts
6A Airflow, Work Surface	75	.2	1.25		15	0	0
7A Auto. Poten. Elec. Analy.	100	1	8.33		100	0	0
37 Camera, Video B/W	15	.5	.63	15	7.5	0	0
40A Cent. Blood Sample	100	.2	1.67		20	0	0
51F Coolant Loop, Liquid	50	24	50	50	1200	0	0
63C Display Numeric	2	8	1.33	2	16	0	0
80 Freezer	200	8	66.67	200	1600	0	0
81 Freezer (Low Temp.)	10	24	10	10	240	10	10
114E Lamp, Port. Hi Int. Photo.	150	.5	6.25	150	75	0	0
126 Microscope	15	.5	.63		7.5	0	0
126J Microscope Ass. Kit	15	.5	.63		7.5	0	0
131J OFO Exp. Pack (2)	40	24	40	40	960	40	40
132 Oscilloscope	75	1	6.25		75	0	0
153A RLC/Console	127	.4	4.23	127	50.8	0	0
156 Signal Conditioners (6)	12	24	12	12	288	0	0
187A Woodlawn Wander	15	24	15	15	360	15	15
TOTALS	1001		224.87	621	5022.3	65	65
	Off Duty Power = $\frac{5022.3-224.87 \times 12}{12}$ = 193.7						
Estimated Crew Involvement ≈2 man-hrs/day during a 12-hour period							

Table 4-11. Dedicated Lab Power Requirement Summary

LAB CODE: MOD III A			ORBIT OPERATIONS				ASCENT	DESCENT
	Equipment Items Using Power	Operating Power (Watts)	On Time Hrs/Day	Average On Duty Power	Peak Power Contribution	Energy Consumption Watt-hrs/Day	Watts	Watts
1A	Accelerometer Coupler (3)	3	24	3	3	72		
6	Air Particle Sampler	50	.4	1.76		20		
6A	Airflow Work Surface	75	.5	3.12		37.5		
11	Analyzer, Gen. Spect'phot'r.	250	1	20.5	250	250		
7	Autoanalyzer	200	1.0	16.66	200	200		
7A	Auto Potentiometer Elec. Analysis	100	1.0	8.34		100		
16F	Ballistocardiogram Coupler	1	1.0	.08		1		
19D	Body Mass Measuring Device	15	.2	.26		3		
26A	Cage, Metabolic C/T	5	24	5	5	120		
26B	Cage, Metabolic Plt. (2)	60	24	60	60	1440		60
26	Cage, Metabolic Rat	20	24	20	20	480		20
30A	Cage, Rat (16)	144	12	144	144	1728		
31	Calculator, Pocket	5	1.0	.42		5		
32	Camera, Cine	13	.5	.54		6.5		
32A	Camera, Controller	100	12	100	100	1200		
37	Camera, Video B/W	15	12	15	15	180		
38	Camera, Video, Color	69	.5	2.88	69	34.5		
38D	Camera Timer, Video	10	.5	.42	10	5		
38F	Cardiopulmonary Analyzer	200	1.0	16.66		200		
40A	Centrifuge, Blood Sample Processor	100	.4	3.34		40		
43A	Centrifuge - Research Δ	354/210	12/12	354	354	6768		
48	Cleaner, Vacuum	100	.4	3.34		40		
50A	Clinostat C/T	10	24	10	10	240		
50	Clinostat Plants	10	24	10	10	240		
50B	Compactor (Solids)	100	.05	.42		5		
51F	Coolant Loop, Liquid	50	24	50	50	1200		
54	Colony Counter (Manual)	50	.5	2.08		25		
63B	Display Keyboard Portable	60	1.0	5.0		60		
63C	Display, Numeric (3)	6	12	6	6	72		
64	ECG Coupler (24)	48	24	48	48	1152	12	12
65	EEG Coupler (8)	16	24	16	16	384	4	4
66C	Electrophys. Receiver	5	1.0	.42		5		
66	EMG Coupler (10)	20	24	20	20	480	6	6
70E	Exercise Equip., Physiol.	18	4	6		72		
76J	Flowmeter, Gas (6)	24	.5	1.0		12		

Table 4-11. Dedicated Lab Power Requirement Summary, Contd

LAB CODE: MOD IIIA (Cont'd)		ORBIT OPERATIONS				ASCENT	DESCENT
Equipment Items Using Power	Operating Power (Watts)	On Time Hrs/Day	Average On Duty Power	Peak Power Contribution	Energy Consumption Watt-hrs/Day	Watts	Watts
77B Freezer, Cryo	10	24	10	10	240	10	10
80 Freezer, General (2)	400	8	133.33	400	3200		
81 Freezer, Low Temp. (2)	20	24	20	20	480	20	20
83 Refrigerator (2)	100	8	33.33	100	800		
87 Gas Analyzer, Infrared	50	.5	4.16		25		
91 Gas Analyzer, Mass Spec. (2)	100	12	100	100	1200	50	50
93 Gas Analyzer, RH	6	24	6	6	144		
98A Holding Unit C&T (2)	60	24	60	60	1440		60
98C Holding Unit, Invt. (2)	100	12	100	100	1200		
101 Holding Unit, Plt. (2)	1000	12	1000	1000	12000	374	374
101B Holding,Unit, Monkey Pod	100/30	12/12	100	100	1560	30	30
101C Holding Unit - Primate (1)	100/30	12/12	100	100	1560	30	30
103B Incubator	5	24	5	5	120		
114E Lamp, Portable Hi. Int. Photo.	150	.5	6.16	150	75		
117 LBNP	26	.4	.86		10.4		
121 Mass Meas. Device (Macro)	15	.3	.38		4.5		
122 Mass Meas. Device (Micro)	15	.3	.38		4.5		
126 Microscope, Comp.	15	.5	.62		7.5		
126A Microscope, Dissecting	100	1.0	8.34	100	100		
126J Microscope, Access. Kit	15	.5	.62		7.5		
132 Oscilloscope	75	1.0	6.26		75		
138 PH Meter	20	.3	.50		6		
138B Photocell Coupler (12)	24	24	24	24	• 576		
139 Plethysmograph, Limb	5	.5	.20		2.5		
143G Pressure Coupler (4)	8	24	8	8	192		
144 Psychomotor Per. Cons.	15	.5	1.25		7.5		
147 Radiation Count - Biochemical	90	.5	3.76		45		
150B Receiver, Biotelemetry	10	24	10		240		
153A Rotating Litter Chair/Console	127	.4	4.24		50.8		
156 Signal Conditioners (24)	48	24	48	48	1152		
156F Sonocardiogram	12	1.0	1.0		12		
162 Sterilizer, Autoclave	300	1.5	37.5		450		
165 Sterilizer, Tool	110	.4	3.66		44		
179 Temperature Block	200	1.5	25	200	300		
179D Thermometer (Electronic)	14	.2	.24		2.8		

Table 4-11. Dedicated Lab Power Requirement Summary, Contd

LAB CODE: IIIA (Cont'd)		ORBIT OPERATIONS				ASCENT	DESCENT
Equipment Items Using Power	Operating Power (Watts)	On Time Hrs/Day	Average On Duty Power	Peak Power Contribution	Energy Consumption Watt-hrs/Day	Watts	Watts
181D Transducer, Pressure (4)	4	24	4	4	96		
182J Vectocardiogram Coupler	2	1.0	.16		2		
182P Ventilation Unit - Vertical (3)	120	24	120	120	2880	120	120
188 Work and Surgical Bench	1000	1.0	83.34	1000	1000		
TOTALS	6896		3034.55	5056	48189.5	656	696
On Duty is considered 12 hours.							
Off Duty Average Power = $\frac{48,189.5 - 3034.55 \times 12}{12}$ = 981.2							
Δ For 182R in Centrifuge 43A	320		320	320	3840		

The total energy consumption was based upon the equipment item operating power levels and their estimated on-times.

The ascent and descent power is tied directly to the requirement to support and monitor the experiment organisms of the various life sciences laboratory concepts. Power is provided only to essential support items during these power-critical phases of the mission. As an example, certain organism support equipment items are operated at two power levels corresponding to the diurnal cycle, one that corresponds to the 12-hour on-duty research operation, and the other "powered down" version corresponding to the off-duty portion of the cycle. When the essential equipment items contain this dual power level capability, the lowest value has always been used during the ascent and descent phases of the mission. The essential equipment item with the highest ascent and descent power requirement is the plant holding unit. The principal investigators (PIs) have defined a requirement for a low level of lighting during these mission phases. The requirement is 187 watts per plant holding unit. A relaxation of this requirement could make a significant difference in the power level requirements of Dedicated Lab MODs IIA, IIIA and IIB, and mini-lab ML-2D.

In support of the life science laboratories, certain mission dependent equipment is required. Table 4-12 presents the likely mission-dependent equipment and the estimated use of it during a typical dedicated laboratory mission. The operation of mini-labs within a shared Spacelab mission will have to consider all sharing payloads; however, the life sciences chargeable portion will never be larger than that established for a dedicated life sciences laboratory. The mission-dependent average power is approximately 0.7 kW for a dedicated laboratory. As can be seen, this power allocation is used primarily by the computer and various mission-dependent equipment items that interface with the computer.

Table 4-13 summarizes the power requirements for all 16 laboratory concepts. This summary includes both on-duty and off-duty averages and peak power levels, daily energy consumption, and ascent and descent requirements.

4.3.1.3 Life Sciences/Spacelab Power Accommodations. The data presented in Tables 4-9 and 4-13 provides the basis for the accommodation analysis. Table 4-9 defines the Spacelab power system capabilities, and Table 4-13 summarizes the life sciences laboratory power requirements.

Figure 4-15 presents the on-duty average and peak power requirements for the 16 laboratory concepts studied. Also shown are the various Spacelab and payload power limit values. The peak power limit for the life sciences payload is 9 kW. The average power available to the laboratory experiment equipment is about 3.3 kW. The mission dependent average power is approximately 0.7 kW for a dedicated laboratory. The off-duty average power of the dedicated laboratories ranges from about 0.7 kW to 1.0 kW.

C.2

Table 4-12. Estimate of Mission-Dependent Equipment Power Level

Spacelab Equipment	Power Level (Watts)	Operating Time (Hours)	On-Duty Average (Watts)
Computer	310	24	310
Exp. I/O Unit	90	24	90
Exp. RAU	28	24	28
Keyboard	20	24	20
CRT Display	100	6	50
Analog/Video Recorder	200	2	33
TV Monitor	60	6	30
Time Display	30	24	30
*Power Conditioning	101	—	101
TOTAL			692

*Assumed 6% of dedicated laboratory average power for power conditioning, etc. (MOD IIIB power 1690 watts)

Table 4-13. Summary of Electrical Power Requirements

LAB CONCEPT	ORBIT OPERATIONS POWER (WATTS) ON DUTY AVERAGE	ON DUTY PEAK	OFF DUTY AVERAGE	OFF DUTY PEAK	ENERGY CONSUMPTION (WATT-HRS/DAY)	ASCENT POWER (WATTS)	DESCENT POWER (WATTS)
COL-2A	10	110	10	10	250	10	10
COL-3A	10	10	10	10	240	10	10
ML-1A	225	621	194	327	5022	65	65
ML-2A	486	1944	212	379	8375	50	50
ML-3A	199	742	155	310	4250	10	10
ML-4A	55	371	17	50	865	0	0
ML-5A	38	229	0	0	458	0	0
ML-2B	488	988	310	477	9578	150	150
ML-2C	563	2619	237	404	9602	65	65
ML-2D	1119	2625	243	410	16,346	252	252
MOD-IA	1570	3210	672	838	26,895	412	472
MOD-IIA	2989	4794	918	1252	46,883	856	976
MOD-IIIA	3034	5056	981	1317	48,190	656	692
MOD-IIB	2752	4400	901	1068	43,834	926	1066
MOD-IIC	1676	3491	858	1181	30,402	582	582
MOD-IIIB	1690	3505	937	1271	31,524	412	412

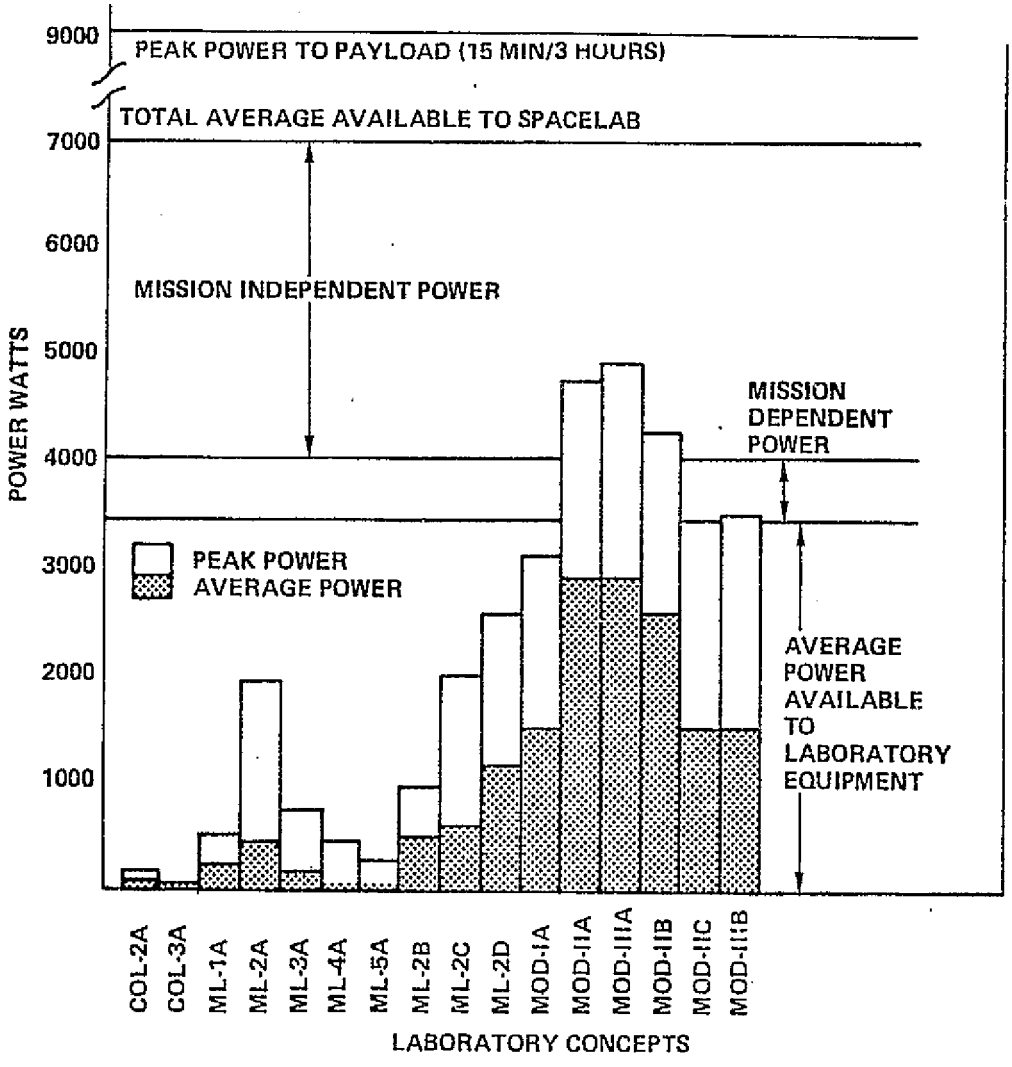


Figure 4-15. Summary of On-Duty Average and Peak Power Requirements

The various power levels of the mini-lab concepts would have to be evaluated on an individual basis. These mini-labs would be flown in shared missions and the power requirements of all sharing laboratories would have to be considered. All power requirements of the dedicated laboratories are within acceptable limits during the on-orbit mission phase.

The accommodation of life sciences energy requirements with available Spacelab resources is shown in Figure 4-16. The total energy available from the Spacelab for the life sciences payloads is 422 kWh. Assuming the Spacelab will be fully powered for a nominal period of 6.5 days, then the daily payload quota of energy is 65 kWh during a seven-day mission. The three dedicated laboratory concepts studied for extended mission durations (MOD IIIA, IIC and IIIB) require the addition of energy kits. All other laboratory concepts are within the energy limits of the standard power system of the Shuttle/Spacelab.

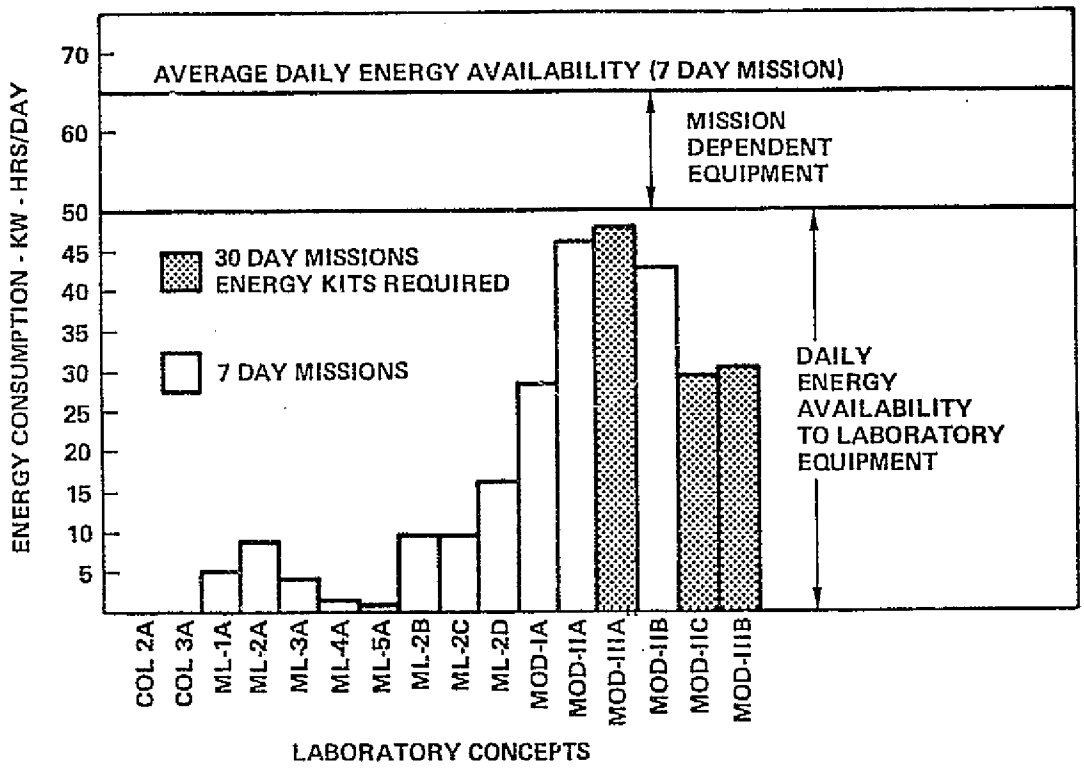


Figure 4-16. Summary of Daily Energy Consumption Requirements

The energy kits to be used for the dedicated laboratories are composed of hydrogen and oxygen tank sets. Each tank-set kit is sized to generate 840 kWh. Depending upon the mounting location the individual kits range in weight from 741 kg to 851 kg each. The total penalty for additional energy kits must include the energy required to sustain the Orbiter as well as the life sciences payload.

The MOD IIIA cannot be extended to a 30-day mission because the landing weight limit of 14,500 kg for the Shuttle would be exceeded. MOD IIC and IIIB, however, are viable options from the standpoint of being within the allowable landing weight limit.

The requirement for ascent and descent power is potentially the most impacting of all power accommodation factors. In all laboratory concepts, a minimum power usage philosophy was used as a guide. The primary power available to the Spacelab from the Orbiter during ascent and descent is 1.0 kW average and 1.5 kW peak. In the present operational concept, Spacelab will be inactive during launch, ascent and descent; therefore, the laboratories are not presently provided with this power or heat rejection capability. Providing limited power during these operational phases is presently under investigation by ESA.

Figure 4-17 indicates that if 1 kW of power is available to the payloads during ascent and descent, only the dedicated lab MOD IIB would exceed the power available. This assumes that no Spacelab systems are operating. The ascent/descent power could be

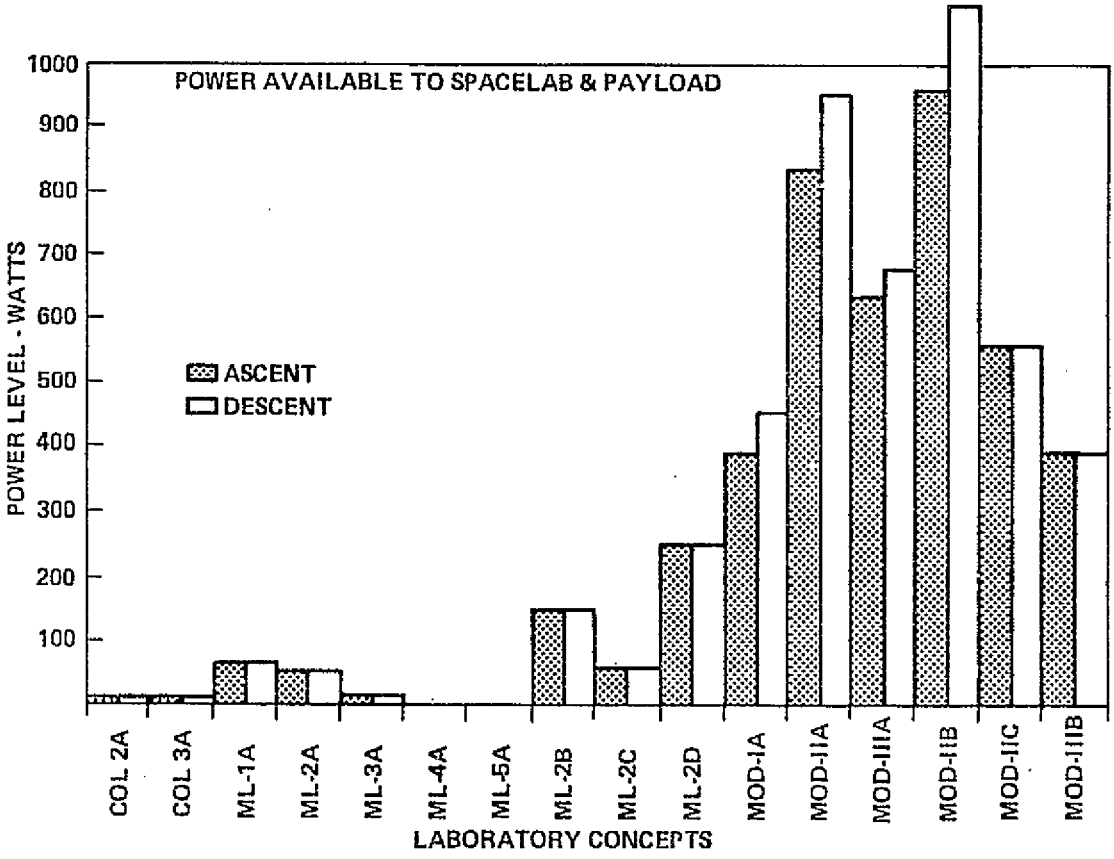


Figure 4-17. Summary of Ascent and Descent Payload Power Requirements

reduced substantially if the requirement for lighting within the plant holding units of Dedicated Labs IIA, IIIA, and IIB were eliminated. The power level for each plant holding unit during the ascent/descent phase is 187 watts.

The power accommodation analysis summarized in Table 4-14 shows some minor impacts in these areas. First, the two carry-on labs, although requiring a minimal amount of power, will need a power interface in the Orbiter crew compartment. The second impact area involves the three dedicated lab concepts (IIIA, IIIB, IIC). These labs require mission extension energy kits for a 30-day mission. Third, the ascent and descent power requirement, which currently is under study by ESA, may be a problem. If the ESA results provide for payload power in the order of 1 kW, only the dedicated lab MOD IIB appears to exceed this limit. The possibility of eliminating the lighting requirements of the two plant holding units during ascent and descent would reduce the MOD IIB power level by 374 watts. Alternative solutions also include the use of storage batteries to supply power during the ascent and descent phases of operation. Weight penalty for a battery and charger is approximately 10 kg/kWh.

Table 4-14. Power Accommodation Summary

LAB CONCEPT	ACCOMMODATION IMPACTS	COMMENTS
COL 2A COL 3A	NONE NONE	ASSUMES POWER INTERFACE IN CREW COMPARTMENT
ML-1A ML-2A ML-3A ML-4A ML-5A ML-2B ML-2C ML-2D	NONE DURING ORBIT	ASCENT & DESCENT POWER REQUIRED FOR ALL BIOMED & BIOLOGY MINI-LABS. A TOTAL OF 1 kW IS AVAILABLE TO SPACELAB DURING ASCENT & DESCENT-MAXIMUM REQUIREMENT IS 0.252 kW FOR ML-2D.
MOD I A MOD II A MOD III A MOD II B MOD II C MOD III B	NONE DURING ORBIT NONE DURING ORBIT 30 DAYS REQUIRES ENERGY KITS NONE DURING ORBIT 30 DAYS REQUIRES ENERGY KITS 30 DAYS REQUIRES ENERGY KITS	ASCENT & DESCENT POWER REQUIRED FOR ALL DEDICATED LABS. POWER RANGES FROM 0.412 kW TO 1.066 kW. 1 kW AVAILABLE TO SPACELAB DURING ASCENT & DESCENT.

4.3.2 ENVIRONMENTAL CONTROL SYSTEM. The Spacelab environmental control subsystem (ECS) includes the environmental control/life support subsystem and the thermal control subsystem. An analysis of the ECS was made so that its compatibility with the various life sciences laboratory concepts could be assessed. The analysis defined the impact and accommodation characteristics of the various payloads. Only those Spacelab ECS characteristics appropriate to the analysis have been presented. A more complete description of the Spacelab ECS is presented in Reference 13.

The following paragraphs describe the relevant Spacelab ECS capabilities, the life sciences payload ECS requirements, and finally the life science payloads/Spacelab ECS impacts and accommodations.

4.3.2.1 Spacelab ECS Capability. An overall schematic of the Spacelab ECS is shown in Figure 4-18. This includes the three coolant loops within the Spacelab and the coolant loop for the pallet. In the module the cabin air cooling loop uses the condensing heat exchanger to control the module atmosphere. Subsystem and experiment racks are cooled by the avionics loop heat exchanger. An additional, liquid-to-liquid experiment loop heat exchanger is provided inside the module. Any experiment heat loads can be connected to the experiment loop heat exchanger. All three heat exchanger loops in the module use the Spacelab water loop.

The ECS provides a number of services to the experiments within the habitable volume as shown in Table 4-15. A temperature and composition controlled atmosphere is maintained within the module by the ECS. A selectable air temperature between 291

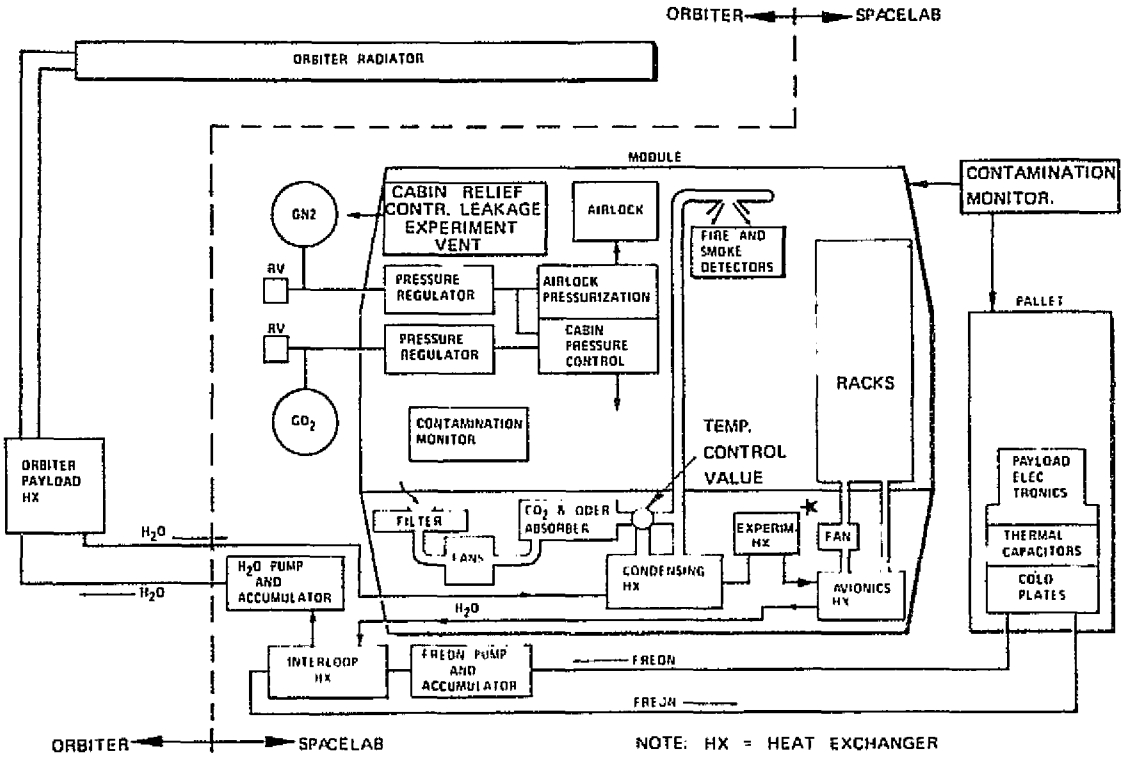


Figure 4-18. Spacelab ECS

Table 4-15. ECS Characteristics

Parameter	Capability
Module	
Crew Size	4 Men
Habitable Air Temperature	291-300°K (18-27°C) controlled to ±1°K (±1°C)
Total Pressure	1.01325×10^5 Pa
O_2 Pressure (nominal)	2.14×10^4 Pa (21% of total by Volume)
Humidity	279°K (6°C) Dew Point to 70% Relative Humidity (not controllable)
CO_2 Partial Pressure (nominal)	666 Pa (5 mm Hg)
Trace Contaminants	Below Harmful Level for Crew
Particulate Matter	5 micron filters
Airlock Repressurization	1.18 m^3, 6 times for a 7-day mission

and 300°K (18 and 27°C) is provided with an air velocity of 5 to 12 m/min in the habitable area. This velocity corresponds to a ventilation rate of 25 to 60 m^3/min. The module atmosphere is a nitrogen/oxygen sea level equivalent. The atmosphere revitalization system controls humidity, carbon dioxide level, trace contaminants, and particulate matter.

The Spacelab environmental control subsystem is designed to transfer up to 8.5 kW of heat to the Orbiter and to accommodate peak loads of 12.4 kW for 15 minutes every three hours. It can accommodate the allowed 7 kW average and 12 kW peak power consumption of the Spacelab and its experiments. The 7 kW includes 3 kW of mission-independent equipment leaving only 4 kW to the experiments and mission-dependent equipment.

The heat removal capability and transport loops available for life sciences experiments and mission-dependent equipment are shown in Figure 4-19. The Spacelab provides three basic paths to transport the experiment heat loads from the module to the Orbiter space radiators. The total heat load for these three loops cannot exceed 4 kW. The avionics heat exchanger provides up to 3 kW capacity and is used to cool the rack-mounted equipment. The experiment heat exchanger loop has a maximum capacity of 4 kW and is used to provide direct cooling to specific equipment items, such as the closed-loop ECS for the organism holding units. The cabin air heat transport loop has a thermal capacity of 1 kW and is used to reject heat from equipment used in the cabin ambient air, such as high intensity photo lights or the open-loop ECS for organisms. The life sciences laboratory concepts use all three heat rejection loops in varying degrees.

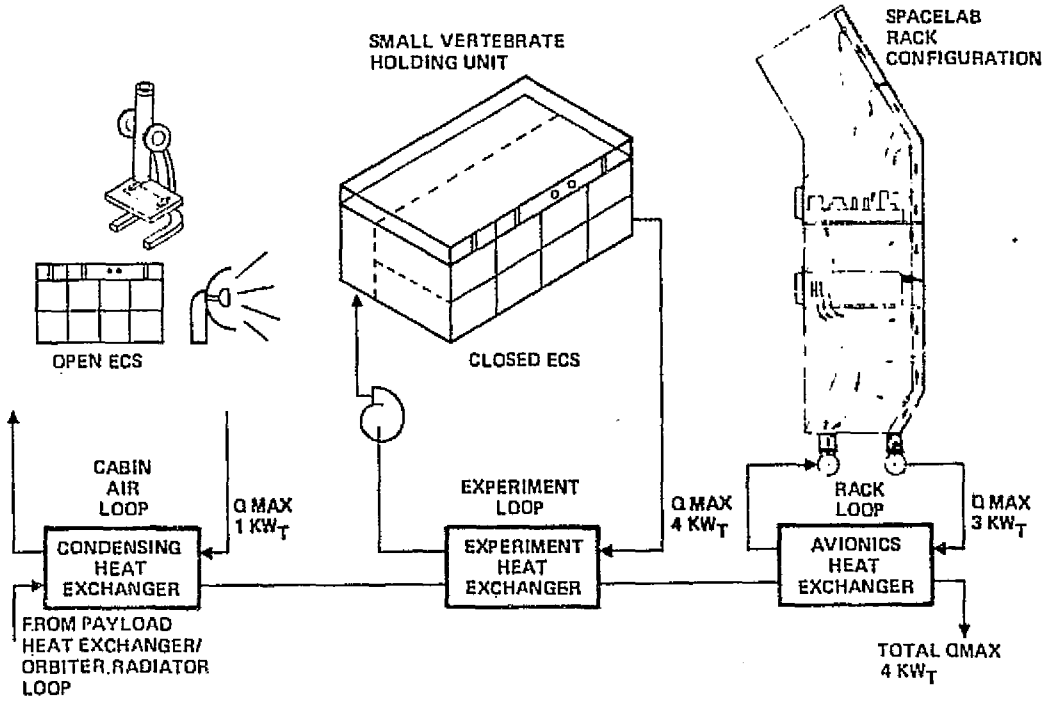


Figure 4-19. Baseline Thermal Control Paths of Spacelab

During ground operations prior to installation of the Spacelab in the Orbiter, the ECS is capable of providing all on-orbit conditions and on-orbit operational cooling capabilities for a complete Spacelab configuration, using GSE services. The following GSE connections are available to allow full conditioning capability without operating flight pumps and fans:

a. Module cabin loop supply and return air duct connectors in the module subfloor area. GSE ducts are provided through the module hatch in the forward end cone.

b. Module avionics loop supply and return air duct connectors in the module subfloor area. GSE ducts are provided through the module hatch in the forward end cone.

c. Igloo supply and return gas connectors. (Not required for life sciences.)

d. Water supply and return connections for the Water Pump Assembly (water cooling loop for module heat exchangers).

e. Freon supply and return connections for the freon pump assembly (for pallet cold plates). (Not required for life sciences.)

After installation of the Spacelab into the Orbiter the ECS can provide limited conditioning for all Spacelab segments when the Orbiter and its GSE is connected and powered up. This mode requires operation of the cabin and avionics loop fans and the freon and water pumps. The overall heat rejection capability of the Spacelab is limited to 1.5 kW in this mode. There is no capability to connect Spacelab GSE to the ECS GSE connections in this mode. The power provided to Spacelab during ascent and descent can also be rejected by the Orbiter during these phases. The ascent and descent power and the thermal control associated with this power is presently under study at ESA.

4.3.2.2 Life Sciences Payload ECS Requirements. The life sciences ECS requirements include rejection of heat loads and support of research organism metabolic loads during on-orbit operation. In addition, during ground operation phases support of the ground crew must be provided. The system support requirements for ground operation phases are defined in Volume V, Book 1 of this report.

The thermal loads are composed predominantly of the electrical power loads associated with various laboratory concepts. Those laboratory concepts that include organisms also have additional heat and environmental loads, due to the organisms' metabolic activity.

Using the power requirement summaries presented in Section 4.3.1.2 and Appendix D of Volume V, Book 2, the heat loads were apportioned to the three heat transport loops. The heat load apportionment was made by reviewing each power-consuming equipment item and determining for the specific payload the heat rejection path to be used for that equipment item. Tables 4-16 and 4-17 present the equipment items cooled by the experiment heat exchanger loop and the cabin air loop, respectively. All other equipment using power is rack cooled and uses the avionics heat exchanger.

Table 4-16. Experiment Heat Exchanger Cooled Equipment Items

EQUIPMENT ITEMS		ML-1A	ML-2A	ML-3A	ML-4A	ML-5A	ML-2B	ML-2C	ML-2D	MOD IA	MOD IIA	MOD IIIA	MOD IIB	MOD IIC	MOD IIIB
28	Cage, Metabolic, Rat												x		
30A	Cage, Rat (16)												x	x	x
51F	Coolant Loop, Liq.	x	x	x			x	x	x	x	x	x	x	x	x
80	Freezer	x	x	x			x	x	x	x	x	x	x	x	x
101B	Holding Unit, Monkey Pod													x	
182R	Vertebrate ECS												x	x	x
188	Work & Surgical Bench		x					x	x	x	x	x	x	x	x

Table 4-17. Cabin Air Cooled Equipment Items

EQUIPMENT ITEMS		ML-1A	ML-2A	ML-3A	ML-4A	ML-5A	ML-2B	ML-2C	ML-2D	MOD IA	MOD IIA	MOD IIIA	MOD IIB	MOD IIC	MOD IIIB
18C	Exercise, Phys. Equip.			x						x	x	x	x	x	x
28	Cage, Metabolic Rat											x			
30A	Cage, Rat (16)								x	x	x	x			
31	Calculator, Pocket									x	x	x	x	x	x
43A	Centrifuge, Research											x			x
48	Cleaner, Vacuum		x		x		x	x	x	x	x	x	x	x	x
63B	Display Keyboard Port.									x	x	x	x	x	x
101B	Holding Unit, Monkey Pod						x					x			
101C	Holding Unit, Primate									x	x	x	x		
114E	Lamp Port. Hi Int. Photo	x	x		x	x	x	x	x	x	x	x	x	x	x
117	LBNP									x	x	x	x	x	x
126	Microscope, Comp.	x	x				x	x	x	x	x	x	x	x	x
126A	Microscope, Disc.		x					x	x	x	x	x	x	x	x
126J	Microscope Access Kit	x	x				x	x	x	x	x	x	x	x	x
153A	RLC/Console	x								x	x	x			
165	Sterilizer, Tool		x				x	x	x	x	x	x	x	x	x
179	Temp Block									x	x	x	x	x	x
182P	Vent. Unit, Sm. Vert.		x				x	x	x	x	x	x	x	x	

It should be noted that equipment items 28, 30A, and 101B reject their heat to both the experiment heat exchanger loop and the cabin air loop, depending upon the laboratory concept considered. This is directly related to the use of the open or closed atmospheric revitalization system. These systems and the organism holding units are currently the subject of studies being funded by NASA and monitored by MSFC. Equipment item specification sheets EI 182P and 182R, defined in Volume V, Book 3, provided the various ECS characteristics used during this study. Reference 2 (Volume II) provides the more detailed system descriptions, basic assumptions, and metabolic data pertaining to the organism ECS assumed for the study.

In addition to the power-related heat loads, the organism metabolic heat loads must also be considered. The organism heat loads have been estimated for 16 rats and one macaque monkey. The other organisms within the laboratory concepts have insignificant metabolic heat loads. Table 4-18 summarizes the metabolic heat loads associated with the various laboratory concepts.

Table 4-18. Metabolic Heat Loads

Laboratory Concept	Metabolic Heat* Watts	Organism Population	
		Vertebrates	Others
ML-2A	47	16 Rats	
ML-2B	66	2 Primates	
ML-2C	47	16 Rats	
ML-2D	47	16 Rats	1 HU Cell & Tissues 1 HU Plants 1 HU Invertebrates
MOD IA	179	4 Primates 16 Rats	
MOD IIA	212	5 Primates 16 Rats	2 HU Cells & Tissues 2 HU Plants 2 HU Invertebrates
MOD IIIA	160	2 Primates 32 Rats	Same as MOD IIA
MOD IIB	113	2 Primates 16 Rats	Same as MOD IIA
MOD IIC	113	2 Primates 16 Rats	
MOD IIIB	94	32 Rats	

*Metabolic heat of 16 rats = 3680 K Joules/day = 47 watts.
Metabolic heat of 1 macaque monkey = 2560 K Joules/day = 33 watts.
HU — Holding Unit

The combined metabolic and power-related heat loads are summarized in Table 4-19. The total heat load for each laboratory is presented along with the individual loads to the three heat transport loops. The maximum heat load encountered is about 3.2 kW for dedicated lab MOD IIA and IIIA.

In addition to the above thermal loads, other ECS requirements dealing with ventilating the organism holding units and controlling the humidity load imposed by the organism populations must be considered. The ventilation unit (EI 182P) provides LiOH for CO_2 control, and high pressure storage for the O_2 supply as well as odor and particulate matter control. Therefore, these functions are not imposed upon the Spacelab ECS requirements.

Table 4-19. Thermal Load Summary (On-Duty Averages)

Laboratory Concepts	Rack Cooled (Watts)	Cabin Air Cooled (Watts)	Experiment Heat Exchanger (Watts)	Total Heat Load (Watts)
Carry-On Labs				
COL 2A	—	10	—	10
COL 3A	—	10	—	10
Mini Labs				
ML-1A	96	12	117	225
ML-2A	83	203 + 47*	200	533
ML-3A	76	6	117	199
ML-4A	41	14	—	55
ML-5A	13	25	—	38
ML-2B	80	291 + 66*	117	554
ML-2C	160	203 + 47*	200	610
ML-2D	716	203 + 47*	200	1166
Dedicated Labs				
MOD IA	562	808 + 179*	200	1749
MOD IIA	1774	948 + 212*	267	3201
MOD IIIA+	1865	902 + 160*	267	3197
MOD IIB	1728	340 + 66*	684 + 47*	2829
MOD IIC	505	340 + 66*	831 + 47*	1789
MOD IIIB+	545	414 + 47*	731 + 47*	1784

*Metabolic heat

+Heat loads are for an open ECS on the Bioresearch Centrifuge — add 320 watts to experiment heat exchanger load if a closed ECS is used.

The ventilation rate is based upon using about 33 kg/hr of air for two small vertebrate holding units or one primate holding unit. An additional, though small, ventilation requirement is imposed by the invertebrate and plant holding units. Each of these holding units requires about 1 percent of the amount (0.33 kg/hr) used for the small vertebrate holding units.

The humidity load imposed upon the Spacelab ECS is based on the organisms' total water turnover rate. The water turnover rate is defined as all the water in urine, feces, respiration, and perspiration. This water load is added to the Spacelab cabin air via evaporation from the holding unit waste management system.

The total cabin air ventilation rate and humidity load for the various laboratory concepts is shown in Table 4-20. The organism populations for these ventilation rates and humidity loads can be found in Table 4-18.

Table 4-20. Cabin Air Ventilation of Organism Holding Units

Laboratory Concept	Cabin Air Interchange (dm^3/min)	Humidity Load (grams/day)
ML-2A	424	828
ML-2B	848	1050
ML-2C	424	828
ML-2D	433	828
MOD-IA	2120	2928
MOD-IIA	2564	3435
MOD-IIIA	1290	2706
MOD-IIB	866	1878
MOD-IIC	848	1878
MOD-IIIB	424	1056

4.3.2.3 Life Sciences/Spacelab ECS Accommodations. The ECS accommodations in five areas are summarized in Table 4-21. The only areas not previously discussed include the heat load to the cabin air loop, and the heat rejection limit during ascent and descent. The heat load to the air loop is not a significant factor and if required part of the load can be easily diverted to the avionics heat exchanger. The life sciences heat loads during ascent and descent are within the stated heat rejection capability of the Spacelab ECS.

Table 4-21. Thermal and ECS Accommodation Summary

ACCOMMODATION REQUIREMENTS	POTENTIAL IMPACTS
MAXIMUM HEAT REJECTION CAPABILITY 4 kW_T	NONE - ALL LABS WITHIN SPACELAB CAPABILITY
CABIN AIR LOOP HEAT REJECTION CAPABILITY 1 kW_T	MOD IIA & IIIA ARE ABOUT 10% OVER - THIS EXCESS CAN BE DIVERTED TO THE AVIONICS LOOP WITH MINIMUM PENALTY.
ASCENT & DESCENT HEAT REJECTION MAX 1.5 kW_T	REQUIRES OPERATION OF CABIN OR AVIONICS LOOP FANS. LIFE SCIENCES HEAT LOADS ARE LESS THAN 1.5 kW_T.
SPACELAB ECS HUMIDITY CONTROL SIZED FOR 4 MEN	MOD IA, IIA, & IIIA BECAUSE OF ORGANISM POPULATION MAY IMPACT HUMIDITY CONTROL - EXCESS HUMIDITY LOAD ABOVE 4 MEN LEVEL RANGES FROM 1 TO 1-1/2 MEN EQUIVALENT.
SPACELAB ECS VENTILATION RATE 25 → 60 m^3/MIN	NONE -- DURING MAN-SURROGATE TESTING CABIN AIR INTERCHANGE IS 10% OR LESS THAN THE TOTAL VENTILATION RATE.

The on-orbit heat loads developed within the 16 laboratory concepts and shown in Figure 4-20 are all within the 4 kW heat rejection capability of the Spacelab. The total life sciences heat loads are composed of the experiment hardware loads, the mission-dependent equipment requirements, and the organism metabolic loads. The maximum load of 3.9 kW occurs with the dedicated labs MOD IIA and IIIA. This total heat load is composed of 3.2 kW from the experiment hardware and organisms and 0.7 kW from the mission-dependent equipment.

The cabin air that is drawn into the organism holding units during man-surrogate testing is used to ventilate and remove water vapor from the holding units. The maximum condensate load due to the organisms is for dedicated lab MOD IIA. This laboratory supports 5 primates and 16 rats; the average water turnover rate for this organism population is 143 grams/hour. The water vapor produced by evaporation from this water turnover rate is equivalent to the humidity load of 2-1/2 men. The Spacelab ECS is designed for a four-man crew and the expected crew size for the MOD IIA laboratory is three men; therefore, of the excess water vapor load of 2-1/2 men equivalent, only about 1-1/2 men equivalent must be accounted for. The preliminary nature of the Spacelab ECS design does not permit an evaluation of the off-design condensate load condition upon the cabin humidity control. The MOD IA and IIIA laboratories have a similar problem in that the equivalent condensate load approximates a two-man level (see Table 4-20). This excess condensate load can be reduced to a one-man equivalent because of the four-man crew size used in the design of the Spacelab ECS.

The life sciences impact on the ECS is not well defined in the area of humidity control. The preliminary state of the Spacelab ECS design does not permit a performance evaluation of the added humidity load imposed by the research organisms. Except in the

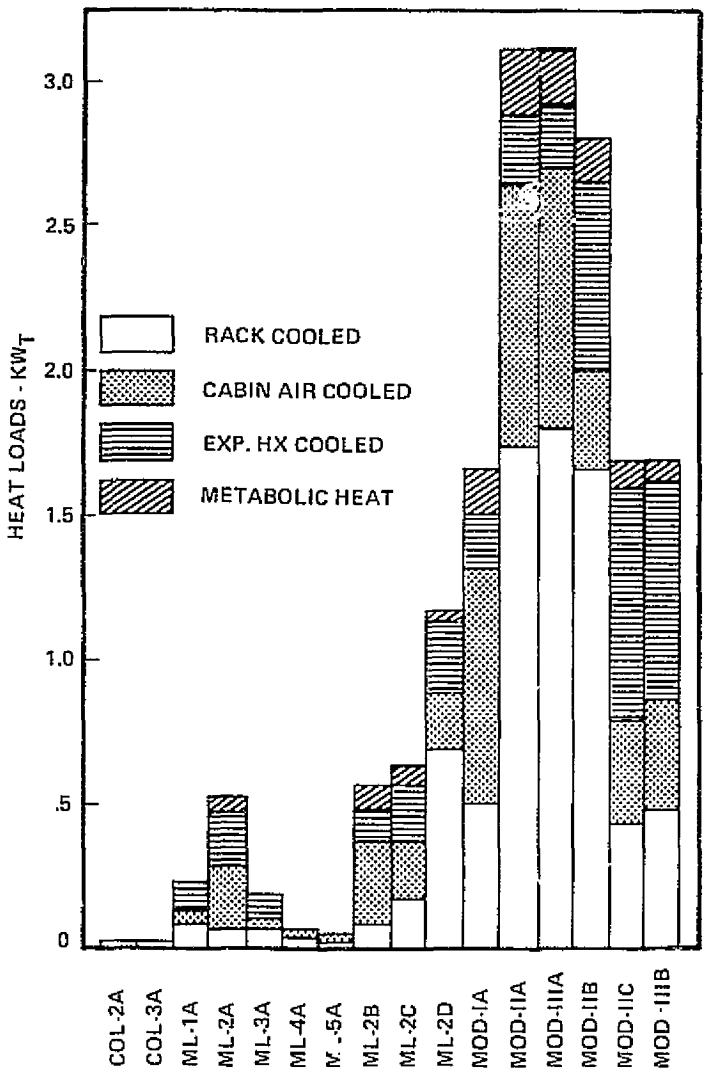


Figure 4-20. Life Sciences Heat Loads Accommodated in Spacelab

case of MOD IA, IIA, and IIIA, the stated Spacelab ECS design for four men should provide on-design humidity control performance of the ECS for all the other laboratory concepts.

Due to the low temperature requirement of coolant for humidity control and its limited quantity, other control methods such as absorption may be required for the holding unit ventilation system.

4.3.3 DATA MANAGEMENT SUBSYSTEM

4.3.3.1 Spacelab CDMS Capability. The latest information on the design of the Command and Data Management Subsystem (CDMS) used in this study is contained in the

Spacelab Payload Accommodation Handbook, May 1975 (Reference 13). The CDMS provides a variety of services to Spacelab and its payloads. These include data acquisition, monitoring, formatting, processing, displaying, caution and warning, recording and transmission in addition to providing command and control capability. These functions are provided by a variety of basic and mission-dependent equipment. Figure 4-21 is an overall block diagram of the CDMS. Two key equipment items are the remote acquisition units (RAUs) and the experiment computer. The RAU provides the interface between experiment outputs and the data bus, input/output (I/O) unit, and the computer. Low speed scientific analog and discrete data can be sampled by the RAU and routed to the Orbiter avionics system for transmission to the ground or, during periods of TDRS unavailability, stored onboard for later transmission. Significant characteristics of the RAU are shown in Table 4-22. Sampling of analog signals is seen to be limited to a maximum of 100 samples/sec.

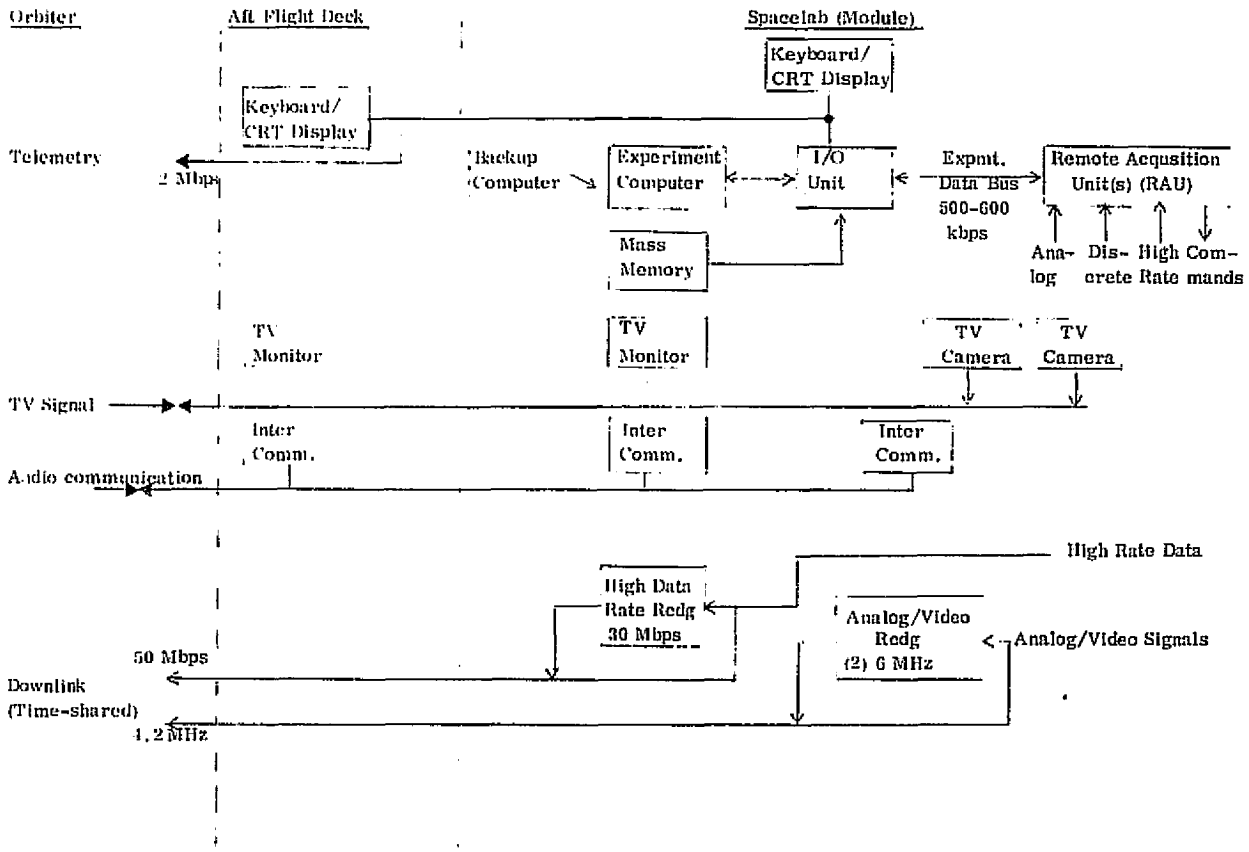


Figure 4-21. Functional Spacelab CDMS Block Diagram

The dedicated permanent computer processes data acquired by the experiment data bus system. The computer facilities allow general-purpose processing for checkout, sequencing and control of experiments, data acquisition, data reduction, formatting/annotation and computing. The characteristics of the experiment computer are shown in Table 4-23. A backup computer, which is primarily intended as backup for the subsystem computer, is also available to experiments in case of experiment computer

failure. In that event, software, which is stored in the mass memory, is read into the backup computer's memory and control is switched over.

Table 4-22. RAU Characteristics

Analog Inputs	
Number	64
Voltage Range	±5.12V
Resolution	8 bit A/D converter
Sampling Rate	100, 10, 1 samples/sec.
Word transfer out	16 bits
Discrete	
Number	64
Voltage input	TTL standard
Sampling Rate	100, 10, 1 samples/sec.
Word transfer out	16 bits
High Rate Digital	
Number	1
Acquisition	1024 bits max. (in 16-bit words)
Equivalent data rate	102.4 kbps
Physical	
Weight	2.3 kg
Size	230 x 88 x 121.5 mm
Power	7 watts, 28 vdc

Besides data acquisition from the RAUs, data bus and computer, there are several other communication channels. High rate digital data can be transferred to the ground at 50 Mbps or stored onboard at 30 Mbps on a high-rate digital recorder. Characteristics of this recorder are given in Table 4-24. The recorder is intended to be used only during non-transmission times in the Orbiter downlink operations. Tape changes are not foreseen. Therefore, the 20-min. recording time limits use of this recorder as a primary data recording medium.

An analog/video recorder is available and provides two channels of up to 6 MHz bandwidth recording for later dump. Downlink from this recorder or in real-time is limited to 4.2 MHz and its use is time-shared with the high digital rate channel.

A video camera for general module surveillance is coupled to video monitors within the Orbiter crew station and/or the operator console in the module. The module monitor is presently capable of providing for color TV. Experiment-provided TV cameras (b/w or color) can be connected to this TV system for monitoring and/or transmission to the ground.

Table 4-23. Experiment Computer Characteristics

Word Length		
Operands	8, 16, 32 bits (fixed point); 24+8 bits (floating point)	
Instruction Set		
Number	128	
Format	16 bits	
Computing Speed		
Register-to-Register	500×10^3 Equiv. fixed point adds per sec	
Register-to-Memory	333×10^3 " " " " " "	
Input/Output		
Number of interrupt levels	8 external, 5 internal	
Interrupt control	Software	
Direct memory access data transfer rate	400-800 k word/sec	
Word length	16 bits + 1 parity + 1 protection	
Memory		
Working memory	64K 16 bit words	
Mass memory (ROM)	8×10^6 words (16 bits)	
Data Bus Rate (for experiments)	500-600K bps	
Physical Characteristics		
	Exp. Comp.	Exp. I/O Unit
Weight, kg	28.75	17.25
Power, W	310	90
Size	1 ATR long	1 ATR long
	25.7 cm W x 19.4 cm H x 49.7 cm L	same
Volume	24.8 dm^3	24.8 dm^3

Table 4-24. High-Rate Digital Recorder Characteristics

Data Rate (I/O)	30 Mbps
Record Time	20 min.
Data Tracks	26
Data Rate/Track	1.15 Mbps
Packing Density/Track	12.5 kbit/in
Record/Reproduce Speed	92 ips
Physical	
Weight	49-45 kg
Power	367 W
Size	53.7 cm x 44.2 cm x 15.3 cm

An intercom unit with master and remote stations in the module provides the audio-communication capability within the module, to and from Orbiter, and from Orbiter to and from the ground.

There are two CRT/keyboard units within the Spacelab module which can be used interchangeably. Each CRT/keyboard allows operator communication with the experiment computer. The keyboards have full ASCII capability.

The preferred mode of data disposition is transmission to ground of all scientific data and some housekeeping data. The latter would be critical engineering parameters needed to ensure operability and calibration of experiment equipment.

4.3.3.2 Life Sciences Payload Data Management Requirements

4.3.3.2.1 Sampled Data Requirements. The sampled data requirements were estimated for each of the 16 proposed payloads by analyzing each data-producing equipment item in the payload, assuming typical operational modes and determining data output characteristics. Tables 4-25 and 4-26 describe the requirements for a mini-lab, ML-1A, and the most comprehensive dedicated lab, MOD IIIA. A complete set of tables for all payloads is in Volume V, Book 2, Appendix E.

The tables contain the name and EI number of each equipment item that has analog or digital output channels which interface directly with the RAU of the Spacelab CDMS. The measurements to be made are described. The frequency of operation describes how often on a mission (daily or smaller time interval) the interface is required. The duration for each operation is also given. Many measurements require continuous monitoring, 24 hours/day. The data rate for both the continuous monitoring and duration-limited operations is estimated and presented in bits per sec (bps). This number is derived from the number of analog measurement channels, the sampling frequency, and the number of bits for each analog-to-digital (A/D) conversion. Five bits A/D (3% accuracy) was assumed for routine monitoring functions like temperatures, pressures, flows and currents. Seven bits A/D (1% accuracy) was assumed for scientific measurements. A continuous data rate is stated only where it may have a significant impact on the data bus. Many measurements have a negligible data rate. The daily total, in bits, is determined from the bit rate and total operating time.

The mission phases during which a sampled data interface is required are stated. Naturally, the on-orbit phase requires the most support but there are critical measurements needed during other phases which may impact the planned Shuttle/Spacelab operation.

The types of processing required of the Spacelab experiment computer are described qualitatively in the table. Generally, the philosophy of 100% downlinking of scientific data, either in real-time or near real-time was assumed. Some of the

Table 4-25. Sampled Data Requirements for Mini-Lab ML-1A

EI	NAME	MEASUREMENT DESCRIPTION	FREQ. OF OPERATION	DURATION OF OPERATION	CONTINUOUS DATA RATE, bps	DAILY TOTAL, bits	SUPPORT NEEDED					PROCESSING REQUIRED	REMARKS
							Pre-launch	Ascent	On-orbit	Descent	Post-launch		
7A	Auto. Potent. Elect. Anal.	Measure pH, pCO_2, pO_2, K, Ca, Na, Cl, glucose	2/day	0.5 hr	Negl.	5 K			x			Conversion to conc. values. Downlink.	
80,81	Freezers	Monitor temperatures	Once/10 min.	-	Negl.	3 K			x	x	x	Out-of-tolerance determination.	
131J	OFO Experiment Packages	8 Otolith signals 4 ECG signals Housekeeping	1/day	24 hr.	100 K	8640 M	x	x	x	x	x	Transmission to ground. Real-time or near real-time.	Otolith channels sampled at 2000 samples/sec; ECG at 500 sps.
153A	Rotating Litter Chair	EOG/EMG, Controls	2/mission	0.5 hr	6.5 K	11.7 M			x			Transmission to ground.	
					Max. Rate 106 KBPS	8650 M							

Table 4-26. Sampled Data Requirements for Dedicated Lab Mod IIIA

EI	NAME	MEASUREMENT DESCRIPTION	FREQ. OF OPERATION	DURATION OF OPERATION	CONTINUOUS DATA RATE. bps	DAILY TOTAL, bits	SUPPORT NEEDED					PROCESSING REQUIRED	REMARKS
							Pre-launch	Ascent	On-orbit	Descent	Post-launch		
64/65/66	ECG, EEG, EMG Couplers	Conditions electrophysiological signals from organisms or man.	16 chls - 24/day 6 chls - 4/day	10 min. 0.5 hr	700 @ 16 chls 3500 @ 6 chls 25.2 K	161M 151M 312 M	x	x	x	x	x	Downlinking, waveform analysis, data compression and display.	Assume 6 high rate, 16 low rate chls.
156/136B/143G/1A	Signal Conditioners, Assorted Couplers	Miscellaneous physical and biophysical msmts, pressure, temps., flows, etc.	Once/min., 24 hrs/day	--	3	252K	x	x	x	x	x	Downlink, out-of-tolerance determination, display.	Assume 35 chls.
77B/80/81/83/103B	Freezers/Refrig.	Monitor temperatures	Once/10 min.	--	Negl.	15K	x	x	x	x	x	Out-of-tolerance determination.	Assume chls/EI.
7	Autoanalyzer	Measures approximately 12 constituents of blood serum.	2/day	0.5	100	300K			x			Conversion to conc. values. Downlink.	
7A	Auto. Poten. Elec. Anal.	Measure 8 properties of blood serum and/or urine.	2/day	0.5	Negl.	5K			x			Conversion to conc. values. Downlink.	
91	Mass Spectrometer(2)	Measure mass no. and peaks of trace contaminants and major atmospheric gases.	--	Continuous	600	52M	x	x	x	x	x	Downlink. Possibly some on-board analysis.	
93	Gas Analyzer, Water Vapor Specific	Measure resistivity of humidity sensors.	Once/min.	--	Negl.	7K	x	x	x	x	x	Out-of-tolerance determination.	
65C	Electrophysiology Receiver	Monitors electrophysiological signals	1/day	1 hr	14K	44.5M			x			Downlink, waveform analysis and display.	
153A	Rotating Litter Chair	EOG/EMG	2/mission	0.5 hr	6.5 K	1.7M			x			Downlink.	
18C	Exercise Eqmt/Pkg	Monitor Ergometer speed output, Treadmill speed. Assume 4 chls.	2/day	1 hr	5 @ 4 chls	144K			x			Downlink, on board display & control.	Assume 4 chls, 1 sample/sec.
38F	Cardiopulmonary Analyzer	Measure 6 gases used in breath-by-breath respiratory analysis.	2/day	0.5 hr	500 @ 6 chls	10.8M			x			Conversion to conc. values. Downlink.	
117/139	LBNP, Limb Plethysmographs	Monitor pressures, temps., and plethys. chls.	1/day	1 hr	35	126K			x			On-board control of expmt. Downlink.	Assume 7 chls, sample/sec.

Table 4-26. Sampled Data Requirements for Dedicated Lab Mod IIIA (cont'd)

EI	NAME	MEASUREMENT DESCRIPTION	FREQ. OF OPERATION	DURATION OF OPERATION	CONTINUOUS DATA RATE bps	DAILY TOTAL, bits	SUPPORT NEEDED: Pre-launch	Ascent	On-orbit	Descent	Post-launch	PROCESSING REQUIRED	REMARKS
182J	VCG Coupler	Converts VCG signals.	2/day	1 hr	21K	151M			x			Downlink. On-board waveform analysis.	
182P	Ventilation Unit, Vertn.	Monitor flow, pressures, etc. Est. 6 sensors.	Once/min	--	Negl.	43K	x	x	x	x	x	Out-of-tolerance determination.	
98A	Holding Unit, Cells & Tissues	Monitor temp.	Once/min	--	Negl.	7K			x	x	x	Out-of-tolerance determination.	
50A	Clinostat, C&T	Monitor motor current	Once/min	--	Negl.	7K			x			Out-of-tolerance determination	
101	Holding Unit, Plants	Monitor temps., light levels	Once/min	--	Negl.	28K	x	x	x	x	x	Out-of-tolerance determination.	Assume 4 chls.
50	Clinostat, Plant	Monitor motor current.	Once/min	--	Negl.	7K			x			Out-of-tolerance determination.	
98C	Holding Unit, Invert.	Monitor temps.	Once/min	--	Negl.	7K	x	x	x	x	x	Out-of-tolerance determination.	
115F	LSS Test Console	Monitor temps., pressures, flows, currents, etc. Assume 10 chls.	Once/10 sec.	12 hrs - 10 chls; 12 hrs - 2 chls	5 1 .	216K 43K 259K			x			Out-of-tolerance determination. Downlink exp. data. Trend analysis.	
144	Psychomotor Perf. Console	Monitor sensor outputs which measure various psychomotor tasks such as tracking steadiness, pattern recognition.	1/day	6 hr	20K	432K			x			Statistical analysis. Downlink.	
43A	Bioresearch Centrifuge	Monitor and control speed, motor current, temps., balancing, ECS, etc.	--	Continuous 24 hrs/day	10	864K			x			Downlink, on-board display, caution/warning.	Assume 10 chls.

computer processing would include conversion to scientific or engineering units, out-of-tolerance determination, formatting and annotation of data, and perhaps some simple data compression. An example of the latter would be deriving heart rate information from ECG signals. If heart rate is the only information desired from the ECG, a large data compression (perhaps 500 to 1) is obtained by the onboard compression. This will reduce the amount of data to be downlined with the obvious disadvantage of tieing up the computer for these periods during which the other measurements functions may also require processing.

A summary of the sampled data requirements for the 16 defined payloads is given in Table 4-27. Shown are maximum data rates anticipated and the daily total data load. The maximum rate was computed by assuming all equipment items "on" at the same time which, while not generally occurring, can occasionally happen. This number can also be compared to the Spacelab data bus handling rate of 500-600 kbps. This comparison is discussed in more detail in the section 4.3.3.3.

4.3.3.2.2 Software Requirements. The dedicated experiment computer of Spacelab will perform many functions for the life sciences laboratories. Determination of the software requirements needed to support these payloads is necessary in order to compare the Spacelab computer capabilities with the laboratory requirements, particularly in the areas of computer speed and memory. Software requirements were developed for two representative payloads - one mini-lab, ML-1A, and one dedicated laboratory, MOD IIIA. These are detailed in Tables 4-28 and 4-29.

Table 4-27. Sampled Data Requirements for Defined Payloads

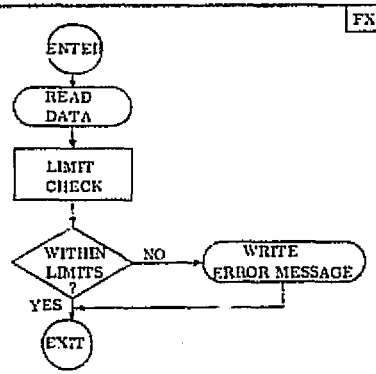
PAYLOAD	CONTINUOUS DATA RATE (kbps)	DAILY TOTAL (kbits)
COL 2A	-	-
3A	-	-
M-L 1A	106	8.65×10^6
2A	25.8	3.7×10^5
3A	13.1	1.5×10^5
4A	0.61	2.6×10^2
5A	-	-
2B	25.8	2.1×10^5
2C	25.8	3.70×10^5
2D	26.4	4.2×10^5
DED 1A	70.4	5.83×10^5
IIA	70.4	5.84×10^5
IIIA	70.4	5.85×10^5
IIB	25.9	3.65×10^5
IIC	25.9	3.65×10^5
IIIB	25.9	3.67×10^5

Table 4-28. Software List for Mini-Lab ML-1A

APPLICATION MODULE		CHARACTERISTICS				COMPUTER LOADING		
NO.	NAME	INPUT	ALGORITHM	OUTPUT	CALLING FREQUENCY (SEC^{-1})	EAPS*	MEMORY (16 BIT WORDS)	
							INSTR	DATA
001	Control Command	[E] Functional and alpha-numeric keyboard coded outputs 2 - 8 bit words [I] Message table 64 - 16 bit words	[FX] 1. Read keyboard data 2. Transfer to CRT output table 3. Test for end of message 4. Decode message 5. Check for invalid operation 6. Write data onto data bus	[E] Formatted commands to Life Science equipment via RAU 4 - 16 bit words	10 Continuously after Spacelab activation →	250	650	70
002	Experiment Schedule	[I] Mission time Stored time-Operational Sequence Table 128 - 16 bit words	[FX] 1. Perform table "Look-up" and identify operational sequence associated with current mission time 2. Write CMD data onto data bus 3. Monitor and verify equipment in proper operational mode 4. Update operational mode table 5. Write error message if improper operation	[E] Formatted commands to Life Science equipment via RAU, error message and anomalous data to CRT display generator 8 - 16 bit words [I] Table defining op. mode 4 - 16 bit words	Initiated at discrete mission elapsed times ~ 8 times/day 10 second execution	-	270	140
003	Data Acquisition (Formatting and Annotation)	[E] Cells and tissues Frog otolith module Rotate litter chair Data parameters 46 - 8 bit words [I] MET 1 - 16 bit word	[FX] 1. Evaluate operational mode 2. Define record ID 3. Define record length 4. Transfer time to data output table 5. Read data from LS equipment 6. Pack 8 bit data in 16 bit words in data output table 7. Write data output table	[E] Formatted record of LS expt. data and time to TM/storage 27 - 16 bit words	10 Initiated by crew through keyboard Continuously during experiment data acquisition →	1390	290	74
004	Concentration Values	[E] Autoanalyzer & Auto Poten. Elect. Analyzer Multiplexed Output Data 3,000 - 8 bit words [I] Test Mode Param. Table of concentration values 64 - 16 bit words	[FX] 1. Write test mode parameters 2. Read input data 3. Perform table "lookup" and identify concentration levels corresponding to input data	[E] Commands to select test sample and to control analyzer. 4 - 16 bit words [I] List of constituents and properties of blood serum and/or urine 12 - 16 bit words	On demand Initiated by crew through keyboard (1 minute execution)	6	290	80 - plus - [3000-16 bit word buffer]

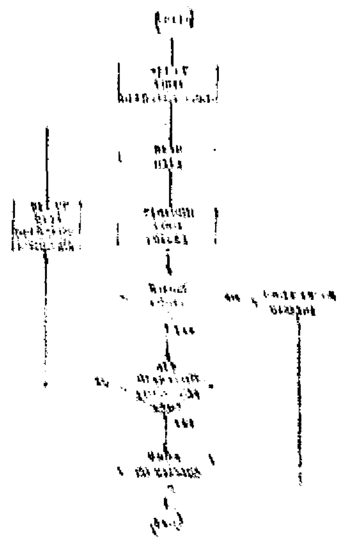
* EAPS = Equivalent Adds Per Sec

Table 4-28. Software List for Mini-Lab ML-1A (cont'd)

APPLICATION MODULE		CHARACTERISTICS				COMPUTER LOADING		
NO.	NAME	INPUT	ALGORITHM	OUTPUT	CALLING FREQUENCY (SEC^{-1})	EAPS*	MEMORY (16 BIT WORDS) INSTR	DATA
005	Performance Monitor	E Cells and tissues unit Prog otolith module Data parameters 46 - 8 bit words	FX  	E Error message with anomalous data for display 8 - 16 bit words	1/10 Initiated by activation of LS X 730 & LS X 740 Continuously while live specimens are on board	140	300	64
006	Display Parameter Lists	E Cells and tissues unit Prog otolith module Rotate litter chair Data parameters 46 - 8 bit words I Scaling constants 36 - 16 bit words	FX 1. Test for display mode 2. Read input data 3. Scale to Engr. units 4. Define display format ID 5. Write CRT output table to display generator	E Scaled & formatted data to display generator 24 - 16 bit words	1/2 Initiated by error Flag or crew action On demand during period LS payload is activated	200	340	106 + [256 - 16 bit word display format]
					Total	1980	2140	3780 5920

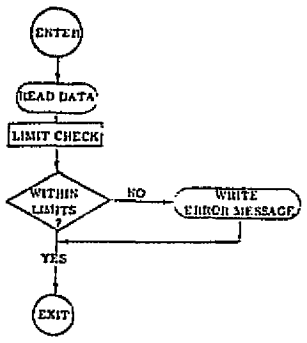
* EAPS – Equivalent Adds Per Sec

Table 4-30. Software List for Dedicated Lab Mod IIIA

APPLICATION MODULE		CHARACTERISTICS				COMPUTER LOADING		
NO.	NAME	INPUT	ALGORITHM	OUTPUT	CALLING FREQUENCY (SEC^{-1})	MASS*	MEMORY (16 BIT WORDS) INSTR	DATA
001	Control Command	Functional and alpha numeric keyboard coded inputs [illegible] words Message table [illegible] 16 bit words	Read keyboard data Test for data; exit if no data Transfer data to CRT output table Test for end of message Decode message Check for invalid operation Write data onto data bus	Formatted commands to Life Science eqpt. via DAC 54 - 16 bit words Data to CRT output table 44 - 16 bit words	10 Continuously after Spacelab activation	200	670	104
002	Check out	Checkout test console (CRT) [illegible] [illegible] Experiment Equipment [illegible] [illegible] [illegible] parameters 180 - 16 bit words Stored parameter limits 414 - 16 bit words		Commands to dedicated lab equipment to setup operating conditions, alarm or error message with anomalous data for display 64 - 16 bit words	On demand (Initiated by crew through keyboard) (10 minute execution) At the beginning of each day's research activity - prior to experiment operation	0	650	428
003	Waveform [illegible]	[illegible] [illegible] 16 bit words	Read [illegible] data [illegible] [illegible] [illegible]	Program control [illegible] [illegible] [illegible] 16 bit words	100 [illegible] [illegible]	12,500	250	50 [illegible]

* Mass [illegible]

Table 4-29. Software List for Dedicated Lab Mod IIIA (cont'd)

APPLICATION MODULE		CHARACTERISTICS				COMPUTER LOADING		
NO.	NAME	INPUT	ALGORITHM	OUTPUT	CALLING FREQUENCY (SEC^{-1})	EAPS*	MEMORY (16 BIT WORDS)	
							INSTR	DATA
004	Performance Monitoring and Data Compression	Signal conditioners, E: Freezers/Refrig., Gas Analyzers, Ventilation Unit, Holding Unit, Clinostat C&T, Holding Unit (Plants), Clinostat (Plant), Holding Unit (Invert) Data Parameters 65 - 8 bit words Stored Limits I 120 - 16 bit words	FX 	E: Error message with anomalous data for display 8 - 16 bit words Table of out-of-tolerance data with ID and time tags I 65 - 8 bit words 66 - 16 bit words	1/60 {Initiated by activation of Life Science expt.} Continuously while live specimens are onboard →	10	480	324
005	Concentration Values	Autoanalyzer & Auto Poten. Elect. Analyzer Multiplexed Output Data E 3,000 - 8 bit words Test Mode Param. I Table of concentration values 64 - 16 bit words	FX 1. Write test mode parameters 2. Read input data 3. Perform table "lookup" and identify concentration levels corresponding to input data	Commands to select E test sample and to control analyzer. 4 - 16 bit words List of constituents I and properties of blood serum and/or urine 12 - 16 bit words	On demand {Initiated by crew through keyboard} (1 minute execution)	6	290	80 - plus - 3000-16 bit word buffer
006	Load Control	Ergometer and/or E treadmill speed and torque parameters MET 1 - 16 bit word 4 - 16 bit words Stored load profiles I 64 - 16 bit words	FX 1. Read input data 2. Perform data conversions 3. Compare load with planned load profile 4. Evaluate control law 5. Generate commands to achieve proper load 6. Write commands	E: Formatted commands to exercise equip. 4 - 16 bit words	1 {Initiated by crew Through keyboard} Continuously during operation of exercise equipment →	540	460	72
007	Statistical Analysis	Two dimensional E position coordinates from Psychomotor Performance Console 2 - 8 bit words	FL 1. Read and store coordinate data 2. Upon completion of experiment compute the mean and variance for the set $Z_i = \left[(x_i - a)^2 + (y_i - b)^2\right]^{1/2}$ $\bar{Z} = \frac{1}{N}\sum_{i=1}^{N} Z_i$ $\sigma^2 = \frac{1}{N}\sum_{i=1}^{N} (Z_i - \bar{Z})^2$	Table of position I coordinates with computed mean 2nd variance 66 - 16 bit words Mean and variance to E display generator 2 - 16 bit words	On demand {Initiated by operator at Psychomotor Performance Console} (1 second execution)	600	160	70

* EAPS - Equivalent Adds Per Sec

Table 4-29. Software List for Dedicated Lab Mod IIIA (cont'd)

APPLICATION MODULE		CHARACTERISTICS				COMPUTER LOADING		
NO.	NAME	INPUT	ALGORITHM	OUTPUT	CALLING FREQUENCY (SEC^{-1})	EAPS*	MEMORY (16 BIT WORDS) INSTR	DATA
008	Chamber Pressure Control	E: Pressure and temperatures from chamber for plethysmographs MET 1 – 16 bit word 4 – 8 bit words I: Stored chamber pressure/temperature profiles 64 – 16 bit words	FX: 1. Read input data 2. Perform data conversions 3. Compare pressure/temperature with planned experiment profiles 4. Generate commands to achieve proper pressure and temperature in chamber 5. Write commands 6. Evaluate command response and output an error message if improper	E: Formatted commands to pressure chamber - Error message to display when response improper 10 – 16 bit words	1 {Initiated by crew Through keyboard} Continuously during operation of Plethysmographs →	510	440	79
009	Data Formatting and Annotation	E: Housekeeping and scientific data from all operating equipments 238 – 8 bit words I: Waveform analysis frequency, out-of-tolerance data, blood constituents, Psychomotor measurements and statistical parameters 6000 – 16 bit words	FX: 1. Evaluate operational mode 2. Define record ID and time tag 3. Define record length 4. Transfer data to output data table, when specific experiments complete 5. Read data from operating equipment 6. Pack 8 bit data into 16 bit words in data output table 7. Write data output table	E: Formatted record of scientific and housekeeping data to TM/storage 150 – 16 bit words	1 {Initiated by crew Through keyboard} Continuously during experiment data acquisition →	6000	400	388 [Data buffer common with module 003]
010	Spectrographic Display	E: Spectrographic data from mass spectrometer or cardiopulmonary analyzer 12 – 8 bit words I: Table of conversion constants 20 – 16 bit words	FX: 1. Read input data 2. Convert to engineering units 3. Establish display grid indices 4. Convert values to display coordinates 5. Format display data 6. Define display format ID 7. Write CRT output table to display generator	E: Scaled and formatted data to display generator 64 – 16 bit words	On demand {Initiated by crew Through keyboard} On demand during payload operation → (10 second execution)	150	420	96 -plus- 256 – 16 bit word display format
011	Trend Data Display	E: Life Science Subsystem Test Console MET 20 – 8 bit words 1 – 16 bit word I: Stored scaling constants 20 – 16 bit words	FX: 1. Read input data 2. Convert to engineering units and store in buffer table 3. Analyze data in buffer, store and compute least squares best fit 4. Establish display grid indices 5. Convert values to display coordinates 6. Define display format ID 7. Write CRT output table to display generator	E: Scaled and formatted data to display generator 64 – 16 bit words I: Buffer data storage 600 – 8 bit words	1/10 {Initiated by activation of LSS Test Console} Continuously except steps 3 – 7 are by crew demand through keyboard command →	4600 (Peak)	455	700 -plus- 256-16 bit word display format

* EAPS – Equivalent Adds Per Sec

Table 4-29. Software List for Dedicated Lab Mod IIIA (cont'd)

APPLICATION MODULE		CHARACTERISTICS				COMPUTER LOADING		
NO.	NAME	INPUT	ALGORITHM	OUTPUT	CALLING FREQUENCY (SEC^{-1})	EAPS •	MEMORY (16 BIT WORDS)	
							INSTR	DATA
012	Display Parameter Lists	Housekeeping and scientific data from operating equipment 238 - 8 bit words (E) Scaling constants 170 - 16 bit words (I)	1. Test for display mode (FX) 2. Read input data 3. Scale to engr. unit 4. Format display data 5. Define display format ID 6. Write CRT output table to display generator	Scaled and formatted data to display generator by equipment/experiment (E) 32 - 16 bit words	1 { Initiated by error flag or crew action } On demand during period the dedicated lab is activated →	440	380	440 - plus - 17 formats of 256 - 16 bit words
					Total	19,996 (Peak)	4,985	16,706
							21.691	

• EAPS - Equivalent Adds Per Sec

The computer software for each payload is organized into application modules serving various functions such as: control command, checkout, experiment scheduling, data formatting/annotating, parameter lists, displays and others. There are six modules for ML-1A and 12 for MOD IIIA. The detailed description for each application module included input/output lists, parameters and characteristics, computational algorithm and calling frequency. Memory size was estimated for both instructions and data in terms of 16-bit words. The memory size, calling frequency and algorithm then allowed an estimation of computer speed given in equivalent (fixed point) adds per second (EAPS). Totals for all modules were then determined.

4.3.3.2.3 Video Data Requirements. A variety of video cameras is available in the equipment inventory to be used by the payloads. There are two black and white (B/W) and one color video camera in the inventory. The characteristics of these cameras are given in Table 4-30 and the estimated usage requirements for the payloads are given in Table 4-31.

Table 4-30. Video Camera Data Characteristics

Characteristic	Color Camera EI 38	B/W Camera #1 EI 37	B/W Camera #2 EI 37
Purpose	Monitoring of color video data including microscopic examinations	Intermittent monitoring of experiment phenomena	Time lapse monitoring of organisms
Duration of Use	0.		
Duration of Use (Payload Dependent)	0.5 to 2 hr/day	0.25 to 4 hr/day	4 to 12 hr/day
Analog Bandwidth or Digital Data Rate	6 M Hz	6 M Hz	55 kbps average digital rate during time lapse
Display (on-orbit)	Spacelab Monitor (B/W)	Spacelab Monitor	Spacelab Monitor
Preservation of Video Data	Real time transmission or store for near real time dump	Real time transmission or store for near real time dump	Real time transmission or store for near real time dump

One B/W camera and the color camera operate as standard, commercial, 6 Mz video systems. Use of the onboard Spacelab video monitor is assumed during operation of these cameras. Additionally, real-time transmission to the ground during periods of TDRS availability is assumed. Short-duration (approximately 30 min.) onboard storage using the Spacelab analog/video recorder with subsequent dumping is also assumed. No long-term storage requirements, necessitating large requirements for video tape, are anticipated.

The second B/W video camera contained in the equipment inventory was assumed to be devoted to time-lapse video monitoring at a range of one frame every 20 seconds.

Table 4-31. Video Data Requirements

Payload	Color Camera Hrs/Day	B/W Camera #1 Hrs/Day	B/W Camera #2 (Time Lapse) Hrs/Day
COL-2A	--	--	--
COL-3A	--	--	--
ML-1A	--	0.25	--
ML-2A	0.5	--	--
ML-3A	--	2.0	--
ML-4A	--	4.0	--
ML-5A	2	--	--
ML-2B	0.5	--	--
ML-2C	1.0	--	--
ML-2D	2.0	--	--
MOD IA	1.0	1.0	6.0
MOD IIA	1.0	1.0	12.0
MOD IIIA	1.0	2.0	12.0
MOD IIB	1.0	1.0	6.0
MOD IIC	1.0	1.0	4.0
MOD IIIB	1.0	2.0	12.0

The total duration of monitoring varies among the payloads from 6 to 12 hr/day as seen in Table 4-31. This type of monitoring is used to observe critical test organisms on a continuous but time-lapse basis. It was assumed that this data would be digitized and processed in order to facilitate its handling at a relatively low and steady rate rather than in bursts of high-rate video data. In this case, the average data rate is estimated to be 55 kbps. This data would be transmitted to the ground on the high data rate channel which will be time shared with the other video signals. Again short term storage and later dump is assumed during periods of TDRS unavailability.

4.3.3.3 Life Sciences/Spacelab CDMS Accommodation. Table 4-32 summarizes the compatibility of the Spacelab CDMS and the life sciences data management requirements, as typified by two payloads: mini-lab ML-1A and dedicated lab MOD IIIA. In both computer support and transmission to the ground, the payload requirements are well within the Spacelab capability. The only apparent conflict is with the video transmission bandwidth. Payload cameras, as discussed in the previous section, have been specified as standard 525-line, 6-M Hz video cameras. The transmission bandwidth of the shared Orbiter high rate channel is 4.2 MHz. However, good resolution video information can be transmitted over channels having bandwidths substantially below 4.2 MHz - as low, in fact, as 1 MHz (Reference 19). The recommendation, therefore, is to reduce the bandwidth requirements to 4.2 MHz. Image resolution will not be greatly sacrificed.

Table 4-32. Payload Processing Requirements vs Spacelab CDMS Capacity

	SPACELAB CAPABILITY	MINI-LAB* ML 1A	DEDICATED LAB MOD IIIA
COMPUTER AND I/O			
DATA BUS RATE (MAX.), KBPS	500-600	106	70
SPEED, EQUIVALENT ADDS PER SEC.			
BASIC S/L CAPACITY	333×10^3 REGISTER TO MEMORY		
EXEC., CONTROL, ETC.	16.5×10^3		
AVAILABLE FOR PAYLOAD	316.5×10^3	1.98×10^3	19.97×10^3
MEMORY, 16 BIT WORDS			
BASIC S/L CAPACITY	64×10^3		
EXEC., CONTROL, ETC.	8×10^3		
AVAILABLE FOR PAYLOAD	56×10^3	5.93×10^3	21.69×10^3
TRANSMISSION TO GROUND			
TELEMETRY – SCIENCE DATA			
RATE, KBPS	2000	106	70
DAILY TOTAL, BITS/DAY	1.5×10^{11}	8.65×10^6	5.85×10^5
HIGH-SPEED DIGITAL			
RATE, MBPS	50	–	0.055
USAGE, HR/DAY.		–	12
VIDEO	20.5 SHARED		
USAGE, HR/DAY		0.25	3
BANDWIDTH, MHZ	4.2	6	6

*REQUIREMENTS MUST BE SUMMED WITH SHARING PAYLOADS TO DETERMINE TOTAL CDMS REQUIREMENTS.

The same comment that applies to mini-labs in other subsystems areas applies here to the CDMS. That is, total impact on Spacelab cannot be determined until the requirements for the sharing payload elements are specified. A recent Convair study (Flight Applications Software Requirements, Sizing and Implications, PDS-SS-01), 29 August 1975) looked at the total requirements for the first Spacelab mission, of which ML-1A is a payload element. It was found that, except in a few areas such as main memory size, the total payload requirements are within Spacelab capability.

4.3.4 ENVIRONMENTAL FACTORS. The major subsystems covered in the preceding sections represent the most important areas in this Phase A study as they established the feasibility of the candidate laboratories in the Spacelab system. There are, however, another group of requirements collectively entitled environmental factors that need to be addressed. These include:

Acoustics
Vibration and Shock
Cleanliness and Contamination
Electrical (emissions and susceptibility)
Magnetic (emissions and susceptibility)
Radiation
Equipment Surface Temperatures

Except in a preliminary way, these were not investigated in this study. Detailed examination and impact analysis of these factors depend on 1) good definition of the Spacelab environment and 2) definition of the user requirements. Some of the former are available in the Spacelab Payload Accommodation Handbook (Reference 13) and will most assuredly be refined and updated in the near future. The user requirements, however, are not

presently available. These, in terms of tolerance limits, need to be established and their impact should be determined as part of the Phase B study.

An example of one potentially impacting area is the acoustic environment. The internal Spacelab module acoustic vibration level is anticipated to be 135 dB (re. 20 $\mu N/m^2$) during approximately two minutes of the ascent phase. A tentative life sciences requirement is that research organisms be exposed to no more than 120 dB during ascent, 80 dB on-orbit. The burden of resolving this difference between requirement and environment falls upon the Spacelab, the organism holding facility, or the organism itself. It is presently unlikely that Spacelab will be redesigned to attenuate the 135 dB level any further. The most logical place for sound pressure attenuation is at the organism holding facility. These facilities are presently undergoing definition and design by MSFC. The resultant acoustic level at the organism will be determined by the design. Even the 120 dB level, if it can be attained, will have an appreciable effect upon the organism and the resulting data received from the organism.

A detailed user evaluation of the resultant level should consider such factors as the use of ground simulation of the acoustic environment to determine data quality effects. Changes in experiment protocol to compensate for these effects should also be considered. In any event, there are a number of questions that need to be answered to ensure that valid biological data will be returned from Shuttle/Spacelab missions.

As with acoustics, the user requirements in the other environmental areas cited above need to be established. These should then be reflected in the preliminary hardware specifications developed in the Phase B study.

4.4 BIORESEARCH CENTRIFUGE IMPACT

A major subtask of the systems analysis portion of the study was to determine the impact of having a Bioresearch Centrifuge in the life sciences program. Specifically, the accommodation of the centrifuge within the Shuttle/Spacelab operational sequence was investigated. Detail designs and cost analyses for selected centrifuge concepts were generated. The impact to ground operation as well as an impact of the centrifuge on the Orbiter attitude control was determined. Finally, recommendations for future directions were made.

The need for a Bioresearch Centrifuge as an on-orbit 1g control device was recommended by the National Academy of Sciences (Reference 6) and the science requirements were discussed in Section 2.1.3. The guidelines and assumptions used for the study analysis were synthesized from this and a NASA/ARC input (Reference 7). Principal of these guidelines and assumptions are:

Minimum radius of 1.37 m (4.5 ft) to reduce coriolis or cross-coupled angular acceleration effects.

Accommodate organisms up to 0.5 kg.

Gravity range 0.1g to 3g.

Startup/shutdown rate - 0.01g/sec.

Design for 16 stations at periphery; habitats sized for rats.

Angular rates altered to achieve g-levels; habitats fixed.

Analyze both closed-loop and open-loop ECS.

Assume one per day stoppages for food/waste management.

A basic philosophy throughout the effort is that the design would follow a low-cost approach. Therefore, the 16 holding stations were similar to those used in the holding units. An open, less expensive, ECS was used (closed-loop ECS was treated as an option), and the centrifuge would be stopped once per day for expendable resupply.

4.4.1 SPACELAB ACCOMMODATION CONCEPTS. The initial step in determining the Bioresearch Centrifuge impact upon the Spacelab was defining and analyzing a set of six centrifuge installation configurations. These configurations were chosen to give a full range of possible installation options within the Spacelab. These six consepts and their characteristics are shown in Figure 4-22. Detail layouts for each concept are included in Volume V, Book 2, Appendix C.

The centrifuge concepts, including the open ECS, ranged from 144 kg to 410 kg in weight and from 3.91m to 2.13m in diameter. The smaller concepts were defined to minimize structural impacts to the floors, racks, and ceilings. The larger diameter concepts were those that best satisfied the science concepts.

Concepts A, B, C, and D are all "roll-axis" configurations — that is, the axis of rotation is parallel to the Orbiter roll axis. Concept A places the centrifuge in the aft end of the existing Spacelab experiment segment. Removal of the last single rack on each side plus 19 inches of floor, ceiling structure, cabling and ducting is necessary. This provides for the largest diameter possible within the Spacelab. Concept B obviates removal of any existing structure by adding an extension module containing the centrifuge. Concept C is a smaller diameter centrifuge which does not require modification to tne floor or ceiling. Concept D, by moving the axis of rotation off the centerline, maximizes the diameter without impinging on the floor structure. In Concept E, the centrifuge is essentially in the aisleway, with its rotation axis parallel to the Orbiter pitch axis. Finally, Concept F shows a yaw-axis orientation. These last two concepts, while feasible, are not too practical since they incur significant loss of crew space and rack space.

Figure 4-22 also shows the accommodation impact areas in terms of scientific, structural and operational considerations. The basic scientific consideration was whether the concept met the 1.37m (4.5 ft) minimum radius criterion. Concepts whose radius is less than this, e.g., Concept D, were considered not viable for vertebrate organisms because

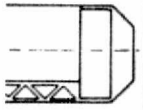
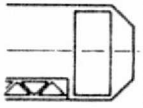
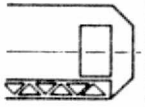
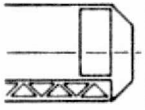
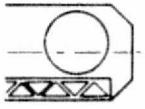
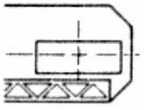
CONCEPT DESCRIPTION	CHARACTERISTICS			ACCOMMODATION IMPACT AREAS		
	DIAM. M	WIDTH M	WEIGHT KG	SCIENCE	STRUCTURAL	OPERATIONAL
A. AFT END SPACELAB MODULE 	3.91 (154 IN.)	0.53 (21 IN.)	250	EXPANSION TO PRIMATES MAY BE RESTRICTED	REMOVE SECONDARY STRUC IN FLOOR/ CEILING. MAY REQUIRE REQUAL. OF S/L ENDCONE MODIFIED.	10% LOSS OF CREW & RACK SPACE
B. EXTENSION TO SPACELAB MODULE 	3.91 (154 IN.)	0.76 (30 IN.)	410	NONE	NEW EXTENSION MODULE NEEDED. ENDCONE MODIFIED. PROBABLE RE-QUALIFICATION OF SPACELAB.	NONE
C. SMALL DIAMETER/ SPACELAB MODULE 	2.13 (84 IN.)	0.76 (30 IN)	144	DOES NOT MEET 4.5 FT RADIUS MIN. USE FOR CELLS/TISSUES	ENDCONE MODIFIED	12% LOSS OF CREW & RACK SPACE
D. OFF CENTER AXIS/ SPACELAB MODULE 	3.00 (118 IN.)	0.53 (21 IN.)	220	MARGINAL MINIMUM RADIUS	SOME CEILING SECONDARY STRUCTURE REMOVED. ENDCONE MODIFIED.	13% LOSS OF CREW & RACK SPACE
E. PITCH AXIS ORIENTATION 	3.20 (126 IN.)	0.58 (23 IN.)	200	NONE	SUPPORT/DRIVE MOUNTING PROBLEMS.	50% LOSS OF CREW SPACE. SAFETY PROBLEMS. MAXIMUM SHUTTLE RCS CROSS-COUPLING
F. YAW AXIS ORIENTATION 	3.61 (142 IN.)	0.76 (30 IN.)	227	NONE	RACKS MODIFIED. SUPPORT/DRIVE MOUNTING PROBLEMS.	30% LOSS OF RACK SPACE. 75% LOSS OF CREW SPACE. SAFETY PROBLEMS. MAXIMUM SHUTTLE RCS CROSS-COUPLING

Figure 4-22. Centrifuge Accommodation Concepts and Evaluation

of the higher angular velocities required and the attendant cross-coupled angular acceleration effects. Another science area was the capability for enlarging the holding stations and hence the height of the centrifuge to accommodate higher vertebrates, namely primates.

In the structural areas, several impacts were found. Many of the concepts will require a modification, however minor, of the Spacelab end cone for structural installation of the centrifuge since most concepts show cantilevering of the centrifuge from the end cone. This could mean a special end cone acquisition for life sciences. Removal of secondary structure in the floors, subflooring, and ceiling occurs in Concepts A and D. Concept B, while not altering the existing Spacelab, does add a longitudinal shell segment and creates a seal interface. Alteration of Spacelab or additions of new segments may require requalification of all or part of Spacelab. This topic is under present review by ESA.

Operationally, loss of crew and/or rack space was the major impact. A detailed study of the impact of a rotating centrifuge on the Orbiter attitude control system was made and is discussed in Section 4.4.3. For roll-axis-oriented centrifuges, the impact is minimal, even over extended coast periods. However, the impact is about ten times as great for the pitch-axis or yaw-axis configurations; thus, even for short coast periods, this impact may be unacceptable.

4.4.2 DETAIL CENTRIFUGE DESIGNS. The next step in the study was the selection of three concepts which spanned the potential science, operational, and structural impact areas. These included the two 3.91m diameter configurations (A and B) and the one 3.0m diameter configuration (D). Each of the three concepts were designed to the level of detail needed to derive realistic cost estimates. Table 4-33 shows this level of detail in the breakdown of the mass properties. The use of lightweight, graphite-epoxy structural elements reduces total weight considerably.

Overall characteristics of the three concepts are given in Table 4-34. Figure 4-23 is a sketch of Concept A. Detail layouts for Concepts A, B and D showing holding station design are given in Volume V , Book 2, Appendix C. Basically, Figure 4-23 shows that the centrifuge is cantilevered from the end cone, although alternate designs for spider-web support from the periphery have been considered. Provisions for a control console and stowage area for the 16 specimen holding stations are included in an adjacent rack. Access to the centrifuge is at a single location near the top of the closure bulkhead. Stations would be sequentially rotated to this position for specimen and food/waste loading and unloading. Shown also is the open-loop ECS; in its non-rotating mode, a blower circulates air, and during rotation, passive circulation is produced by vanes. Characteristics of this and the other two designs are given in Table 4-34.

All of the designs were based on an open-loop ECS, meaning that air was drawn in from the habitable module, passed through the holding units, filtered and returned to the cabin. This approach satisfies the man-surrogate biomedical research requirement

that the organisms breathe the same air as the crew. However, complete closed-loop system were also considered as alternatives. Figure 4-24 shows two concepts of a closed-loop ECS. Fixed hardware includes plumbing, ducting, condensor/separator, heater, blowers, etc. This was estimated to total 60 kg. Duration-dependent hardware includes LiOH canisters for CO_2 removal, and O_2 makeup and storage tanks.

Table 4-33. Estimated Mass Properties of Centrifuge Concepts

Centrifuge Element	Elements		Concept Mass (kg)		
			A	B	D
Holding Stations (16)		R[1]	72	72	72
Rack Support for Hldg Stats.			7	7	7
Centrifuge Disk	GE[2]	R	38	38	22
Radial Beams	GE	R	16	16	12
Circumferential Beams	GE	R	4	4	3
Rim	GE		2	2	2
Kick Frame			—	10	—
Slip Ring		R	5	5	5
Fan			2	2	2
Hub and Spindle			5	5	4
Plenum	GE	R	2	2	2
Drive Motor/Gear Reducer			4	4	3
Fasteners, Clips, Wiring, etc.		R	3	3	3
Support Spiders/Bulkhead	GE		17	17	14
Closure Bulkhead/Handrail	GE		18	18	18
Launch Restraint Struts (2)			2	2	1
Balancing System		R	14	14	14
Control Panel			14	14	14
Sidewall (Struct, Insul, etc.)			—	134	—
Contingency (10%)			25	41	22
Total			250	410	220

Notes: 1 - Rotating Elements

2 - Graphite-Epoxy Elements

Table 4-34. Summary of Centrifuge Characteristics

Characteristic	Concept		
	A	B	D
Weight of Rotating Elements, kg	146	146	124
Total Weight, Open-Loop ECS, kg	250	410	220
Δ For Closed-Loop ECS Weight, kg			
7 days	70	70	70
30 days	104	104	104
Power, drive 1/4 hp + lighting, watts	354	354	275
Radius to Specimen Station, m	1.9	1.9	1.49
Angular Velocity, rad/s			
for 1g	2.27	2.27	2.56
3g	3.93	3.93	4.44
Moment of Inertia kg-m^2	470	470	253
Angular Momentum (3g) N-m-s	1850	1850	1120

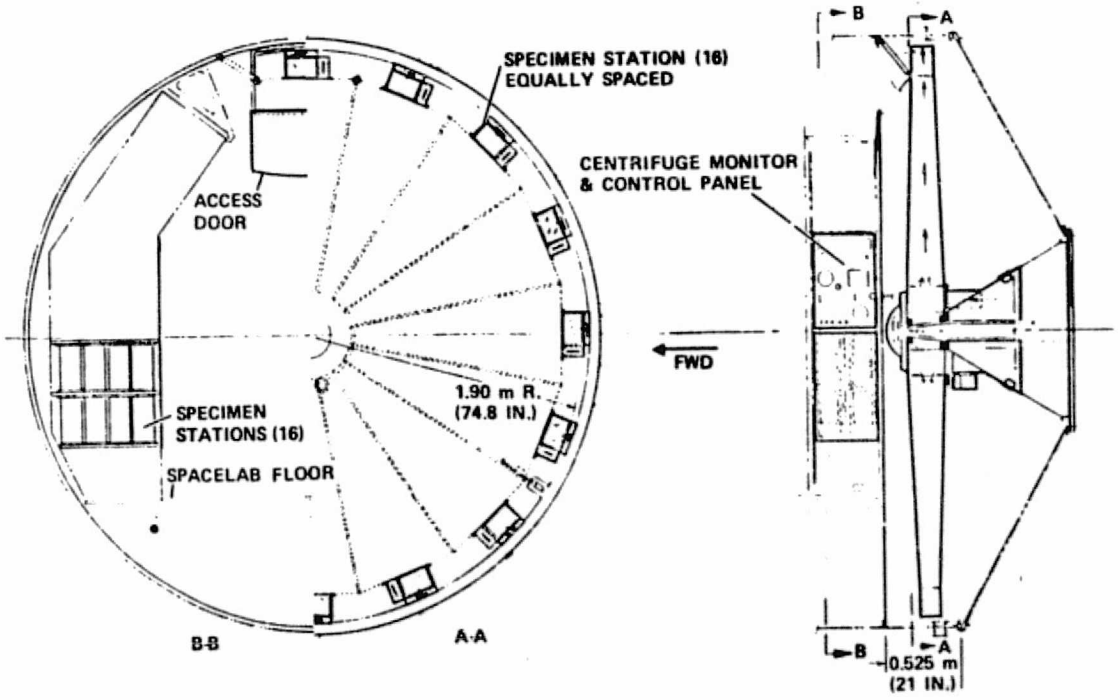


Figure 4-23. Bioresearch Centrifuge Concept — Aft End/Spacelab Module (Concept A)

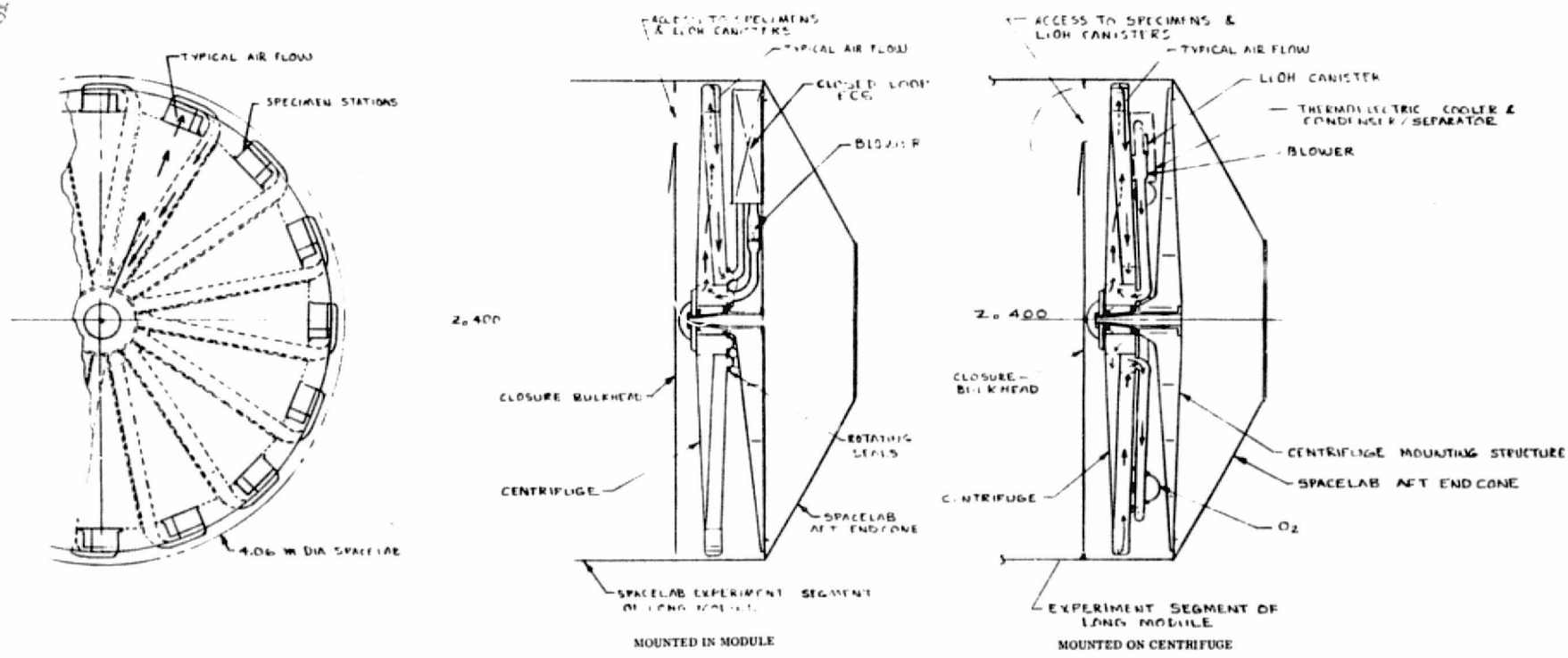


Figure 4-24. Closed Loop Centrifuge Air Circulation Concepts

This hardware was estimated to be 10 kg for 7-day missions and 44 kg for 30-day missions. The delta weight penalties for closed-loop ECS is therefore 70 kg and 104 kg for 7- and 30-day missions, respectively. The additional power penalty has been estimated to be 320 watts.

4.4.3 IMPACT OF CENTRIGUGE ON ORBITER ATTITUDE CONTROL. The gyroscopic effect of ideal, undisturbed rotating machinery tends to aid in maintaining the inertial attitude of the carrier vehicle. However, the slightest disturbance or imperfection will not only destroy its utility in that respect but will cause the machinery to become itself a source of disturbance. This disturbance must be compensated like any other Orbiter-generated disturbance torque (crew motion, venting) or those caused by the external environment.

Since the Orbiter is constantly subjected to come of these disturbances, the rotating centrifuge on board can adversely impact the vehicle control system under conditions where:

a. The angular momentum of the centrifuge caused excessive coupling between the Orbiter axes perpendicular to the spin axis (momentum vector) of the centrifuge.

b. The principal axis of inertia angular offset from the spin axis yields high torque disturbances.

c. The centrifuge center of mass offset from the spin axis causes excessive force perturbations.

Other effects, such as bearing friction, spin up and shut down, are not considered here but should be made part of any more detailed analyses.

4.4.3.1 Assumptions and Basic Equations. For purposes of this analysis the equations which describe the angular motion of the Orbiter are given in simplified form under the following assumptions:

a. The centrifuge is mounted at the center of mass of the carrier vehicle such that the spin axis is parallel to a body axis.

b. The body axes are the principal axes of the Orbiter (no products-of-inertia terms).

c. The Euler angles Ψ, θ, ϕ (yaw, pitch and roll, respectively) are with respect to an inertial frame of reference.

d. The Orbiter is in a circular orbit about the earth.

e. The angular velocities and displacements are small so that second order terms are neglected.

We then have:

$$I_X\ddot{\phi} + H_Z\dot{\theta} - H_Y\dot{\Psi} = -\dot{H}_X + L_X$$

$$I_Y\ddot{\theta} - H_Z\dot{\phi} + H_X\dot{\Psi} = -\dot{H}_Y + L_Y$$

$$I_Z\dot{\Psi} + H_Y\dot{\phi} - H_X\dot{\theta} = -\dot{H}_Z + L_Z$$

where:

H is the angular momentum of the centrifuge and the subscript indicates the direction of the spin axis in terms of the parallel Orbiter axis.

$\dot{H}$ refers to the acceleration (spinup and shutdown) of the centrifuge and is not used in this analysis.

L is the disturbing torque about the subscript axis.

Note that where the centrifuge is mounted parallel to the roll (X) axis, H_X has a value equal to the momentum of the centrifuge whereas $H_Y = H_Z = 0$ because of assumption (a) above.

Mid-mission Orbiter characteristics for a typical life sciences dedicated mission are shown in Table 4-35 (Reference 15). The data includes the mass properties of the Orbiter with the Spacelab, crew and payload on board.

Table 4-35. Orbiter Mass Properties

Weight (kg)	Centre of Gravity (STN)			Moments of Inertia ($kg\text{-}m^2$)		
	X_o	Y_o	Z_o	I_X	I_Y	I_Z
87214	2786	1.0	953	1.07×10^6	7.76×10^6	7.96×10^6

The characteristics of the larger centrifuge diameter (concept A) with the closed-loop air circulation system, providing 3g at the specimen stations, was used in this analysis:

Rotating Mass	250 kg
Radius to Specimen Station	1.9m
Spin Inertia (I_S)	470 $kg\text{-}m^2$
Angular Momentum	1850 N-m-sec
Rotation	37.6 rpm
Frequency	3.93 rad/sec
	0.625 Hz

4.4.3.2 Orbiter Reaction to Disturbance. When a disturbance or a forcing control correction is introduced in the Orbiter system, the angular momentum of the rotating centrifuge interacts with the mass properties of the Orbiter to produce a periodic coning motion which in effect cross-couples the two axes perpendicular to the spin axis.

To illustrate the point, assume the centrifuge spin axis is oriented along the roll (X) axis (present baseline) of the Orbiter and that an angular impulse (L_Y) is imparted to the vehicle by the reaction control system (RCS) to effect a pitch control correction. Applying these conditions, we have:

$$\dot{H} = H_Y = H_Z = L_X = L_Z = 0$$

which simplifies the equations of motion to

$$I_X\ddot{\phi} = 0$$

$$I_Y\ddot{\theta} + H_X\dot{\Psi} = L_Y$$

$$I_Z\ddot{\Psi} - H_X\dot{\theta} = 0$$

The Orbiter roll axis (parallel to the centrifuge spin axis) is not affected by the centrifuge, but both the pitch and yaw axes respond to its rotation. The equations for these two axes are rewritten:

$$\ddot{\theta} = \frac{L_Y - H_X\dot{\Psi}}{I_Y}$$

$$\ddot{\Psi} = \frac{H_X\dot{\theta}}{I_Z}$$

Integrating $\ddot{\Psi}$ and substituting into the pitch equation yields

$$\ddot{\theta} + \frac{H_X^2}{I_Y I_Z}\theta = \frac{L_Y}{I_Y}$$

which has the characteristics of a harmonic oscillator having a frequency

$$\omega = \frac{H_X}{\sqrt{I_Y I_Z}}$$

This in fact is the coning frequency of the system.

The time solutions for the pitch and yaw angles can be written as

$$\theta(t) = \frac{L_Y}{H_X}\frac{1}{\omega}\sin\omega t = \frac{L_Y}{H_X}\sqrt{\frac{I_Z}{I_Y}}\sin\left(\frac{H_X}{\sqrt{I_Y I_Z}}\right)t$$

$$\Psi(t) = \frac{L_Y}{H_X}(1-\cos\omega t) = \frac{2L_Y}{H_X}\sin^2\left(\frac{H_X}{2\sqrt{I_Y I_Z}}\right)t$$

Assuming no other disturbance, without the rotating centrifuge the attitude control system would expect

$$\theta(t) = \frac{L_Y}{I_Y}t \text{ and } \dot{\Psi} = 0$$

in response to the pitch pulse. Instead, the presence of the centrifuge will cause the Orbiter to describe a type of elliptical coning motion as shown in Figure 4-25.

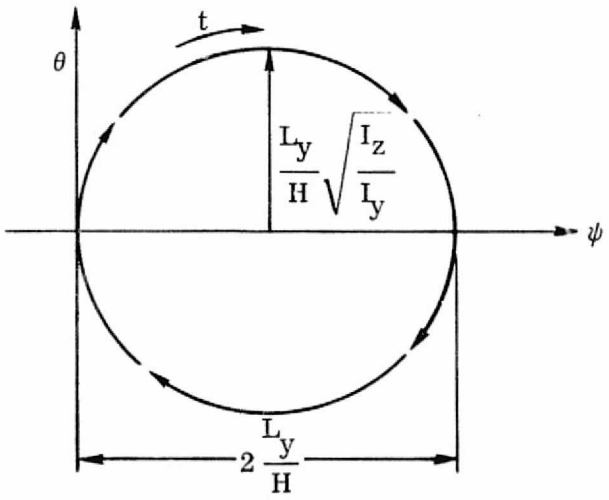


Figure 4-25. Orbiter Coning Motion in Response to Pitch Pulse

This characteristic motion resulting from control impulses can be obtained for various orientations of the centrifuge merely by setting the desired conditions in the equations of motion and obtaining the time solutions.

Note that in the above example a yaw pulse (instead of a pitch pulse) would yield the same coning frequency and a coning ellipse with semi-axes of

$$\frac{L_Z}{H}\sqrt{\frac{I_Y}{I_Z}} \text{ and } \frac{L_Z}{H}$$

4.4.3.3 Cross-Coupling Ratios. The coning period is the time required for a complete elliptical traverse of the centrifuge momentum vector in response to an applied RCS angular impulse. The present combination of Orbiter and centrifuge yields coning periods that are much larger than the anticipated coast periods between RCS pulses. A better measure of the effect of the presence of the centrifuge on the Orbiter attitude control system is the cross-coupling ratio. This is defined as the ratio of the undesired transverse angular deviation to the deviation in the desired direction (i.e., paralleling the applied RCS angular impulse) at the end of a coast period.

The time taken by the Orbiter to traverse the attitude deadband is dependent on the magnitude of the control impulse and the disturbances encountered as well as the amplitude of the attitude control deadband. To blanket these variations, the cross-coupling ratios were computed for time bands covering coast periods of 1 to 5 minutes and 9 to 15 minutes. Table 4-36 summarizes the results. The values show that the impact of the centrifuge momentum is considerably less when the spin axis is aligned with the Orbiter roll axis (present baseline); cross-coupling in this configuration is slight, even over extended coast periods.

Table 4-36. Cross-Coupling Ratios

Centrifuge Spin Axis Orientation	Coning Period (min.)	Coast Time (min.)					
		1	3	5	9	12	15
Roll (X) Axis	445						
Pitch Pulse		$\frac{\Psi}{\theta}$ 0.007	0.021	0.035	0.063	0.082	0.104
Yaw Pulse		$\frac{\Psi}{\theta}$ 0.007	0.021	0.036	0.064	0.084	0.106
Pitch (Y) Axis	165						
Roll Pulse		$\frac{\Psi}{\theta}$ 0.007	0.021	0.035	0.063	0.085	0.107
Yaw Pulse		$\frac{\Psi}{\sigma}$ 0.052	0.156	0.260	0.472	0.634	0.798
Yaw (Z) Axis	163						
Pitch Pulse		$\frac{\Psi}{\theta}$ 0.052	0.156	0.260	0.476	0.634	0.798
Roll Pulse		$\frac{\Psi}{\theta}$ 0.007	0.021	0.036	0.065	0.087	0.110

With the centrifuge momentum vector aligned with the Orbiter pitch or yaw axes, cross-coupling is significant but probably acceptable over short coast periods. For longer periods, however, the gyroscopic effect of the centrifuge is quite evident as the roll angle resulting from applied control yaw or pitch impulses approaches that of the commanded angle. The effect for pitch- or yaw-axis orientation is approximately an order of magnitude larger than for roll-axis centrifuges.

4.4.3.4 Centrifuge Unbalance. Two types of unbalance are considered, both of which will cause local torque and force perturbations at the spin frequency.

a. The centrifuge is spun eccentrically from its center of mass.

b. The spin axis is inclined at some angle from the principal axis of the centrifuge.

To produce 3g at the specimen stations, the centrifuge is operated at 0.625 Hz. This frequency is in the same general area as that produced by crew-induced forces (1 Hz) which have been estimated at 22.4 newtons (N) per crewman. The root-sum square of forces produced by two crewmen on the flight deck and two in the Spacelab approximates 64 N, — a not insignificant disturbance level which may require compensation in the attitude control system.

Although zero centrifuge unbalance would be ideal, as a matter of practicality it may not be necessary to reduce it much below levels already existing onboard, i.e., those induced by the crew.

With the centrifuge located approximately 2.5m from the Orbiter center of mass, assume a conservative 40 N force unbalance and a torque unbalance of 100 N-m. This converts into a product of inertia.

$$I_{ST} = \frac{100}{\omega^2} = \frac{100}{(3.93)^2} = 6.5 \text{ N-m-sec}^2$$

The same result will be produced by an angular offset (α) of the centrifuge principal axis

$$\tan 2\alpha = \frac{2\, I_{ST}}{I_S - I_T}$$

$$\alpha = 1/2 \tan^{-1} \left[\frac{2\, I_{ST}}{I_S \left(1 - \frac{I_T}{I_S}\right)} \right] \text{ radians}$$

A transverse moment of inertia $I_T = 0.5\, I_S$ yields an allowable principal-axis offset of 1.6 degrees. Such an offset would produce the same 100 N-M torque unbalance.

An allowable center-of-mass offset can also be computed from the equivalent product of inertia:

$$I_{ST} = \sum m_i x_i y_i$$

$$Y = \frac{6.5}{(250)(2.5)} = 0.01 \text{ m}$$

Thus, a 1-cm spin axis eccentricity will produce the same unbalance.

4.4.4 CENTRIFUGE EVALUATION AND RECOMMENDATION. A Bioresearch Centrifuge is feasible and its impact upon the Spacelab varies from minor to major depending on the concept selected. The three selected concepts, A, B and D, all meeting the basic

science requirements, have different structural modification impacts ranging from disruption of the existing Spacelab to new hardware design and development. The question of requalification of Spacelab cannot be answered now, as it is presently under review by ESA. However, it is anticipated that the extension module concept (B) will involve a greater impact than the other concepts in this area.

Costs for the three concepts were estimated and are given (FY 75 $) in Table 4-37. The costs for all concepts include design and development, component test articles, one prototype/engineering model (can be backup), system development testing, systems engineering, and program management. Development costs were based on the detailed hardware estimates given in Table 4-33. No costs were included for Spacelab modification, or requalification if required.

Table 4-37. Bioresearch Centrifuge Cost Estimate Summary

(1975 - M$)

Centrifuge	Development	Unit	Total
Concept A	2.75	0.34	3.09
Concept B	3.68	0.40	4.07
Concept D	2.50	0.32	2.82

It is obvious that the Bioresearch Centrifuge will be an expensive equipment item, not only in terms of its development costs but also its impact on the Spacelab system. Integration with the Spacelab may require special GSE and testing facilities. In addition, the total ground functional flow and turnaround operations of Spacelab may be impacted due to installation and removal of such a complex item.

Therefore, a detailed feasibility study is recommended as the next step. This study would consider among other things the current ESA review of Spacelab/centrifuge impact, scientific justification versus the cost of having such a device in the life sciences program, and total ground and on-orbit operations impact of the centrifuge. Such a study should be initiated soon, as the Bioresearch Centrifuge will require a fairly long development and has a relatively early need date.

4.5 GROUND SUPPORT ANALYSIS

A major effort in this study was to identify the ground support requirements associated with the complete development and operation of the life sciences payloads. Four major subtasks were accomplished under the ground support analysis task, which

a. Identified ground activities flow of experiment and Spacelab hardware, biological specimens, and related documentation through the various levels of payload integration and operations.

b. Determined conflicts of ground activities flow with Spacelab hardware availability.

c. Determined facility and GSE requirements to support integration levels I through IV and post-mission processing.

d. Re-examined the life sciences access requirements, including support services, GSE, and physical access.

There were a large number of guidelines and assumptions used. These are listed in Table 4-38. Also, several baseline data sources were used for this analysis. The important sources were:

a. Spacelab ground operations functional flow, MSFC Drawing No. 40A88000, Rev D 6/20/1975.

b. Spacelab baseline processing flow timeline allocation, MSFC Drawing No. 40A88004, undated.

c. KSC payload integration office — status, May 1975.

d. Spacelab experiment integration plan, MSFC draft copy, September 1974.

e. Ground access requirements for life sciences payloads on-pad loading, CASD/NAS-75-001, February 1975.

f. Shuttle turnaround analysis report Star 007, June 1975.

g. Spacelab — Life Sciences Mission 12, DRM SE012-013-2H, July 1975.

4.5.1 BASIC GROUND OPERATIONS ACTIVITIES FLOW. Figure 4-26 shows the overall life sciences ground activities flow. Each of the centers identified in this flow is responsible for a specific phase of the life sciences experiment integration activity level. The major integration levels in ground processing of experiment/payloads are:

Level IV - integration and checkout of experiment equipment with individual experiment mounting elements (e.g., racks and rack sets).

Level III - combination, integration and checkout of all experiment mounting elements (e.g., Spacelab racks and rack sets) with experiment equipment already installed, and of experiment and payload/carrier software.

Level II - integration and checkout of the combined experiment equipment and experiment equipment and experiment mounting elements with the flight subsystem support elements, including the necessary preinstallation testing with simulated Orbiter interfaces.

Level I - integration and checkout of the payloads with the Shuttle Orbiter.

Table 4-38. Ground Support Analysis Guidelines and Assumptions

1.	Level III Integration activities will take place at KSC.
2.	Life sciences specimens and/or simulators will be used for experiment/specimen compatibility and integration tests.
3.	Spacelab mission-dependent equipment, specifically racks/rack sections and associated electronics (e.g., switching panels, RAUs converters) will be delivered to Level IV integration sites already configured for mission.
4.	Consider KSC Launch and Landing site only.
5.	Work within the 160-Hour KSC Shuttle Turnaround Allocation and KSC Spacelab Turnaround Allocation - Shuttle Turnaround Analysis Report - STAR 007 (Reference 20).
6.	Use framework of current ground flow sequences for Spacelab and Shuttle.
7.	One location (e.g., Experiment Development Center, Subcontractor) will be used for "collecting" experiment equipment for total mission, to allow compatibility testing of shared rack configurations and installation of common experiment equipment.
8.	Access to Payload Changeout Room (PCR) will be provided after Shuttle hazardous operations.
9.	Orbiter payload bay doors will be opened during on-pad operations.
10.	Spacelab ECS and power will be available during on-pad specimen loading.
11.	PCR can receive personnel and equipment prior to PCR movement into operational position.
12.	Launch site will make provisions for life sciences personnel to ingress Orbiter at landing strip and Orbiter Processing Facility (OPF) to retrieve time-critical specimens.
13.	For purposes of this study, assume life sciences personnel will be on station in Payload Operations Center (POC) a minimum of 8 hours prior to landing and 17 after landing to monitor ground activities through all specimen removal.
14.	The Orbiter is considered fully operational.
15.	Payload/experiment processing is based on a one-shift/5-day work week for integration Levels IV and III, and two-shift/5-day work week for Levels II, I, and post-mission processing.

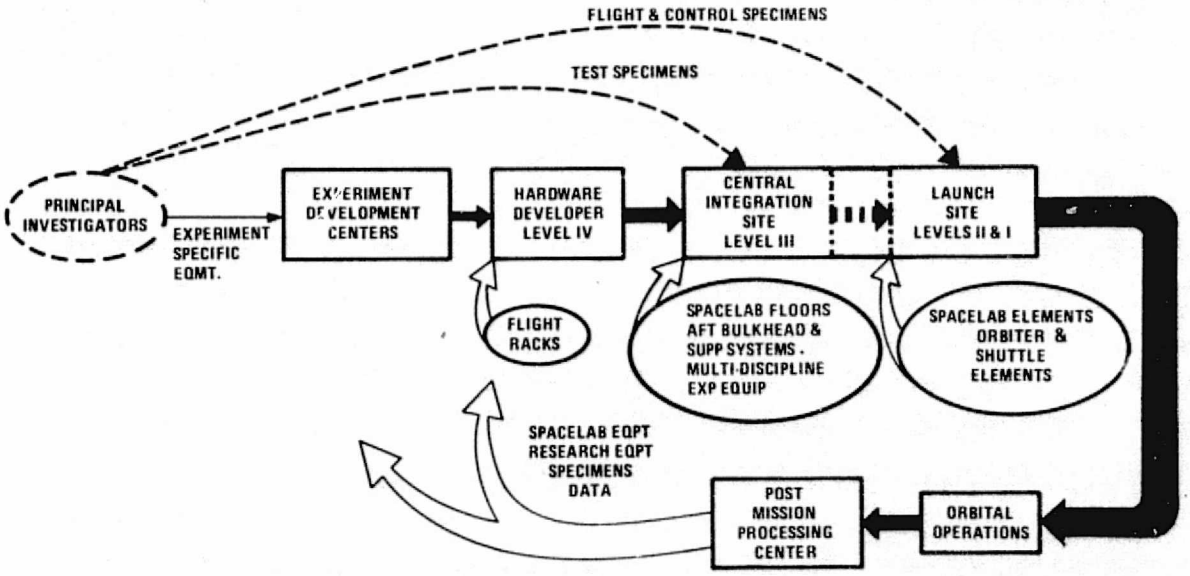


Figure 4-26. Life Sciences Ground Activities

Note that the Central Integration Site (Level III) and launch site (Levels II and I) integration functions are shown physically located at the same site. This change in integration activity location is a recent development and may have an impact on the amount of activity required in Level IV integration. A pictorial representation of the total ground operation function flow is given in Figure 4-27.

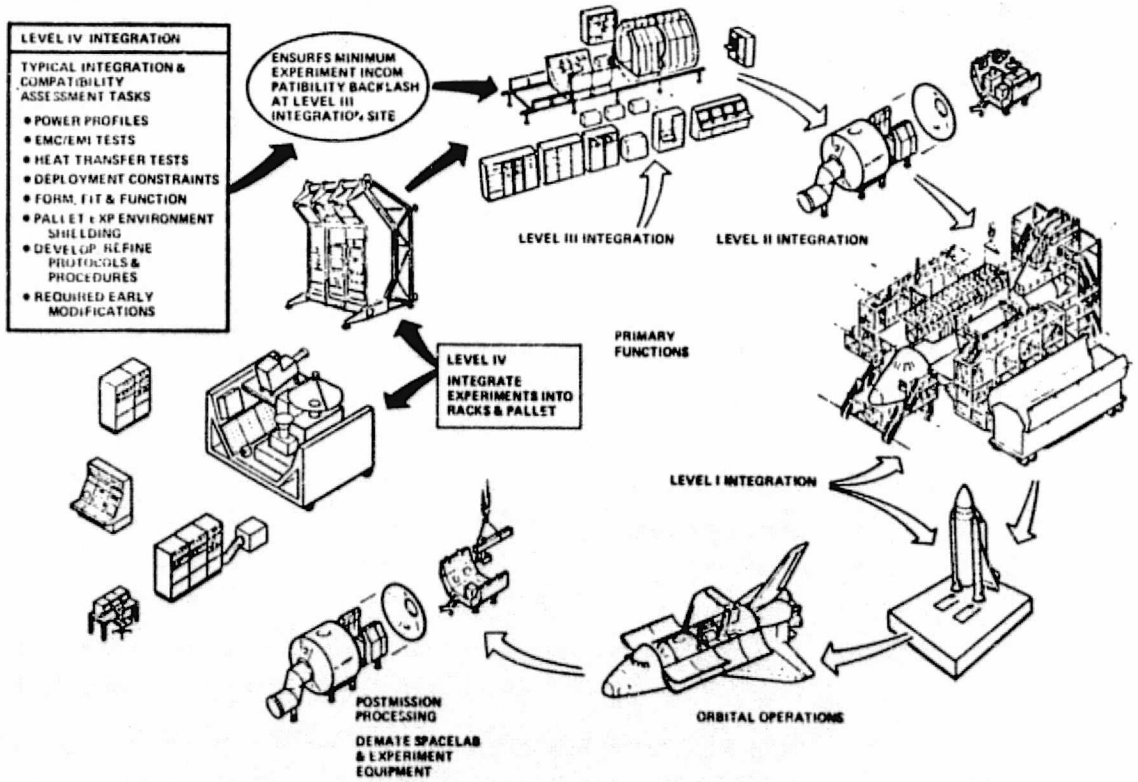


Figure 4-27. Basic Ground Operations Function Flow

The functions tabulated in Table 4-39 and assigned to the various integration sites are based on a life sciences dedicated Spacelab configuration, but they also apply to those activities associated with mini-lab configurations. Spacelab buildup and other launch site functions are noted only where life sciences personnel participation is required. The integration levels are developed in more detail in the next section.

Table 4-39. Integration Site Function Identification

Experiment Development Centers (EDC)	Hardware Developer Level IV Integration	Central Integration Site (CIS) Level III Integration	Launch Site Levels II & I Integration	Post-Mission Processing Site
• Establish & develop protocols, procedures & mission requirements	• Acquire & accept flight racks & floor panels	• Prepare ground support facilities to interface with experiment requirements	• Support payload specialist training	• Retrieve data
• Initiate EAM*	• Mate experiment to racks & floor panels	• Receive & accept experiment equipment	• Prepare ground support facilities to interface with experiment requirements	• Retrieve specimens
• Update & review PAM, SEICA, ADP & FDD integration documentation.*	• Install experiment equipment & validate	• Mate experiment equipment assemblies to floors & support systems	• Preparation of life sciences flight & specimens	• Demate & remove experiment equipment
• Acquire, test & accept specific experiment equipment	• Provide inputs to EAM, SEICA, PAM, FDD & ADP*	• Integrate & verify experiment software	• Receive & inspect experiment equipment	• Prepare experiment equipment for transport to EDCs & PIs
• Acquire mockup racks	• Acquire, test & accept experiment support equipment	• Integrate & validate L/S experiments	• Mate experiment equipment to spacelab modules & support systems	
• Provide payload specialist training	• Perform experiment compatibility assessment	• Perform integrated systems test	• Functional interface verification	
• Perform experiment pre-delivery interface review	• Provide mockup racks to EDCs	• Initiate PAM, SEICA, FDD & ADP documentation*	• Integrate software	
	• Support payload specialist training	• Provide payload specialist training	• Final experiment calibration	
			• Simulated orbital mission test	
			• Specimen installation	
			• Countdown	
			• Liftoff	

* EAM – Experiment allocation matrix
PAM – Payload allocation matrix
SEICA – Spacelab experiment integration compatibility analysis
ADP – Acceptance data package
FDD – Flight definition document

4.5.2 LIFE SCIENCES GROUND SUPPORT REQUIREMENTS. The life sciences experiment ground support requirements have been analyzed to define and develop detailed function flows and timelines. These were subsequently analyzed to determine their compatibility with the defined levels of functional and physical experiment/payload integration, including planned launch site operations. Each level of integration is described in terms of task description, guidelines and assumptions, NASA center functions, activity scenario, function flows, and timelines. This description facilitates identification of center responsibility and task planning.

The ground support anzlysis was performed on a typical dedicated Shuttle lab configuration consisting of 16 Spacelab rack sections, two floor-mounted experiments and a centrifuge assembly to provide a worst-case configuration. Also used was a typical mini-lab configuration consisting of two rack sections and one floor-mounted experiment.

4.5.2.1 Level IV Integration Activities. Level IV integration is the assembly of individual instruments, specific experiments, and their unique supporting equipment into a compatible package to accomplish specific mission objectives. It will occur at one or more Experiment Development Centers (EDCs).

Level IV integration begins with the acquisition and inspection of Spacelab mission-dependent equipment, e.g., racks and associated equipment being prepared for the specific mission. This applies only to dedicated discipline racks. Shared discipline racks will probably require the use of mockup hardware. Completion of an experiment predelivery interface design review releases the experiment equipment for installation into the flight hardware and validation of the assemblies. The centrifuge and rack assemblies will be "soft" mated with an aft-bulkhead mockup and the experiment peculiar GSE validated for interface with experiments and verified for on-line integration activities. Completion of experiment installation into racks/floor panels and equivalent carrier mockups will allow specific experiment tests and component-to-component, carrier-to-component compatibility assessments to be made. Experiment principal investigators will make test article specimens available for equipment validation. Level IV activities will conclude with demating of experiment peculiar GSE and preparation of all experiment equipment for transit to the Level III Integration Site (Figure 4-28) illustrates the overall functional flow for a typical life sciences dedicated lab. Each element in this flow describes a unique function or block of activity. Each was further defined in terms of subfunctions and the required manpower by classification and hours. Table 4-40 shows an example of this for one of the 25 functions on Figure 4-28. From this it was possible to timeline the entire Level IV activity as shown in Figure 4-29. The major assumptions were:

a. EDCs will utilize rack mockups/templates prior to Level IV activity to satisfy and support experiment predelivery interface design review requirements.

b. Bioresearch centrifuge assembly will be delivered after interfaces with simulated aft bulkheads have been validated.

c. Test specimens and/or simulators will be used for each installed experiment compatibility test.

d. Spacelab mission-dependent hardware rack sections will be delivered to work locations configured for mission, e.g., converters, RAU's, switching panels already installed.

e. One location (e.g., EDC, Hardware Developer) will be used for "collecting" experiment equipment for total mission, to allow compatibility testing of shared rack configurations and installation of common experiment equipment.

4.5.2.2 Level III Integration Activities. Level III integration is the assembly of experiments, experiment rack assemblies, and experiment-peculiar GSE with Spacelab elements. Presently, it is planned that this activity occur at the operations and checkout building of the Central Integration Site (NASA/KSC).

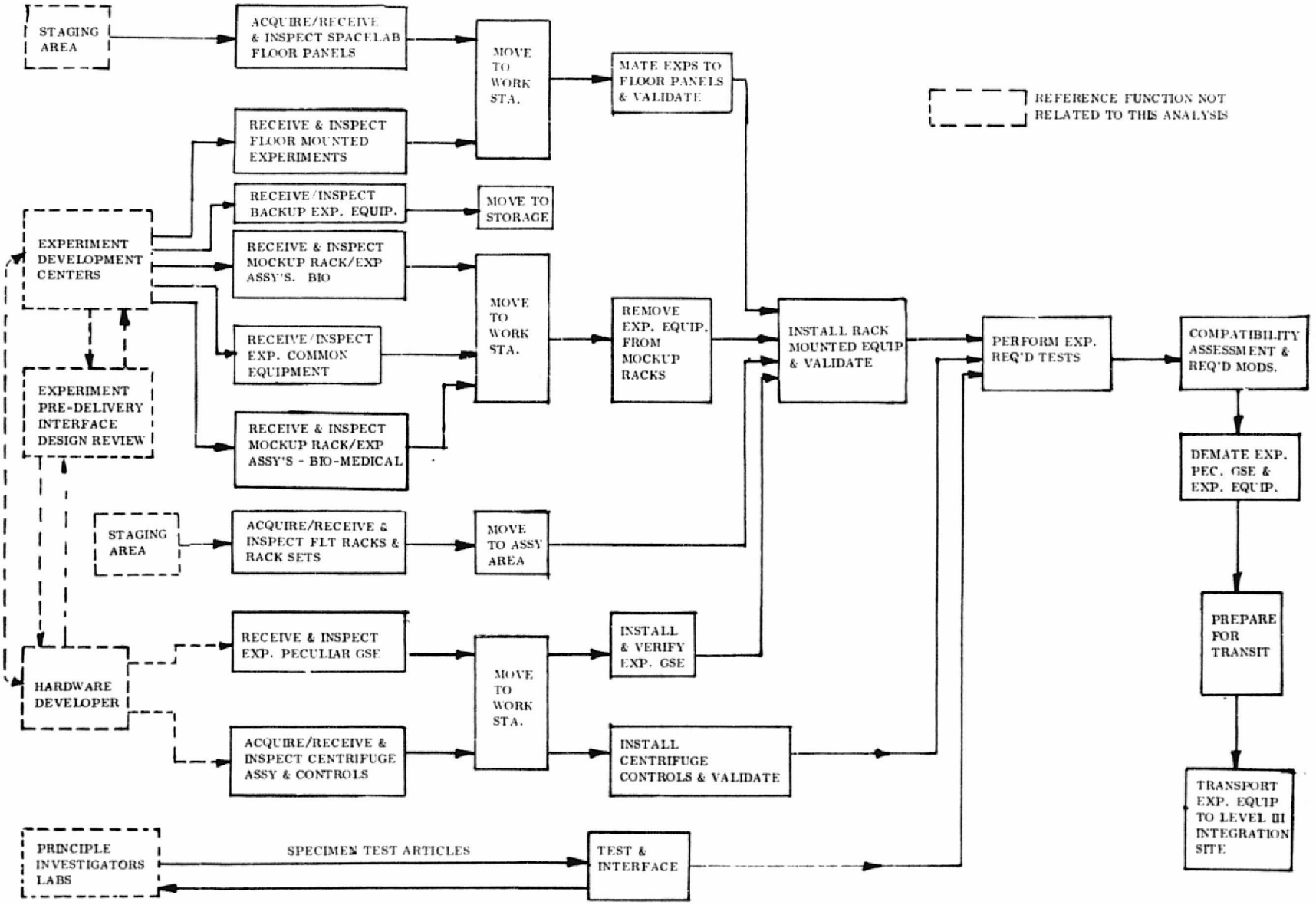


Figure 4-28. Level IV Integration Function Flow — Typical Dedicated Laboratory

Table 4-40. Typical Level IV Integration Function Description

Task Complexity Driver	Function No., Title & Description
Configuration consists of 6 double racks, 6 single racks, 3 floor mounted experiments and approx. 240 experiment components. Function Time 70 hr Baseline Allocation 28 hr Personnel/Manhours Technician/ 138 Engineer/ 100 Scientist/ 60 Mechanic/ 27 Liaison/ — Contingency —— Total 325 Responsible Agency - EDC Experiment Peculiar GSE Rack mounting stands. Spacelab power simulator. Spacelab cooling system sim. Spacelab RAU interface sim.	D3 Install Rack Mounted Equip. and Validate • Connect and verify facility support interfaces • Install experimental equipment items in racks • Install rack controls of floor mounted experiments • Install inter-equipment item wiring harness • Install experiment to rack connector cabling • Verify mechanical interfaces • Mate electrical interfaces • Perform continuity, megger and bonding checks • Perform visual and mechanical inspection • Functionally verify experiments • Functionally install loose items • Close-out appropriate EAM, PAM and SEICO open items • Secure and review Acceptance Data Package • Weigh Flight Hardware for data input to FDD and for transit purposes

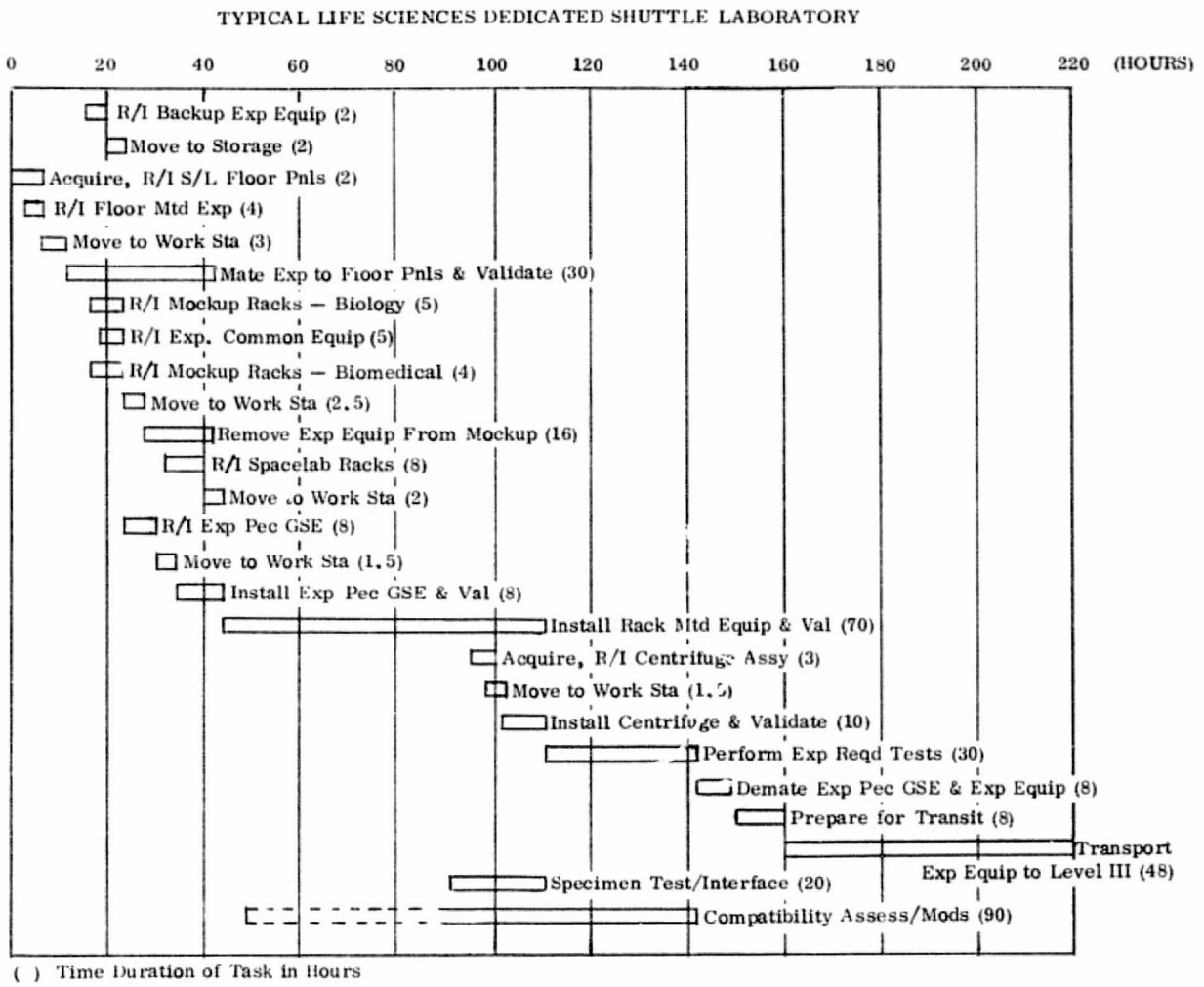


Figure 4-29. Level IV Integration Activity Timeline

Level III integration activity begins with receipt, inspection, and acceptance of experiments, experiment rack and floor assemblies, associated support equipment, and software. The racks are then mated to the Spacelab floors, connected to the Spacelab subsystems, validated, and in turn "soft" mated to the bulkhead/centrifuge assembly. This assembly/mating sequence is followed by a series of integration and interfacing tests involving, among others, core segment simulator, Spacelab support systems, simulated data management, man-machine interfaces, electromagnetic interference and compatibility, power profiles, and environment control systems. During the later tests, some payload specialist training will take place. The principal investigators will make available test specimens for use during the integration activity. Level III integration will conclude with stowage of non-time-critical items after a final integrated systems test. The experiment "train" assembly will then be prepared for mating with the core and experiment modules to begin Level II activities. Figures 4-30 and 4-31 show the functional flow and timeline respectively for Level III integration of a dedicated lab. A mini-lab configuration will follow much the same pattern.

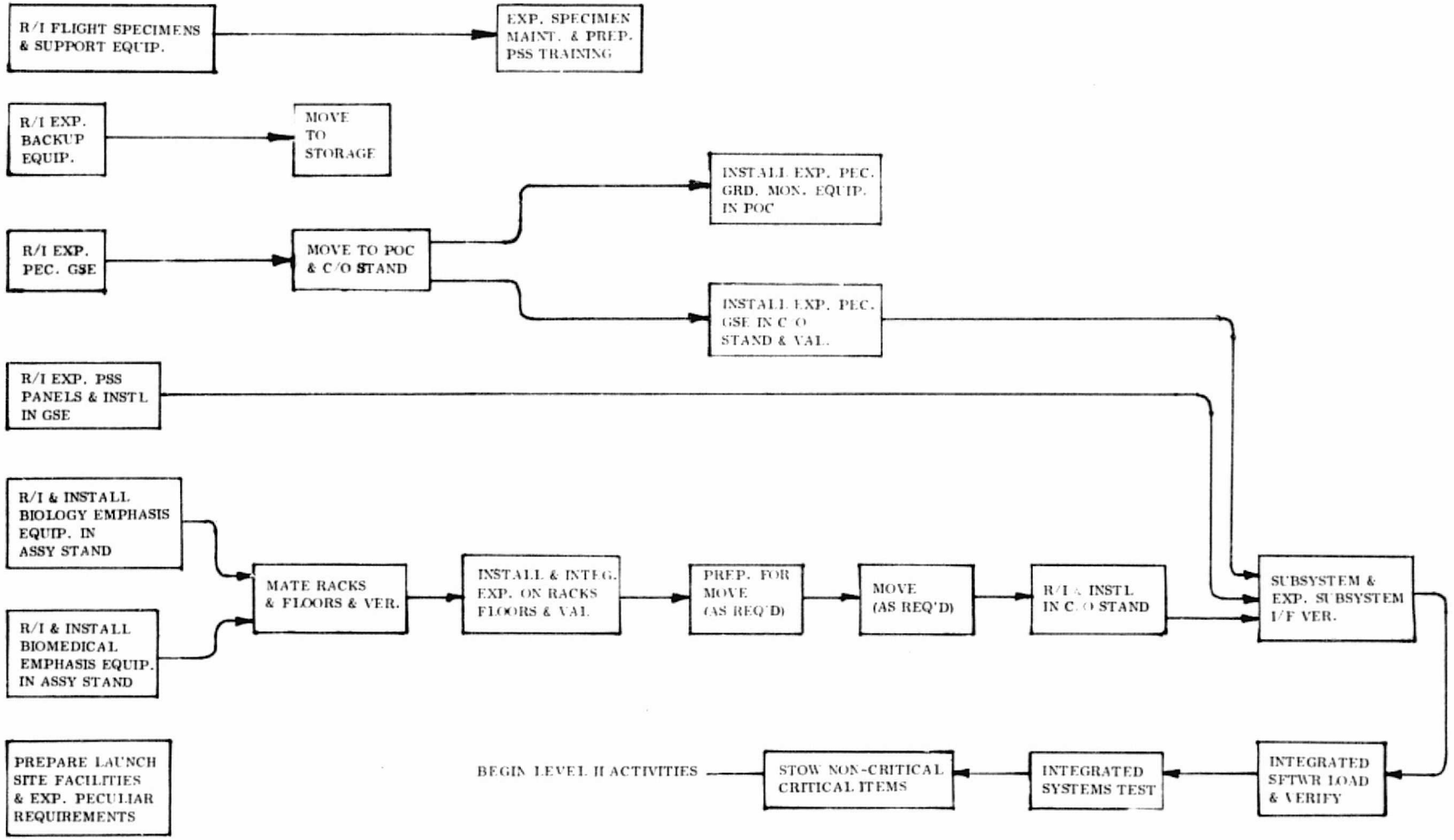


Figure 4-30. Level III Integration Functional Flow

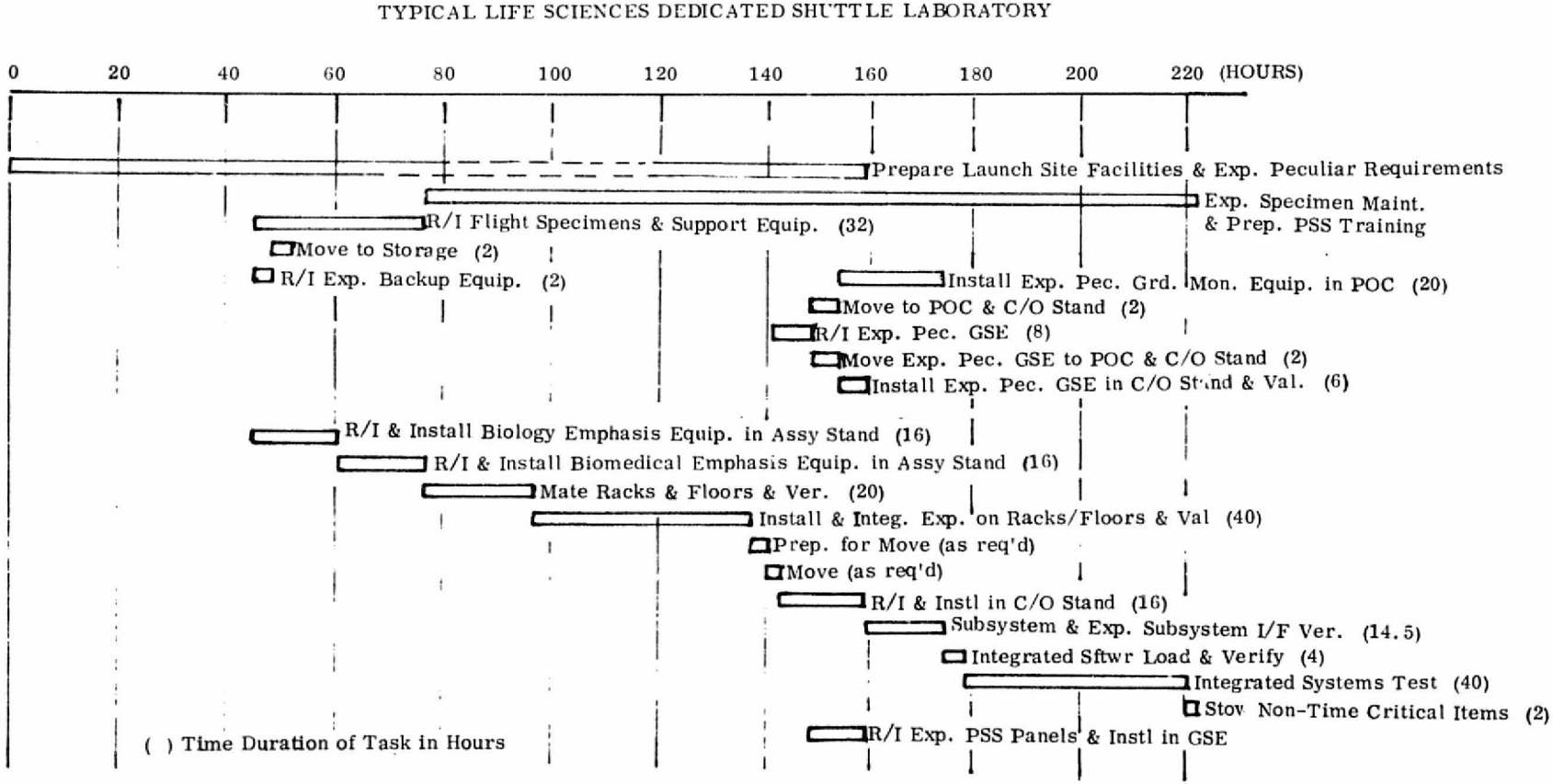


Figure 4-31. Level III Integration Activity Timeline

Parallel with the flight hardware integration activity, launch site facilities are prepared for the life sciences mission as follows. The PCR will be validated to provide LN_2 service and to allow Spacelab access GSE to be located and verified. The POC designated payload/experiment console area will be readied to accept life sciences ground monitoring equipment and the bio-labs will accept the delivery of, and begin maintenance and preparation of, the specimens selected for flight operations.

4.5.2.3 Level II Integration Activities. Level II integration is the integration and checkout of the combined life sciences experiments and experiment-mounting elements together with the flight subsystem support elements into the Spacelab. This activity will occur in the Manned Space Operations Building (MSOB) and Bio/Medical Labs at NASA/KSC.

The Spacelab core segment work bench, control center rack and associated flight equipment will be mated with the experiment rack assemblies and Bioresearch Centrifuge for integration functions. During this phase bulkheads, pressure shells for core, and experiment segments will also be mated. After a seal leak test of Spacelab, verification of on-board systems and interfaces will lead to functional tests, experiment final calibration and, in conjunction with the Orbiter simulator, a simulated mission sequence test will be conducted. Level II integration is completed with a weight and c.g. test and Spacelab is ready for installation in the Orbiter. During Level II integration of Spacelab, a parallel operation will be specimen preparation in the Bio-Labs, payload specialist training, and rehearsals for on-pad loading of specimens into the Spacelab. Figures 4-32 and 4-33 show the function flow and timeline for this Level II activity.

It is assumed that:

a. The Spacelab mid-body access hatch will be installed and available for life sciences on-pad access.

b. The internal access GSE for vertical (on-pad) specimen loading will be installed in the Spacelab and verified during this activity.

c. POC life sciences monitoring equipment will be installed and verified prior to Spacelab Simulated Mission Sequence Test, and validated during the test.

4.5.2.4 Level I Integration Activities. Integration of Spacelab into Orbiter, preparation of Shuttle vehicle elements for launch, and insertion of life sciences specimens prior to launch are the principal tasks of Level I integration. These activities will all occur at NASA/KSC at the Orbiter Processing Facility (OPF), Vehicle Assembly Building (VAB), Payload Changeout Room (PCR), Launch Pad and Bio/Medical Labs, and Payload Operations Center (POC).

Figures 4-34 and 4-35 show the function flow and timeline for Level I activity. Level I integration begins with arrival of the Spacelab at OPF followed by Spacelab installation into the Orbiter payload bay. Checkout and verification of Orbiter/Spacelab interfaces

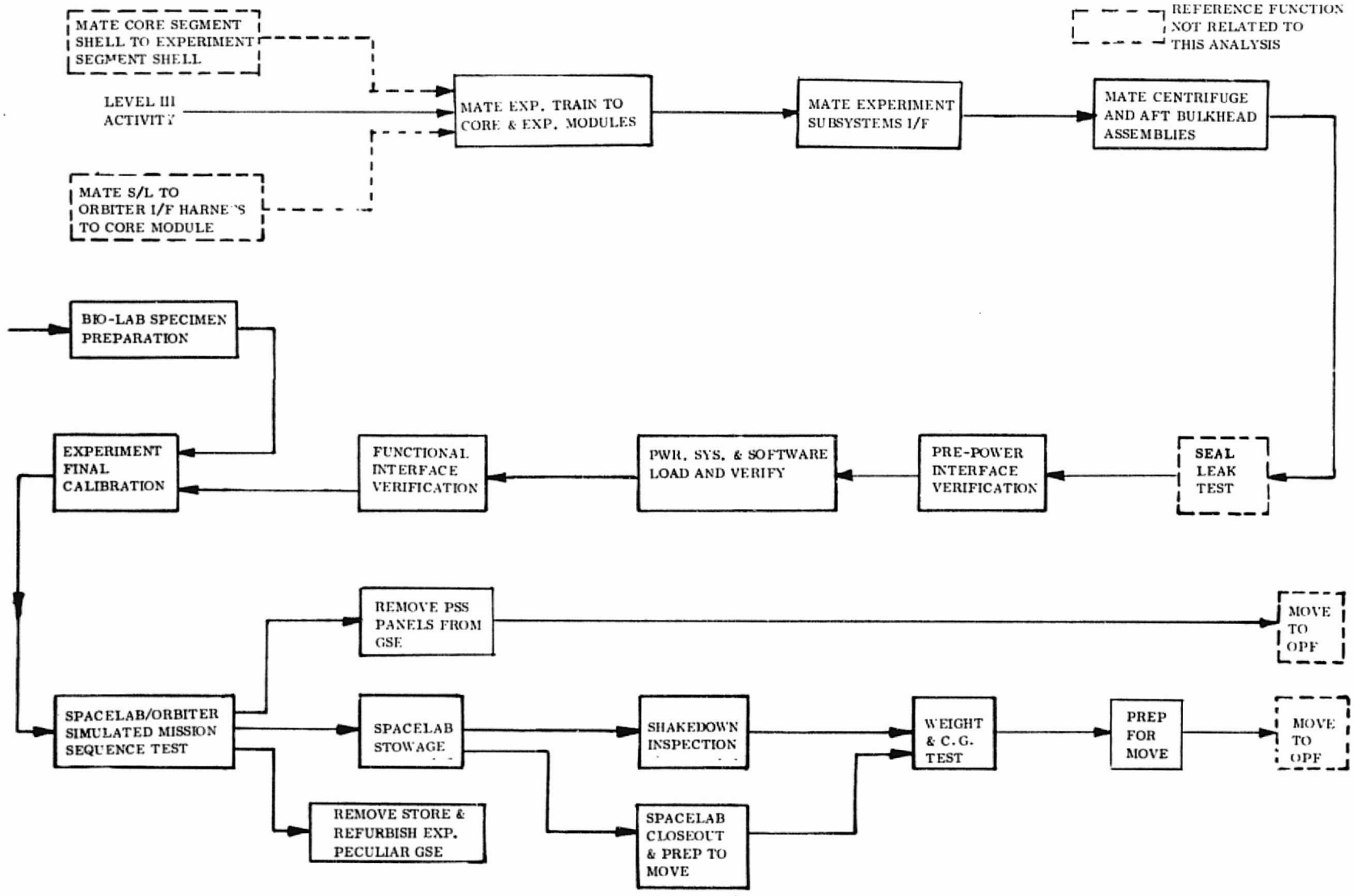
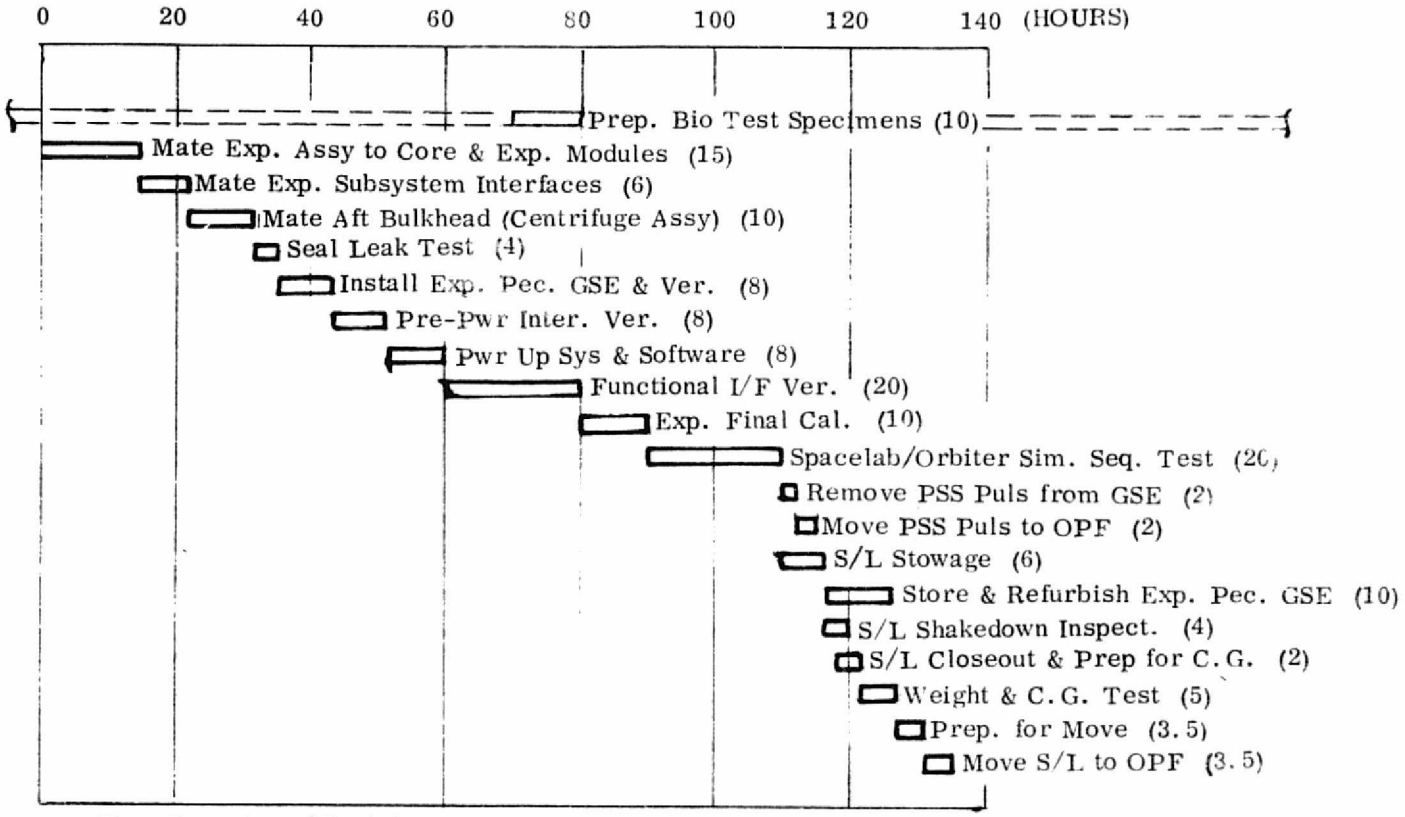


Figure 4-32. Level II Integration Function Flow

TYPICAL LIFE SCIENCES DEDICATED SHUTTLE LABORATORY



( ) Time Duration of Task in Hours

Figure 4-33. Level II Integration Activity Timeline

is followed by an Orbiter Integrated Test. Before preliminary Spacelab inspection and closeout, it is recommended that GSE intended for use during on-pad ingress operations be prepositioned in Spacelab at this time for ease of on-pad specimen loading operations. No experiment activity is planned affecting life sciences experiments or the Spacelab during Orbiter and Shuttle vehicle element buildup operations.

At approximately T-50 hours, the experiment access and service GSE required for on-pad loading will be located in the PCR and checked out. At approximately T-15 hours the specimens are transported to the PCR and made ready for insertion. Some scientific activity is anticipated before insertion. Actual insertion will begin after Shuttle hazard servicing is complete and the pad area is open. Prior to specimen insertion, the Spacelab ECS will be made operable and LN_2 loaded into the experiment freezer. The specimens are then installed and continuously monitored and verified with ground stations. The on-pad loading operation will conclude with personnel evacuation from the PCR and the mission ready for the countdown. Life sciences experiment personnel will be located in the POC to monitor specimens through the liftoff and ascent phase.

It is assumed that:

a. The Spacelab mid-body access will be installed and available for specimen installation.

Figure 4-34. Level I Integration Function Flow

b. Access to PCR will be provided to life sciences personnel after Shuttle hazardous operations.

c. Spacelab ECS and power will be available during on-pad specimen loading.

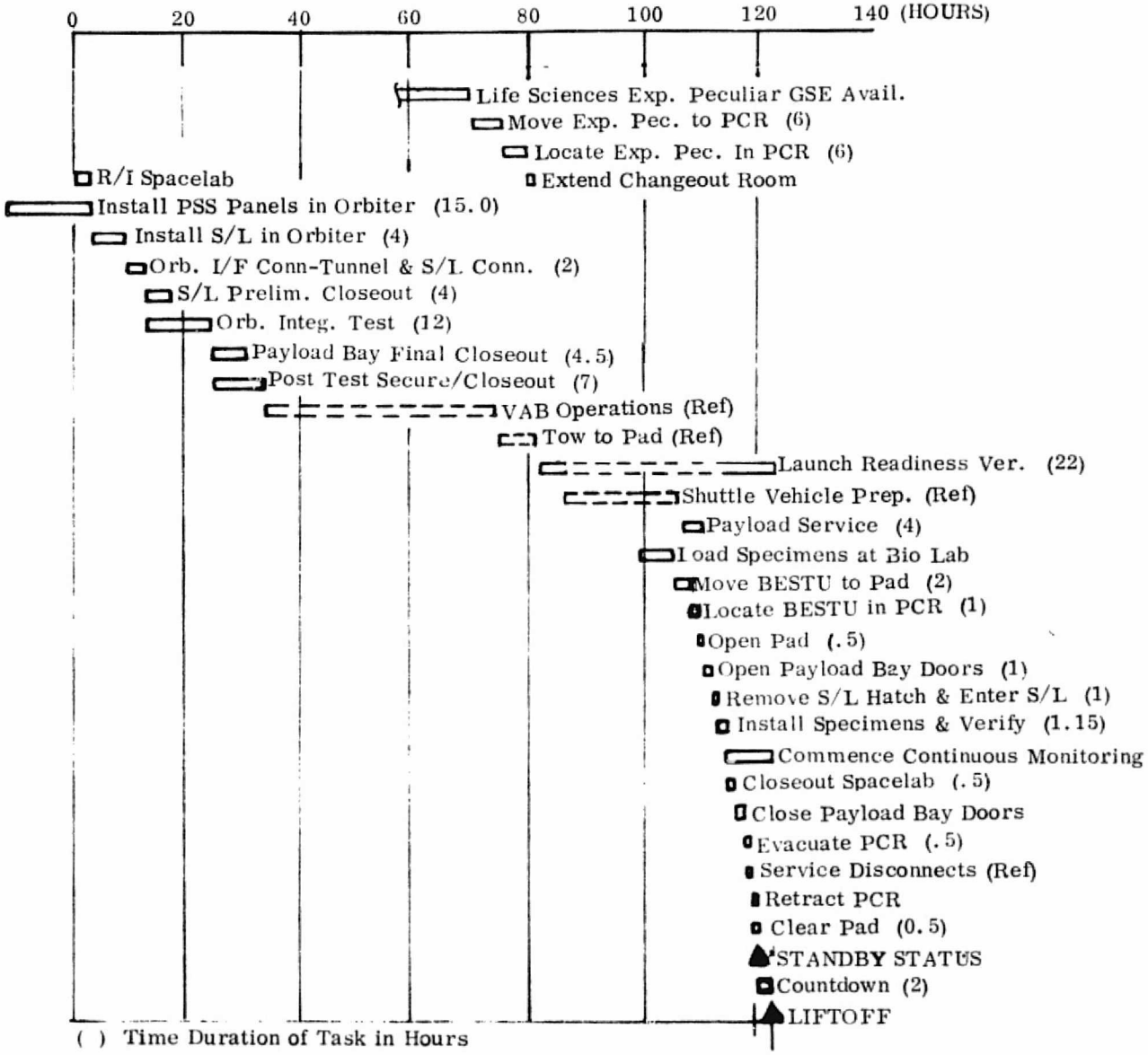


Figure 4-35. Level I Integration Activity Timeline

4.5.2.5 Post-Mission Processing Activities. Post-mission processing includes the retrieval of specimens and data, experiment equipment demate from Orbiter, preliminary equipment inspection, and initiation of the refurbishment and reflight cycle. It occurs at the Orbiter landing strip, Orbiter Processing Facility (OPF), Manned Space Operations Building (MSOB), and Central Integration Site - all at NASA/KSC.

Life sciences post-mission processing begins with a unique requirement to remove certain specimens from Spacelab within two hours of touchdown and commence

scientific activity. The remainder of the specimens will be protected in environmental enclosures (e.g., freezers) and are planned for removal at first access to the Spacelab after safing operations and access GSE installation in the OPF. Following this operation, KSC will remove the Spacelab and transport it to the MSOB for initiation of Spacelab and experiment equipment demate functions. The experiment phase of post-mission processing is concluded with transit of experiment equipment, both airborne and ground, to CIS for post-mission testing and equipment distribution to the various users. Figures 4-36 and 4-37 show the detail function flow and timeline of this mission phase. The assumptions used in developing this scenario were:

a. Spacelab racks and floor panels are mission discipline dedicated and are allocated to the responsible EDC's.

b. An experiment (specimen holding unit) transfer system will be available in the Spacelab tunnel for use on both orbit and ground operations.

c. Launch site will make provisions for life sciences personnel to ingress Orbiter at landing strip and OPF to retrieve time-critical specimens.

d. For purposes of this study assume life sciences personnel will be on station in POC a minimum of 8 hours prior to landing and 17 after landing to monitor ground activities through specimen removal.

4.5.3 GROUND INTERACTIONS AND CONSIDERATIONS

4.5.3.1 Dedicated Mission Flight Hardware. The detailed ground support timelines developed in the preceding sections were combined into an integrated ground support activity timeline, shown in Figure 4-38. Both dedicated laboratory and mini-lab buildup are shown. The upper section of the chart depicts the entire ground processing of a typical dedicated laboratory mission, beginning with Level IV integration activity and continuing through the return of data, specimens, and experiment equipment to the user.

The timelines were based on a 16-rack section, two floor-mounted experiments, and a a Bioresearch Centrifuge assembly. This configuration was used to derive a worst-case timeline. The times shown are working hours and weeks. Levels III and IV have one-shift, eight-hour days, while Levels I and II have two-shift working days.

The lower chart shows a typical mini-lab configuration based on a two-rack section and one floor-mounted experiment. Level II and I integration activity time periods remain essentially the same and fit within the launch site operational time frame. The Level III activity timeline, however, is totally dependent on the multi-discipline mission level of complexity (e.g., Spacelab plus Pallet(s) or Spacelab only) and thus is indeterminate at this time. Level IV integration activity for mini-lab is reduced, but again will vary according to the specific mini-lab configuration.

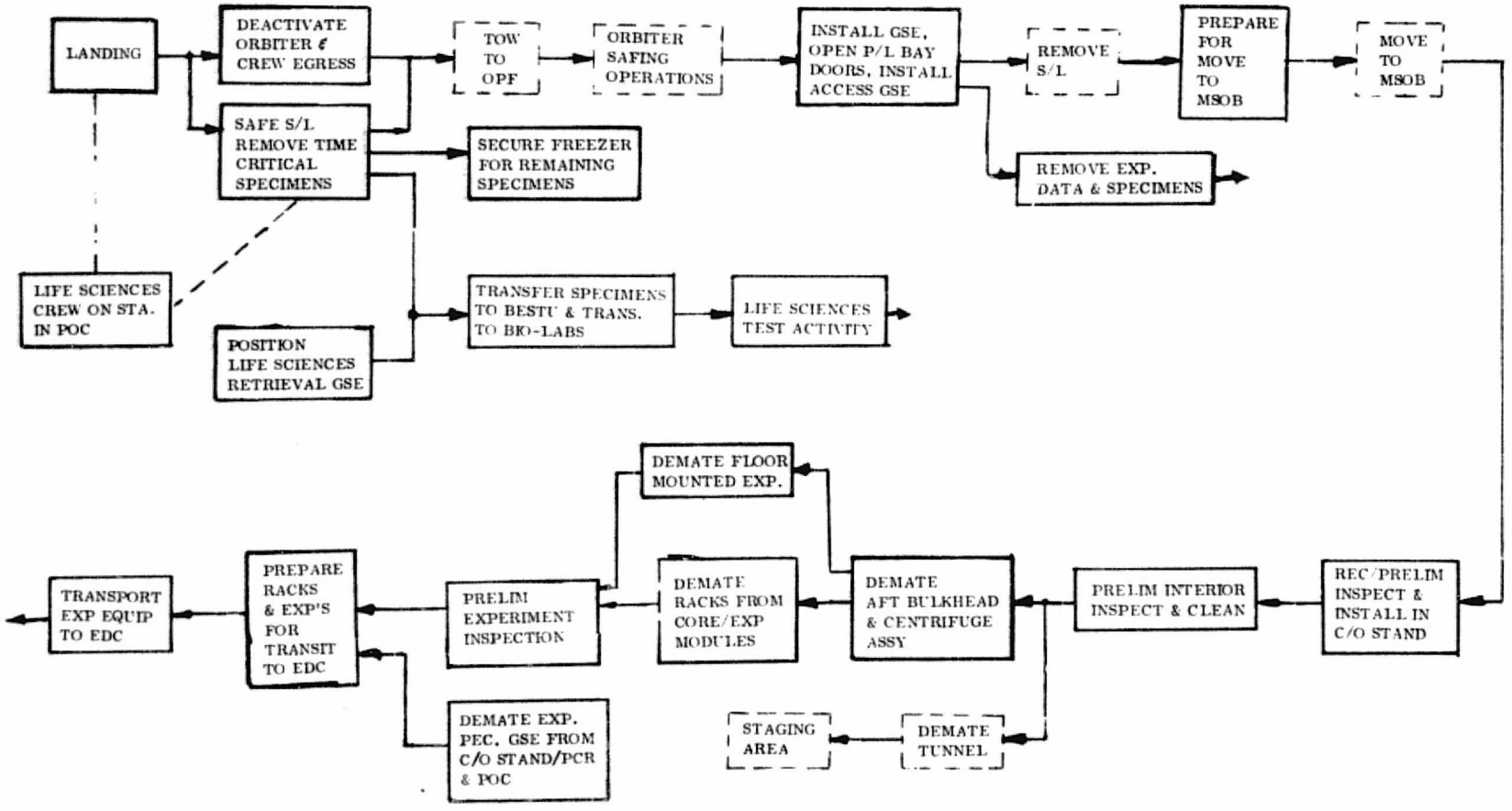


Figure 4-36. Post-Mission Processing Function Flow

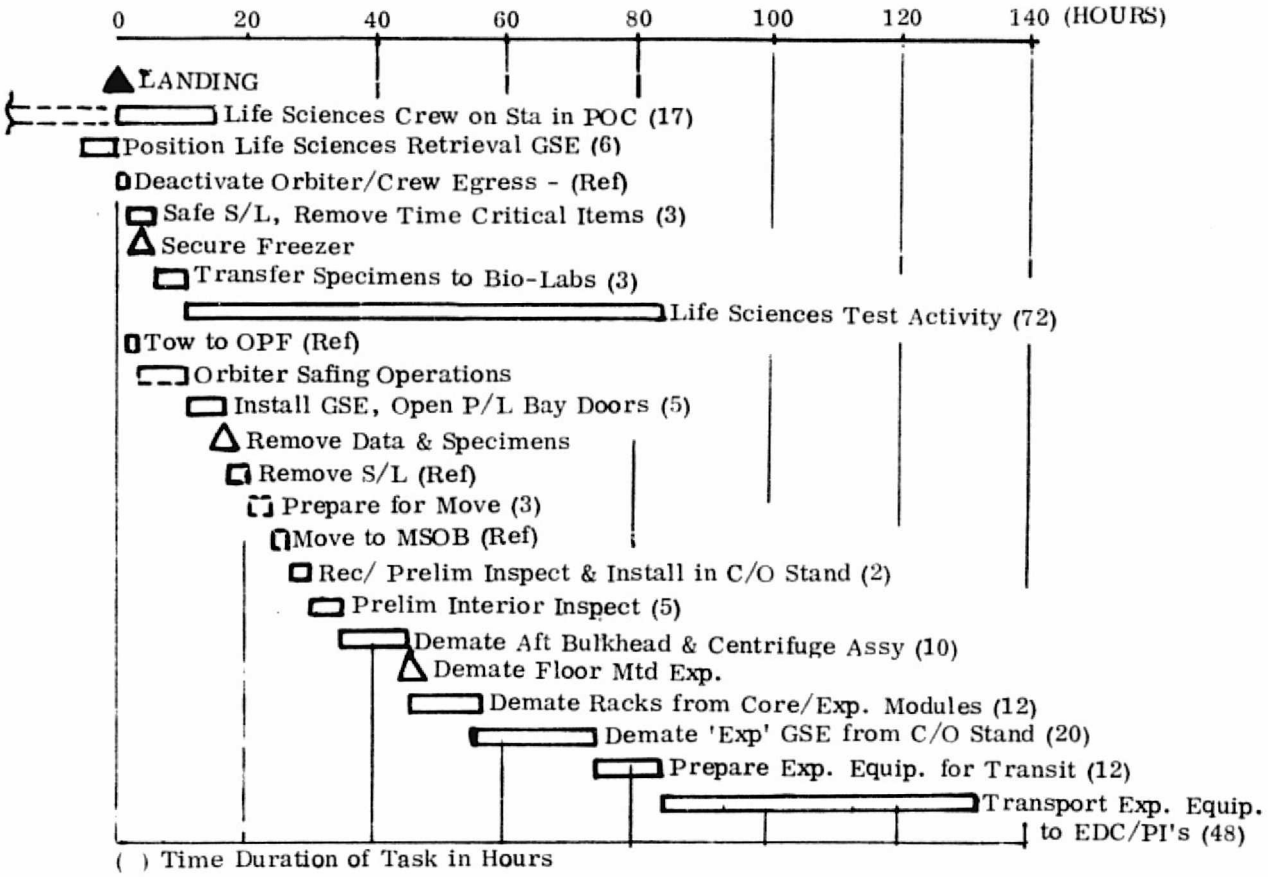


Figure 4-37. Post-Mission Processing Activity Timeline

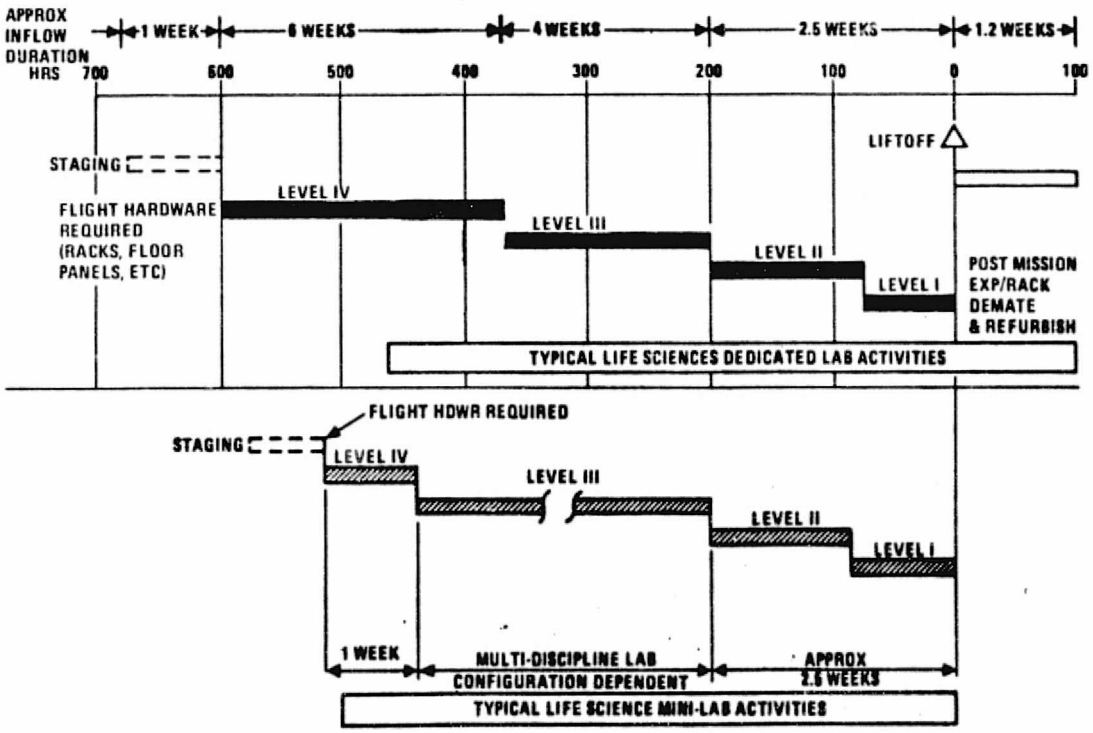


Figure 4-38. Integrated Ground Support Activity Timelines

In order to determine potential hardware (i.e., Spacelab mission-dependent equipment) availability conflicts during a typical Spacelab flight sequence, the information in Figure 4-38 was combined with a sample year of life sciences mission activity. Figure 4-39 shows the launch schedule taken from the baseline mission model of Figure 3-6, along with two non-life sciences Spacelab flights shown in the overall NASA mission model (Reference 5). To support the life sciences missions, a variety of Spacelab-dependent equipment is required: experiment racks (single and double configuration), tunnel and aft bulkhead, and associated electrical/electronic hardware (experiment switching panel, experiment RAUs, inverters/converters).

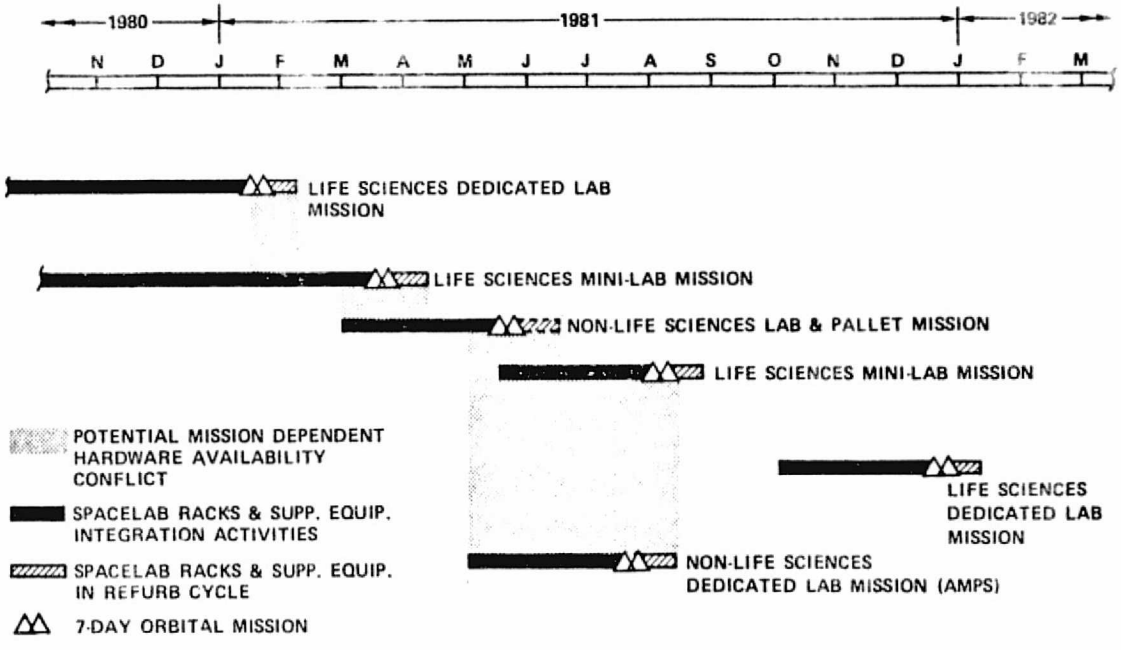


Figure 4-39. Potential Mission-Dependent Equipment Availability Conflicts

The availability of Spacelab mission-dependent equipment to support the missions shown depends entirely on the flight configuration compared to the total inventory of flight hardware. The early-year flight schedule (1981) has the greatest impact on availability because of planned extended durations of Levels IV and III. A fully operational Shuttle flight and integration schedule would show less impact.

The conclusion of this analysis was that in order to support Level IV and Level III integration activity and to accomplish scheduled launch commitments, life sciences dedicated laboratory missions will require dedicated mission-dependent equipment. With its own racks, floor panels, RAUs, etc., life sciences laboratory development would be less constrained by tight Spacelab flight schedules.

4.5.3.2 Ground Support Facilities and GSE. The experiment ground-support equipment impact is primarily in the area of facilities and launch pad access operations. The facility requirements identified in this study are summarized in Table 4-41. The quantity requirements for floor space and power levels are estimates which will be updated in later studies. The off-line experiment functions of Levels IV and III integration phases will be performed at the Experiment Development Centers (EDC) and Central Integration Site (CIS). A major requirement at the CIS is the medical/biological lab facility to accommodate specimen test and flight article preparation. Sufficient floor area exists at the Level II and I integration site (launch site) to meet the requirements of the remaining activities. With the exception of the LN_2, the servicing fluids and gases indicated on the chart are required at the medical/biological labs.

Table 4-41. Ground Support Facility Requirements Summary

GROUND SUPPORT FACILITIES & INTERFACE REQUIREMENTS	LEVEL IV INTEGRATION		LEVEL III INTEGRATION		LEVEL II & I INTEGRATION		POST MISSION PROCESSING	
MEDICAL/BIOLOGY PREPARATION LAB	N/A		X		X		X	
CALIBRATION LAB	N/A		X		X			
DARK ROOM	N/A				X		X	
DATA PROCESSING	N/A		X		X		X	
RADIOACTIVE STORAGE (ISOTOPE STORAGE)	N/A		X		X		X	
	DEDICATED	MINI-LAB	DEDICATED	MINI-LAB	DEDICATED	MINI-LAB	DEDICATED	MINI-LAB
FLOOR SPACE (SQ FT) LAB	N/A	N/A	1000	200	1000	200	1000	200
STORAGE	200	100	200	100	200	100	200	100
INTEGRATION	2500	200	2000	200	2000	200	2000	100
PAYLOAD OPS CENTER	N/A	N/A	N/A	N/A	100	50	50	50
PAYLOAD CHANGEOUT ROOM	N/A	N/A	N/A	N/A	100	80	N/A	N/A
ENVIRONMENT								
(LAB) TEMP 295-301K°	N/A		X		X		X	
(INTEGRATION) TEMP 290-305K°	X		X		X		X	
(LAB) HUMIDITY 50 ± 10%	N/A		X		X		X	
(INTEGRATION) HUMIDITY 70% MAX	X		X		X		X	
CLEANLINESS 100K	X		X		X		X	
ELECTRICAL POWER	DEDICATED	MINI-LAB	DEDICATED	MINI-LAB	DEDICATED	MINI-LAB	DEDICATED	MINI-LAB
28 VDC kw	3	1	2.7	1	2.7	1	N/A	N/A
115 VAC, 60 Hz, 1φ kw	1	.5	2	1	2	1	2	1
FLUIDS/GASES FILL & DRAIN SUPPLY SYSTEM CERTAIN GASES EXP. SUPPLIED (INCLUDE ELECTROLYTE) LN_2	N/A		N/A		X		X	
NATURAL GAS	N/A		N/A		X		X	
AIR	N/A		X		X		X	
GN_2	X		X		X		X	

Subsequent to the Spacelab installation in the Orbiter, experiment requirements ... primarily in the launch pad area (payload changeout room) for on-pad access during specimen insertion and facilities for life sciences experiment monitoring equipment.

One major life sciences peculiar GSE item was reconfirmed during the study. This is an organism holding and transfer unit to be used in transporting the biological organisms from the preparation laboratory to the launch pad and payload changeout room (PCR). This item, called the Bioexperiment Support and Transfer (BEST) unit, has been described in detail in previous studies (References 2 and 3). The remaining GSE requirements are those relative to the life sciences experiment equipment.

Those peculiar to the EIs in the common equipment inventory are summarized in Table 4-42. The worksheets from which the table was developed are found in Volume V, Book 2, Appendix F. As seen in the table, supportive equipment of a general nature is required the most often. This is particularly true during Level IV integration. There appear to be no major peculiar GSE requirements for laboratory buildup.

Table 4-42. Equipment Item GSE Requirements Summary

GSE Category	GSE Requirements	No. of EIs
Handling and Transportation	Special Shipping Containers	20
	Transportation	1
	Handling Equipment	18
Servicing Equipment	Pressurized Gases	5
	Liquids	10
	Cryogens	2
Checkout and Maintenance	Monitoring Equipment	1
	Checkout Equipment	40
	General Test Equipment	76
	Power/Environ/Simulation	8
	Special Maint. Aids/Tools	1
	General Tools	116
	Calibration/Checkout Gases	4
	Leak Test Equipment	18

4.5.3.3 Life Sciences/Spacelab Mission Scenario. Life sciences flight research consists of several sequential experiment phases initiated in PI laboratories, continuing through launch, on-orbit, and recovery operations, and terminating in the PI laboratories. The orbital research is but one phase of this scenario. Figure 4-40 illustrates the overall scenario.

Following mission preparation, the specimens and the applicable research equipment will be transported to the launch site and held until launch. While the organisms are being transported between facilities, however, they will require support in terms of EC/LS, electrical power, and data montioring.

Various ground support and flight preparations will occur at the launch site. Examples include attachment of biosensors, checkout of electronic equipment, and checkout of the supporting subsystems aboard Spacelab. During the last several hours of countdown, the organisms will be loaded aboard Spacelab and launched. Following the orbital research period, organisms will be returned to earth, removed from Spacelab, and transported to the launch site holding area for eventual return to the principal investigator's biolaboratory.

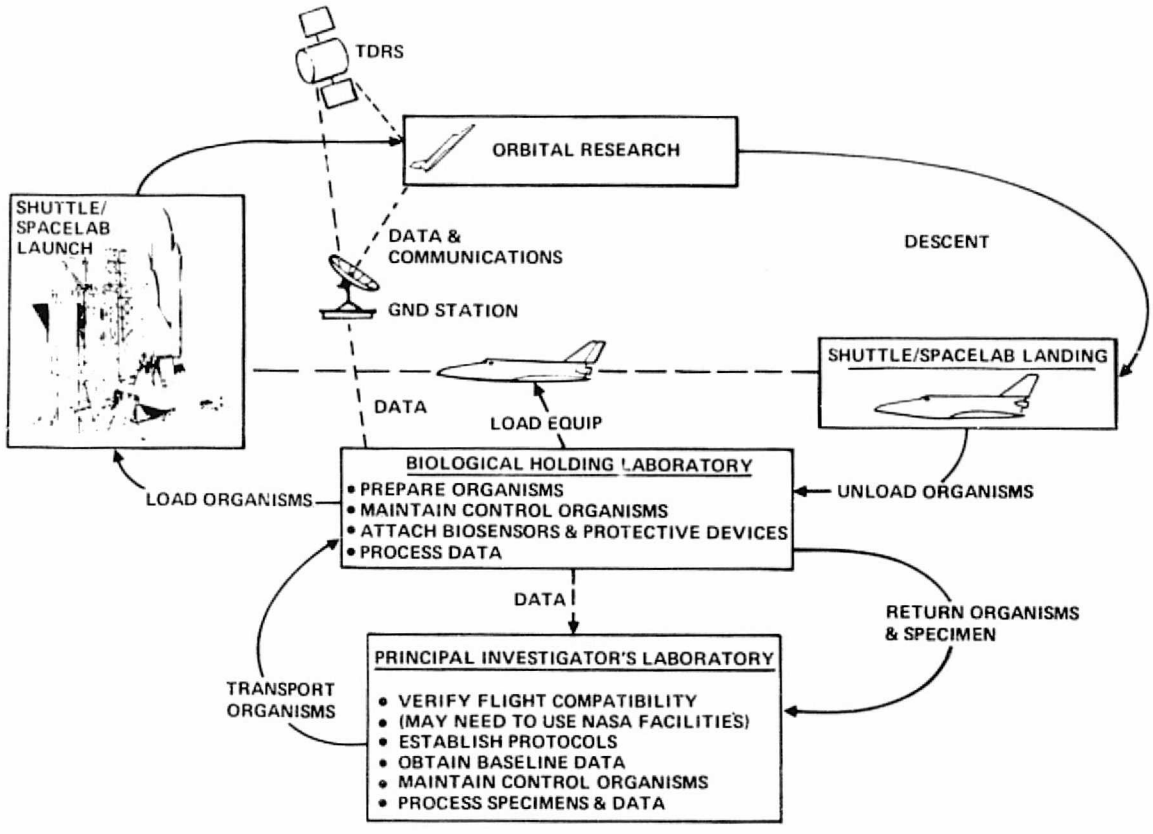


Figure 4-40. Life Sciences/Spacelab Mission Scenario

One very important phase of this scenario is the installation of the organisms aboard the Spacelab. The need for research samples and measurements immediately before and after gravitational level changes means that access to these organisms is required. Various launch/landing access requirements for life sciences payloads have been established by the NASA life sciences working group. The major of these requirements are:

a. Specimen data and samples (blood, tissue, cells, etc.) are required within 6 hours before liftoff.

b. Last ground access to first on-orbit access — 8 hours desired (12 hours maximum).

c. First access on orbit no later than liftoff plus 2 hours.

d. If specimens are loaded early (other than launch day), daily access is required for 3 men, 8 hours/day, continuously, at same time each day.

e. Landing access no later than two hours after landing.

The requirements were chosen as the minimum acceptable to meet the scientific objective of establishing valid baseline data for both the ground controls and the flight specimens. The additional need to minimize disturbances, noise, power shutdowns,

vehicle motion, etc., is consistent with the overall requirement that the flight specimens must be exposed to the same environment as the biological controls.

A recent Convair study (Reference 21) investigated various options of obtaining access to the Spacelab for loading of or obtaining samples from the organisms. The prelaunch options considered installation via the Orbiter cabin or the EVA hatch, both of which require transfer down the vertical Spacelab tunnel or use of a modified Spacelab hatch. Figure 4-41 shows the desired method of meeting the life sciences insertion and access requirements. This on-pad loading mode minimizes the time from last on-ground access to first on-orbit access. The modified Spacelab hatch is presently in a review cycle by ESA. Approval of on-pad specimen loading via the modified Spacelab (location 3) and the payload changeout room will drastically reduce payload requirements for:

a. Special access ground support equipment.

b. On-line ground support services, e.g., continuous ground power and data monitoring.

c. Expanded on-pad time allocation.

d. Impact on planned Orbiter on-line ground operations.

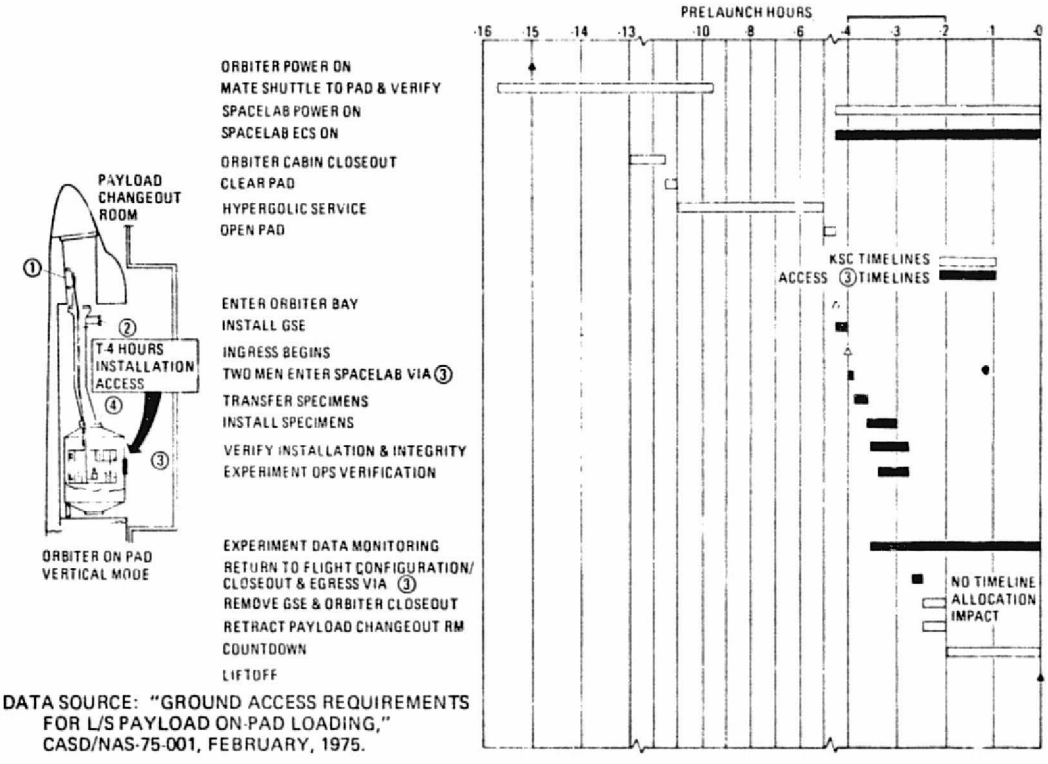


Figure 4-41. Life Science Payload Specimen Insertion On-Pad Access

Orbiter and Spacelab operational flow allocations are shown by the open bars in Figure 4-41. The Orbiter flow allocation shows that the launch pad must be cleared of all personnel between T-11 and T-4 hours to allow hazardous servicing, and

cleared again at T-1 hours for the launch countdown. The times before T-11 hours and from T-2 to T-4 hours are periods when personnel access is allowed and are candidate periods for Spacelab life sciences access. Last access at T-10 hours with first on-orbit access at launch plus 1 hour meets the maximum life sciences requirement of 12 hours, but is undesirable because it allows no countdown holds or other contingency time. Last access between T-4 and T-2 hours has minimum impact on the Orbiter processing flow allocation and allows a four-hour contingency in the desired eight-hour last access to first access requirement.

The planned postlanding operations with access to Spacelab are proposed to begin at crew exchange. Access at this time can be accomplished by a life sciences specialist brought aboard the Orbiter during the crew exchange. This relieves the flight crew from these duties and avoids the problem of possible physiological degradation interfering with specimen/sample removal. Specimen access is required while the Orbiter is on the runway and before planned safing. Orbiter towing must be delayed until specimen removal or examination is completed, since such work cannot be accomplished during towing vibration. This delay could be for as long as two hours. This access impacts Orbiter safing operations, and the hazards involved require further study. Environmental control may be terminated at the completion of specimen removal or examination. Removal of refrigerated specimens is not time-critical, but does require power to the refrigerator/freezers until it is accomplished.

An alternative approach is to transfer the specimens to the Orbiter mid-deck before descent and offload at crew egress. However, this approach would be desirable only on selected missions, such as mini-labs, which have relatively small populations of organisms. The recommended mode is on-the-ground removal and transfer.

An important requirement reconfirmed in the study is the maintenance of power, ECS, and data monitoring services any time specimens are aboard, whether prelaunch or postlanding. Use of battery power for sustaining specimen ECS and critical data monitoring through several days of ground operation is acceptable but not desirable.

SECTION 5

COST AND PROGRAMMATIC ANALYSES

This section contains a summary description of the results of the Task III study. Information relative to the details used to perform the cost and programmatic analyses are found in Volumes III and IV.

5.1 COST ANALYSIS

The objectives of the cost analysis task are to support the comparison and evaluation of the alternative mission model options and to provide preliminary cost estimates for the initial laboratories in the mission model.

During conceptual phase studies, cost data is needed for design tradeoff studies and other parametric approches to concept evaluation and selection as well as for budgetary and mission planning activities. Because of the desire to evaluate numerous alternatives during these conceptual studies and because of the generally brief and preliminary definition of both technical concepts and programmatic aspects, only a parametric cost methodology is able to provide the efficient and rapid response necessary. A cost model tailored to the needs of the life sciences laboratory program was therefore developed, based on previous model work carried out under Convair's Life Sciences Payload Definition and Integration Study (Reference 2) and Space Transportation System Payload Data and Analysis (SPDA) (Reference 22).

Cost estimating relationships (CERs) were used for the majority of the cost elements making up the life sciences program cost model. Initially, costs were developed for all of the EIs in the master equipment inventory. Several techniques were employed for estimating the cost of the EI inventory, and each item was estimated with the most appropriate methodology.

These various approaches are listed in Table 5-1. About 31% of the EIs which were modified commercial equipment were estimated using a parametric methodology based on the study carried out by Rockwell International and Beckman Instruments analyzing the use of commercial equipment in Skylab (Reference 23). Another 24% were estimated

TABLE 5-1. EQUIPMENT ITEM ESTIMATING METHODOLOGY

Commercial Equipment Modification (Parametric)	31%
Cost Estimating Relationships	24%
Engineering Estimates	21%
"Detailed" Estimates	15%
Quotes	9%
	100%

using CERs developed in 1974 during Convair's SPDA Task 6 Cost and Schedule Analysis (Reference 22). Engineering estimates were used on 21% of the EIs, based on current or historical costs of similar hardware which represented similar or comparable analogs in terms of complexity, requirements, etc. About 15% of the items were estimated using a brief manhours and materials estimate. The remaining 9% of the EIs were based on vendor quotes from equipment manufacturers or cognizant NASA monitors in the case of on-going development programs. In addition, vendor quotes or current catalog prices were used for the starting point for most commercial equipment modifications estimated by the parametric technique noted above.

Because of the number of EIs (121 total where costs are incurred) and the range of value (about $1K to almost $4M), it is instructive to see where the majority of EI inventory cost occurs. Figure 5-1 shows a simple plot at cumulative total EI inventory acquisition value in millions of dollars versus number of EIs arranged in decreasing order of cost (i.e., the most expensive EI first and least expensive last). As may be seen, approximately 75% of the EI inventory acquisition cost is accounted for by 11 of the EIs. Obviously these are the high-cost new development hardware which one would expect to require the majority of these funds. Table 5-2 presents a list of the 20 highest cost EIs together with their development and unit costs as currently estimated for use in this study.

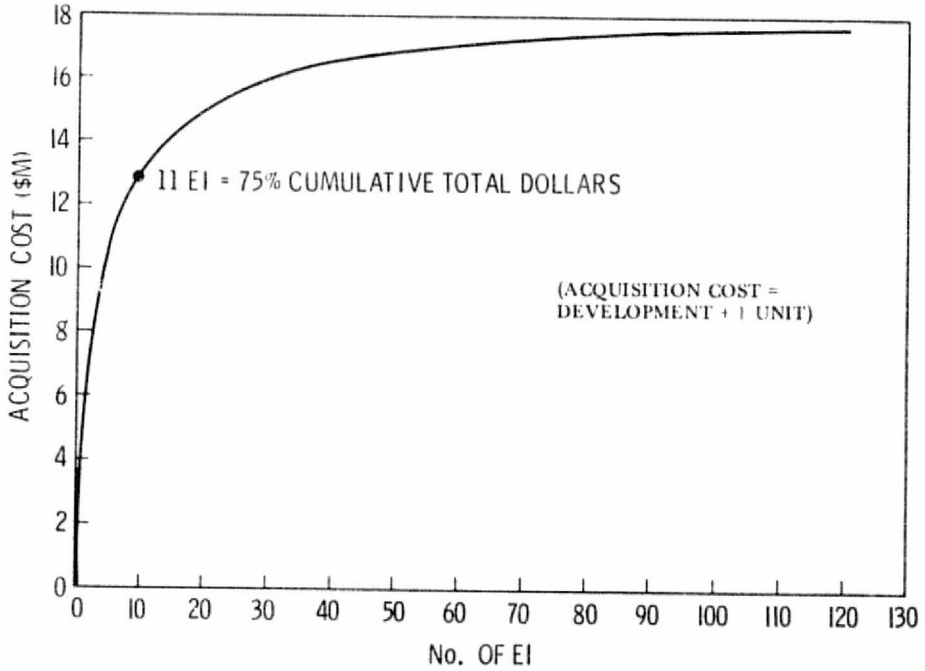


Figure 5-1. Cumulative EI Cost

These EI costs then serve as input to the model and serve as a basis for calculating the remaining "wraparound" laboratory costs. This input consists of the summation of EI cost both with and without commonality. EI cost without commonality represents the total unit value of all EIs making up the particular laboratory under consideration. The EI cost with commonality represents the summation of the unit costs of all the

new EIs in the laboratory not available from previous labs or storage. Both of these values are used in the model as drivers for estimating relationships used therein. The ground rules used in these estimates are presented in Table 5-3.

TABLE 5-2. MAJOR COST EIs

EU	EI	EI Name	Development $K	Unit $K
42	182R	Vertebrate ECS	3593	354
23	43A	Bioresearch Centrifuge	2751	337
41	101C	Primate Holding Unit	1808	167
80	115F	Life Support System Test Console	967	210
10	103	Vertebrate Holding Unit	948	59
1	122	Micro Mass Measurement	550	100
91	144	Psychomotor Performance Console	374	78
6	162	Sterilizer-Autoclave	315	31
10	38	Metabolic Cage — Rats	282	27
42	182P	Vertebrate Ventilation Unit	236	31
4	188	Work and Surgical Bench	207	34
31	38F	Cardiopulmonary Analyzer	0	220
4	83	Refrigerator	183	27
4	80	General Purpose Freezer	167	22
4	77B	Cryogenic Freezer	159	21
50	101	Plant Holding Unit	82	65
5	91	Gas Analyzer, Mass Spec	0	140
4	81	Low Temperature Freezer	122	15
31	156F	Sono-Cardiogram	10	100
41	101B	Holding Unit, Monkey Pod	20	81

For each option a matrix was prepared where each of the laboratories was shown, in sequence, versus the EI master equipment inventory. Quantities of EIs required for each laboratory flight were entered, as well as the development and production costs for each EI. The time between flights is noted and provides a basis for determining whether a new EI unit must be procured or if it is available from a previous lab which is then noted in the matrix. A six-month rule was used wherein an EI must be available for the integration cycle at least six months before the flight, otherwise a new unit is required. The costs of the laboratories and the program are not sensitive to this assumption since flight hardware production accounts for only 8% of the entire program. The values for the EIs are then summed for the total complement of hardware as well as for the new items only. Both of these values are used on the model as drivers for estimating relationships used therein. All associated program costs (the "wraparounds" such as system test, system engineering and integration, Level III integration) are then calculated parametrically, using as inputs the summation of the particular laboratory's

EI unit cost. Costs for the EI and associated higher-level WBS elements are then accumulated appropriately to provide cost for each laboratory in sequence in the option (Figure 5-2).

TABLE 5-3. COST ESTIMATE GROUNDRULES

- CURRENT CONSTANT FY 1975 DOLLARS
- ASSUME ALL DEVELOPMENT, PRODUCTION & LEVEL IV INTEGRATION TASKS ACCOMPLISHED BY A PRIME CONTRACTOR (8% FEE INCLUDED)
- COST INCLUDES ALL LABORATORY HARDWARE & TASKS FOR NONRECURRING, RECURRING PRODUCTION & RECURRING OPERATION PHASES
- HIGHER-LEVEL COST ELEMENTS EXCLUDED:
  - SPACELAB USER CHARGE
  - SHUTTLE USER CHARGE
  - COMMON GSE, FSE, FACILITIES & OPERATIONS
  - LEVEL I & II INTEGRATION
  - NASA IMS
  - PI SUPPORT/GROUND CONTROL EXPERIMENTS
- LIFE SCIENCES PROGRAM COST ELEMENTS EXCLUDED:
  - PI-PECULIAR EXPERIMENT EQUIPMENT
  - SPACELAB MISSION-DEPENDENT SUBSYSTEM EQUIPMENT
  - COMMON GSE & FACILITIES
- FIRST USER RULE APPLIED TO ALL EIS & COST INCURRED AT TIME EI REQUIRED
- A COMMON HOLDING UNIT WAS ASSUMED
- SPACELAB USERS HANDBOOK (SECTION 8) USED FOR EXPERIMENT DESIGN REQUIREMENTS

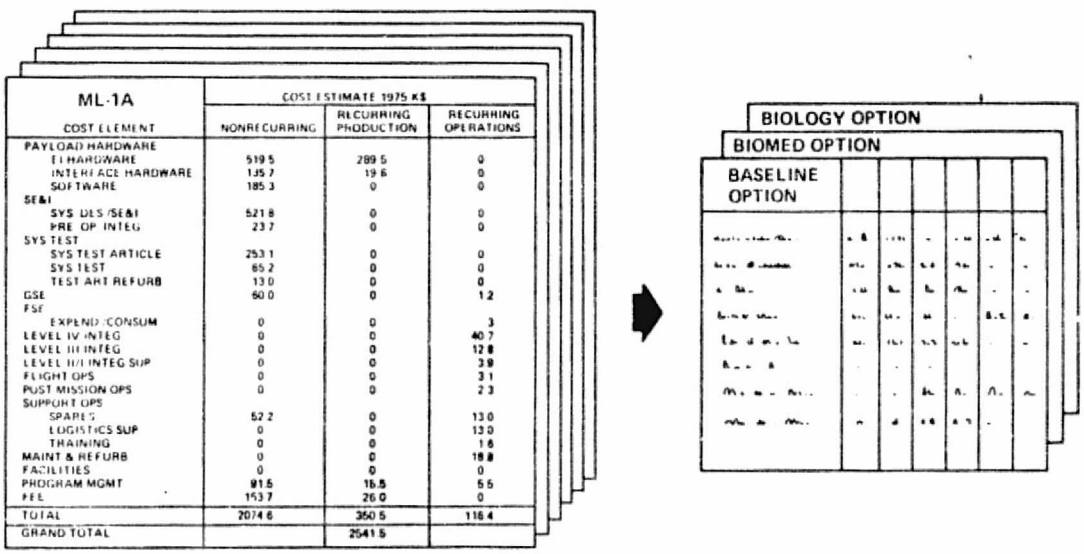


Figure 5-2. Laboratory and Program Option Cost Estimates

Annual funding requirements were then generated, using the model cost estimates spread with idealized cost distribution curves as defined in DRMF 003M according to the summary program schedules.

These option costs by laboratory are presented in Tables 5-4, 5-5, and 5-6 for the baseline, biomedical, and biology options, respectively. These figures show the flight sequence, laboratory type, and status (new, modification, or straight reflight), together with development, production, and operation costs.

Because of the reuse of EIs and the first user rule, it must be noted that both the non-recurring and recurring production costs of any particular laboratory are specifically dependent upon the sequence of development and flight as well as the prior flown laboratories. Any changes in this sequence will impact the laboratory cost shown. EI costs, both development and production, are charged at the time the EI is needed.

TABLE 5-4. LABORATORY COST SUMMARY —
Baseline Option (Development & 5 Years Operations)

FLIGHT SEQUENCE	LAB	STATUS	1975 M$			
			NON-RECURRING	RECURRING PRO-DUCTION	RECURRING OPER-ATIONS	TOTAL
1	COL-2A	NEW	0.42	0.04	0.01	0.47
2	COL-3A	NEW	0.14	0.03	0.01	0.18
3	ML-1A	NEW	2.07	0.35	0.12	2.54
4	MOD-IA	NEW	21.16	3.79	1.23	26.18
5	ML-3A	NEW	3.25	0.88	0.27	4.40
6	ML-3A	REFLIGHT	0.01	0	0.27	0.28
7	MOD-IA	REFLIGHT	0.03	0	1.23	1.26
8	ML-3A	REFLIGHT	0.01	0.86	0.27	1.14
9	MOD-IIA	MODIF	7.22	1.40	1.65	10.27
10	ML-2A	NEW	3.89	0.66	0.33	4.88
11	MOD-IIA	REFLIGHT	0.04	0	1.65	1.69
12	ML-5A	NEW	0.21	0.01	0.01	0.23
13	MOD-IIA	REFLIGHT	0.04	0	1.80	1.84
14	ML-4A	NEW	2.47	0.44	0.20	3.11
15	MOD-IIA	REFLIGHT	0.04	0	1.80	1.84
16	ML-3A	REFLIGHT	0.01	0	0.27	0.28
17	MOD-IIIA	MODIF	6.71	0.68	1.83	9.22
18	ML-3A	REFLIGHT	0.01	0	0.27	0.28
19	MOD-IIIA	REFLIGHT	0.04	0	1.83	1.87
					TOTAL	71.96

The total life sciences payload-unique costs for the baseline option are about $72M. This includes 19 flights over an operational period of 5 years. It includes two carry-on labs, five minilabs, and one dedicated lab modified twice for increased capability.

The biomedical option cost is approximately $69M for a 16-flight program over an operational period of 7 1/2 years. This option, in addition to emphasizing biomedical research, also reflects a stretched flight program and delayed dedicated laboratory capability. The total cost for this option is virtually identical to the baseline if the

TABLE 5-5. LABORATORY COST SUMMARY —
Biomedical Option (Development & 7 1/2 Years Operations)

FLIGHT SEQUENCE	LAB	STATUS	1975 M$			
			NON-RECURRING	RECURRING PRO-DUCTION	RECURRING OPER-ATIONS	TOTAL
1	COL-2A	NEW	0.42	0.04	0.01	0.47
2	COL-3A	NEW	0.14	0.03	0.01	0.18
3	ML-1A	NEW	2.07	0.35	0.12	2.54
4	ML-2B	NEW	4.26	0.80	0.29	5.35
5	ML-2B	REFLIGHT	0.01	0.89	0.29	1.19
6	ML-2A	MODIF	3.32	0.42	0.33	4.07
7	ML-2C	MODIF	0.58	0.11	0.36	1.05
8	ML-5A	NEW	0.23	0.01	0.01	0.25
9	ML-4A	NEW	3.96	0.40	0.20	4.56
10	MOD-IA	NEW	18.39	2.18	1.23	21.80
11	MOD-IIB	MODIF	9.02	1.00	1.15	11.17
12	MOD-IIB	REFLIGHT	0.03	0	1.15	1.18
13	MOD-IIC	MODIF	0.55	0.10	1.10	1.75
14	MOD-IIC	REFLIGHT	0.02	0	1.10	1.12
15	MOD-IIIB	MODIF	5.82	0.58	1.07	7.47
16	MOD-IIIA	MODIF	2.29	0.37	1.83	4.49
					TOTAL	68.64

TABLE 5-6. LABORATORY COST SUMMARY —
Biology Option (Development & 7 1/2 Years Operations)

FLIGHT SEQUENCE	LAB	STATUS	1975 M$			
			NON-RECURRING	RECURRING PRO-DUCTION	RECURRING OPER-ATIONS	TOTAL
1	COL-2A	NEW	0.42	0.04	0.01	0.47
2	COL-3A	NEW	0.14	0.03	0.01	0.18
3	ML-1A	NEW	2.07	0.35	0.12	2.54
4	ML-2D	NEW	7.86	1.26	0.43	9.55
5	ML-2A	MODIF	3.81	1.07	0.33	5.21
6	ML-2D	REFLIGHT	0.01	0	0.43	0.44
7	ML-2C	MODIF	0.04	0	0.37	0.41
8	ML-2D	REFLIGHT	0.01	0	0.43	0.44
9	ML-2B	MODIF	1.06	0.25	0.29	1.60
10	MOD-IIB	NEW	22.67	2.01	1.15	25.83
11	MOD-IIB	REFLIGHT	0.03	0	1.15	1.18
12	MOD-IIB	REFLIGHT	0.03	0	1.15	1.18
13	MOD-IIC	MODIF	0.10	0	1.10	1.20
14	MOD-IIC	REFLIGHT	0.02	0	1.10	1.12
15	MOD-IIIB	MODIF	5.79	0.57	1.07	7.43
16	MOD-IIIB	REFLIGHT	0.02	0	1.07	1.09
					TOTAL	59.87

additional three flights (two reflights of ML-3A and one reflight of dedicated lab Mod IIIA) are neglected, although the annual funding requirements are substantially different. This is to be expected since the EI requirements for these two options are quite similar.

The biology option total cost is about $60M for a 16-flight program over 7 1/2 years on an identical flight schedule to the biomedical option. The lower cost of this option reflects a lesser requirement in terms of EI equipment.

Costs for all flights of a particular option are summarized in sequence for estimating phased-funding requirements.

Using program schedule information and the individual laboratory cost estimates, annual funding requirements were estimated for each of the alternate mission model options. These phased funding requirements are shown in Figure 5-3.

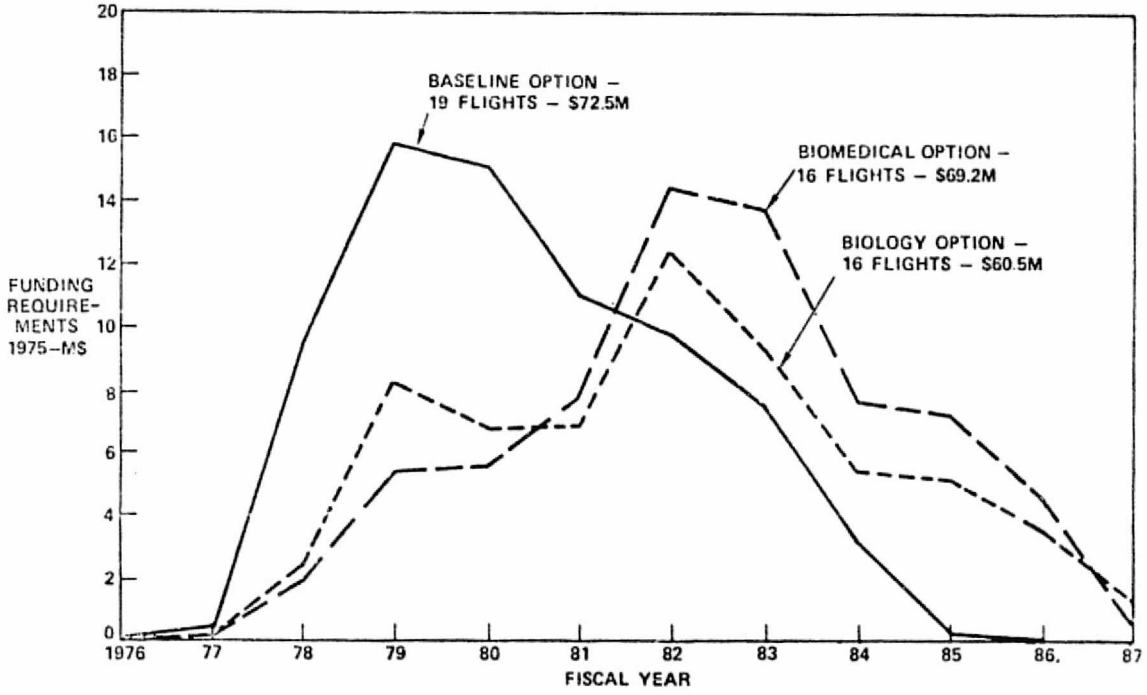


Figure 5-3. Annual Funding Requirements for Program Options

As may be seen the funding peaks of $12M to $16M are generally similar and are directly related to the availability of the first full-capability dedicated laboratory. The funding peaks for the biomedical and biology options are slightly lower because the schedules are stretched sufficiently to decrease the individual laboratory funding requirements overlap. The early-year funding requirement for each option is also related to the timing of the dedicated laboratory.

The fall-off of any particular option in the last year or two shown is not significant and is a result of exclusion of costs for subsequent follow-on flights. A sustaining cost of $5 to $20 million per year could result, depending upon laboratory type, flight rate, and amount of new or improved equipment introduction.

It should be noted the baseline option includes 19 flights, three more than the two alternate options. (These three flights include one reflight of MOD IIIA and two reflights of ML-3A).

The program costs shown, of course, exclude Shuttle transportation user charges, Spacelab user charges, common GSE, FSE, facilities, and common operational activities. EI update or modification allowance is also excluded.

It is concluded from the cost and programmatic analysis that the total program cost or funding peaks do not vary to any great degree for programs of similar capability.

The funding curves for the stretched options, biomedicine and biology, are generally similar and show only minor differences. Peak funding rate is related to the timing of the dedicated laboratory in all cases and does not vary significantly unless the schedule is stretched to the point where laboratory funding overlap is reduced. Early-year funding is also again directly related to the rate of buildup of the dedicated laboratory capability, as may be seen in the baseline option compared with the stretched versions.

5.2 PROGRAMMATIC ANALYSIS

The objectives of the programmatic analysis are to:

a. Support the cost analysis task in the generation of annual funding requirements.

b. Generate preliminary scheduling data for early laboratories.

c. Identify "tall pole" schedule incompatibilities,

d. Identify long-lead and advanced technology equipment items.

These tasks are illustrated in Figure 5-4. Initially, the general functional flow scenario identified the major tasks and their interrelationships throughout the lifetime of the laboratory. From this scenario and major program timing milestones, including the flight schedule (Figure 5-5), a master schedule was generated to provide time phasing of the various task areas and a basis for determining time-critical constraints and "tall pole" schedule incompatibilities. Based on this master plan, individual laboratories occurring in the latter phase of a particular program option are scheduled to its specific milestones.

The primary milestones used in establishing the example laboratory master schedules (see Vol. III) are the flight schedules for each of the options. The development of these schedules, based on the scientific research requirements and the alternate ground rules for laboratory build up or evolution and flight frequency, has been discussed in Section 3.3.

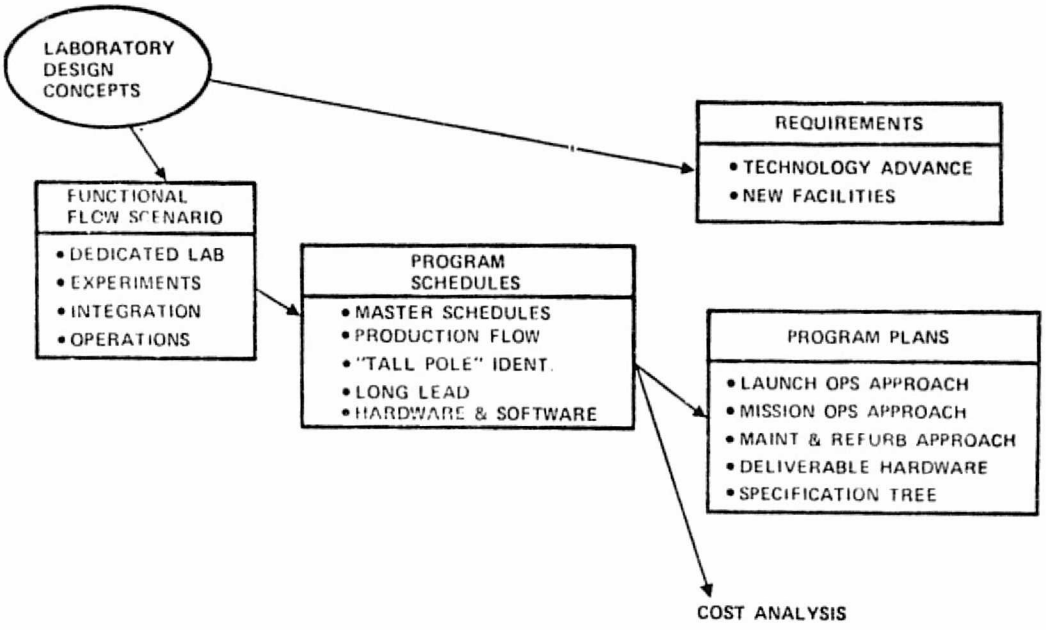


Figure 5-4. Programmatic Analysis Overview

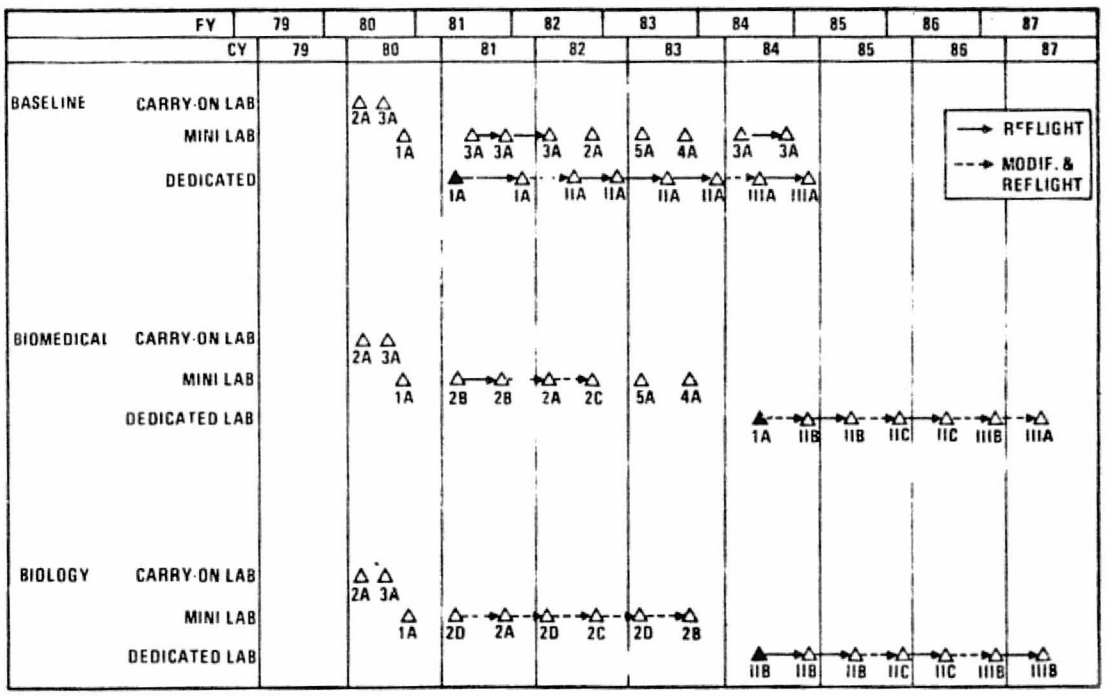


Figure 5-5. Program Option Flight Schedule Comparison

Potential schedule problems for certain equipment item developments occur in the early portion of all options. Specifically, these include organism holding units/cages and freezer/refrigerator equipment items. Avoidance of these schedule "tall poles" may be accomplished by initiation of SRT or early development or, alternatively, by compression of development duration. These problems are significant only in the early laboratories where insufficient time is available from the time of assumed life science payload Phase C/D go-ahead in mid CY 1977.

During the analysis of EI technical requirements and equipment availability, certain items were identified as requiring early attention because of the advanced technology necessary, or because of potential schedule problems due to the development duration involved. These items are listed in Table 5-7. Some of these equipment items also carry with them the requirement for development of advanced operational techniques and procedures, such as surgical procedures in null-gravity. In most cases, the development of those items listed is already underway or is being initiated by NASA.

TABLE 5-7. LIFE SCIENCES EQUIPMENT ITEMS
ADVANCED TECHNOLOGY REQUIREMENTS

EI NO.	EU NO.	NAME	HARDWARE RATING	ESTIMATED DEVEL TIME, YRS	CURRENT STATUS
7	5	AUTOANALYZER (GEMSAEC)	NEW DEVEL.	2	UNDER CONTRACT
7A	5	AUTOMATED POTENTIOMETRIC ELECTROLYTE ANALYZER	SRT	1	UNDER CONTRACT
30A	40	CAGE, RAT/HAMSTER, STANDARD	SRT	2	UNDER STUDY
38	1	CAMERA, VIDEO COLOR	MODIF.	2	UNDER CONTRACT
38F	31	CARDIOPULMONARY ANALYZER	SRT	3	UNDER CONTRACT
43A	23	BIORESEARCH CENTRIFUGE	SRT	4	PRE PHASE A
77B	4	FREEZER, CRYOGENIC	SRT	2½	UNDER STUDY
80	4	FREEZER, GENERAL (-20 C)	SRT	2½	UNDER STUDY
81	4	FREEZER, LOW TEMPERATURE (-70°C)	SRT	2½	UNDER STUDY
83	4	REFRIGERATOR	SRT	2½	UNDER STUDY
91	5	GAS ANALYZER, MASS SPECTROMETER	REDESIGN	3	UNDER CONTRACT
98A	60	HOLDING UNIT, CELLS/TISSUES	SRT	3	UNDER STUDY
98C	70	HOLDING UNIT INVERTEBRATES	SRT	3	UNDER STUDY
99	40	HOLDING UNIT, COMMON	SRT	3	UNDER STUDY
101	50	HOLDING UNIT, PLANTS	SRT	3	UNDER STUDY
101B	41	HOLDING UNIT, MONKEY POD	NEW DEVEL	1½	RTOP
101C	41	HOLDING UNIT, PRIMATE	SRT	3	UNDER STUDY
103	40	HOLDING UNIT, SMALL VERTEBRATES	SRT	3	UNDER STUDY
122	4	MASS MEASUREMENT DEVICE, MICRO	NEW DEVEL.	3	PRE PHASE A
162	6	STERILIZER, AUTOCLAVE	NEW DEVEL.	2	PRE PHASE A
188	4	WORK AND SURGICAL BENCH	SRT	3	RTOP

The table lists several parameters bearing on the importance of the items and their development status. These parameters include the EI category, hardware status rating, and estimated development time in years. The hardware rating indicates whether the item is a new development, requires redesign, or requires some degree of technology development (SRT). The estimated development time reflects total duration necessary, except for items currently under development, in which case it is an estimate of the incremental additive time from the present to completion of the project. The last column provides the current status of the EI.

SECTION 6

SUMMARY AND CONCLUSIONS

This, the concluding study of the four-study series started in 1970, completes the data base needed for the initiation of the Phase B activity. The common operational research equipment (CORE) approach provides a unique flexibility to NASA in making early mission commitments with a minimum programmatic or scientific risk.

Throughout the entire four-study series, science emphasis has been a paramount consideration. Specific equipment items as well as the makeup of the various laboratory concepts defined were exemplary. The overall study was based upon the establishment of life sciences research requirements and the equipment items and laboratory concepts to perform these research requirements.

6.1 SUMMARY OF MAJOR STUDY TASKS

The initial study task (Task 1) resulted in the selection and definition of three mission models. These mission models provided the variability of laboratory development options needed for the subsequent accommodation and planning activity of the study. Figure 6-1 presents the selected mission model options, their corresponding laboratory concepts, and flight schedules.

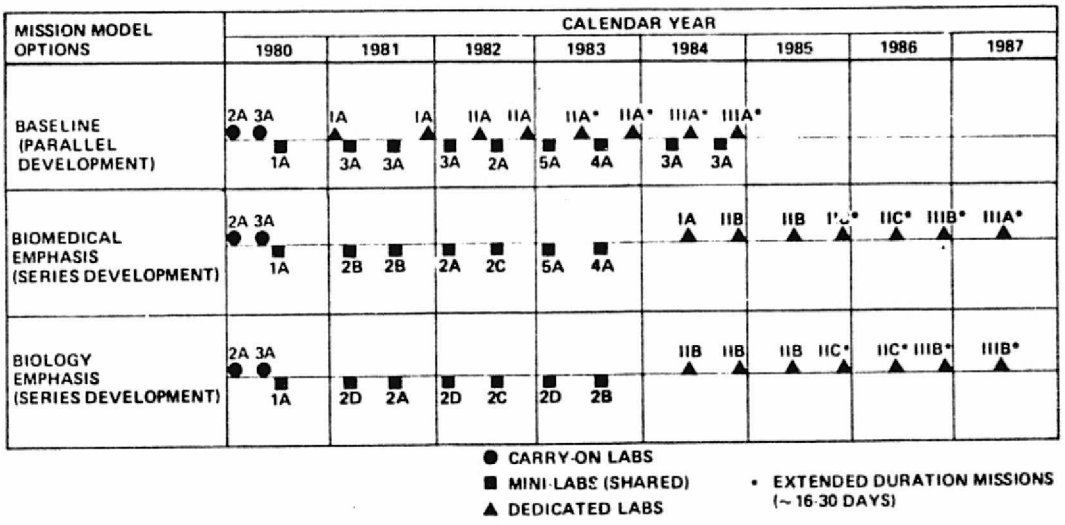


Figure 6-1. Selected Life Sciences Mission Models

The research capability of the 16 laboratory concepts is shown in Figure 6-2. This capability matrix shows the primary research emphasis is on biomedicine using man and man-surrogates (i.e., vertebrates). Pure biological research is performed mostly by dedicated laboratories with the exception of biology mini-lab ML-2D. Depending on the experiment makeup, the research emphasis of a particular mini-lab or dedicated lab can be pointed toward biomedicine or biology. Man-systems

integration and life support/protective systems as research areas are covered by mini-labs 4A and 5A and baseline dedicated laboratories IIA and IIIA.

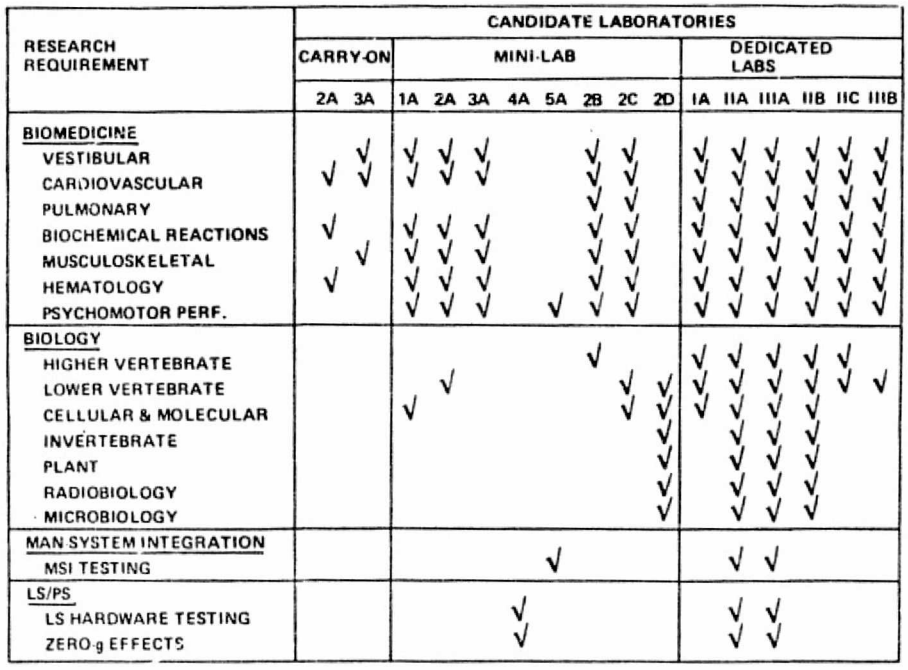


Figure 6-2. Spectrum of Laboratory Payload Capability

The second major task accomplished the engineering analysis and integration of the various laboratory concepts with the Shuttle/Spacelab.

The bioresearch centrifuge was analyzed to determine its impact upon the systems and mission operations. The result of this analysis is summarized in Table 6-1.

Table 6-1. Centrifuge Impact Summary

Area	Impacts	Recommendation
3 Sizes (Diameters)	Each has varying scientific, programmatic & Spacelab accommodation impacts	A requirements and feasibility study be undertaken in the near future to define in depth the scientific development, operational and programmatic aspects of a bioresearch centrifuge.
Structure	Integration with Spacelab may require special hardware - Aftcone, extension module	
Operations	Ground functional flow & turnaround times	

The research equipment selected for the laboratory concepts was used in Spacelab layout accommodations, and subsystem interface impact definitions. The results of these investigations are summarized in Table 6-2.

Table 6-2. Spacelab Accommodation & Interfaces Summary

AREA	IMPACTS	RECOMMENDATION
PHYSICAL ACCOMMODATION	DEDICATED LABS MOD IIA & IIIA ARE LARGER THAN S/L LONG MODULE. MOD IIIA EXCEEDS LANDING WEIGHT LIMIT.	DROP FROM CONSIDERATION. REPLACE WITH ALTERNATIVE DEDICATED LABS MOD IIB, IIC & IIIB.
POWER	30-DAY PAYLOADS REQUIRE ENERGY KITS. TOTAL PAYLOAD WEIGHT IS REDUCED TO MEET SHUTTLE LANDING WEIGHT LIMIT.	CONSIDER REDUCED DEDICATED LABS IIC & IIIB FOR 30-DAY MISSIONS.
	MOST P/L REQUIRE ASCENT/DESCENT POWER. ONLY 1 kW IS AVAILABLE TO SPACELAB PLUS PAYLOAD.	USE BATTERIES DURING ASC/DES. WT PENALTY APPROX. 10 kg/kW-HR.
	PLANT HOLDING UNITS LIGHTING IMPOSES LARGE POWER PENALTY DURING ASC/DES.	TIMELINE LIGHTING REQUIREMENTS TO REDUCE (OR ELIMINATE) DURING ASC/DES.
THERMAL/ECS	POTENTIAL HUMIDITY CONTROL PROBLEM IN S/L HAVING LARGE ANIMAL & CREW POPULATIONS; e.g., MOD IA, IIA, IIIA	DETERMINE OFF-DESIGN CHARACTERISTICS OF SPACELAB ECS WITH THESE LOADS.
ACOUSTICS	ASCENT LEVEL OF SPACE LAB (135 dB) EXCEEDS LS REQUIREMENT (120 dB)	HOLDING FACILITIES DESIGN MAY ATTENUATE NOISE & VIBRATION TO ACCEPTABLE LEVELS. IF NOT, CONSIDER RELAXING REQUIREMENT, CONTROL AT ORGANISM LEVEL OR FACTORING INTO EXPERIMENT PROTOCOLS.
DATA MANAGEMENT	6 MHz BANDWIDTH P/L VIDEO CAMERAS 4.2 MHz TRANSMISSION CAPABILITY	REDUCE REQUIREMENT TO 4.2 MHz. NO LOSS OF VIDEO QUALITY.
	NEAR-REAL-TIME DATA DUMP FROM RECORDERS POSSIBLY CANNOT BE TRANSMITTED AT SAME TIME AS REAL-TIME DATA.	DATA MULTIPLEXER NOW UNDER CONSIDERATION WHICH WILL PERMIT INTERLEAVING OF REAL-TIME & NEAR-REAL-TIME DATA.
	PAYLOADS REQUIRE DATA MONITORING DURING ASC/DES. SPACELAB CDMS NOT OPERABLE.	SUPPLY BATTERY OPERATED PAYLOAD TAPE RECORDER TO MONITOR CRITICAL EXPERIMENT PARAMETERS.

The ground support analysis reviewed the scenario of equipment and organism flow through the four levels of integration. The findings of the ground support analysis are presented in Table 6-3.

Table 6-3. Ground Support Analysis Summary

PROBLEM AREAS	RECOMMENDATIONS
•AVAILABILITY OF SPACELAB FLIGHT HARDWARE TO SUPPORT TOTAL MISSION INTEGRATION ACTIVITY	- ACQUIRE LIFE SCIENCES DISCIPLINE DEDICATED HARDWARE (RACKS, FLOORS, RAU, ETC.).
•ON-PAD SPACELAB ACCESS	- USE ACCESS SIDEWALL HATCH (PRESENTLY UNDER STUDY). - ON MULTI-DISCIPLINE MISSIONS, SELECT SHARING PAYLOADS THAT DO NOT REQUIRE SCIENTIFIC AIRLOCK. - PROVIDE POWER, ECS, DATA MNTG WHENEVER SPECIMENS ABOARD.
•POSTLANDING ACCESS	- TRANSFER SPECIMENS TO ORBITER MID-DECK BEFORE DESCENT & OFFLOAD AT CREW EGRESS - ON SELECTED MISSION BASIS. - PROVIDE ORBITER TUNNEL SPECIMEN TRANSFER FACILITIES
•SUPPORT FACILITIES	- EXPANSION OF MEDICAL/BIOLOGY FACILITIES LAB
•PAYLOAD SPECIALIST TRAINING ALLOCATIONS	- ALLOWANCE REQUIREMENTS MUST BE DEFINED & IMPLEMENTED

The third and final study task involved the programmatics and costs associated with the three mission models. It is concluded from the cost and programmatic analysis that the total program cost and funding peaks do not vary to any great degree for programs of similar capability.

The funding curves for the biomedicine and biology options are generally similar and show only minor differences. Peak funding rate is related to the timing of the dedicated laboratory in all cases and would not vary significantly unless the schedule is stretched to the point where laboratory funding overlap is reduced. Early-year funding is also directly related to the rate of buildup of the dedicated laboratory capability.

The programmatics analysis revealed potential timing and schedule problems in certain areas including: organism holding units/cages, freezers/refrigerators, vertebrate ventilation unit, and micro-mass measurement device. These potential problems may be solved either by early starts or compressed development durations.

6.2 STUDY CONCLUSIONS AND RECOMMENDATIONS

Conclusions -

- Science capability of laboratories reflects current scientific community requirements.
- Laboratory concepts and research equipment presently defined are exemplary and will be matured as subsequent program phases unfold.
- Commonality of equipment supports a wide range of research, permitting NASA to proceed on the program with a minimum risk for changes in scientific priority.
- Phase A study results provide a firm foundation for initiation of Phase B program laboratory concepts, CORE inventory, costs and schedules, and interface definitions.

Recommendations -

- Establish early flight experiment protocols, experiment organisms and PI involvement plans.
- Initiate bioresearch centrifuge requirements and feasibility study.
- Define consequence of potential environmental factor impacts: acoustics, vibration, EMI, cleanliness and contamination, shock accelerations and radiation.
- Resolve Phase A accommodation impacts and proposed solutions.

SECTION 7

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