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DEFINITION OF LIFE SCIENCES LABORATORIES FOR SHUTTLE/SPACELAB

VOLUME I ✦ EXECUTIVE SUMMARY

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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 era. 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, 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 flight.

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

The second study was performed under Contract NAS8-29150 during 1972-1973. This study employed several of the smaller laboratories from the previous study to determine

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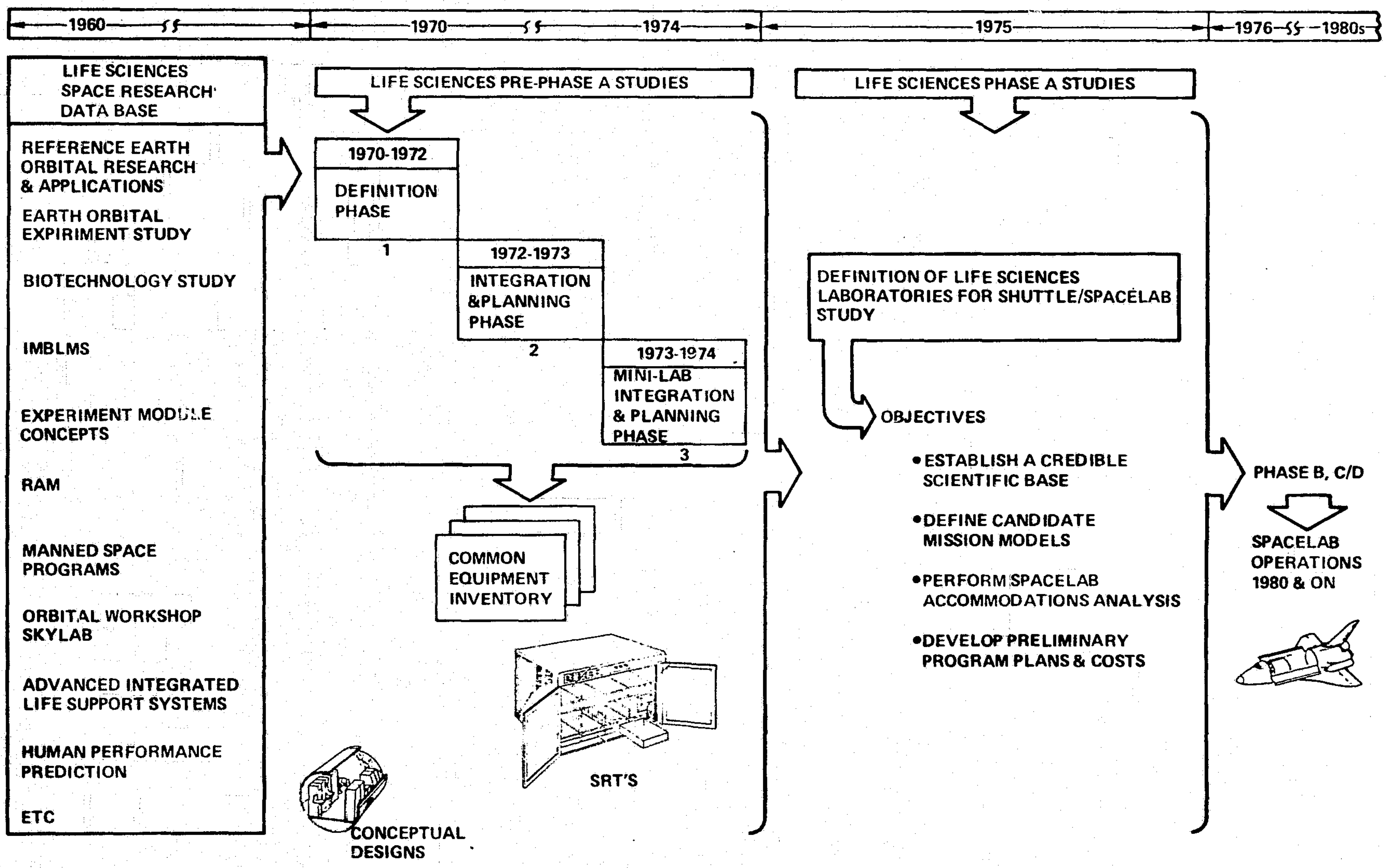


Figure 1-1. Life Science Payload Definition & Integration Studies Chronology

compatibility with the Shuttle 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 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 laboratory or in the crew compartment of the Shuttle Orbiter.

The third study 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 of the previous study.

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.

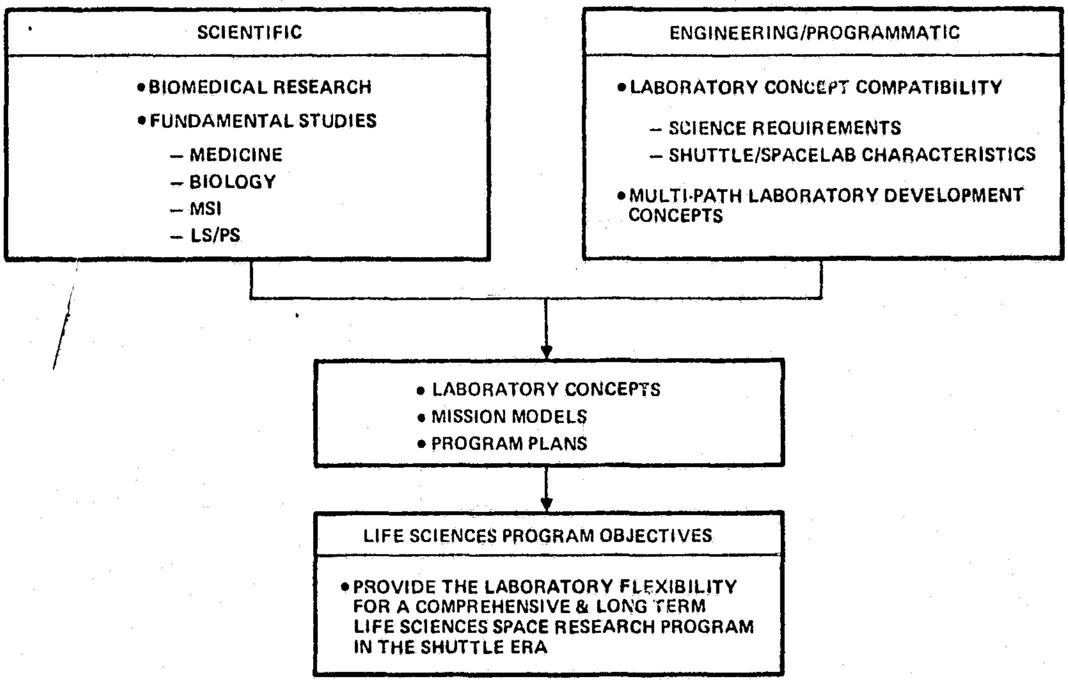


Figure 1-2. Study Objectives

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.

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.

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 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.

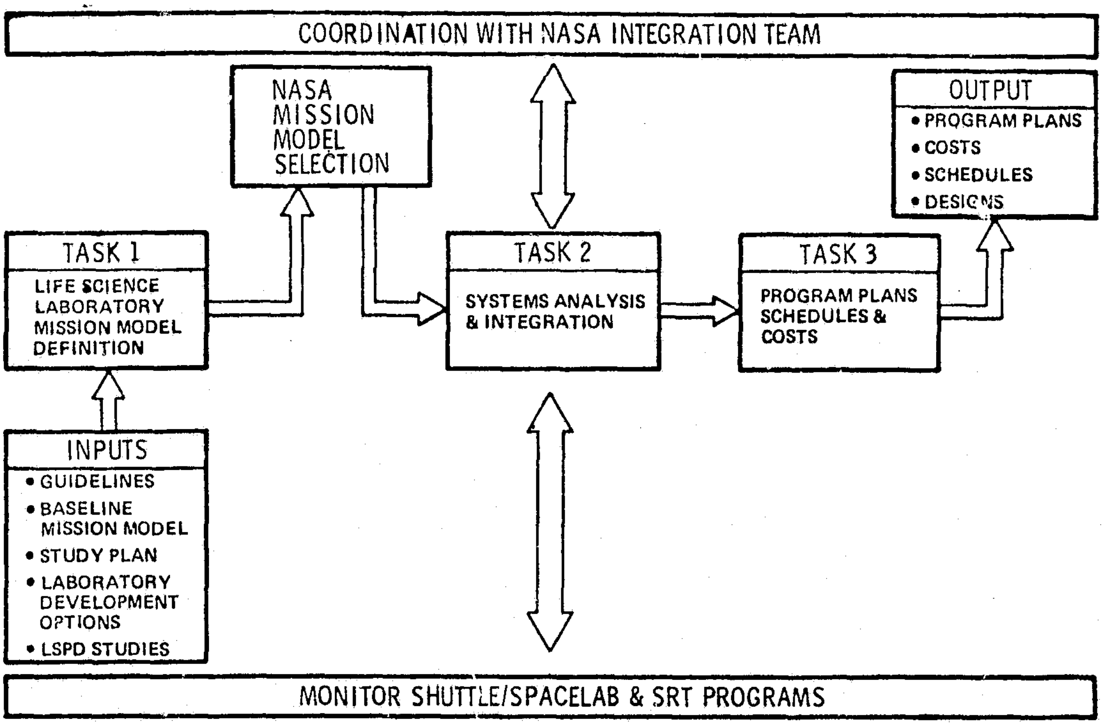


Figure 1-3. Program Overview

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 was developed by integrating data from several sources, including the OMSF/MMS payload descriptors (August 1974), and the Yardley Flight model (November 1974). 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.

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

SECTION 2

STUDY FOUNDATIONS

The guiding philosophy of the life sciences program for the Shuttle era has been the development of a general laboratory facility. The laboratory concepts resulting from this facility approach will be capable of supporting a broad spectrum of research. They will contain essentially all major equipment items required to carry out routine research functions involved in specific research protocols. Accordingly, they also provide a means to analyze and flag out science, cost, schedule and technical drivers to guide early development and planning. This approach enables the NASA to evolve life sciences laboratory concepts that are compatible with program and space environmental constraints. These laboratory concepts will be used by potential principal investigators (PIs) in defining experiments that are compatible with the operational environments. Feedback from PIs during the developmental and operational phases will define specific update requirements for this broad laboratory capability. Additional hardware development can be tailored to specific requirements and thus provide the program flexibility required to respond to changing requirements.

Two aspects of this study were crucial to this general facility approach. First, a comprehensive base of research requirements was established. Past studies, results of Skylab and recommendations of the life sciences community were reviewed and a set of requirements for each life sciences research discipline was synthesized. Secondly, a common equipment inventory which satisfies the equipment requirements of the research was developed. This body of equipment has been defined, reviewed, altered and updated by industry, outside consultants, and the NASA Life Sciences Working Group over the past few years and currently represents a consensus of many researchers as to what constitutes the basic hardware complement of a general life sciences laboratory. The development of life sciences research requirements and the common equipment inventory are discussed in the following paragraphs.

2.1 LIFE SCIENCES RESEARCH REQUIREMENTS FOR SHUTTLE/SPACELAB

The major objective of this task was to generate a time-sequenced life sciences research plan for Shuttle/Spacelab missions. The research plan and related functions comprise a major driver for this entire study since subsequent laboratory hardware and development schedules are based upon these results. Accordingly, it is imperative that the plan accurately reflects the combined best interests of the manned space program and the life sciences research community. Specific life sciences research protocols for Spacelab missions are not available at this time. The approach followed in this task has therefore emphasized a thorough analysis of existing, more generally defined research requirements for future space missions (Figure 2-1). This information was used to develop a plan broad in scope to perform essentially all routine, commonly employed

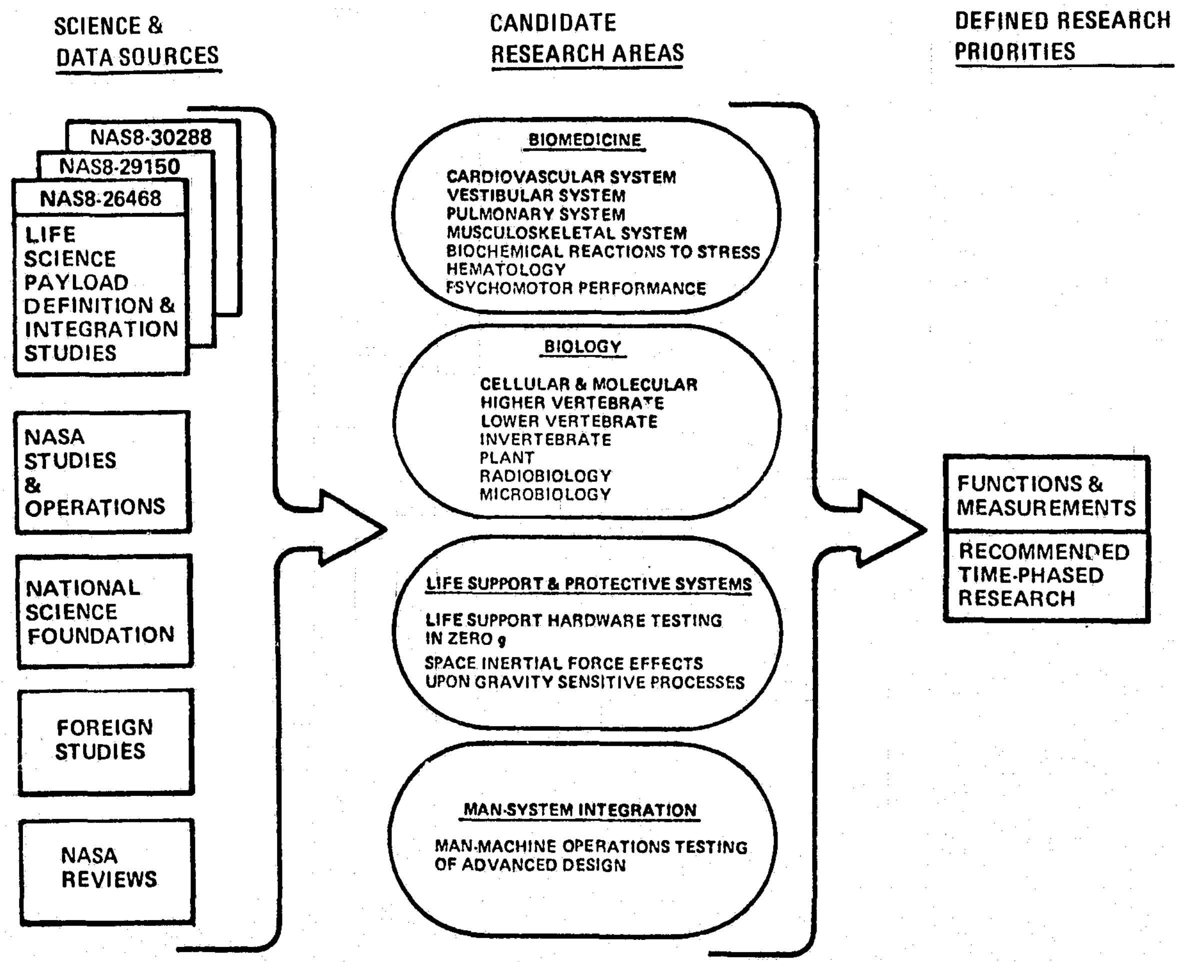


Figure 2-1. Flow of Science Input to Defined Research

research functions required by future PIs. This approach enables realistic science, schedule, cost and technical requirements to be analyzed and defined now while deferring hardware development commitments until specific research requirements are defined.

Figure 2-1 portrays the collection of these research requirements from a broad scientific base; categorizes them within the biomedical, biology, life support/protective systems, or manned systems integration areas; and finally defines both the resulting research functions/measurements and the priority of the defined research areas.

2.1.1 <u>ORGANIZATION OF LIFE SCIENCES RESEARCH.</u> This activity included a thorough review of pertinent data defining life sciences space research requirements. The data elements extracted from the various input sources were synthesized into a set of requirements for each life sciences research discipline. Table 2-1 lists the major sources of new input data used during the current study to augment the prior study sources.

Table 2-1. 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.

The principal information elements sought during the literature reviews were:

- Recommended Research Areas
- Mission Duration Required, i.e., 7 or 30 days
- Scheduling Considerations – early vs late in program
- Experiment Organisms Preferred
- Data Acquisition Needs
- Bioresearch Centrifuge Requirements
- Application of Results to Life Processes on Earth

The above information was segregated into one of the four life sciences discipline categories. Each of the research areas was further subdivided into research topics. 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 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 new source documents contained numerous recommendations for both non-invasive human studies and invasive studies on animals to generate basic understanding of mechanisms of cardiovascular adaptation to zero g and techniques to prevent unwanted responses.

Recommended cardiovascular system research was tabulated as three research topics under this system and are shown in Figure 2-2. The figure also indicates the other research requirement areas defined during the literature review for both the biomedicine and biology disciplines. As implied, each research area (i.e., vestibular, pulmonary, musculoskeletal, etc.) was further subdivided into detail research topics.

2.1.2 RESEARCH FUNCTIONS/MEASUREMENTS REQUIREMENTS. The definition and organization of research requirements described in Section 2.1.1 produced a detailed breakdown of research topics for each life sciences research area. Each of these research requirements was then analyzed to determine functions and measurements required to accomplish that element of the research plan. As an example, those determined to be necessary for non-invasive studies of altered vascular flow/volume/pressure relationships in human subjects are shown in Table 2-2. 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.

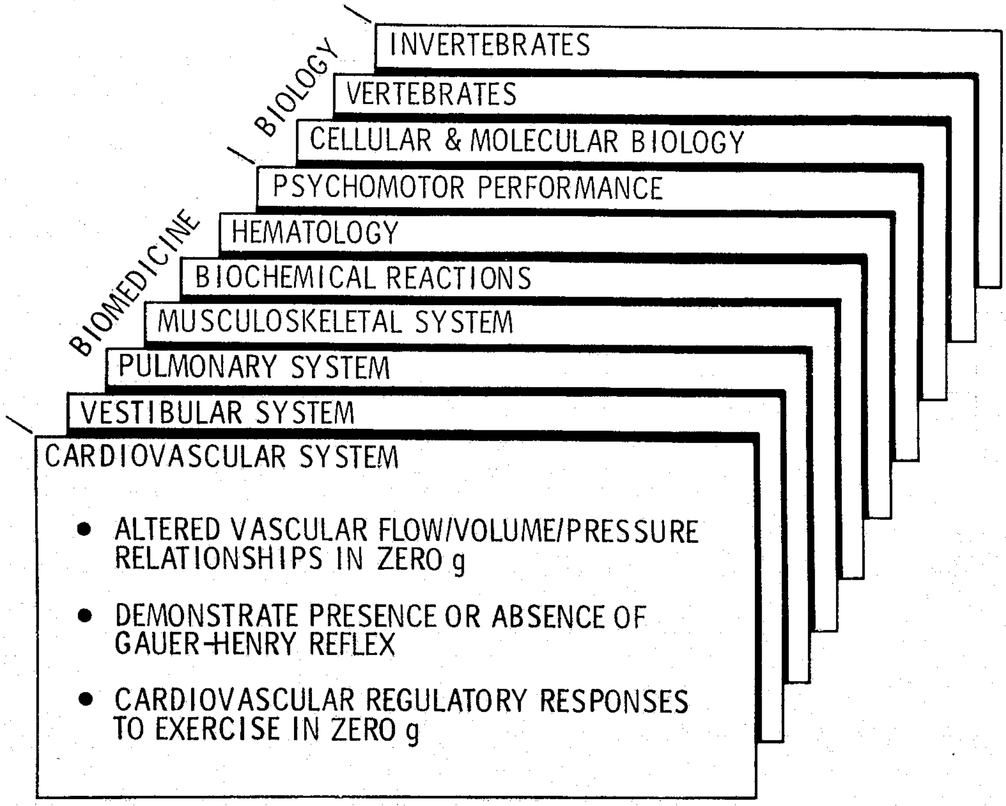


Figure 2-2. Research Areas/Topics

Table 2-2. 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 RECORD CHAMBER PRESSURES DETERMINE CHAMBER VOLUMES DERIVE VENTRICULAR COMPLIANCE
PULMONARY CAPILLARY BLOOD VOLUME	IMPLANT DEPTH CELLS MEASURE ORGAN BLOOD FLOW
PULMONARY CAPILLARY BLOOD FLOW	RECORD ECG/VCG/PULSE DERIVE STROKE VOLUME DERIVE CARDIAC OUTPUT
VENOUS CAPACITANCE	COLLECT BLOOD SAMPLES SEPARATE PLASMA COLLECT 24-HOUR URINES MEASURE URINE VOLUMES FREEZE & STORE BLOOD & URINE SAMPLES
ARTERIAL FLOW IN LIMBS	DERIVE BODY FLUID COMPARTMENT VOLUMES
RENAL BLOOD FLOW	MAINTAIN ANIMALS RECORD FOOD & FLUID INTAKE HISTOLOGICAL & BIOPSY PREP. ENVIRONMENTAL MONITORING PERFORM BIOCHEMICAL ANALYSIS
COLLECT BLOOD SAMPLES	
SEPARATE PLASMA	
COLLECT 24-HOUR URINES	
MEASURE URINE VOLUME	
FREEZE & STORE BLOOD & URINE	
DERIVE BODY FLUID COMPARTMENT VOLUMES	
DETERMINE HEART CHAMBER VOLUMES	
RECORD ECG/VCG/PULSE	
DERIVE STROKE VOLUME	
DERIVE CARDIAC OUTPUT	
ENVIRONMENTAL MONITORING	
PERFORM BIOCHEMICAL ANALYSES	

Also shown is 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 instruments (e.g., doppler flow meter and echocardiogram) are recommended.

2.1.3 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. These findminimized 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. These involved 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 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 that payload specialists with less tolerance for dynamic loading than the crews of previous space missions will be on-board.

Scheduling priorities for the required research were accordingly guided by the potential of a recommended research activity to resolve a significant 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.

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 non-ambulatory 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 reapplication of constant g during reentry 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 in order of priority for each research topic. The results are presented in Table 2-3. The matrix indicates the recommended research organism and a nominal mission duration for each research areas. These data were subsequently utilized in defining payloads and the candidate mission models.

2.2 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, outside consultants and the NASA Life Sciences Working Group over the past few years. The current inventory contains those equipment items needed to support the functions and measurements driven out by the research requirements discussed in Section 2.1. 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, and chemical analysis, among others.

2.2.1 <u>COMMON EQUIPMENT INVENTORY DEVELOPMENT</u>. The analysis and update of the life sciences equipment inventory began with consideration of the two inventories developed during the previous studies. The original CORE inventory has been extensively reviewed by the Life Sciences Working Group in the past and represented a consensus equipment complement for a dedicated laboratory. The carry-on laboratory

Table 2-3. Recommended Time-Phased Life Sciences Research

RESEARCH (IN TIME-PHASED ORDER)	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

equipment 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. Additions to the inventory were made by including Skylab items, equipment currently undergoing development, and new items defined where deficiencies occurred.

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 are derived from a variety of sources. Figure 2-3 shows the principal ones. The EIs listed are representative and are not inclusive. A large number of items (approximately 40 percent) are presently available commercially and require little or no modification. Typical modification might include vibration tolerance improvement and zero-g operability assurance. Items in this category are referred 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.

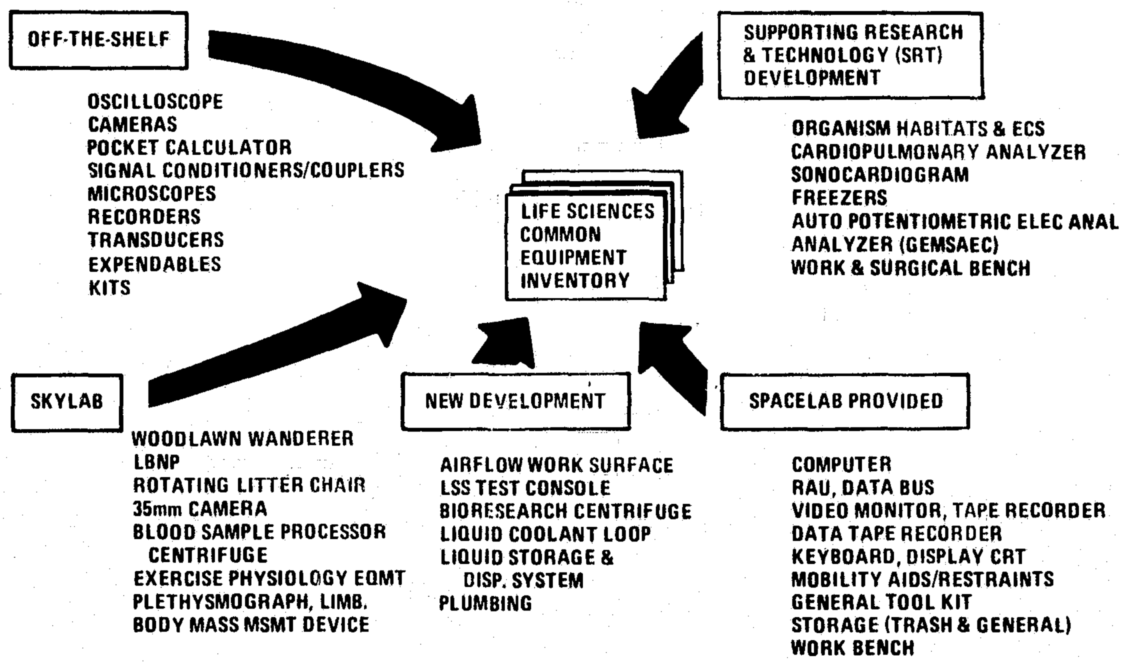
The Spacelab-provided EIs have been retained in the inventory but are presently baselined into the Spacelab program and do not require life sciences development. Their inclusion in the inventory indicates capability available to life scientists.

Certain items within the inventory are presently being funded by NASA as 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, and vacuum manifolds 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, account for close to 90 percent of the inventory development costs.

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

2.2.2 COMMON EQUIPMENT INVENTORY DESCRIPTION. The entire common equipment inventory consists of 176 items. These are categorized into regular, intermittent, Spacelab, and PI equipment items. Regular and intermittent items are those deemed essential for laboratory development. Spacelab items are those supplied by the Spacelab. PI items are exemplary of the research-specific equipment provided by the experimenter.



Preliminary quantity breakdown:

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

Figure 2-3. Common Equipment Inventory Makeup

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 2-4 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 NASA/MSFC report, "Life Sciences Working Group Payload Evolution Working Papers for Shuttle Payload Planning" (July 1975).

The specification sheets and disposition record are published as a separate volume of this report.

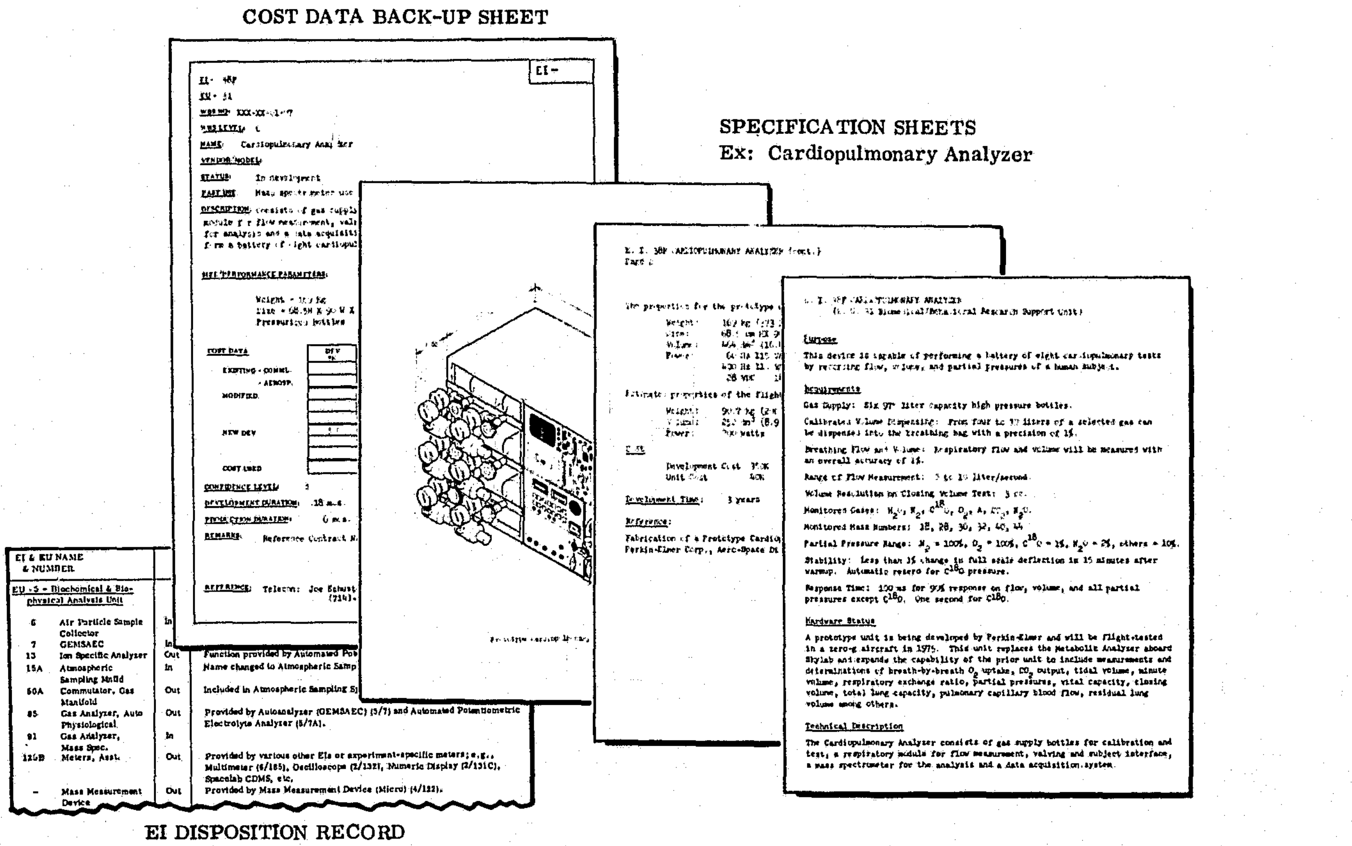


Figure 2-4. Example Equipment Item Definition Package

2.2.3 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 2-5. This example shows a portion of the CORE inventory. The equipment items (EIs) 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. 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.

The above case illustrates the characteristic flexibility of the CORE approach. It provides NASA the assurance that early mission commitments can be made with a minimum of programmatic or scientific risk.

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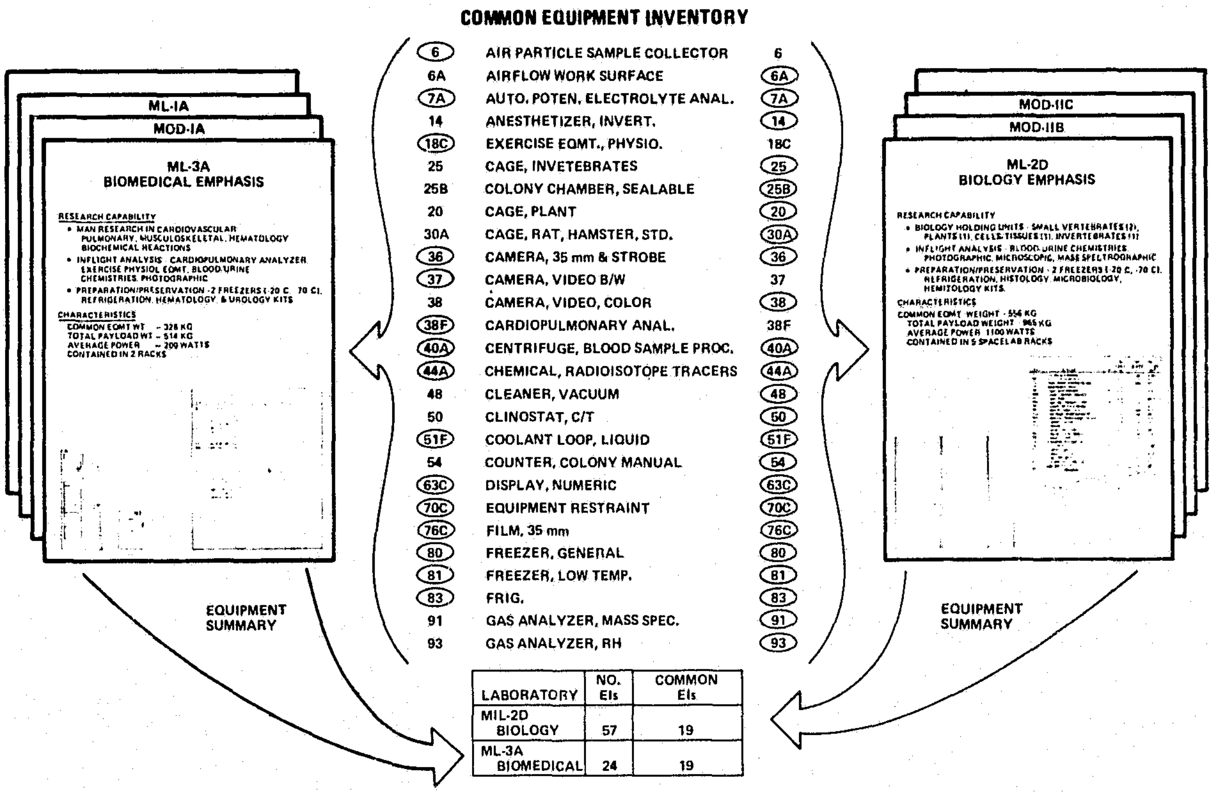


LABORATORY	NO. EIs	COMMON EIs
MIL-2D BIOLOGY	57	19
ML-3A BIOMEDICAL	24	19

Figure 2-5. Example of Equipment Commonality

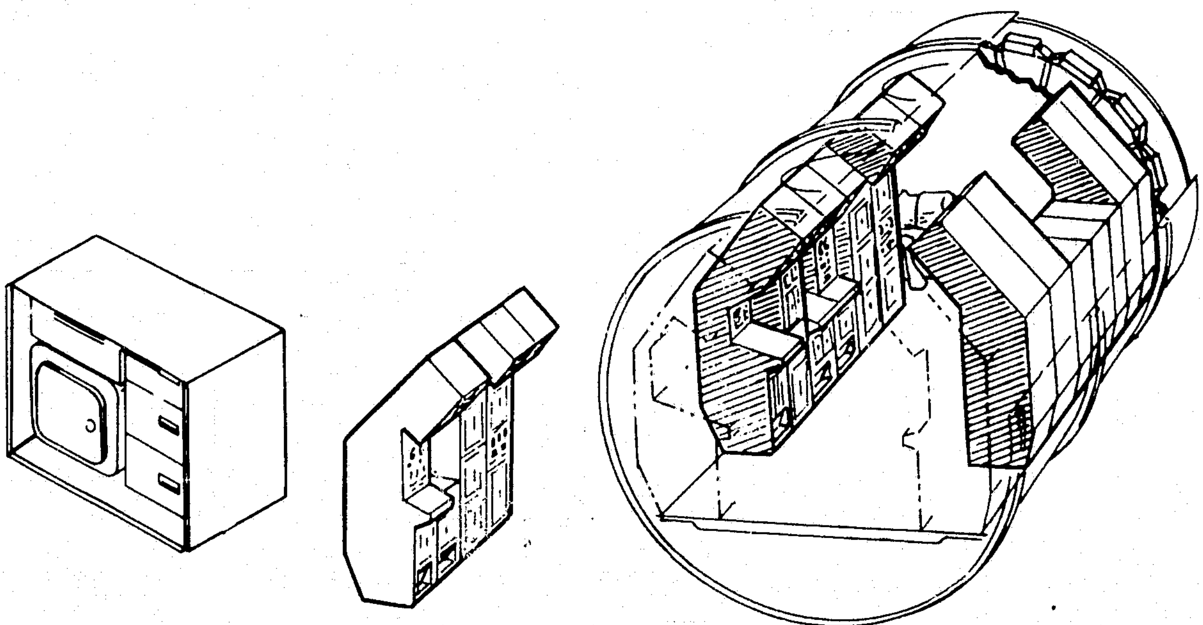
SECTION 3

STUDY RESULTS

This section briefly describes the payloads and mission models used to satisfy the scientific research priorities for life sciences. The payloads are described with respect to their accommodations or impacts to the Shuttle/Spacelab. The cost and programmatic aspects of the life sciences program are also reviewed.

3.1 PAYLOADS AND MISSION MODELS

3.1.1 PAYLOAD CLASSES. The guidelines defined three classes of laboratories — carry-on laboratories, mini-laboratories, and dedicated laboratories. Figure 3-1 shows pictorially these three laboratory concepts.



Carry-on Lab   Mini-Lab   Dedicated Lab

Figure 3-1. Life Sciences Laboratory Concepts

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 was 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. While basically intended to be flow early in the Shuttle program, particularly during the proof-test missions, they can be taken aboard any flight of opportunity.

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 up to several hundred 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, crew, and environmental. Due to the multidiscipline nature of the flight not all of the payload specialists will be life scientists. Consequently, mini-labs emphasize sampling for ground analysis rather than extensive on-board analysis.

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. 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 subsystems 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.

3.1.2 LABORATORY DEFINITIONS. To provide the flexibility desired for the life sciences research program, 20 different laboratories were originally selected for consideration. These consisted of four carry-on, eight mini-labs, and eight 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 3-1.

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 provides for 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. This laboratory

Table 3-1. 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

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 in-depth analysis within each. 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 are 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, by the selection of experiments, can also cover biomedical areas. MOD IIB has the complete biology capability from primates to plants, while MOD IIC supports large and small vertebrates. MOD IIIB contains small vertebrates only but adds the Bioresearch Centrifuge. It and MOD IIC are 30-day missions.

The spectrum of research capability of the 16 laboratories includes all life sciences research requirement areas. The laboratories provide the principal research emphasis 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. 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.

3.1.3 MISSION MODELS. Development of the mission models considered such factors as scientific responsiveness (priority of research), equipment inventory buildup, and funding spreads. Two modes of laboratory development considered were parallel and series. Parallel development covers 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. A baseline flight schedule (NASA mission model) was used to create the various mission models. This schedule is shown in Figure 3-2.

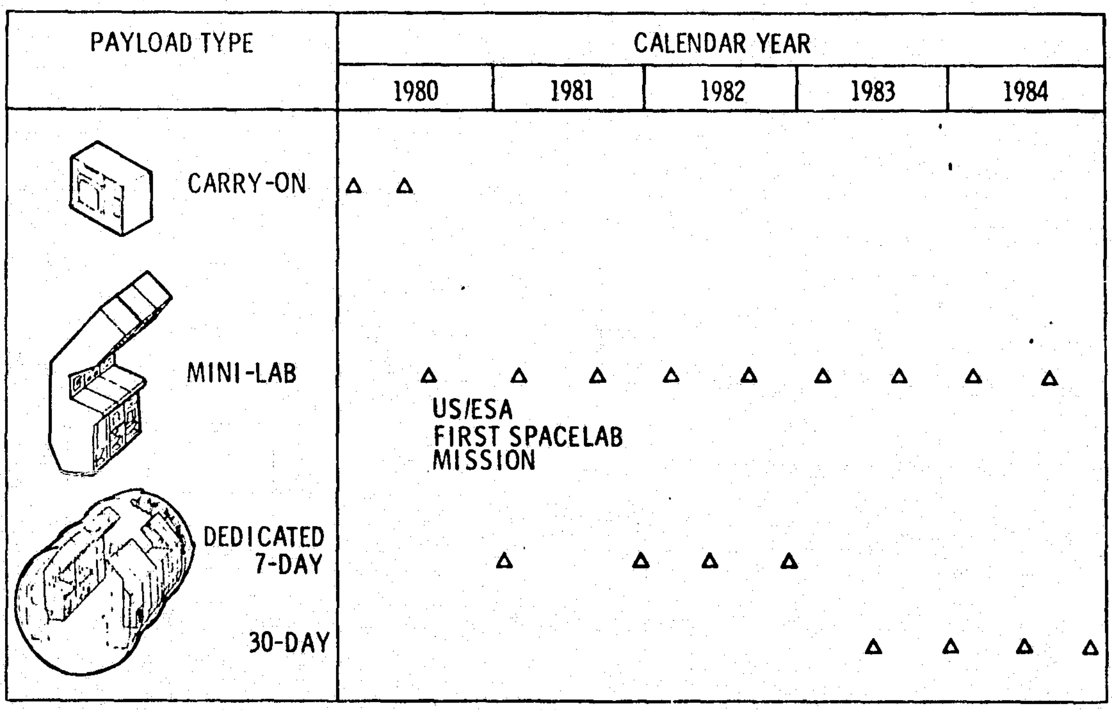


Figure 3-2. Baseline Mission Model Flight Schedule

This baseline flight schedule shows two carry-on laboratories, tentatively on Shuttle flights 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 1961. The baseline generally shows two fights 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 the mission models.

The various candidate laboratory concepts defined in Table 3-1 were used to develop four mission models. During 1980, all four models have the same flight schedule composed of three laboratories; namely, two carry-on laboratories, COL-2A and COL-3A, and mini-lab ML 1A for the first Spacelab mission.

The baseline mission model uses the parallel development of the mini-labs and dedicated laboratories and covers a 5-year period. The breakdown of the laboratory types includes the three mentioned above during 1980 plus seven more mini-labs and eight dedicated laboratories. Option 1 is similar to the baseline; however, a reduced dedicated laboratory capability is included that coincides with the baseline's first dedicated laboratory flight date.

Option 2 is a series development, starting with the mini-labs and finally working into the dedicated laboratories in a 6-1/2-year period. This approach delays the peak funding required about two years later than the baseline. Option 3 is a series development similar to Option 2. The basic difference is the stretchout in time to 7-1/2 years and the absence of any overlap in mini-lab and dedicated laboratory operations.

The four candidate mission models 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. Option 3 was subsequently renamed the biomedical emphasis mission model. After a review of NASA Headquarters in July, a third mission model, emphasizing biology research, was added. These three selected mission models are shown in Figure 3-3.

The major difference between the biomedical emphasis and biology emphasis models is the use of 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, depending on the experiment complement selected for a particular flight. The flexibility of the payload's common equipment allows this duality of research emphasis.

3.1.4 EQUIPMENT ITEM BUILDUP. Figure 3-4 shows the cumulative equipment item total needed for each flight date of the three mission models. 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 considerable reuse in subsequent flights. The

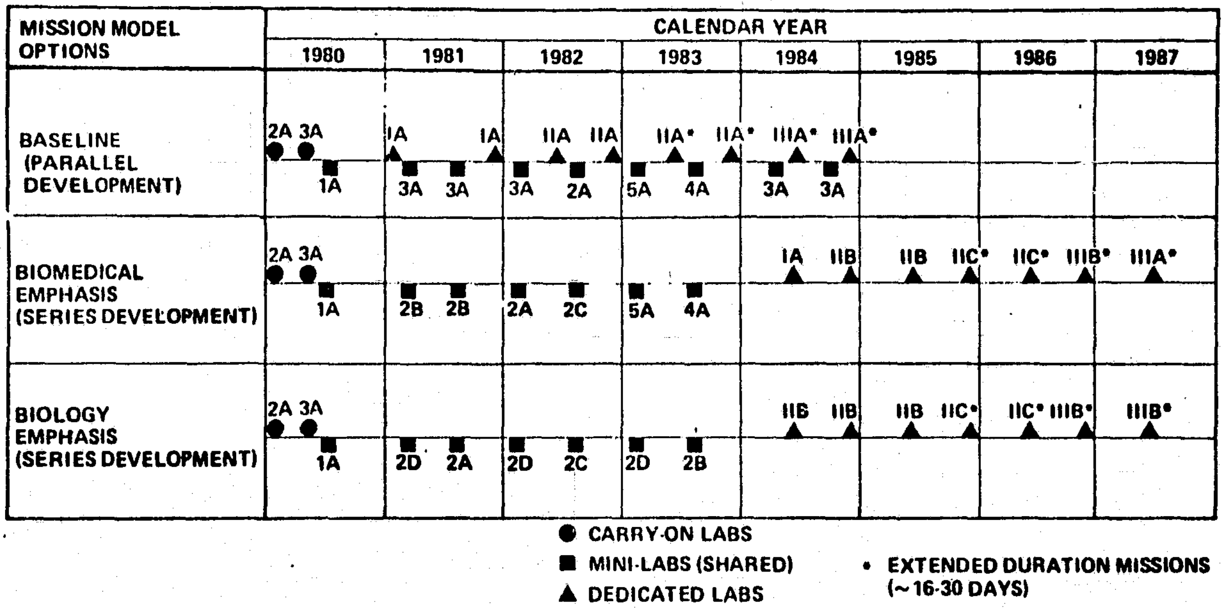


Figure 3-3. Selected Life Sciences Mission Models

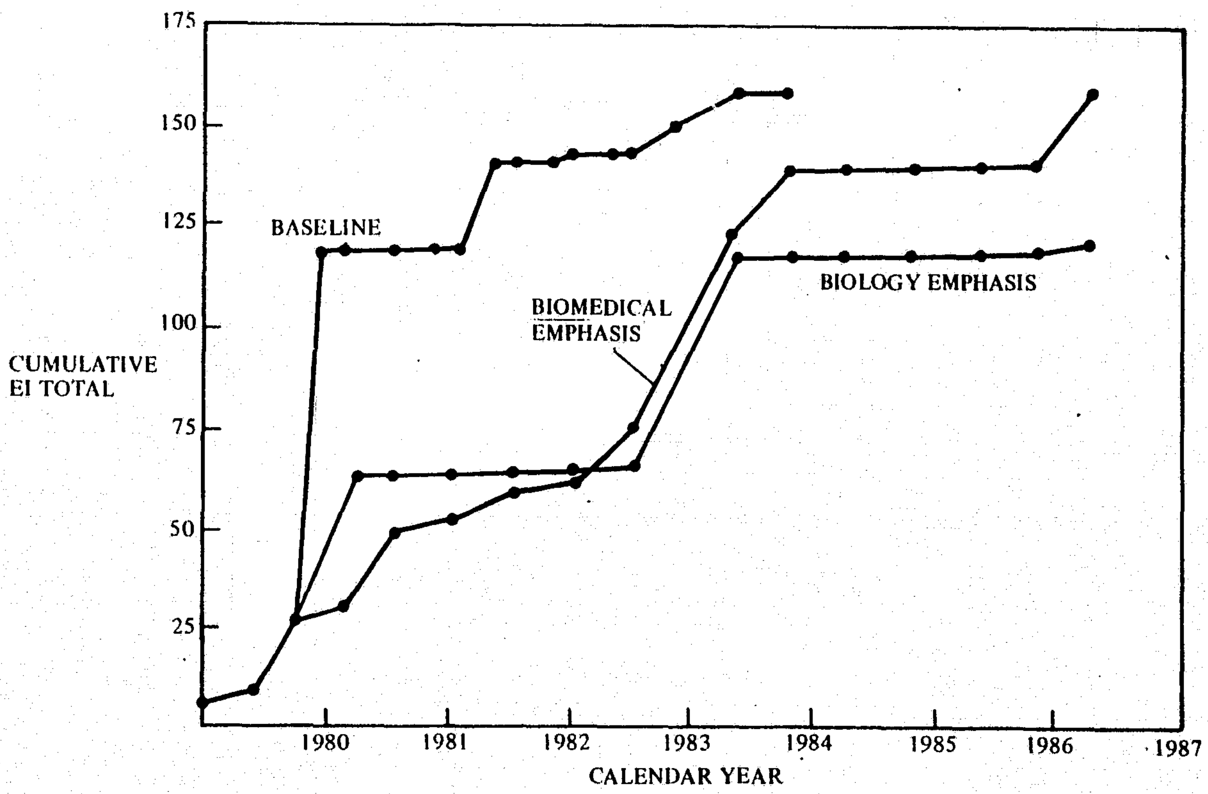


Figure 3-4. EI Development vs Need Date

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.

3.2 SYSTEM ANALYSIS AND INTEGRATION

The system analysis and integration tasks covered the following specific areas:

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

b. Accommodate the defined payloads with Spacelab.

c. Define the interface requirements (power, thermal, data, etc.) of the payloads.

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

3.2.1 BIORESEARCH CENTRIFUGE IMPACTS. The inclusion or exclusion of a Bioresearch Centrifuge in the life sciences Spacelab program is a significant decision. To assist in making this decision, preliminary scientific and programmatic impact studies were performed.

The National Academy of Sciences (NAS) has established as a guideline the requirement for a Bioresearch Centrifuge, principally as a 1-g control device to be used on-orbit. The specified research organisms range from small vertebrates down to cellular and molecular biology specimens. NAS specified a minimum radius of 1.37m (4.5 ft) in order to diminish the effects of g-gradients and angular accelerations.

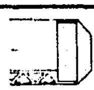
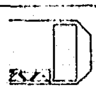
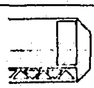
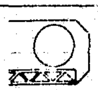
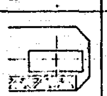
The guidelines presented in Table 3-2 and used in defining the Bioresearch Centrifuge concepts were taken from the NAS recommendations and a NASA/ARC report "Requirements and Recommendations for Spacelab Centrifuge." Conflicting information was reconciled where necessary to produce the guidelines and assumptions presented.

As the initial step in determining the Bioresearch Centrifuge impacts upon the Spacelab, a set of six centrifuge installation configurations were defined and analyzed. These concepts, A through F, are summarized and shown in Table 3-3. The configurations were chosen to give a full range of possible installation options with the Spacelab. The centrifuge concepts, including an 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 requirements.

Table 3-2. Bioresearch Centrifuge Design Guidelines and Assumptions

- Minimum radius of 1.37m (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.
- Analyze both closed-loop & open-loop ECS.
- Assume one per day stoppages for food/waste management.
- g-levels achieved by altering angular rates. Habitats fixed.

Table 3-3. Bioresearch Centrifuge Accommodation Configuration Evaluation

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

The impact areas covered scientific, structural, and operational considerations. The basic scientific consideration was whether the concept met the minimum 4.5-ft radius requirement. In addition, the potential for growth of the holding stations to accommodate primates was evaluated.

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

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installation of the centrifuge. 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. 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.

The second step in the study was the selection of three concepts (A, B and D) which spanned the potential science, operational, and structural impact areas. These included the two 3.91m diameter configurations and the one 3.00m diameter configuration. Each of these three concepts was designed to a level of detail needed to derive cost estimates. Table 3-4 summarizes some of the design characteristics of concept A.

Table 3-4. Concept A Design Characteristics

Weight of rotating elements	146 kg
Total weight (open loop ECS)	250 kg
Δ closed loop ECS weight	104 kg
Structure — graphite epoxy radial and circumferential beams, disk, rim, plenum, bulkhead and support spider.	
Total drive power (drive and lighting)	1/4 hp 354 watts
Angular velocity for 1g for 3g	2.27 rad/s (21.7 rpm) 3.93 rad/s (37.6 rpm)
Moment of Inertia	470 kg - m^2
Angular Momentum (3g)	1,850 N-m-sec

The principal conclusion is that any of the three selected centrifuge concepts would meet the basic science requirements for a Bioresearch Centrifuge. However, the impact on Spacelab integration and operations, along with costs, varies to such a degree that a specific concept cannot be recommended until all factors are considered. 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.

3.2.2 ACCOMMODATIONS AND INTERFACE REQUIREMENTS. The objective of the accommodation and interface task was to determine the requirements imposed upon the Shuttle/Spacelab by the payloads. The 16 payloads along with their equipment listings were the primary inputs. Layouts of all laboratories were made by using standard Spacelab racks. Interface support requirements were determined for each payload. These included weight, power, volume, ECS/thermal, command and data management. The requirements were then compared with Spacelab capabilities, primarily as determined from the Spacelab Payload Accommodations Handbook, dated May 1975. Impacts with the Spacelab design were identified and recommendations proposed.

3.2.2.1 Physical Accommodations. A typical layout for the dedicated laboratories is shown in Figure 3-5. This one, MOD IA, is 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 layouts show the laboratory filling the entire 16 racks of the Spacelab long module. Additional equipment is placed in the center aisleway, overhead stowage areas, and 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 3,314 kg.

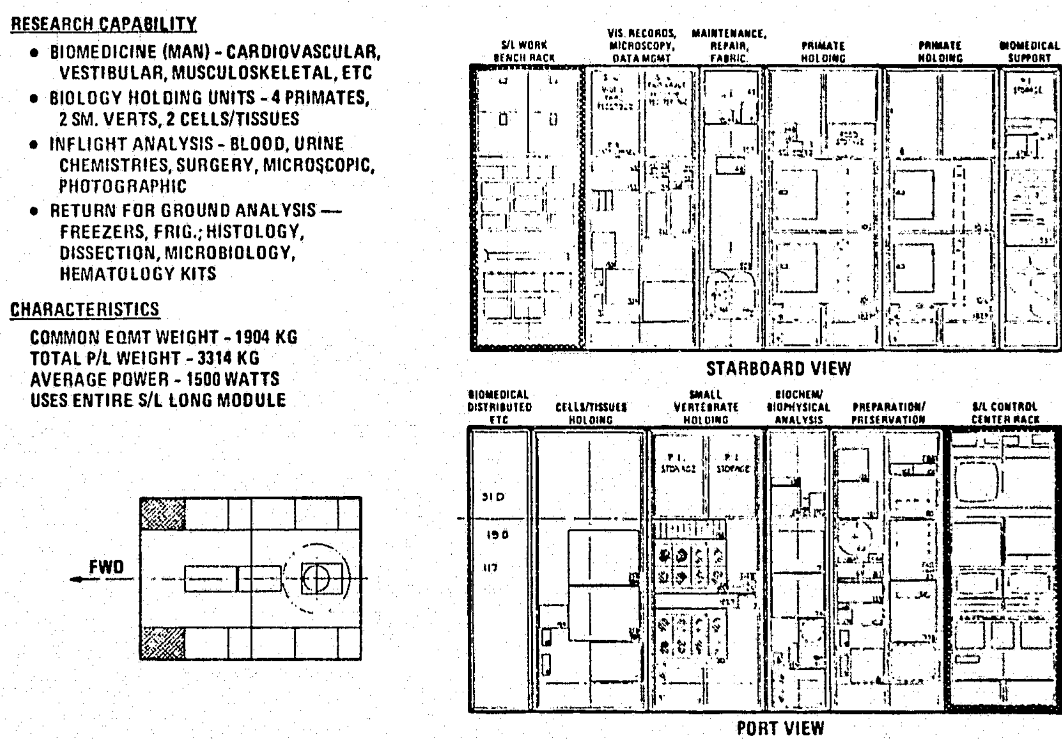

Figure 3-5. Dedicated Laboratory Layout
MOD IA — Biomedical Emphasis Lab

The weight and volume accommodation of the 16 laboratory concepts is summarized in Table 3-5. The layouts determined the number of Spacelab racks required. The list of common equipment for each laboratory was used to determine the total weight of the payload. Allowances for mission dependent, interface and PI specific equipment were added to this quantity.

Table 3-5. 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-2A through MIL-2D)
COL-3A	ORBITER STORAGE	16.8	2	18.8		
MIL-1A	1 1/2	347	150	497		
MIL-2A	3	460	275	735		
MIL-3A	2	328	186	514		
MIL-4A	2	185	171	356		
MIL-5A	1/2	25.5	41	66.5		
MIL-2B	3	364	247	611		
MIL-2C	3	500	254	754		
MIL-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

SPACELAB ACCOMMODATION:

14,500 KG (32,000 LB) LANDING WEIGHT LIMIT
16 RACKS (OR EQUIVALENT) IN LONG MODULE

Mission-dependent equipment consists of such items as racks, RAUs, power switch panels, converters, experiment computer, and handrails. Allowances for a fully dedicated laboratory in a long module were 991 kg. Allowances for mini-labs and dedicated labs of less than full size were factored from this value 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 determined by factoring, according to rack usage, an estimate of 230 kg needed for dedicated lab MOD IA. The PI equipment allowance was computed as 10% of the common inventory total. Although an estimate of 20-30% may be more accurate for dedicated laboratories, 10% appears to be a reasonable estimate at this point in the payload development.

The total Shuttle landing weight was calculated by including all elements carried by the Shuttle, i.e., Spacelab, mission-independent equipment, transfer tunnel, experiment payload and, for extended duration missions, the required energy kits and expendables. Dedicated lab MOD IIIA exceeds the Shuttle landing weight limit. In addition, it and MOD IIA volumetrically exceed the long module rack accommodations.

3.2.2.2 Electrical Power Interface. The electrical power requirements were analyzed to determine the compatibility of the life sciences payload with the Spacelab power system resources. 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 3-6.

Table 3-6. 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

The power requirements summarized in Table 3-7 were estimated for each of the 16 proposed payloads by analyzing each power consuming equipment item in the payload. Typical operational protocols were used to determine the average power, peak power, ascent/descent power, and total energy consumption.

The power accommodation summary presented in Table 3-8 shows minor impacts in three 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 W. 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/kW-hr.

3.2.2.3 Thermal and ECS Interface. The Spacelab provides three basic paths to transport the experiment heat loads from the laboratory to the Orbiter space radiators

Table 3-7. Summary of Electrical Power Requirements

LAB CONCEPT	ORBIT OPERATIONS POWER (WATTS)				ENERGY CONSUMPTION (WATT-HRS/DAY)	ASCENT POWER (WATTS)	DESCENT POWER (WATTS)
	ON DUTY		OFF DUTY				
	AVERAGE	PEAK	AVERAGE	PEAK			
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	2019	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

Table 3-8. 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.

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(see Figure 3-6). The total heat load for these three loops cannot exceed 4 kW_T. The avionics heat exchanger provides up to 3 kW_T capacity and is used to cool the rack-mounted equipment. The experiment heat exchanger loop has a maximum capacity of 4 kW_T 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_T 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 16 laboratory concepts use all three heat rejection loops in varying degrees.

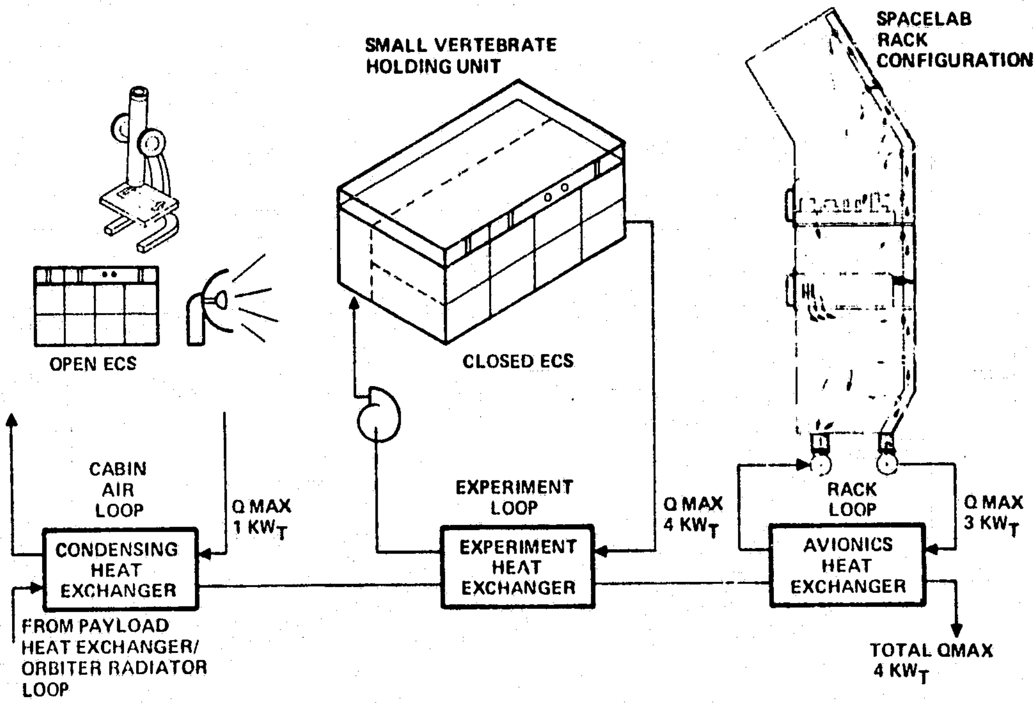

Figure 3-6. Baseline Thermal Transport Paths

Table 3-9 summarizes the heat loads and the thermal control loops used to reject the heat loads of the 16 laboratory concepts. 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. The heat loads developed within the 16 laboratory concepts are all with the 4 kW_T heat rejection capability of the Spacelab.

Cabin air is drawn into the organism holding units during man-surrogate testing. This cabin air is used to ventilate and remove water vapor from the holding units. The air is treated to remove odors and contaminants prior to return to the cabin condensing heat exchanger. 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

Table 3-9. Laboratory Heat Loads

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.

turnover rate for the organisms includes all water in urine, feces, and perspiration. These rates along with the air ventilation rates of all laboratory concepts with organisms are summarized in Table 3-10. The water vapor produced by evaporation of the MOD IIA 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, the excess water vapor load of 2-1/2 men equivalent can be reduced to about 1-1/2 men. 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. 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.

Table 3-10. 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

Humidity control may be a significant problem due to the low temperature requirement of coolant and its limited quantity. Other humidity control methods such as absorption may be required for the holding unit ventilation system.

3.2.2.4 Control and Data Management Interface. The compatibility of the Spacelab Control and Data Management System (CDMS) and the life sciences payload requirements was determined by first estimating the sampled data requirements for all 16 candidate payloads. A general philosophy of minimal on-board analysis and total transmission to the ground was adopted. Each signal source was identified, and characteristics of daily operation determined. The number of data channels, their sampling rate, and required precision determined the data rate. Computation of the daily total, in bits/day, was based on the operating characteristics. The mission phases during which CDMS support is needed (prelaunch, ascent, etc.) were identified.

To determine the Spacelab computer loading, the payload computer software requirements were estimated for two driving payloads — mini-lab ML-1A and dedicated laboratory MOD IIIA. Various software application modules were organized for each payload. These modules had specific functions such as command/control, checkout, formatting, and annotating. Detailed description for each module included module input/output lists, parameters and characteristics, computational algorithm, and calling frequency. The computer loading was then determined by estimating the computer speed, in equivalent (fixed point) adds per second (EAPS), and total memory (instructions plus data). Sixteen-bit words were used throughout.

Table 3-11 summarizes the compatibility of the Spacelab CDMS and the life sciences data management requirements, as typified by mini-lab ML-1A and dedicated lab MOD IIIA. In both computer support and transmission to the ground, the payload requirements are well with the Spacelab capability. The only apparent conflict is with the video transmission bandwidth. Payload cameras, up to this point, have been specified as standard 525 line, 6 MHz 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. The recommendation, therefore, is to reduce the bandwidth requirements to 4.2 MHz. Image resolution will not be greatly sacrificed.

Table 3-11. 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	2.55×10^3	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.	20.5 SHARED (with video usage)	–	12
VIDEO			
USAGE, HR/DAY		0.25	3
BANDWIDTH, MHZ	4.2	6	6

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

Mini-lab ML-1A has the highest data rate of all the payloads, roughly 100 kbits/sec. This is due primarily to the frog otolith experiment which has eight otolith signal channels; each channel is being sampled at the rate of 2,000 samples/sec. Continuous monitoring of this data yields the high rates and daily total. Sequential sampling and non-transmission during periods of low experimental activity would reduce these levels if desirable.

The same comment that applies to mini-labs in other subsystems applies here to the CDMS. That is, total impact on Spacelab cannot be determined until the requirements for the sharing payload elements are specified.

3.2.3 GROUND SUPPORT ANALYSIS. An important operational aspect of the life sciences/Spacelab program involves the detail step-by-step ground support analysis. This activity has uncovered significant areas of potential impact in the past, i.e., on-pad access to organisms.

The ground support analyses functional flow as shown in Figure 3-7 covers the movement of life sciences laboratory equipment and organisms through the varying levels of integration. Timelines were developed and Spacelab equipment availability conflicts determined. Facilities to support the life sciences laboratories at various integration sites were defined.

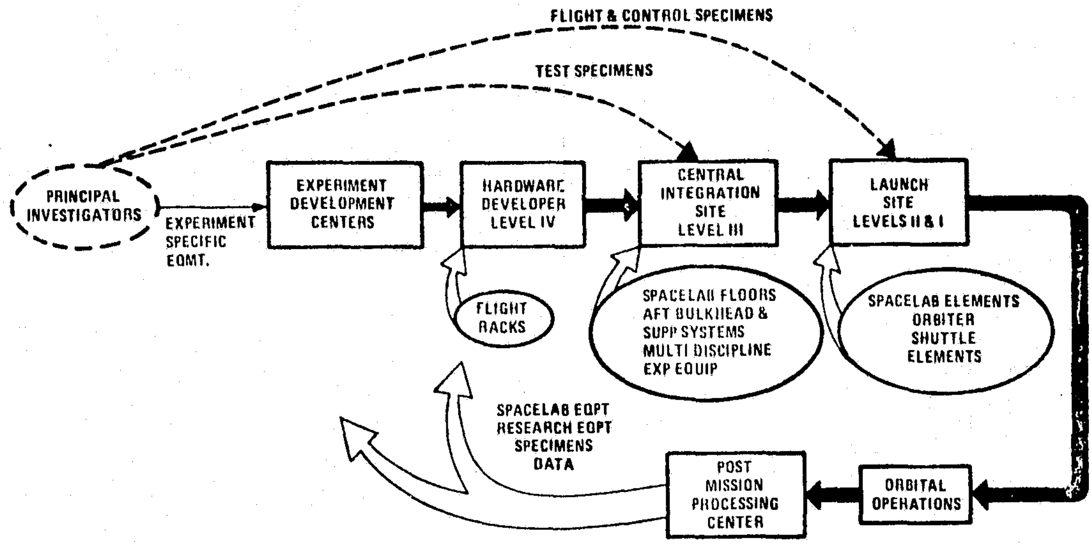

Figure 3-7. Functional Flow

As a result of the ground support analysis it was determined that dedicated Spacelab racks and floors were required to prevent schedule impacts. The need for on-pad access was reviewed and the use of the Spacelab modified air lock for on-pad access was reconfirmed. In addition to the above study outputs, another significant ground support analysis output defined the facility requirements for the life sciences program.

Table 3-12 summarizes these facility requirements. The off-line experiment functions of Levels IV and III integration phases will be performed at the Experiment Development Centers and Central Integration Site (CIS). A major requirement at the CIS is the medical/biological lab facility to accommodate specimen test articles. Sufficient floor area exists at the Levels II and I integration site (launch site) to meet the requirements of these activities. With the exception of the LN_2, the servicing fluids and gases indicated are required at the medical/biology labs.

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

Table 3-12. Life Sciences Experiments 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	

3.3 COST AND PROGRAMMATICS

3.3.1 COST ANALYSIS. Annual funding requirements were estimated for each of the three mission model options described in Section 3.1.3. These funding requirements are shown in Figure 3-8.

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-capacity 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 other two options. These three flights were reflights of previously developed laboratories.

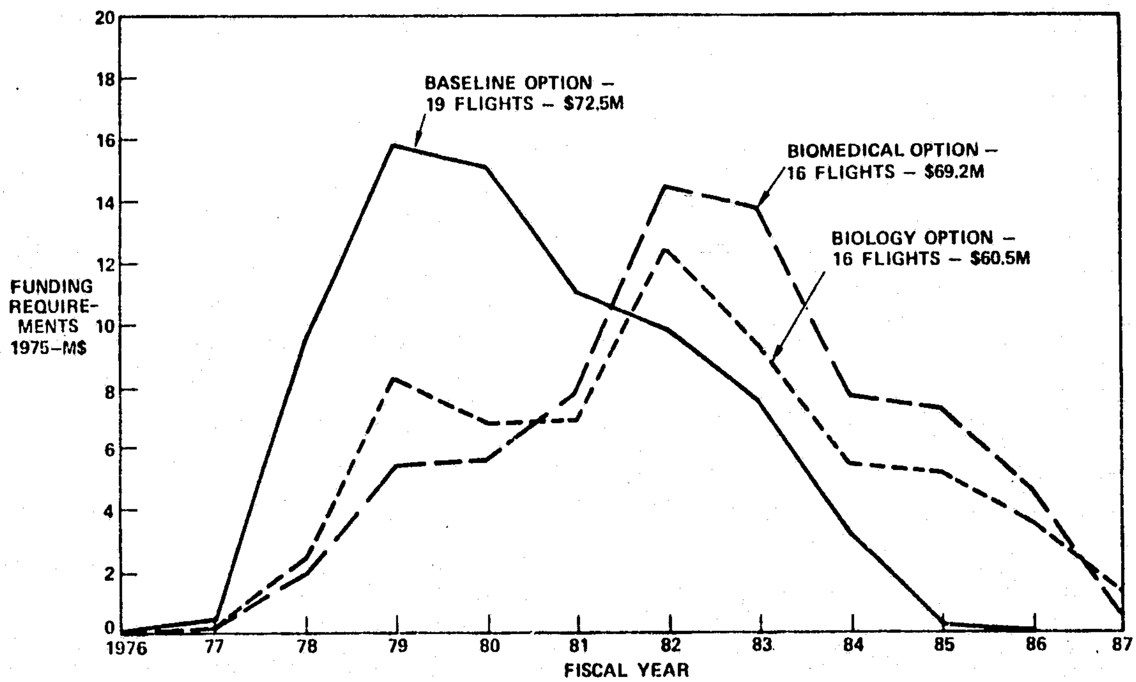

Figure 3-8. Annual Funding Requirements Program Option Comparison

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

It is concluded from the cost and programmatic analysis that the total program cost or funding peaks does not vary to any great degree for programs of similar capability. Peak funding rate is related to the timing of the dedicated laboratory in all cases. Early-year funding is 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.

3.3.2 PROGRAMMATIC ANALYSIS. The objectives of the programmatic analysis were: (1) to support the cost analysis task in the generation of annual funding requirements; (2) generate preliminary scheduling data for early laboratories; (3) to identify "tall pole" schedule incompatibilities; and (4) to identify long-lead and advanced technology equipment items.

During the review of equipment item requirements and 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 3-13. 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. The table lists several parameters bearing on the importance of the items and their

Table 3-13. Advanced Technology Requirements for Life Sciences Equipment Items

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

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 type 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 4

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.

4.1 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 4-1 presents the selected mission model options, their corresponding laboratory concepts, and flight schedules.

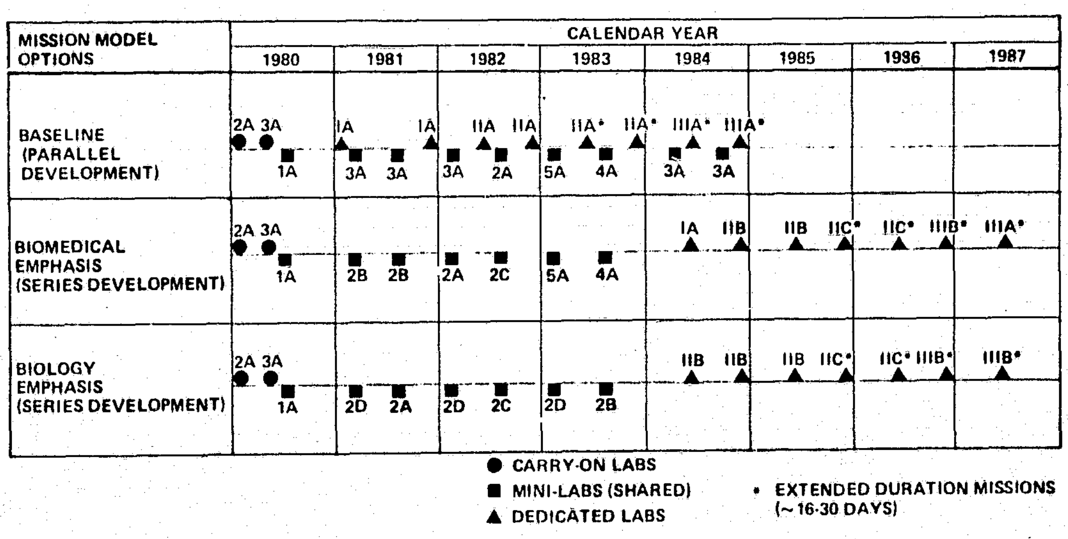

Figure 4-1. Selected Life Sciences Mission Models

The research capability of the 16 laboratory concepts is shown in Figure 4-2. 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.

RESEARCH REQUIREMENT	CANDIDATE LABORATORIES															
	CARRY-ON		MINI-LAB								DEDICATED LABS					
	2A	3A	1A	2A	3A	4A	5A	2B	2C	2D	IA	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						√						√	√			

Figure 4-2. 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 4-1.

Table 4-1. 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 4-2.

Table 4-2. 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 4-3.

Table 4-3. 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

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The third and final study task involved the programmatic and costs associated with the three mission models. It is concluded that the total program costs or funding peaks do not vary to any great degree for the three mission models. 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 the 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.

4.2 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.