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SPACE BIOLOGY INITIATIVE PROGRAM DEFINITION REVIEW

TRADE STUDY 6

SPACE STATION FREEDOM / SPACELAB MODULES COMPATIBILITY

FINAL REPORT

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Space Biology Initiative (SBI) Definition Review Trade Study
Trade Study Number 6

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By
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Foreword

The "Rack Compatibility Trade Study" was performed as part of the Space Biology Initiative (SBI) Definition Trade Studies Contract which is a NASA activity intended to develop supporting data for JSC use in the Space Biology Initiative Definition (Non-Advocate) Review with NASA Headquarters, Code B, scheduled for the June-July 1989 time period. The task personnel researched, acquired, recorded, and analyzed information relating to rack compatibility for space biology equipment.

This effort is one of four separate trade studies performed by Eagle Engineering, Inc. (EEI). Although the four trade studies address separate issues, the subject of SBI Hardware, the objectives to document the relative cost impacts for the four separate issues, and the intended audience are common for all four studies. Due to factor beyond control of the study management organizations, the trade studies were required to be completed in approximately one half of the originally planned time and with significantly reduced resources. Therefore, EEI immediately decided to use two proven time-and-resource-saving principles in studying these related SBI issues. The first principle employed was commonality. The study methodology was standardized where appropriate, the report formats were made the same where possible, a common database was developed, and the cost analysis techniques development and consultation was provided by a common team member. An additional benefit of this application of commonality with standardized material is to facilitate the assimilation of the study data more easily since the methods and formats will become familiar to the reader. The second principle employed was the phenomenon of the "vital few and trivial many" or sometimes known as the "Pareto principle" (see SBI #96). These are terms which describe the often observed phenomenon that in any population which contributes to a common effect, a relative few of the contributors account for the bulk of the effect. In this case, the effect under analysis was the relative cost impact of the particular SBI issue. If the phenomenon was applicable for the SBI hardware, EEI planned to study the "vital few" as a method of saving time and resources to meet the limitations of the study deadlines. It appears the "vital few and trivial many" principle does apply and EEI adopted the Principle to limit the number of hardware items that were reviewed.

The study was performed under the contract direction of Mr. Neal Jackson, Horizon Aerospace Project Manager. Mr. Mark Singletary, GE Government Services, Advanced Planning and Program Development Office, provided the objectives and policy guidance for the performance of the trade study. The direct study task personnel include:

EEI Project Manager:	Mr. W.L. Davidson (Bill)
Trade Study Manager:	Ms. Carolyn Blacknall
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List of Abbreviations and Acronyms

A	Amps
AI	Artificial Intelligence
APM	Attached Pressurized Module
ARC	Ames Research Center
BmRP	Biomedical Research Project (Human/Crew Members)
BRP	Biological Research Project (Non Human/Rodents, primates or plants)
BSHF	Biological Specimen Holding Facility
CDMS	Command and Data Management Subsystem
CDR	Critical Design Review
CER	Cost Estimating Relationship
CHeC	Crew Health Care
CR	Change Request
DDS	Data Display System
DDT&E	Design, Development, Test and Evaluation
DMS	Data Management System
DR	Double Rack
ECF	Exercise Countermeasure Facility
ECLSS	Environmental Control and Life Support System
ECS	Environmental Control Subsystem
EDCO	Extended Duration Crew Operations
EHS	Environmental Health System
EPDS	Electrical Power Distribution System
EPSP	Electrical Power Switching Panel
ESA	European Space Agency
FSU	Functional Support Unit
GBPS	Giga Bytes per Second
GPWP	General Purpose Work Bench
HMF	Health Maintenance Facility
HRM	High Rate Multiplexer
HQUL	Hardware Quantity and Usage List
HRF	Human Research Facility
H2	Hertz
IATA	International Air Transport Association
I/F	Interface
JEM	Japanese Experiment Module
JCP	JEM Control Processor
JSC	Johnson Space Center
KHZ	Kilohertz
KW	Kilowatt
LAB	Laboratory
LAN	Local Area Network
LSE	Laboratory Support Equipment
LSFEP	Life Sciences Flight Experiment Program
LSLE	Life Sciences Laboratory Equipment
LSPD	Life Sciences Project Division

LSRF	Life Science Research Facility
MBPS	Mega Bytes per Second
MDE	Mission Dependent Equipment
MDM	Multiplexer-Demultiplexer
MDU	Medical Development Unit
MLI	Multi-Layer Insulation
MPAK	Middeck Payload Accomodations Kit
MUS	Multilateral Utilization Study
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (of Japan)
NIU	Network Interface Unit
NSTS	NASA Space Transportation System
PI	Principal Investigator
PIP	Payload Integration Plan
PMC	Permanent Manned Capability
POCC	Payload Operations Control Center
RAU	Remote Acquisition Unit
RMOAD	Reference Mission Operational Analysis Document
SAIS	Science & Applications Information System
SBHB	Space Biology Hardware Baseline
SBI	Space Biology Initiative
SDP	Standard Data Processor
SLS	Spacelab Life Sciences
SPC	Signal Processing Converter
SR	Single Rack
SSF	Space Station Freedom
SSFP	Space Station Freedom Program
SSIS	Space Station Information Systems
SSP	Standard Switch Panel
STS	Space Transportation System
TBD	To Be Determined
TDRSS	Tracking and Data Relay Satellite System
TFU	Theoretical First Unit
U.S.	Unites States
VAC	Volts/Alternating Current
VDC	Volts/Direct Current
W	Watts
WAN	Wide Area Network

Glossary and Definitions

Assembly

An accumulation of subassemblies and/or components that perform specific functions within a system. Assemblies can consist of subassemblies, components, or both.

Certification

The process of assuring that experiment hardware can operate under adverse Space Station Freedom environmental conditions. Certification can be performed by analysis and/or test. The complete SSFP definition follows. Tests and analysis that demonstrate and formally document that all applicable standards and procedures were adhered to in the production of the product to be certified. Certification also includes demonstration of product acceptability for its operational use. Certification usually takes place in an environment similar to actual operating conditions.

Certification test plan

The organized approach to the certification test program which defines the testing required to demonstrate the capability of a flight item to meet established design and performance criteria. This plan is reviewed and approved by cognizant reliability engineering personnel. A quality engineering review is required and comments are furnished to Reliability.

Component

An assembly of parts, devices, and structures usually self-contained, which perform a distinctive function in the operation of the overall equipment.

Experiment

An investigation conducted on the Space Station Freedom using experiment unique equipment, common operational equipment of facility.

Experiment Developer

Government agency, company, university, or individual responsible for the development of an experiment/payload.

Experiment unique hardware

Hardware that is developed and utilized to support the unique requirements of an experiment/payload.

Facility

Hardware/software on Space Station Freedom used to conduct multiple experiments by various investigators.

Flight Increment

The interval of time between shuttle visits to the Space Station Freedom. Station operations are planned in units of flight increments.

Flight increment planning

The last step in the planning process. Includes development of detailed resource schedules, activity templates, procedures and operations supporting data in advance of the final processing, launch and integration of payloads and transfer of crew.

Ground operations

Includes all components of the Program which provide the planning, engineering, and operational management for the conduct of integrated logistics support, up to and including the interfaces with users. Logistics, sustaining engineering, pre/post-flight processing, and transportation services operations are included here.

Increment

The period of time between two nominal NSTS visits.

Interface simulator

Simulator developed to support a particular Space Station Freedom or NSTS system/subsystem interface to be used for interface verification and testing in the S&TC and/or SSPF.

Integrated logistics support

Includes an information system for user coordination, planning, reviews, and analysis. Provides fluid management, maintenance planning, supply support, equipment, training, facilities, technical data, packaging, handling, storage and transportation. Supports the ground and flight user requirements. The user is responsible for defining specific logistics requirements. This may include, but not be limited to resupply return in term of frequency, weight, volume, maintenance, servicing, storage, transportation, packaging, handling, crew requirements, and late and early access for launch site, on-orbit, and post-mission activities.

Integrated rack

A completely assembled rack which includes the individual rack unique subsystem components. Verification at this level ensures as installed component integrity, intra-rack mechanical and electrical hookup interface compatibility and mechanisms operability (drawer slides, rack latches, etc.).

Integration

All the necessary functions and activities required to combine, verify, and certify all elements of a payload to ensure that it can be launched, implemented, operated, and returned to earth successfully.

Orbital replaceable unit (ORU)

The lowest replaceable unit of the design that is fault detectable by automatic means, is accessible and removable (preferably without special tools and test equipment or highly skilled/trained personnel), and can have failures fault-isolated and repairs verified. The ORU is sized to permit movement through the Space Station Freedom Ports.

Payload integration activities

Space Station Freedom payload integration activities will include the following:

Pre-integration activities shall include receiving inspection, kitting, GSE preps and installation, servicing preps and servicing, post deliver verification, assembly and staging (off-line labs), rack and APAE assembly and staging, alignment and post assembly verification.

Experiment integration activities shall include experiment package installation into racks, deck carriers, platforms, etc., and payload to Space station interface verification testing. When the Freedom element is available on the ground, Space Station Freedom integration activities (final interface testing) shall include rack or attached payload installation into Freedom element (e.g., pressurized element, truss structure, platform) and shall include payload-to-element, interface verification, followed by module, truss, or platform off-loading of experiments, as required, for launch mass for follow-on increments, Space Station Freedom integration activities shall include rack or attached payload installation into the logistics element and verification of the payload-to-logistics element interface.

Integration activities (final interface testing) shall include: rack or attached payload installation into Space Station Freedom element (e.g., lab module, truss structure, platform) on the ground, when available, and shall include payload to element interface verification, configure and test for station to station interface verification, followed by module, truss or platform off-loading of experiments, as required, for launch mass.

Launch package configuration activities shall include configuring for launch and testing station to NSTS interfaces, (if required), stowage and closeout, hazardous servicing, (if required), and transport to the NSTS Orbiter.

NSTS Orbiter integrated operations activities shall include insertion of the launch package into the orbiter, interface verification (if required), pad operations, servicing, closeout, launch operations, and flight to Space Station Freedom.

On-orbit integration activities shall include payload installation and interface verification with Space Station Freedom.

Hardware removal that includes rack-from-module and experiment-from-rack removal activities.

Payload life cycle

The time which encompasses all payload activities from definition, to development through operation and disbursement.

Permanent manned capability (PMC)

The period of time where a minimum of capabilities are provided, including required margins, at the Space Station Freedom to allow crews of up to eight on various tour durations to comfortably and safely work in pressurized volumes indefinitely. Also includes provisions for crew escape and EVA.

Physical integration
: The process of hands-on assembly of the experiment complement; that is, building the integrated payload and installing it into a standard rack, and testing and checkout of the staged payload racks.

Principal Investigator
: The individual scientist/engineer responsible for the definition, development and operation of an experiment/payload.

Rack staging
: The process of preparing a rack for experiment/payload hardware physical integration: encompasses all pre-integration activities.

Space Station Freedom
: The name for the first Unites States permanently manned space station. It should always be interpreted as global in nature, encompassing all of the component parts of the Program, manned and unmanned, both in space and on the ground.

Subassembly
: Two or more components joined together as a unit package which is capable of disassembly and component replacement.

Subsystem
: A group of hardware assemblies and/or software components combined to perform a single function and normally comprised of two or more components, including the supporting structure to which they are mounted and any interconnecting cables or tubing. A subsystem is composed of functionally related components that perform one or more prescribed functions.

Verification
: The process of confirming the physical integration and interfaces of an experiment/payload with systems/subsystems and structures of the Space Station Freedom. The complete SSFP definition follows. A process that determines that products conform to the design specification and are free from manufacturing and workmanship defects. Design consideration includes performance, safety, reaction to design limits, fault tolerance, and error recovery. Verification includes analysis, testing, inspection, demonstration, or a combination thereof.

1.0 Introduction

1.1 Background

The JSC Life Sciences Project Division has been directly supporting NASA Headquarters, Life Sciences Division, in the preparation of data from JSC and ARC to assist in defining the Space Biology Initiative (SBI). GE Government Services and Horizon Aerospace have provided contract support for the development and integration of review data, reports, presentations, and detailed supporting data. An SBI Definition (Non-Advocate) Review at NASA Headquarters, Code B, has been scheduled for the June-July 1989 time period. In a previous NASA Headquarters review, NASA determined that additional supporting data would be beneficial in clarifying the cost factors and impact in the SBI of miniaturizing appropriate SBI hardware items. In order to meet the demands of program implementation planning with the definition review in late spring of 1989, the definition trade study analysis was adjusted in scope and schedule to be complete for the SBI Definition (Non-Advocate) Review.

1.2 Task Statement

This study will identify the differences in rack requirements for Spacelab, the Shuttle Orbiter, and the United States (U.S.) laboratory module, European Space Agency (ESA) Columbus module, and the Japanese Experiment Module (JEM) of Space Station Freedom. The study will also assess the feasibility of designing standardized mechanical, structural, electrical, data, video, thermal, and fluid interfaces to allow space flight hardware designed for use in the US laboratory module to be used in other locations.

1.3 Application of Trade Study Results

The SBI cost definition is a critical element of the JSC submission to the SBI Definition (Non-Advocate) Review and the results of this trade study are intended to benefit the development of the SBI costs. It is anticipated that the GE PRICE cost estimating model will be used to assist in the formulation of the SBI cost definition. This trade study is planned to be produced in the form of factors, guidelines, rules of thumb, technical discussions, and rack comparison matrices which will provide insight on the mechanical and structural, electrical, data and video, and thermal and fluid interfaces between SBI equipment and Spacelab, Shuttle Orbiter mid-deck, and the U.S., JEM, and ESA Space Station laboratory modules.

1.4 Scope

The space biology hardware to be investigated has been defined and baselined in Appendix A, Space Biology Hardware Baseline (SBHB). By study contract direction, no other space biology hardware has been considered. The complexity and importance of the subject could warrant an extensive study if unlimited time and resources were available. However, due to the practical needs of the real program schedule and budget, the depth of study has been adjusted to satisfy the available resources and time. In particular, cost analyses have emphasized the determination of influential factors and parametric relationships rather than developing detailed, numerical cost figures. While program objectives and mission definitions may be stable in the early program phases, hardware item specifications are evolving and usually change many times during the design phase. For this reason, the trade study analyses have focused on the category and function of each hardware item rather than the particular, current definition of the item. In the process of acquiring trade study data, certain information could be considered a snapshot of the data at the time it was recorded for this study. The data have been analyzed as defined at the time of recording; no attempt has been made to maintain the currency of acquired trade study data.

1.5 Methodology

The methodology used in performing the Rack Compatibility Trade Study, shown in Figure 1.5, consists of the initial, important phase of search and acquisition of related data; followed by a period of data integration and comparison of rack requirements, and finally, the assessment phase where the feasibility of designing standardized interfaces to allow space biology flight hardware to be used in racks in all modules.

1.5.1 Data And Documentation Survey

A literature review and database search were conducted immediately upon study initiation. Information pertaining to Shuttle mid-deck lockers, Spacelab racks, and Space Station Freedom racks in the U.S., ESA, and JEM modules were collected and analyzed. Documents containing information on Spacelab and Space Station Freedom racks and on Shuttle locker accommodations are listed in the bibliographies in Section 4.1. Every attempt was made to utilize the most up-to-date versions of these documents in this Rack Compatibility Trade Study.

1.5.2 Database Development

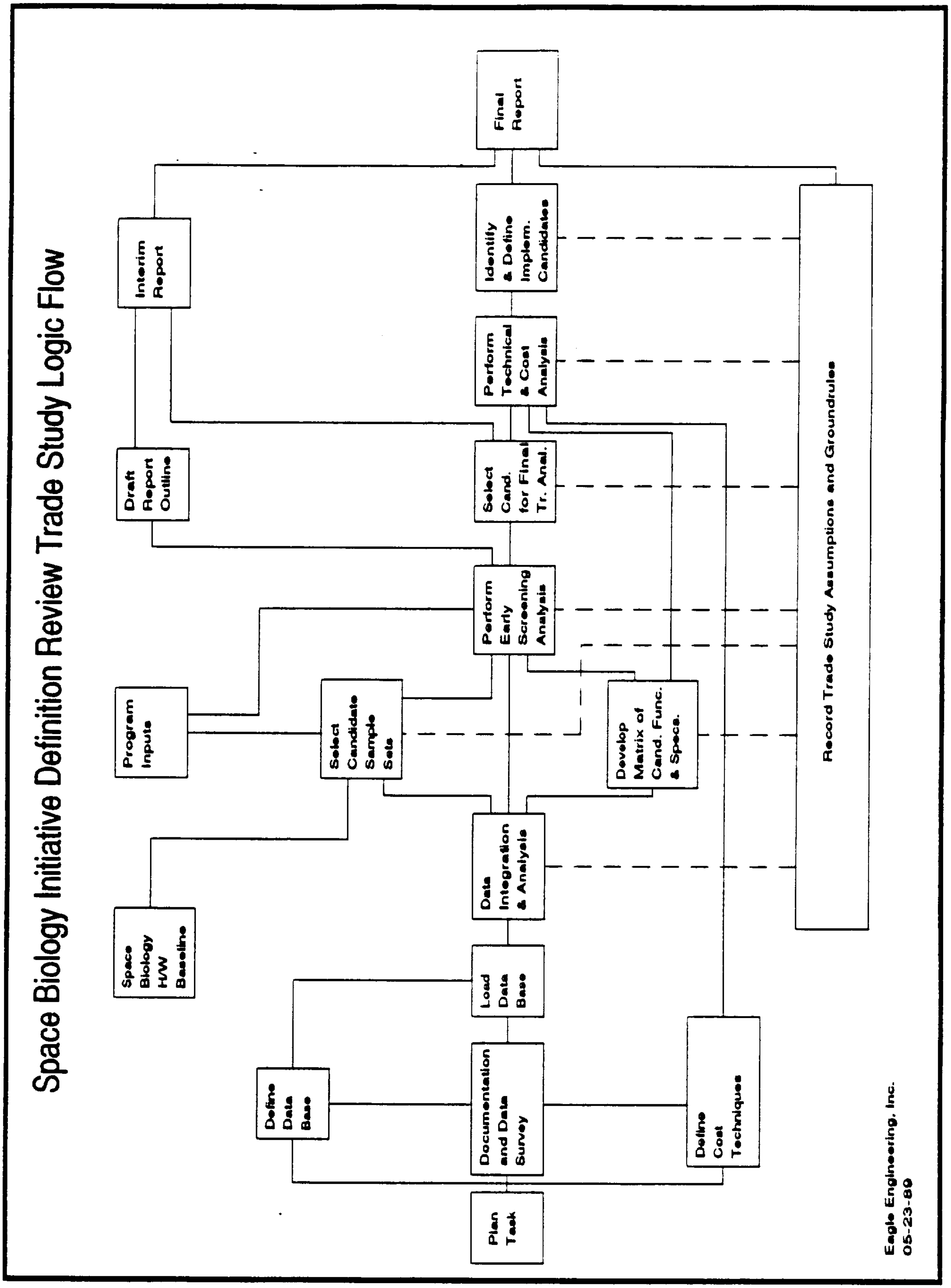
An analysis of the trade study data needs was performed to provide an understanding of the logical database design requirements. Based on the knowledge gained in the database analysis, the trade study data structures were developed and implemented on a computer system. The pertinent information collected from the data and documentation survey was input to the trade study database.

1.5.3 Survey Data Integration and Comparison

Data on racks and experiment interfaces were entered into the relational data base. Information was then sorted into the following categories to facilitate comparison of similar rack interfaces and accommodations:

Mechanical and Structural Interfaces,
Electrical Interfaces,
Thermal and Fluid Interfaces, and
Data and Video Interfaces.

Figure 1.5 Space Biology Initiative Definition Review Trade Study Logic Flow



2.0 Executive Summary

2.1 Assumptions And Groundrules

In the process of performing the subject trade study, certain data or study definition was not available or specified. Assumptions and groundrules have been established to document, for the purposes of this trade study, the definition of important information which is not definite fact or is not available in the study time period. Major assumptions and groundrules which affect the four EEI trade studies are provided in Table 2.1-1, Common SBI Trade Study Assumptions and Groundrules. Assumptions and Groundrules which directly and uniquely effect this trade study are provided in Table 2.1-2, Rack Compatibility Trade Study Assumptions and Groundrules.

2.2 Rack and Comparisons Experiment Interface

This study examines the physical, electrical, thermal, and data interfaces between experiments and racks located in the three laboratory modules on the Space Station, the Spacelab, and lockers in the Shuttle Orbiter. At present, the three laboratory modules on Space Station Freedom are not designed to provide the user with common experiment to rack interfaces. This could result in the design of an experiment that is limited to only one module, the design of several experiment systems with different interfaces for each module, or be limited to experiment change-out as part of a rack level set of experiments. Common interfaces between Space Station modules and Spacelab and Shuttle Orbiter could allow early test flights for Space Station experiments using the Shuttle as well as allow quick change-out and flexibility among missions.

2.2.1 Mechanical and Structural Interfaces

The mechanical and structural interfaces between experiments and racks were examined for the Space Station Freedom U.S. lab module, the ESA Columbus module, and the JEM module and, also, for Spacelab and Shuttle Orbiter. This section compares height, width, depth, internal diameter, and structural weight. This information is provided in Table 2.2.1.

2.2.2 Electrical Interfaces

The electrical interfaces between experiments and racks were examined for the Space Station Freedom U.S. lab module, the ESA Columbus module, and the JEM module, and also for Spacelab and Shuttle Orbiter. This section compares voltages, current, power, and power converters. This information is provided in Table 2.2.2.

2.2.3 Thermal And Fluid Interfaces

The thermal and fluid interfaces between experiments and racks were examined for the Space Station Freedom U.S. lab module, the ESA Columbus module, and the JEM module, and also for Spacelab and Shuttle Orbiter. This section compares types of fluid interfaces, pressures, vacuum venting capabilities, waste gas and liquid accommodations, and the type of gasses provided. This information is provided in Table 2.2.3.

2.2.4 Data And Video Interfaces

The data and video interfaces between experiments and racks were examined for the Space Station Freedom U.S. lab module, the ESA Columbus module, and the JEM module, and also for Spacelab and Shuttle Orbiter. This section compares bus frequency, bus time, high and low data rates, LAN interfaces and processing capabilities. This information is provided in Table 2.2.4.

2.2.5 Spacelab Versus Space Station Experiment Interface Philosophy

The management of experiment resources for Spacelab flights were suited to the short missions of Spacelab. Space Station must be approached considering a very different set of inherent capabilities and limiting resources. The Spacelab Science Plan was developed with much stronger time constraints on orbit and ground development was organized in mission format with long-lead times and extensive mission-specific configurations. These constraints result in very crew-intensive timelines with limited flexibility.

Space Station Life Sciences Research will more effectively serve the needs of the scientific community by being organized with respect to developing capabilities which may be effectively used to carry out a highly flexible and evolutionary science program, rather than using the mission-by-mission approach used for Spacelab.

This permits creative and innovative scientific developments while still following the guidelines and priorities established by NASA Life Sciences Flight Experiment Program (LSFEP). By designing the Space Station to a capabilities requirement rather than specific missions requirements, the value of the Space Station is expanded to encompass the broadest population of Life Science disciplines and interests. Table 2.2.5 presents a comparison between current Life Sciences planning and experiment factors for the Spacelab and the proposed approach for the Space Station suggested in Life Sciences Study for the Space Station, SBI #94.

Current Spacelab preflight mission development activities require a premission schedule lead time of approximately four years for planning and preparation. It is expected that as the Space Station and programmatic elements mature the resultant time and requirements constraints will be significantly reduced and the processing procedures would approach the efficiency and routine of modern medical laboratories.

2.3 Interface Design Feasibility Summary

The Experiment Standard User Interface Study by the JSC Life Sciences Project Division is investigating the feasibility of designing a set of standard equipment mechanical, electrical, data, and cooling interfaces between the equipment and the spacecraft systems. William G. Davis is the NASA Technical Manager for this report, cataloged as SBI #39. This trade study concludes that the standardized interface suggestions of the Interface Study will result in a significant savings in design, development, test, and evaluation (DDT&E) and operational and maintenance costs.

The advantages of having standard interfaces are that one experiment system design can be flown in any of the three Space Station modules or the Spacelab. The experiment ground integration and verification process for equipment is simplified significantly by the use of standard data interfaces that can be evaluated by automated electronic systems. The use of standard mechanical interfaces will not require the flight experiment system to be integrated into the Spacelab racks as early as is presently required.

The development cost for experiment systems can be reduced by allowing the equipment developers to work with commercially available standard input and output data and video interface circuits. The special spacecraft interface requirements can be accommodated by the interfacing equipment at the rack level.

2.3.1 Mechanical And Structural Interfaces

The compatibility of experiment to rack interfaces must be founded on the compatibility of mechanical and structural interfaces. Standardized mechanical interfaces consist of built-in equipment to allow installation from the front of the rack on generic chassis slides without using tools. The mounting system can be designed with significant margins for the stress of launch and landing where required, such as on Spacelab. The installation of experiments in the Space Station racks on orbit will result in a significant weight savings due to light mounting systems that are unloaded during launch.

2.3.2 Electrical Interfaces

Electrical interface compatibility is also of primary importance in a study of standardized experiment to rack interfaces. At the time the Experiment Standard User Interface Study was written, the primary power sources available to the experiments on Spacelab was 115 VAC 400 Hz and 28 VDC. The U.S. Space Station module was planning for primary power of 208 VAC at 20 KHz with conversion available, at the experimenter's expense, to 28 VDC and 115 VAC 60 Hz. The power available in the Japanese module and the ESA module were not defined, but the ESA module was proposed to be 120 VDC. Even with changes in these requirements, it is obvious that commonality and standardization do not exist. One of the objectives of the study is to recommend identical power accommodations and interfaces in any of the Space Station or Spacelab modules.

2.3.3 Thermal And Fluid Interfaces

Standardized experiment to rack interface feasibility must also consider the compatibility of thermal and fluid interfaces. The experiment cooling interface to the spacecraft avionics cooling air can be simplified by using fans within the experiment chassis that will "dump" the experiment heat load into the ambient rack air volume. The ambient rack air volume will be maintained within the prescribed limits by the spacecraft thermal control system. Current investigations have identified fan assemblies that have variable speeds which are determined by either temperature or command inputs.

2.3.4 Data And Video Interfaces

The standardized data interface that is being investigated for the experiments is an IEEE-488 parallel data bus configuration. Utilization of this widely accepted data transfer technique will provide not only a standard interface, but will also allow the experiment to be designed using commercially available and proven circuitry. A standard parallel data bus interface module in each rack will be used to route data from each experiment within the rack to the spacecraft data system or from one experiment box to another. All special isolation and grounding requirements for each module or spacecraft would be accommodated in this data bus interface module.

The present Spacelab video input and output requirements are somewhat unique variations of standard video RS170 signal characteristics. The unique variations have been the source of many problems for previous experimenters. It is planned that the standardized interface would accommodate variations and allow the experimenter to work with completely standard characteristics. Standardization between the Spacelab and Space Station video systems must be further evaluated to determine if this is feasible.

2.4 Relative Cost Impact

The standardized interfaces examined in this study appear to provide commonality with little weight and volume penalty. The benefits of standardization, including experiment location flexibility, experiment changeout and quick response ability, experiment design simplification, and more efficient experiment checkout and verification imply that standardized interfaces would actually lower life cycle costs. See Appendix C, Table 7-1 for Life Cycle Costs.

2.5 Future Work

2.5.1 Compatibility of Specific SBI hardware

An area of future work directly related to this trade study is a task to evaluate specific items of SBI hardware in terms of the compatibility of rack interfaces and the effect on project science and cost. It is estimated that standardized interfaces will decrease experiment planning and development times and reduce DDT&E, operational, and maintenance costs.

2.5.2 Coordination and Support for Standardized Interfaces

The trade study has indicated that the practical aspects of achieving compatibility of racks in the various space modules. An important contribution to space biology experimentation would be a future task to study and develop methods for facilitating common interest between the SBI and other organizations to achieve successful rack compatibility. The International partners should be made aware of the Experiment Standard User Interfaces Study and the advantages of implementing standardized interfaces.

2.5.3 Awareness of Standardized Interface Cost Benefits to Other Organizations

Related to the above task is potential future work to analyze, develop, and define the relative cost to the various space projects of not having rack compatibility between different space laboratory modules. This may encourage some organizations to consider the benefits of standardized rack interfaces.

2.5.4 Standardized Rack Interfaces With Other Facilities

The design of a set of standardized experiment-to-spacecraft interfaces will simplify the mechanical cooling and electrical interfaces between the experiment and the spacecraft systems. The possibility of outfitting other facilities potentially usable by SBI, such as the Industrial Space Facility, with these standardized interfaces should be investigated.

2.5.5 Evaluation and Testing of Standard Interfaces

The Experiment Standard User Interfaces Study by the JSC Life Sciences Project Division investigated the possibility of standardized interfaces between the U.S. Laboratory module, the European Space Agency's Columbus Module, the Japanese Experiment Module, Spacelab, and the Shuttle Orbiter. This Rack Compatibility Trade Study, confirms that standardized mechanical, electrical, data, video, thermal, and fluid interfaces would make the design, development, testing, installation, maintenance, and changeout of experiments faster, less expensive, and more flexible. The interfaces suggested by the Standard Interfaces Study should be built into rack models for evaluation and testing.

2.5.6 Investigation of Standardization of Aircraft Racks

The International Air Transport Association (IATA), a regulating organization for the world's airlines, has successfully standardized many systems and aspects of commercial transport aircraft, including the packaging and installation of avionic equipment in racks (SBI #95). These racks are built to the same standards by the free world's aircraft manufacturers. A study of the methodology used by IATA to accomplish this standardization would be a valuable assist in equipment and rack standardization for space flight.

2.6 Conclusion Summary

Experiment to rack interfaces, and rack to module interfaces should be standardized. Standardization will benefit experiment location flexibility, changeout ability, checkout and verification, and flight testing. Standardized interfaces will simply experiment design, and the experiment integration process. The technical and economic negatives to standardization are insignificant compared to the potential benefits. Standardization of experiment to rack interfaces should be implemented, and the international partners should be included in the implementation process.

Table 2.1-1 Common SBI Trade Study Assumptions and Groundrules

1) Where project, hardware, and operations definition has been insufficient, detailed quantitative analysis has been supplemented with assessments based on experienced judgement of analysts with space flight experience from the Mercury Project through the current time.

2) Space flight hardware cost is primarily a function of weight based on historical evidence.

3) The effects of interrelationships with space biology and life science hardware and functions other than the SBI baseline hardware are not considered in the trade study analyses.

4) Trade study information, once defined during the analysis for the purpose of establishing a known and stable baseline, shall not be changed for the duration of the trade study.

5) Hardware life cycle costs cannot be studied with quantitative analyses due to the unavailability of definition data on hardware use cycles, maintenance plans, logistics concepts, and other factors of importance to the subject.

6) The SBI hardware as identified is assumed to be designed currently without any special emphasis or application of miniaturization, modularity, commonality, or modified commercial off-the-shelf adaptations.

7) It is assumed that the required hardware performance is defined in the original equipment specifications and must be satisfied without regard to implementation of miniaturization, modularization, commonality, or modified commercial off-the-shelf adaptations.

Table 2.1-2 Rack Compatibility Trade Study Assumptions and Groundrules.

1) Space Station Freedom payload accommodations will evolve over time. This study deals only with initial capabilities.

2) Space Station Freedom U.S. Module, ESA Columbus Module, and JEM Module rack and interface information is based on NASA information published in February, 1989, (SBI #02).

3) For the purpose of this study, the Spacelab configuration and payload experiment accommodations are defined as those of Spacelab 4, also known as Spacelab Life Sciences-1, (SLS-1).

4) The Experiment Standard User Interface Study by the JSC Life Sciences Project Division, with William G. Davis as Technical Manager is the only study found which considers standard rack to experiment design feasibility.

Table 2.2-1 Rack Comparison - Mechanical and Structural Interfaces

PARAMETER	VALUE	UNITS	MODULE
Internal Module Diameter	152 ID	in	ESA
Internal Module Diameter	157.5 ID	in	JEM
Internal Module Diameter	166 ID	in	U.S. Lab
Rack Depth	25	in	ESA
Rack Depth	800	mm	ESA
Rack Depth	32.5	in	JEM
Rack Depth	914.4	mm	JEM
Rack Depth	35	in	U.S. Lab
Rack Depth	914	mm	U.S. Lab
Rack Depth - Double Rack	29.9	in	Spacelab
Rack Depth - Double Rack	760	mm	Spacelab
Rack Depth - Single Rack	29.9	in	Spacelab
Rack Depth - Single Rack	760	mm	Spaclab
Rack Gross Weight	No Info	kg	ESA
Rack Gross Weight	600	kg	JEM
Rack Gross Weight	761	kg	U.S. Lab
Rack Height	74.5	in	ESA
Rack Height	1892.3	mm	ESA
Rack Height	74.5	in	JEM
Rack Height	1892.3	mm	JEM
Rack Height	74.5	in	U.S. Lab

Table 2.2-1 Rack Comparison - Mechanical and Structural Interfaces

PARAMETER	VALUE	UNITS	MODULE
Rack Height	1892.3	mm	U.S. Lab.
Rack Height - Double Rack	75.4	in	Spacelab
Rack Height - Double Rack	1892.3	mm	Spacelab
Rack Height - Single Rack	75.4	in	Spacelab
Rack Height - Single Rack	1892.3	mm	Spacelab
Rack Pyld. Capacity	200-400	kg	ESA
Rack Pyld. Capacity	TBD	kg	JEM
Rack Pyld. Capacity	400-700	kg	U.S. Lab
Rack Structural Weight	No Info	kg	ESA
Rack Structural Weight	TBD	kg	JEM
Rack Structural Weight	135	lbs	U.S. Lab
Rack User Volume	38.8	cu-ft	ESA
Rack User Volume	TBD	cu-ft	JEM
Rack User Volume	38.5	cu-ft	U.S. Lab
Rack Width	41.5	in	ESA
Rack Width	1054	mm	ESA
Rack Width	41.5	in	JEM
Rack Width	1054	mm	JEM
Rack Width	41.5	in	U.S. Lab
Rack Width	1054	mm	U.S. Lab
Rack Width - Double Rack	41.4	in	Spacelab

Table 2.2-1 Rack Comparison - Mechanical and Structural Interfaces

PARAMETER	VALUE	UNITS	MODULE
Rack Width - Double Rack	1052	mm	Spacelab
Rack Width - Single Rack	22.2	in	Spacelab
Rack Width - Single Rack	563.5	mm	Spacelab
Rack Material	Graphite Epoxy	Matrls.	ESA
Rack Material	Al Alloy	Matrls.	JEM
Rack Material	Graphite Skin/Al Core	Matrls.	U.S. Lab

Table 2.2-2 Rack Comparison - Electrical Interfaces

PARAMETER	VALUE	UNITS	MODULE
117/203 Vac at 400 Hz (3 phase)	Yes	Volts	Spacelab
120 Vdc	Yes	Volts	ESA
120 Vdc	Yes	Volts	JEM
120 Vdc	Yes	Volts	U.S. Lab
24 to 32 Vdc (28 nominal)	Yes	Volts	Spacelab
Converter Losses	Charged to Users	Volts	ESA
Converter Losses	Charged to user	Volts	JEM
Converter Losses	Charged to Users	Volts	U.S. Lab
Current	TBD	Amps	ESA
Current 15 A	Yes	Amps	U.S. Lab
Current 25 A	Yes	Amps	JEM
Current 30 A	Yes	Amps	U.S. Lab
Current 75 A	Yes	Amps	U.S. Lab
Physical I/F	TBD	I/F	ESA
Physical I/F	TBD	I/F	JEM
Physical I/F	TBD	I/F	U.S. Lab
Power 1 kW	Yes	kW	ESA
Power 1.5 kW	Yes	kW	ESA
Power 11 kK Pallet-only config.	Yes	kW	Spacelab
Power 15 kW	Yes	kW	U.S. Lab
Power 3 kW	Yes	kW	ESA
Power 3 kW	Yes	kW	JEM

Table 2.2-2 Rack Comparison – Electrical Interfaces

PARAMETER	VALUE	UNITS	MODULE
Power 3 kW	Yes	kW	U.S. Lab
Power 6 kW	Yes	kW	U.S. Lab
Power 8.5 kW Module and Pallet Config.	Yes	Kw	Spacelab
Prog. Provided Pwr. Converters	No		ESA
Prog. Provided Pwr. Converters	No	Volts	JEM
Prog. Provided Pwr. Converters 120 Vac	Yes	Volts	U.S. Lab
Prog. Provided Pwr. Converters 28 Vdc	Yes	Volts	U.S. Lab
Unique Power Converters	User Provided	Volts	ESA
Unique Power Converters	User Provided	Volts	JEM
Unique Pwr. Converters	User Provided	Volts	U.S. Lab

Table 2.2-3 Rack Comparison - Thermal and Fluid Interfaces

PARAMETER	VALUE	UNITS	MODULE
Argon Gas	Yes	Gas	JEM
Argon Gas	Yes	Gas	U.S. Lab
Argon Gas I/F	line from storage vessel	I/F	JEM
Argon Gas I/F	Direct I/F from rack	I/F	U.S. Lab
Cooling Capacity	8.85 max to orbiter	Kw	Spacelab
Fluid I/F	TBD (USER DEPENDENT)	I/F	ESA
Fluid Types	Fluids provided by pyld.	Fluid	ESA
Helium Gas	Yes	Gas	JEM
Helium Gas	Yes	Gas	U.S. Lab
Helium Gas I/F	line from storage vessel	I/F	JEM
Helium Gas I/F	Direct I/F from rack	I/F	U.S. Lab
Krypton Gas	Yes	Gas	JEM
Kryton Gas I/F	line from storage vessel	I/F	JEM
Liquid Nitrogen	Yes	Liquid	U.S. Lab
Liquid Nitrogen I/F	line from storage vessel	I/F	U.S. Lab
Mass Flow	TBD (USER DEPENDENT)	Flow	ESA
Mass Flow	TBD	Flow	JEM
Mass Flow	TBD	Flow	U.S. Lab
Nitrogen Gas	Yes	Gas	JEM
Nitrogen Gas	Yes	Gas	U.S. Lab
Nitrogen Gas I/F	Direct I/F from rack	I/F	JEM
Nitrogen Gas I/F	Direct I/F from rack	I/F	U.S. Lab

Table 2.2-3 Rack Comparison - Thermal and Fluid Interfaces

PARAMETER	VALUE	UNITS	MODULE
Oxygen Gas	Yes	Gas	JEM
Oxygen Gas	Yes	Gas	U.S. Lab
Oxygen Gas I/F	line from storage vessel	I/F	JEM
Oxygen Gas I/F	Direct I/F from rack	I/F	U.S. Lab
Pressure	TBD (USER DEPENDENT)	PSIA	ESA
Pressure	TBD	PSIA	JEM
Pressure	TBD	PSIA	U.S. Lab
Ultrapure Water	Yes	Liquid	JEM
Ultrapure Water	Yes	Liquid	U.S. Lab
Ultrapure Water I/F	Direct I/F from rack	I/F	JEM
Ultrapure Water I/F	Direct I/F from rack	I/F	U.S. Lab
Vacuum Vent Port	TBD	Port	JEM
Vacuum Vent Port	Yes	Port	Spacelab
Vacuum-Vent Port	TBD-Access	Port	ESA
Vacuum-vent Port	Yes	Port	U.S. Lab
Waste Gas Port	Yes	Port	ESA
Waste Gas Port	Yes	Port	JEM
Waste Gas Port	Yes	Port	Spacelab
Waste Gas Port	Yes	Port	U.S. Lab
Waste Liquid Port	Yes	Port	ESA
Waste Liquid Port	Yes	Port	JEM
Waste Liquid Port	Yes	Port	Spacelab

Table 2.2-3 Rack Comparison - Thermal and Fluid Interfaces

PARAMETER	VALUE	UNITS	MODULE
Waste Liquid Port	Yes	Port	U.S. Lab

Table 2.2-4 Rack Comparison - Data Management and Video Interfaces

PARAMETER	VALUE	UNITS	MODULE
Bus Frequency	1	MHz	ESA
Bus Frequency	1	MHz	JEM
Bus Frequency	4.2	MHz	Spacelab
Bus Frequency	1	MHz	U.S. Lab
Bus Time	10	Microsec	ESA
Bus Time	10	Microsec	JEM
Bus Time	10	Microsec	U.S. Lab
Data Rate JCP	TBD	MBPS	JEM
Data Rate MDM	1	MBPS	U.S. Lab
Data Rate RAU	5.12	KBPS	Spacelab
Data Rate SDP	10	MBPS	U.S. Lab
Data Rate SPC	4	MBPS	JEM
Data Rate STAU	1	MBPS	ESA
Data Rate STP	TBD	MBPS	ESA
High Data Rate	32	MBPS	ESA
High Data Rate	100	MBPS	JEM
High Data Rate	50	MBPS	Spacelab
High Data Rate	1	GBPS	U.S. Lab
LAN I/F JCP	Yes	I/F	JEM
LAN I/F MDM	Yes	I/F	U.S. Lab
LAN I/F SDP	Yes	I/F	U.S. Lab

Table 2.2-4 Rack Comparison - Data Management and Video Interfaces

PARAMETER	VALUE	UNITS	MODULE
LAN I/F SPC	Yes	I/F	JEM
LAN I/F STAU	Yes	I/F	ESA
LAN I/F STP	Yes	I/F	ESA
Proc. Cap. JCP	TBD	MIPS	JEM
Proc. Cap. MDM	0	MIPS	U.S. Lab
Proc. Cap. SDP	4	MIPS	U.S. Lab
Proc. Cap. STAU	0	MIPS	ESA
Proc. Cap. STP	TBD	MIPS	ESA
Proc. Cap. STP	0	MIPS	JEM
UPDP Data Rate	TBD	I/F	ESA
UPDP Data Rate	TBD	MBPS	JEM
UPDP Data Rate	TBD	I/F	U.S. Lab
UPDP LAN I/F	Yes	I/F	ESA
UPDP LAN I/F	Yes	I/F	JEM
UPDP LAN I/F	Yes	I/F	U.S. Lab
UPDP Proc. Cap.	TBD	MIPS	ESA
UPDP Proc. Cap.	TBD	MIPS	JEM
UPDP Proc. Cap.	TBD	MIPS	U.S. Lab
Video Inst. Tape Recorder	2	VITR	Spacelab

Table 2.2.5 Comparison of Spacelab and Space Station Experimentation Factors

	Spacelab	Space Station
Available Time on Orbit	Fixed, limited (10 days)	Variable, 20-180 days
Crew Participation Scheduling:	Crew intensive, fixed to optimize mission	Variable, to optimize science
Timeline:	Inflexible	More Flexible
Science training:	Mission specific	General per objectives
Instrumentation:	Mission specific	General capabilities
Consumable supplies:	Limited, specific, non-renewable	Extended, comprehensive, renewable
Science return on Investment:	Expensive, high risk	Comparatively economical (lower risk)
Time in Service	Mission Flight Time (7-10 days)	20-30 years
Implementation Lead Time for New Expt's	Typically 2-5 years	6 mos-2 years

3.0 Trade Study Database

The trade study database has been implemented on the dBase IV program by Ashton-Tate. The database definition including a database dictionary is provided in Appendix D.

3.1 Database Files

Four types of dBASE IV files were created for the Space Biology Initiative (SBI) Trade Studies database. These files are database files, index files, report files and view files. Database files have the file name extension dbf. A database file is composed of records and records comprise fields which contain the data. Index files have the file name extension ndx. Index files are used to maintain sort orders and to expedite searches for specific data. Report files have the file name extension frm. Report files contain information used to generate formatted reports. View files contain information used to relate different database (dbf) files. View files link different database files into a single view file.

3.2 Database Management

The development of the SBI Trade Studies database consist of two major steps, logical database development and physical database development. Defining attributes and relationships of data was the major emphasis of the logical database development. The attributes and relationships of the data were determined after analysis of available data and consultation with other SBI team members. Based on the knowledge from the logical database development, the physical structure of the database was developed and implemented on a computer. Setting up the database on a computer was the second major development process. The first step of this process was to determine how to store the data. dBASE IV allows data to be stored as character, numeric, date or logical data types. The second step was to create the database files. After the database files were created, the actual data was entered. For a complete listing of the database structures see Appendix D.

3.3 Database Use

To the maximum extent possible, data generated in performance of this trade study was stored in the database. This approach not only facilitated analysis and comparison of trade data, but also enabled the efficient publication and editing of tables and figures in the study report. In addition, the data are available in the database for future evaluation using different screening logic and report organization.

4.0 Documentation Survey

A literature review and database search were conducted immediately upon study initiation. Library searches were make using titles, authors, key words, acronyms, phrases, synonyms, time periods and any possible (both in-person and by telephone) having knowledge of the study subject activities. Interviews with personnel were make throughout the initial portion of the study.

4.1 Documentation Sources

4.1.1 Complete SBI Trade Study Bibliography

The complete list of all references used in the four Eagle Engineering, Inc. trade studies is provided in Appendix B. A unique SBI reference index number has been assigned to each information source and was used to identify references in these trade studies. For more information on a referenced source, locate the source by SBI number in Appendix B.

4.1.2 Rack Compatibility Trade Study Bibliography

Particular reference information from Appendix B that is of special importance to module rack compatibility was repeated and compiled in Table 4.1.2. This rack compatibility bibliography shows the references that were used for the modules rack compatibility analysis.

4.2 Documentation Data

This section summarized existing data from documentation sources for the data used in this Rack Compatibility Trade Study. Brief descriptions of the individual U.S. Lab Module, ESA Columbus Module, JEM Module, Spacelab and Shuttle Orbiter payload accommodations are provided.

4.2.1 U.S. Module

The United States laboratory module is a pressurized module of the Space Station Freedom. Information on the U.S. laboratory module was obtained mainly from the multilateral utilization study entitled "Station Interface Accommodations for Pressurized and Attached Payloads", SBI# 02, and from the notes of the U.S. Lab Review Workshop, SBI# 86. More detailed information on documentation sources can be found in the bibliography in section 4.1. Figure 4.2.1-1 shows a fully outfitted U.S. standard equipment rack.

4.2.1.1 Electrical Interfaces

The U.S. laboratory module will provide 120/208 VDC at 60 Hz. potential. Power available is 3 KW, 6 KW, or 15 KW, depending on experiment location. The current is 15 A, 30 A, or 75 A, also depending on the location. Program provided power converters are 28 VDC, 120 VAC, 60 HZ, single phase.

4.2.1.2 Data and Video Interfaces

The U.S. laboratory module provides multiplexer/demultiplexer (MDM), standard data processor (SDP), and user supplied data processor interfaces to the payload local area network (LAN). The data rates are 1 MBPS for the MDM, 10 MBPS for the SDP, and TBD for the user supplied data processor. The U.S. lab module provides a high rate fiber optic link via direct patch with up to 1 GBPS capability. The time and frequency bus has 10 microseconds accuracy relative to universal time at 1 megahertz frequency.

4.2.1.3 Thermal and Fluid Interfaces

The U.S. laboratory module supplies both liquid cooling interfaces and air cooling interfaces for experiment payloads. The liquid cooling interfaces are to station-provided coldplates (0.4 KW, 0.6 KW, 1 KW) or rack interface heat exchanger (8 KW). The coolant is single phase water at a low temperature loop of 4 to 21 °C (40 to 70°F) or at a high temperature loop of 21 to 50°C (70 to 122°F). The liquid cooling capacity is up to 15 KW at a rack. This is location dependent.

Air cooling interfaces in the U.S. laboratory module are supply air duct/diffusers and an air duct to payload drawer. Both air cooling ducts have rates which have not been determined at this time. The air cooling capacity is 1.5 KW nominal and 3.0 KW maximum cooling per rack. Fluids available to the payload are: Ar, He, O2, CO2, H, and N2.

4.2.2 ESA Module

The European Space Agency's (ESA) Columbus Attached Pressurized Module (APM) internal architecture is adapted to a laboratory configuration. Information on the ESA module was obtained from the Columbus Reference Configuration Report, SBI# 51, and the Multilateral Utilization Study (MUS) entitled "Station Interface Accommodations for Pressurized and Attached Payloads", SBI# 02. For more details on a referenced source, see the bibliography information in Section 4.1. Payload accommodation is provided at the rack locations as per Figure 4.2.2-1. Payloads can be replaced in total (with instruments integrated) or on drawer level as necessary.

4.2.2.1 Mechanical and Structural Interfaces

The locations labeled in Figure 4.2.2-1 as "P/L" provide the following volume per racks for payload accommodation:

lateral (right/left)	12 double size racks (DR)	$=16.8\ m^3$
lateral (right/left)	3 single size racks (SR)	$=2.1\ m^3$
ceiling	7 double size racks	$=9.8\ m^3$
ceiling	1 single size rack	$=0.7\ m^3$

Each single rack has a volume of 0.7 cubic meters, and each double rack has a volume of 1.4 cubic meters. Storage locations are shown in Figure 4.2.2-1. Payload storage of 2.8 m^3 is available in two lateral (right/left) double racks. This includes two single racks for hatch inclusion. The general purpose work bench (GPWB) and airlock stowage is also payload dedicated for 3.5 m^3 of stowage. The total volume available for payload experiments and stowage is:

29.3 m^3 P/L accommodation (in racks) net volume 21 m^3
2.8 m^3 P/L storage
3.5 m^3 GPWB and P/L

4.2.2.2 Electrical Interfaces

The ESA Columbus module provides the following electrical interfaces:

Lateral double rack (max. 3 per side)	2000 watts/average 3000 watts/average
Lateral single racks	1000 watts/average 1500 watts/peak
Ceiling rack	750 watts/average 1000 watts/peak
Power level	120 VDC +1/-3, 5% at I/F

Remark: Above power is available only within the 10 kw average and 12 kw peak when supplied by the Space Station to the attached pressurized module.

4.2.2.3 Thermal and Fluid Interfaces

Heat dissipation per experiment rack is in line with the electrical power distribution. In the ESA Columbus module, ceiling racks have only air cooling and lateral racks have air and water cooling. Payload vacuum and venting is 1 paper each interface line in lateral racks only.

4.2.2.4 Data Interfaces

The following experiment data is supplied to the Payload Data Bus:
1 MPS via NIU network node
300 KPS via STAU network node

Two network nodes per single rack equivalent are projected. Experiment high rate data multiplexer interface is 32 MPS. Payload application video data has not been determined.

4.2.3 JEM Module

The Japanese Experiment Module (JEM) is a pressurized Space Station Freedom module. Information on the JEM module was mainly obtained from the multilateral utilization study entitled "Station Interface Accommodations for Pressurized and Attached Payloads", SBI # and from a briefing handout entitled "NASDA Standard Rack Envelope Study Status", SBI# 02. For more details on a referenced source, see the bibliography information in Section 4.1. Figure 4.2.3-1 illustrates the JEM module internal layout.

4.2.3.1 Mechanical and Structural Interfaces

The JEM module equipment racks measure 74.5"h x 41.5"w x 32.5"d, or 1892.3 mm x 1054 mm x 914.4 3 mm. Internal module diameter is 157.5 inches, or 4 meters. JEM modules plan to use double racks; the use of single racks has not been determined.

4.2.3.2 JEM Electrical Interfaces

The JEM module will be equipped with 120 VDC potential. The JEM module provides two lines of 3 KW of power at 25 A.

4.2.3.3 Thermal and Fluid Interfaces

The JEM module supplies both a liquid cooling interface and an air cooling interface through a station-provided coldplate. Cooling capacity has not been determined. The coolant is single phase water with inlet temperatures of 25-30°C (77-86°F) in the high temperature loop, 8-10°C (46-50°F) in the medium temperature loop, and 2°C (36°F) in the low temperature loop. The liquid cooling capacity is 6 KW per rack. Fluids available to the payload are: Ar, He, Kr, N_2, O_2, CO_2, and dry air.

4.2.3.4 Data and Video Interfaces

The JEM module provides signal processing converter (SPC), JEM control processor (JCP), and user provided data processor interfaces to the payload local area network (LAN). The signal processing converter provides a data rate of 4 MBPS. Data rates for the JEM control processor and user supplied data processor have not been determined. Processing capabilities are also not established at this time. The JEM module provides a high data rate of 100 MBPS via direct patch. The time and frequency bus has 10 microseconds accuracy relative to universal time and 1 megahertz frequency.

4.2.4 Spacelab Module

The Spacelab module is a pressurized module flown in the cargo bay of the Shuttle Orbiter. Information on the Spacelab module was mostly obtained from "Spacelab Configurations", SBI# 56. Spacelab Mission 4 Integrated Payload Requirements Document, SBI# 27, and the Spacelab Payload Accommodations Handbook, SBI# 92. For more details on a referenced source see the bibliography information in Section 4.1.

The Spacelab pressurized module provides a controlled environment for users and their equipment. In defining Spacelab accommodations, it should be noted that throughout the on-going Spacelab programs, interfaces and capabilities are being redefined, updated, and planned.

There are two basic configurations for the module, which contains two double racks and one single rack per side. The second configuration is the long module. The long module contains four double racks and two single racks per side. For the purposes of this study, we will concentrate on Spacelab Mission 4, also called Spacelab Life Sciences - 1, or SLS-1. Figure 4.2.4.1 shows a view of the SLS-1 module.

4.2.4.1 Mechanical and Structural Interfaces

Each module is divided into two segments, the core segment and the experiment segment. In the case of a long module, the core segment is the forward half of the module, consisting of five single-rack widths, and the experiment segment is the rearward half of the module also consisting of five single-rack widths. Within the core segment of the long module, the forward two rack widths are designated as subsystem and the other three widths are designated experiment. Those areas designated as subsystem are used to accommodate the Spacelab systems hardware and standard Spacelab equipment (i.e., Mass Memory Unit, Intercom Master Station, High Data Rate Recorder (HDRR), tools). The three rack spaces designated experiment may also be used to accommodate subsystem equipment if the need for space arises. Such is the case with the use of rack 4 for subsystem equipment when flying a long module. Within the experiment segment all rack space is allocated to the payload.

The short module is simply the core section of the long module. The allocations of the rack spaces are identical to those in the long module core segment: two rack widths designated subsystem and three rack widths designated experiment.

4.2.4.1.1 Accommodations For Floor-Mounted Experiments

The floor of the Spacelab provides support and mounting attach points for standard experiment racks and/or experiment equipment. The center panels of the floor are known as the center aisle. A certain volume envelope, known as the payload envelope, has been established in the center aisle for accommodating floor-mounted experiments. The center aisle is also outfitted to provide for the use of some Spacelab resources. Cutouts in the center aisle provide for Electrical Power Distribution System (EPDS)/Command and Data Management Subsystem (CDMS) interface through a connector bracket which provides power and support for an experiment Remote Acquisition Unit, Environmental Control Subsystem (ECS) interface through a cutout for cabin loop airflow, and Experiment utility interface through a cutout with attachment provisions for an experiment-provided connector bracket.

4.2.4.1.2 Experiment Racks

Experiment racks are standard 19-in. wide racks provided to accommodate standard as well as nonstandard equipment. These racks are mission-dependent Spacelab subsystem equipment and can be removed if required. Experiment equipment can be mounted using the same attachment points in the floor and the overhead structure. Two types of racks are available: single racks with an overall width of 563.5 mm and double racks with an overall width of 1052 mm. Both types of racks are 760 mm deep at their greatest depth and 1892.3 mm high. A double rack of standard configuration is shown in Figure 4.2.4-2.

The following Spacelab mission-dependent subsystem equipment (MDE) may be located within some racks:

One Experiment Power Switching Panel (EPSP) may be included per rack if elements within the rack require power.

One Remote Acquisition Unit (RAU) may be used when experiment requires downlink of data or an interface with the experiment computer.

One experiment heat exchanger and one experiment-dedicated coldplate, may be located only in rack 4.

Remote intercom stations may be located only in racks 4,7, and 10.

Air cooling systems and fire suppression systems are located within all racks that require power.

4.2.4.1.3 Rack Numbering

For ground processing and integration purposes, the spacelab racks are numbered 1 through 12. This rack numbering system is shown in Figure 4.2.4-3.

4.2.4.1.4 Allowable Envelope

Experiments that require no standard Environmental Control System (ECS) cooling ducts, fire suppression, or rear struts for cabling attachments, may use the entire internal depth allowed by the basic rack structure.

4.2.4.2 Electrical Interfaces

Electrical power constraints for Spacelab SLS-1 based on fuel cell capability and thermal constraints are:

7.8 KW maximum continuous
11.4 KW peak for 15 min. (limited to once every 3 hours)

The following voltages are provided:

24 V to 32 VDC power
115 V to 200 V_{rms} AC power, 400 HZ

Power for racks is received through the Electrical Power Distribution System (EDPS). The EDPS receives its DC power from a dedicated Orbiter hydrogen/oxygen fuel cell through the

Orbiter bus system which is connected to the Spacelab emergency box. The AC power is generated from the dc main power by the Spacelab inverters. This power (AC and DC) is distributed to the Experiment Power Switching Panels (ESPS). These panels represent the power interface for experiments in the racks and to dedicated connector brackets in floor cutouts for experiments on the center aisle. Power flow diagrams and specific power characteristics can be found in the Spacelab Payload Accommodation Handbook (SBI #92).

4.2.4.3 Thermal and Fluid Interfaces

Spacelab racks are cooled by the avionics air loop. The avionics air loop has a heat exchanger located in the subfloor. The airflow distribution may be adjusted to the specific payload needs by means of rack shutoff valves located at the bottom of all racks.

4.2.4.4 Data and Video Interfaces

The Spacelab 4, SLS-1 mission requires 3 experiment Remote Acquisition Units (RAU's). High rate serial data is acquired via the 16 experiment input signals of the High Rate Multiplexer (HRM). Data acquired by the Subsystem Computer and Experiment Computer are downlinked via the HRM. Input rates accepted by the HRM must be 1.31 KBPS to 500 KBPS. Data will be downlinked from the HRM at 1 MBPS.

Spacelab 4 provides experiments with the capability for real-time downlinked video. The MDE Video Switch has 14 video/analog switch inputs and 9 outputs. Only 1 channel of video data may be transmitted at a time, due to bandwidth limitations in the KU-band downlink, Time signals originate in the Orbiter Master Timing Unit (MTU) and are sent to Spacelab via the Payload Timing Buffer.

4.2.5 Shuttle Orbiter

Information on the Orbiter Middeck and Aft Flight Deck payload accommodations was obtained mainly from "Shuttle/Payload Interface Definition Document for Middeck Accommodations", SBI# 52, and from "Spacelab Configurations", SBI# 56. For more details on a referenced source, see the bibliography information in Section 4.1. Payloads may be located in the Middeck in the following three areas:

a. AFT surface of wire trays of Avionics Bays 1 and 2.
b. Forward surface of wire trays of Avionics Bay 3 A.

Payloads shall be attached to the surface of the wire trays forming bulkheads of Avionics Bays Number 1,2 and 3 A. See Figure 4.2.4-1 for middeck locker layout.

Often Life Science experiments require Orbiter Middeck stowage. Middeck stowage is ideal for items to be stowed for a Spacelab mission which must be loaded into the Orbiter late and offloaded early to preserve them. Some examples would be live plants and animals; temperature-critical items such as biological samples which must be refrigerated; and time-critical items which would exceed their shelf life if loaded at Spacelab closeout.

4.2.5.1 Mechanical and Structural Interfaces

Middeck payload mounting provisions shall consist of standard modular stowage locker accommodation or Middeck Payload Accommodations Kit (MPAK). The maximum weight of a payload which is to stowed in a modular stowage locker shall not exceed 54 pounds. The maximum weight of the payload, the stowage locker shell, stowage trays, and protective provisions, such as dividers, bungees, and vibration isolating foam shall not exceed 70 pounds. Payloads that cannot be stowed inside trays shall be stowed directly in a locker, provided the payload is isolated from vibrating contract with the locker and has zero "g" retention for on-orbit activities. Payloads, where possible, should be designed to the size and shape of a small or large stowage tray. A standard Modular Stowage Locker provides 2 cubic feet of stowage volume. Figure 4.2.4-2 shows a Middeck locker and typical stowage packaging.

Some panel area and volume in the Orbiter aft flight deck are available to support Spacelab payload operations. The aft flight deck is divided into three workstations: the mission station, the on-orbit station, and the payload station. The payload station and part of the on-orbit station are dedicated to experiment operation. The following paragraphs summarize the payload accommodations in the aft flight deck. See Figure 4.2.4-3 for panel locations.

4.2.5.2 Electrical Interfaces

Orbiter Main DC electrical power is available to payloads via ceiling outlet connectors. Power shall be available for periods up to 8 hours in duration during on-orbit operations. No power shall be available during ascent and/or descent mission phases. Circuit protection for the middeck ceiling outlets is provided by 10 amp circuit breakers (derated to 9.5 amps) which also shall protect flight deck utility outlets. In order to allow mixing with other standard Middeck payloads, power usage is limited to a maximum of 5.0 amps (approximately 115 watts). The payload will be limited to the use of only one middeck utility outlet at any one time. All payload wiring connecting to Orbiter power sources shall be sized to be consistent with appropriate circuit protection devices. If a payload reduces the size of the wiring on its side of the interface, additional current limiting devices must be provided.

4.2.5.3 Thermal and Fluid

Payload waste heat shall be considered dissipated to cabin air. A payload may be cooled with or without payload provided capability to internally circulate cabin air during on-orbit operations. Payloads which are required to operate during EVA or EVA pre-breathe periods shall design cooling based on 10.2 psia cabin pressure. Payloads generating waste heat and not incorporating in the design a means of rejecting this heat to the cabin air by means of a fan or similar means shall be constrained to a maximum continuous heat load in the standard stowage locker of 60 W. The design value for the free convective heat transfer coefficient shall be 0.25 Btu/hr F ft^2 for 14.7 psia or 0.17 Btu/hr F ft^2 for 10.2 psia cabin pressure.

When a payload provides an air circulation fan which discharges to the cabin, the maximum air outlet temperature shall not exceed 120°F. The forced cooling design shall be compatible with investment of contamination from the cabin or provide protection from that contamination. Additionally, the cooling system shall not contribute to further contamination of the cabin.

4.2.5.4 Data and Video Interfaces

Panels R7 and L11 can be fully dedicated to Spacelab hardware. A Spacelab Data Display System (DDS) with a keyboard can be accommodated in L11. Additional Spacelab hardware is located in the lower portion of L16 and L17 marked "additional volume for electronics" in Figure 4.2.4-3. A second DDS for the Spacelab payload can be installed in the mission station at panel R11.

Table 4.1-2 Bibliography for Rack Comparision Trade Study

ID #	AUTHOR	TITLE	VOL., NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SB102	Kozarsky, D.	Latest Space Station Rack Studies		NASA MSFC		Huntsville, AL.	02/02/89
SB151	NASA JSC	Columbus Reference Configuration Report		NASA JSC	RP 1213800000	Houston, TX.	05/31/88
SB152	NASA HQ	Shuttle/Payload I/F Definition Document for Middeck Accomodations		NASA HQ	NSTS 21000	Washington, DC	03/01/88
SB153		Rack Accomodations Users Manual					/ /
SB168	Hamaker, Joe	Telephone interview relating to MSFC history and techniques for cost estimating.		Cost Analysis Branch Chief MSFC		Huntsville, Al.	04/27/89
SB179	Booker, Clef	Personal Interview - Minaturization on amplifiers, computers and modularity		NASA JSC/SP 341 Man-System Division		Houston, TX.	04/04/89
SB191		NASDA Standard Rack Envelope Study Status		NASDA			/ /
SB192		Spacelab Payloads Accomodations Handbook		NASA MSFC	SLP/2104	Huntsvillle, Al.	08/16/85
SB193		Station Interface Accomodations for Pressurized and Attached Payloads		NASA			02/01/89
SB194		Life Sciences Study for the Space Station		Management and Technical Services Co.		Houston, TX.	08/01/84
SB195	Crenshaw, John	Personal Interview with John Crenshaw - Discussion of standarized avoins (mounted on racks) in airlines.				Houston, TX.	05/16/89

Figure 4.2.1-1 U.S. Standard Equipment Rack, Fully Outfitted

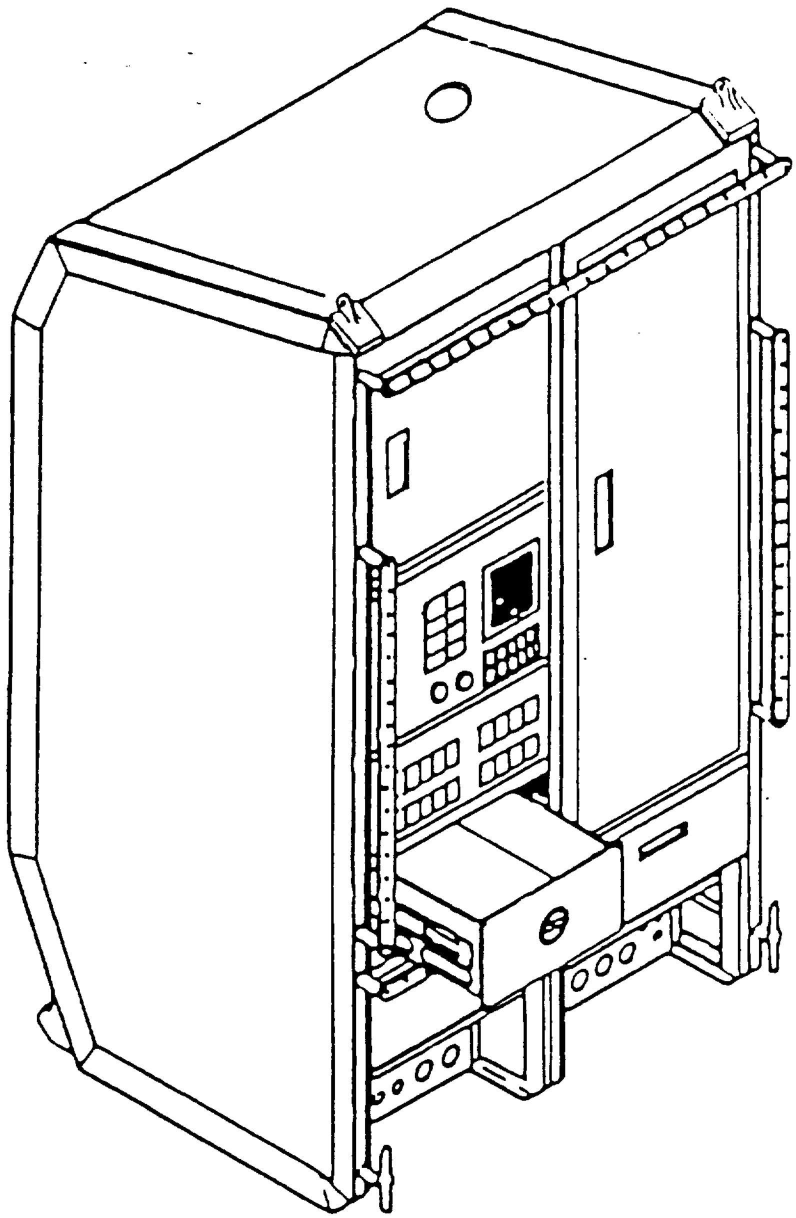


Figure 4.2.2-1 Payload/Experiment Racks as Distributed in the ESA Laboratory

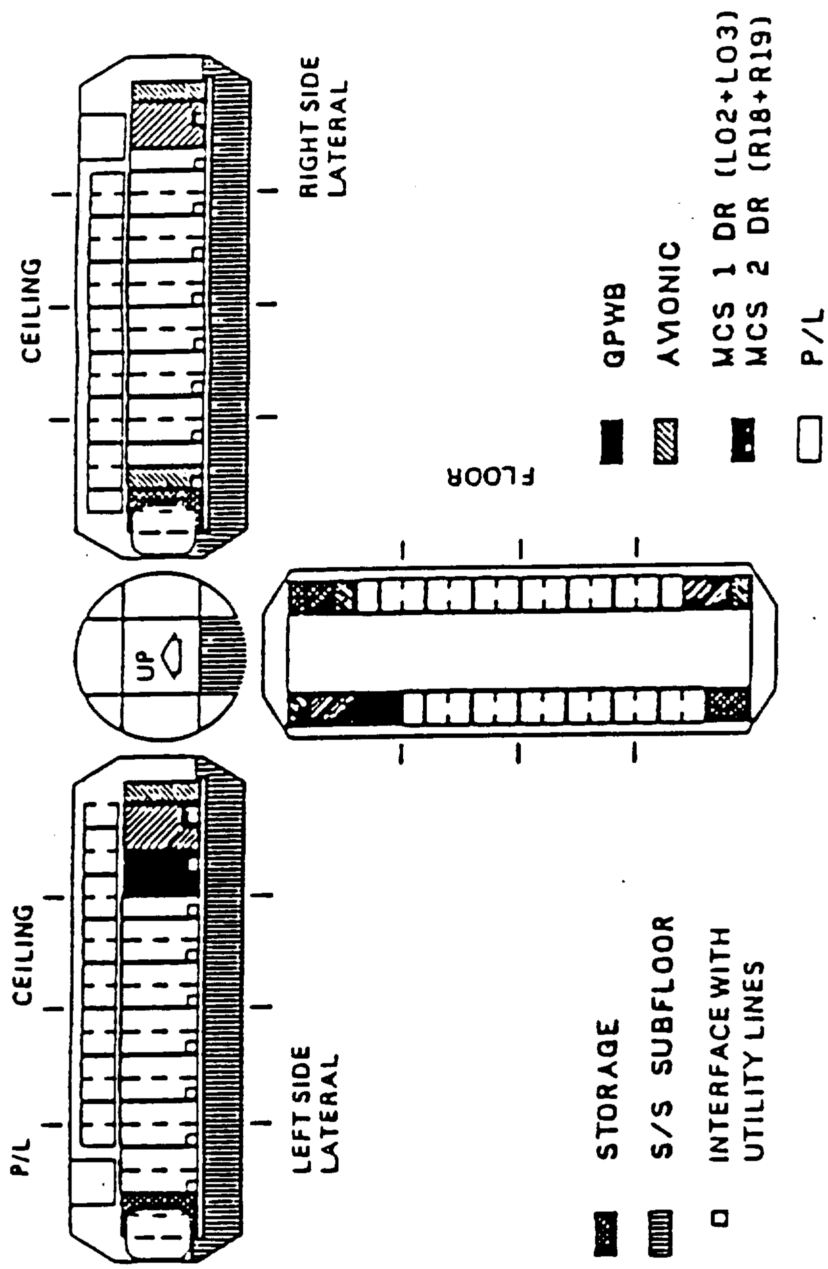


Figure 4.2.3-1 JEM Pressurized Module Internal Layout

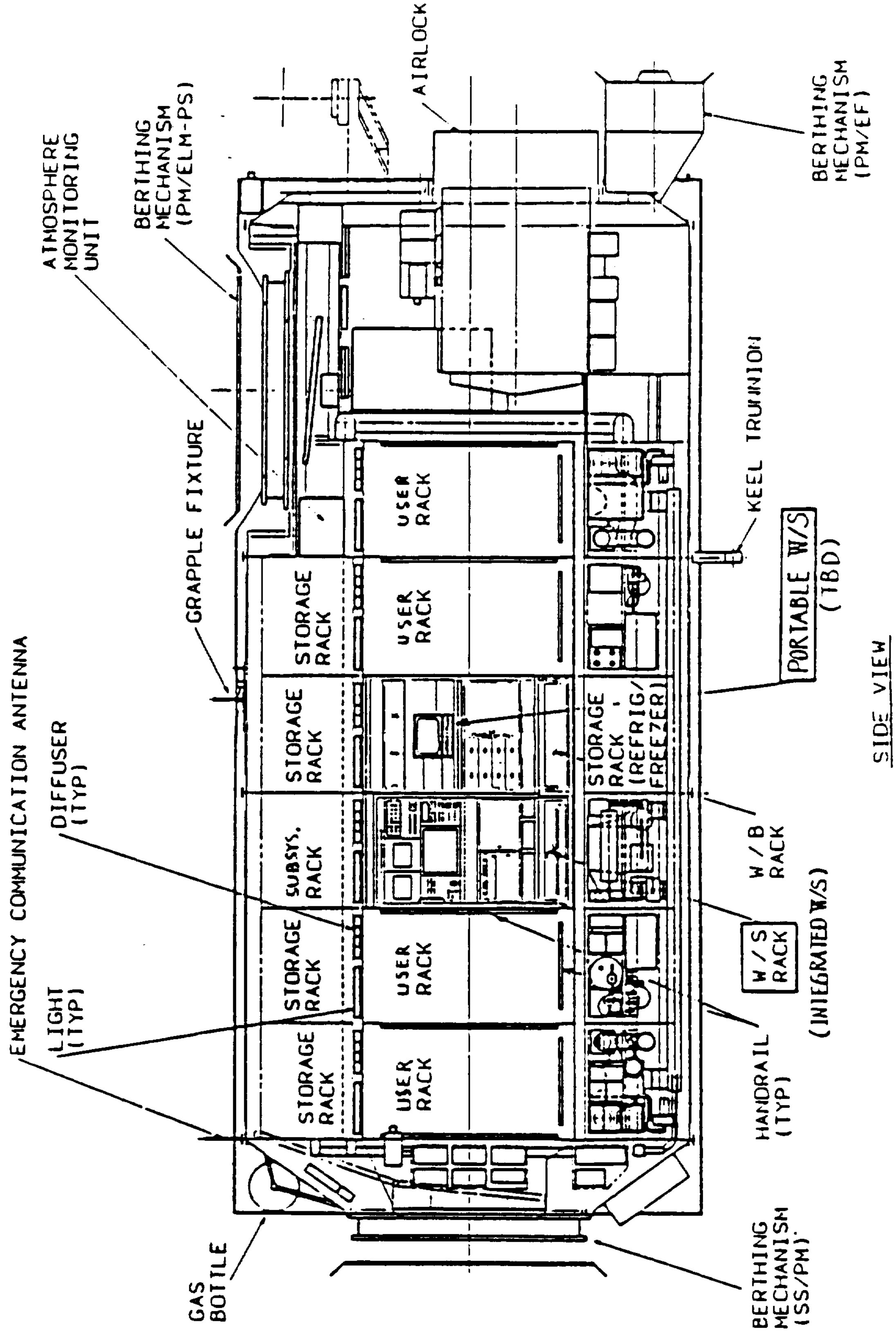


Figure 4.2.4-1 Spacelab Segments

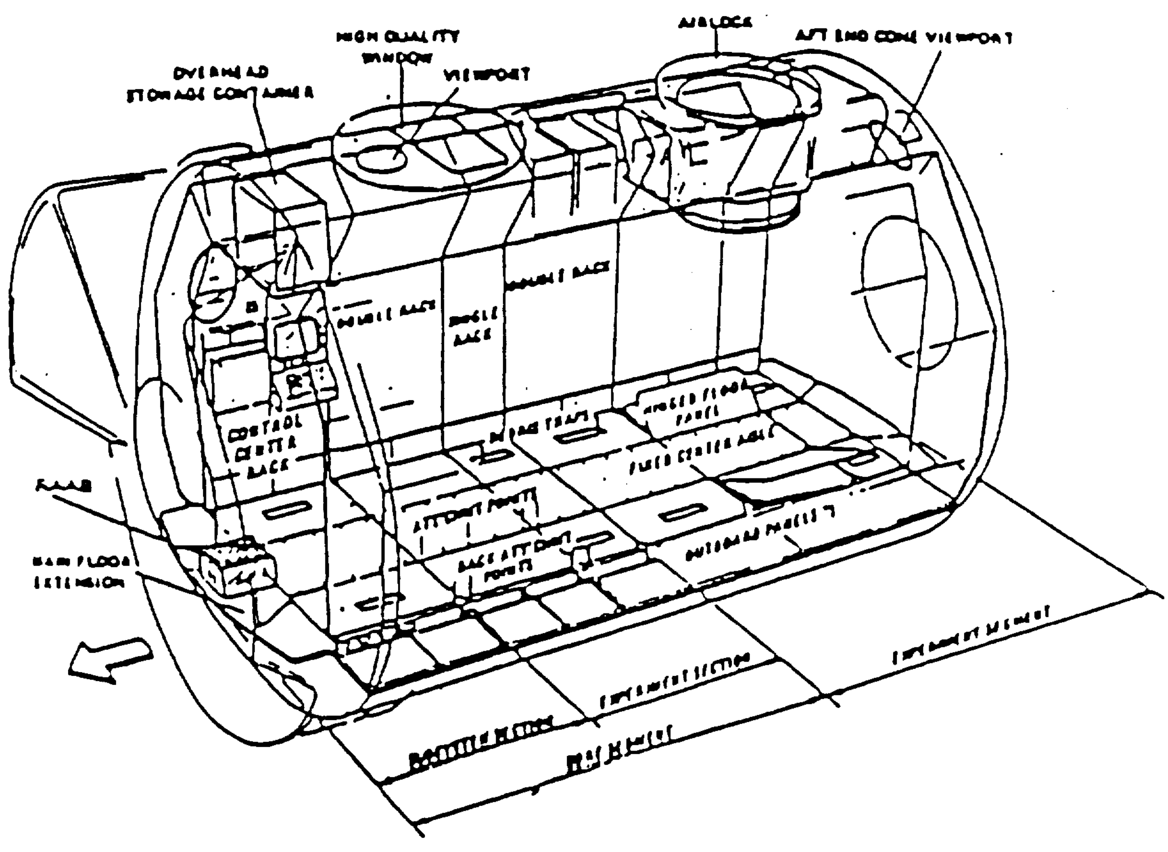


Figure 4.2.4-2 Spacelab Standard Double Rack

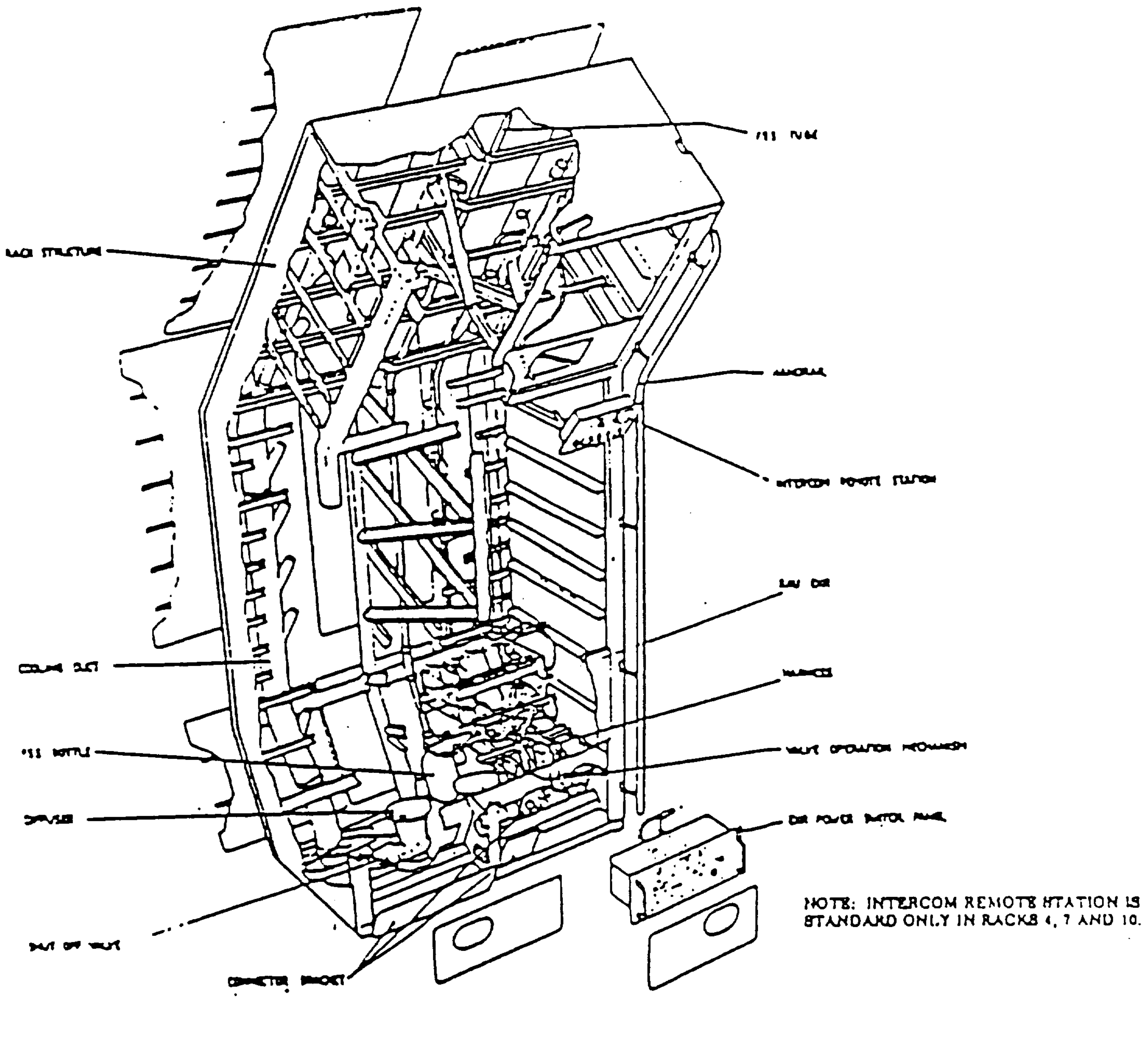


Figure 4.2.4-3 Spacelab Rack Numbering System

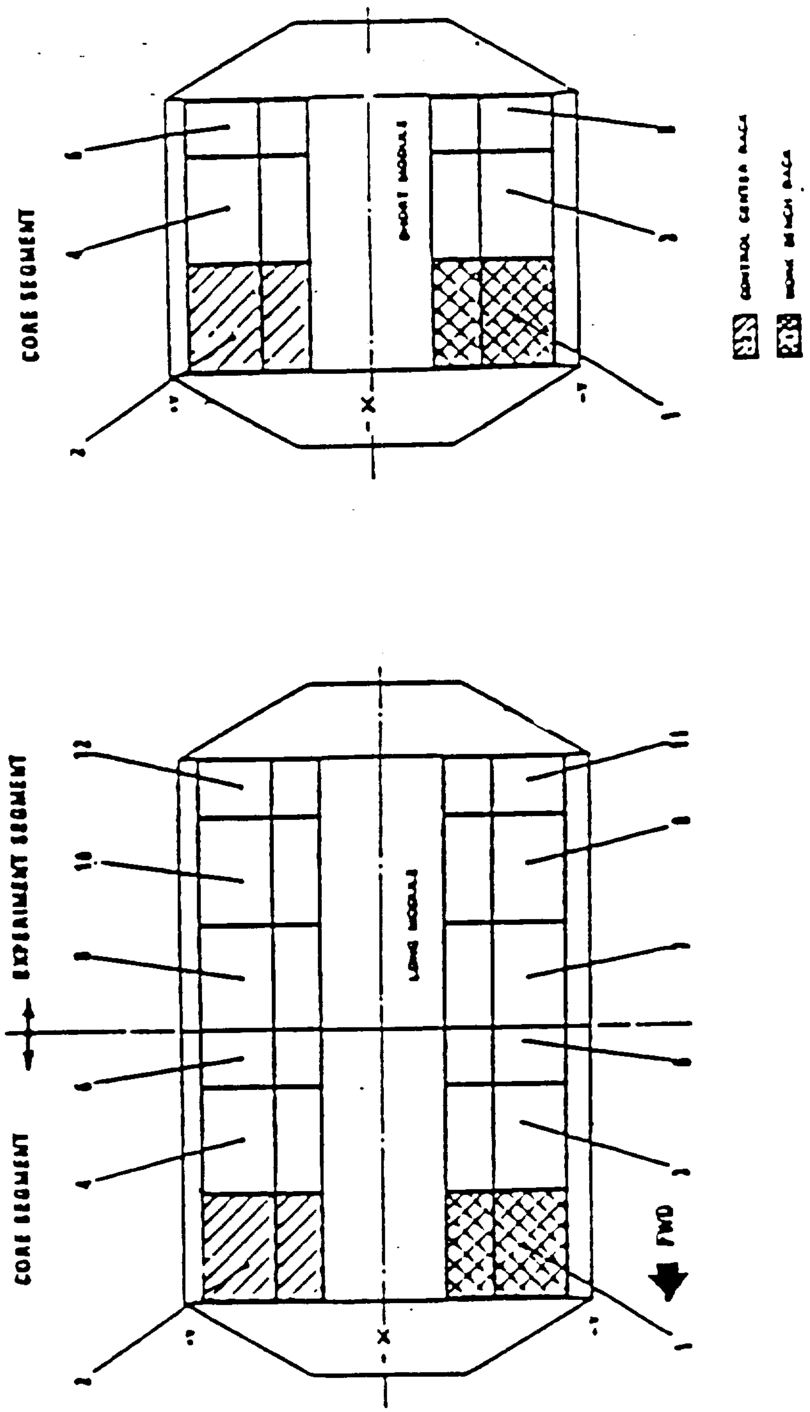


Figure 4.2.5-1 Orbiter Middeck Locker Layout

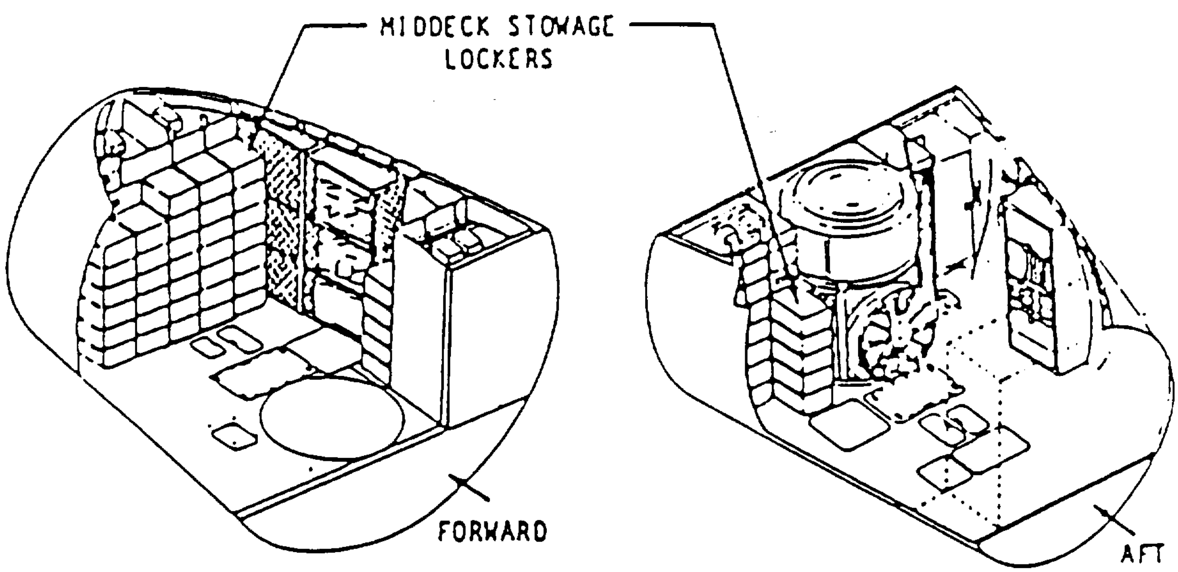


Figure 4.2.5-2 Middeck Locker and Typical Stowage Packaging

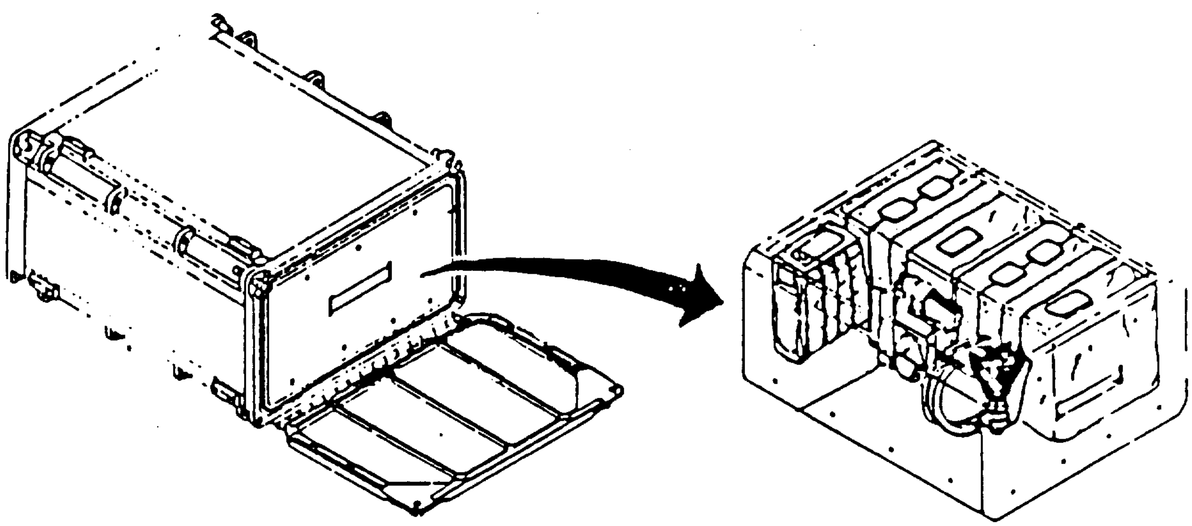
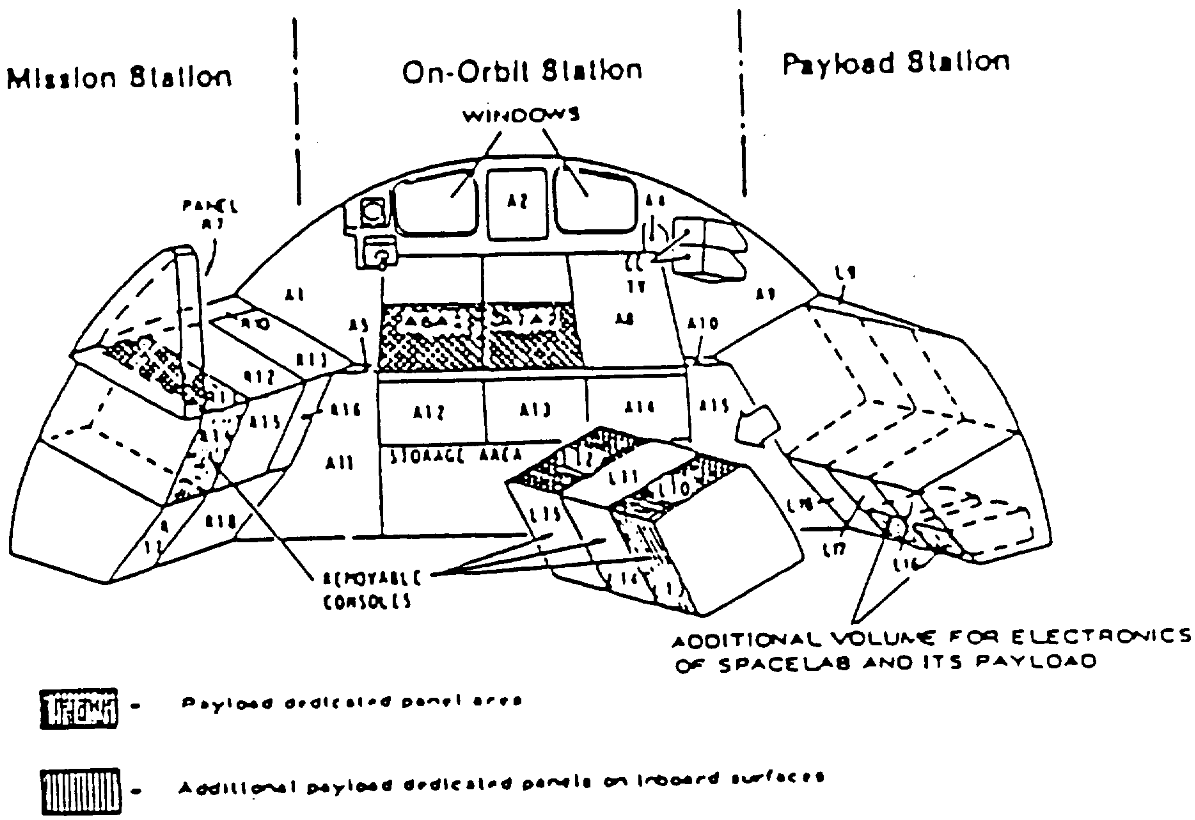


Figure 4.2.5-3 Orbiter Aft Flight Deck



5.0 Trade Study

5.1 Rack Matrices Development

Information was collected for Spacelab, Shuttle Orbiter, and the United States (US) module, the Japanese Experiment Module (JEM), and European Space Agency (ESA) Columbus module. This information included experiment-to-rack mechanical, structural, electrical, data, video, thermal, and fluid interfaces. Comparison matrices of these data were formed and given in the following tables:

Table 2.2.1 Mechanical and Structural Interfaces
Table 2.2.2 Electrical Interfaces
Table 2.2.3 Thermal and Fluid Interfaces
Table 2.2.4 Data and Video Interfaces

5.2 Rack Interface Feasibility Analysis

The feasibility of standard mechanical, structural, electrical, data, video, thermal, and fluid interfaces between SBI equipment and spacecraft systems are being studied at NASA's Johnson Space Center. This section considers the work of the Experiment Standard User Interface Study, SBI# 39, by the JSC Life Sciences Project Division, William G. Davis, Technical Manager. The information in this section is taken from the July 1988 Progress Report. For the purposes of this trade study, the Experiment Standard User Interface Study may be referred to as simply the Interface Study.

5.2.1 Mechanical and Structural Interfaces

Mechanical problems can arise during installation of experiment systems into racks. The basic problem of dimensional variations from one rack to another rack is very difficult to avoid in large sheet metal structures such as the Spacelab racks and probably the Space Station racks, according to the Interface study. An objective of the Interface Study is to design, fabricate, and demonstrate a set of mechanical experiment interface assemblies that provide a standard mechanical user interface. The design as it is presently being developed will provide for installation from the front of the rack with no tools. The design also considers the problems that have arisen in the area of stress analysis and will provide a mechanical mounting system that have positive margins when analyzed for STS launch and landing loads.

Figure 5.2.1, Spacelab/Space Station Panel Units, illustrates Spacelab and Space Station racks broken down to the panel unit (PU) level. One panel unit = 1.75 inches. The Spacelab Lower rack (34 PU's) and the Space Station rack (35 PU's) are sufficiently similar to utilize the Lower Spacelab rack for initial hardware comparison studies. A concept of the Interface Study is to develop standardized interfaces which may be demonstrated and tested in a Spacelab single/double rack structure. These concepts may then be extended to the Space Station double rack without alteration of the basic concepts.

5.2.2 Electrical Interfaces

Another objective of the Interface Study is to provide the user with one type of power at the experiment-to-rack interface in the Spacelab rack, the US Lab Module, the ESA module, or the Japanese module. At present, the power available to the Spacelab experiments is 28 VDC and 115 VAC 400 HZ. Conversion of the basic 208 VAC 20 KHz power source to one or two of the more common types, (e.g. 28 VDC and 115 VAC 400 HZ) seems to be a reasonable standardization. The Interface Study recommends using 28 VDC and 115 VAC based on the amount of experiment development that has taken place with 28 VDC power and the fact that Spacelab is already configured in this way.

5.2.3 Thermal and Fluid Interfaces

A cooling concept intended to simplify the experiment-to-spacecraft cooling interface from the rather complex direct hose coupling method used on Spacelab is shown in Figure 5.2.3. The object of the proposed experiment cooling is for the experiment to exchange its heat load with the air within the rack structure, and the Spacelab avionics system cools the circulated air. The experiment housing would utilize internal fans to remove the heat load. Initial analysis in the Interface Study shows that this heat exchange process is practical in a Spacelab rack. Details of this analysis work is shown in Appendix C of the Experiment Standard User Interfaces Study, SBI #39. Development tests will include the operation of one of the LSPD mockup Spacelab racks with several controllable heat load sources in experiment type chassis mounted in the rack using cooling fans to transfer the experiment heat load to the rack air volume. The Space Station rack cooling mechanism is not fully defined at this time; therefore, study efforts were concentrated on new cooling techniques in a Spacelab rack.

Cooling fans were also investigated in the study. The fans have speed control based on either a temperature sensor input or by pulse width modulation from a microcomputer. Other aspects, such as cooling fan noise must also be considered. These aspects will be best evaluated using prototype experiment assemblies and various fan assemblies. Appendix D of the Experiment Standard User Interfaces Study provides information that on the evaluation and selection of fans.

5.2.4 Data and Video Interfaces

5.2.4.1 Data Interfaces

The Interface Study is investigating the use of a standard parallel data bus interface concept in each rack. This data bus interface concept could be used to route data from identified data ports within the rack to the spacecraft data system or could also route data from one experiment box to another. This would eliminate the necessity for many unique experiment box to experiment box to another. This would eliminate the necessity for many unique experiment-box-to-experiment-box cables. Several parallel data bus systems have been evaluated and the advantages and disadvantage of each are documented in Appendix B of the Experiment Standard User Interfaces Study, SBI #39. The report found that the IEEE-488 parallel data bus system appears to be a very practical data communications mechanism.

Each rack would incorporate a data interface module to route the data from the experiments and convert the data into the appropriate parallel data buss or serial data stream to be interfaced with the spacecraft data system. The data interface module could be reprogrammed to perform the various data routing functions that would be necessary when new experiments are installed in the rack. The data interfacing connector could be automatically connected to the data bus during the mechanical installation process.

5.2.4.2 Video Interfaces

The Experiment Standard User Interfaces Study made no specific recommendations for experiment to spacecraft video interfacing. The Interface Study cited the experience of the JSC Life Sciences Experiment Division with interfacing experiments with the Spacelab video system as good example of the difficulties that arise from the use of non-standard interfaces. The Interface Study's video objective is to allow the hardware developer to utilize standard input and output video circuits and specialized level shifting, and impedance isolation requirements. The fact that the Spacelab video system is analog and the Space Station system is planned to be fully digital will require a rather extensive evaluation to determine the practicality of a fully standardized video interface. The physical interfacing of experiment video input and outputs can be achieved through the same connector used for data transfer.

Figure 5.2.1 Spacelab/Space Station Panel Units

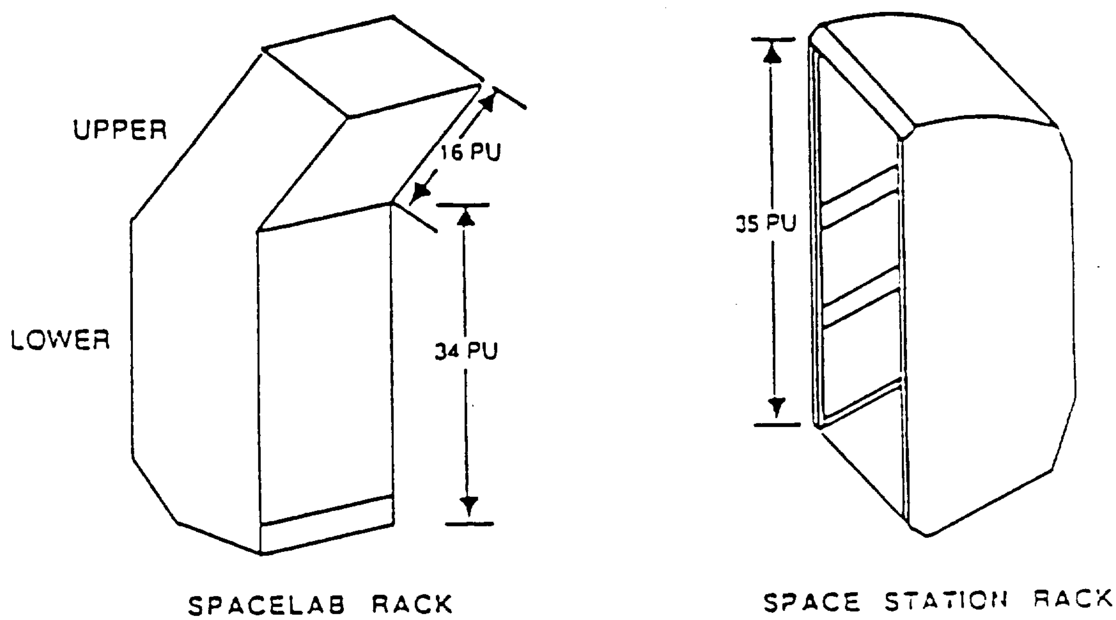
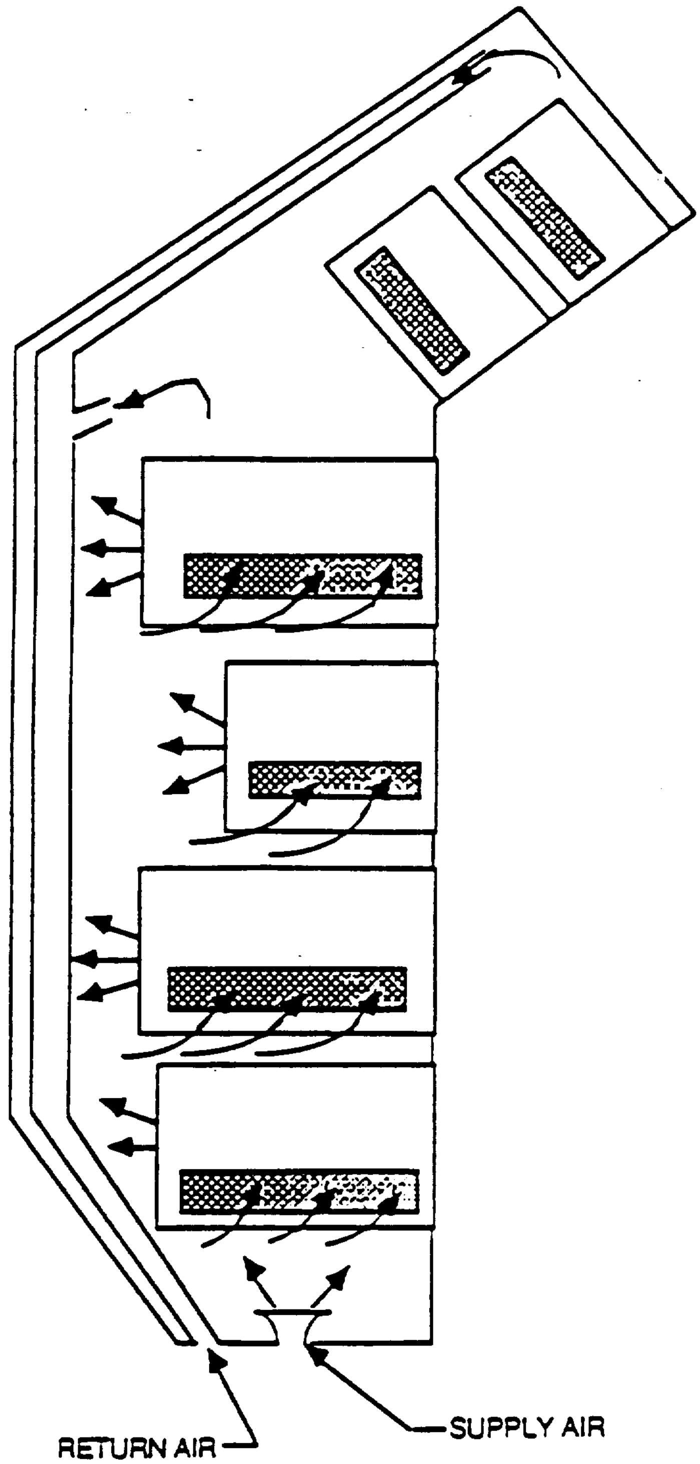


Figure 5.2.3-1 Spacelab Rack Cooling Concept



6.0 Conclusions

A set of standardized experiments-to-spacecraft interfaces would simplify the mechanical, cooling, and electrical interfaces between the experiment and the spacecraft systems. Standardized interfaces could make the installation and usage of experiments on Space Station, Spacelab and other missions as user-friendly and flexible as possible with a minimum weight and volume penalty. This standardization would also result in the following benefits.

6.1 Experiment Location Flexibility

Providing standardized interfaces in the Life Sciences Space Station experiment racks would allow the use of one experiment system in all three Space Station modules. The staging of the experiment racks with standard interfaces prior to launch of the racks would eliminate the limitations on experiment locations in the Station. Spacelab racks could also be outfitted with the same standard interfaces. This would allow the use of one experiment design on Spacelab or Space Station.

6.2 Experiment Changeout Ability

On Space Station Freedom several experiments will use the same rack for different experiments for varying lengths of time. The ability to replace part of the experiment systems in a rack during flight will be a significant factor in satisfying the needs of the individual experiments.

The amount of SBI science achieved can be enhanced by the ability to replace experiment systems at less than a full rack level. If the racks in the U.S., the ESA, and the Japanese Space Station modules do not have identical mechanical, electrical, and cooling interfaces, the flexibility of changing experiment locations within and among the modules will be lost. Interchangeability of location will be possible with the use of standardized user interface systems installed into the racks prior to launch.

Further studies should be done to define a set of standard experiment mechanical, electrical, data, and cooling interfaces between the equipment and the spacecraft systems.

6.3 Experiment Design Simplification

Standardized experiment-to-spacecraft interfaces would simplify the design of the experiment interfaces by the principle investigator or hardware developer. The video and data interface circuits that are required for proper interfacing with the present Spacelab subsystems have some rather unique requirements that have caused integration problems for some life sciences experiments in the past. Based on the experiences of the JSC Life Sciences Project Division in resolving these interface problems, developing standard interfaces using accepted and proven industry and scientific standards would greatly simplify experiment hardware design.

6.4 Experiment Checkout and Verification

Standardized mechanical and electrical interfaces will allow faster and more efficient experiment checkout and verification. Computer controlled automated test and checkout equipment can very quickly provide a detailed evaluation of the experiment operation. This improvement in experiment verification and checkout should improve the ability to quickly process an experiment assembly through the extensive testing processes that are presently required before an experiment can be launched or activated.

6.5 Experiment Flight Testing

With standardized interfaces, proposed Space Station experiments could be flown on a Spacelab mission to demonstrate the feasibility of in-flight experiment removal from and integration into the racks. This would be a demonstration of Space Station technology and methodology while the Space Station program is still in the development stages.

6.6 Quick Response Experiments

Racks staged with standard interfaces leads to the possibility of flying quick response experiments since the integration process would be simple. The providing of experiment chassis by NASA to be used in student-type experiments would also be useful.

6.7 Cost Impact

The cost of making racks compatible between the spacecraft and the modules covered by this trade study would be primarily due to the need for inter-program coordination and standardization. Although these costs would cause some increase in the programmatic area due to the need for ICD's, common interface data, and common inter-program rack configuration control, the benefits should be substantial. From an overall life cycle cost perspective (overview of several programs), the benefits of being able to change racks between modules and between spacecraft, the benefits of common ground checkout and pre-flight preparation cycles, and the benefits of having standard data formats are potentially invaluable. There is not sufficient data available to quantify these benefits at this time, but there is no question that they are worth further study and deserve support by all those involved in the SBI program.

Appendix A - Space Biology Hardware Baseline

LIFE SCIENCES HARDWARE LIST FOR THE SPACE STATION FREEDOM ERA

December 1988
UpDated 23 Mar. 1989

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS		
			VOLUME (cu. m)	MASS (kg)	POWER (watts)
	1.8 METER CENTRIFUGE FACILITY (1)				
	SPECIMEN SUPPORT GROUP (1A)				
1	1.8 M Centrifuge	C	2.40	1100	1500
2	Equipment Washer/Sanitizer	W	0.96	320	2500
3	Life Sciences Glove Box (Copy 1 of 2)	W	0.96	350	800
4	Modular Habitat Holding System	C	0.48	200	500
5	Plant Growth Module	C	0.10	50	550
6	Primate Module	C	0.10	50	220
7	Rodent Module	C	0.07	40	230
	BIOLOGICAL SAMPLE MANAGEMENT FACILITY (2)				
	BIOWASTE COLLECTION & MONITORING GROUP (2A)				
8	Fecal Monitoring System (24 Hr)	E	0.12	25	50
9	Urine Monitoring System (24 Hr)	E	0.20	60	50
	BIOLOGICAL SAMPLE STORAGE GROUP (2B)				
10	Freeze Dryer	W	0.07	19	140
11	Freezer (-20 deg. C)	W	0.48	120	300
12	Freezer (-70 deg. C)	W	0.48	120	300
13	Freezer Cryogenic (-196 deg. C) w/ Snap Freezer	W	0.09	20	0
14	Radiation Shielded Locker (Copy 1 of 2)	W	0.20	80	0
15	Refrigerator (4 deg. C)	W	0.48	120	300

source codes: C=1.8 CFP, S=SBI, E=EDCO, W=WP-01

				...WARE PARAMETERS MASS (kg)	POWER (watts)
				8	0
				1	0
				40	450
				26	200
				2	34
				1	0
				TBD	TBD
				4	0
				80	100
				300	700
				350	800
				80	200
				1	0
				2	0
				10	50
				4	20
				2	0
33	Saliva Collection Unit		01	~~1~~ .2	0
34	Sample Preparation Device	S	0.17	22	150
35	Shielded Isotope Container	E	0.02	22	0
36	Specimen Labeling Tools/Device	W	0.01	4	20
37	Surgery/Dissection Tools	W	0.06	20	0
38	Sweat Collection Device	S	~~0.01~~ .005	~~TBD~~ 5.05	~~0~~ .15

source codes: C=1.8 CFP, S=SBI, E=EDCO, W=WP-01

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS VOLUME (cu. m)	MASS (kg)	POWER (watts)
	BIOLOGICAL SAMPLE MANAGEMENT FACILITY (2), (con't)				
	RODENT SUPPORT GROUP (2D)				
39	CO2 Administration Device	S	0.01	3	0
40	Rodent Blood Collection System	S	0.03	10	50
41	Rodent Caudal Vertebrae Thermal Device (CVTD)	S	0.01	2	50
42	Rodent Guillotine	S	0.01	4	0
43	Rodent Restraint	S	0.01	3	0
44	Rodent Surgery Platform	S	0.01	3	0
45	Rodent Surgery/Dissection Unit	S	0.01	3	0
46	Rodent Urine Collection System	S	0.03	10	50
47	Rodent Veterinary Unit	S	0.03	10	0
	PRIMATE SUPPORT GROUP (2E)				
48	Primate Blood Collection System	S	0.05	2	140
49	Primate Handling Equipment	S	0.01	1	0
50	Primate LBNP Device	S	0.05	3	140
51	Primate Surgery Platform	S	0.04	5	0
52	Primate Surgery/Dissection Unit	S	0.02	5	0
53	Primate Urine Collection System	S	0.01	10	14
54	Primate Veterinary Unit	S	0.03	10	0
55	Small Primate Restraint	S	0.05	2	0

source codes: C=1.8 CFP, S=SBI, E=EDCO, W=WP-01

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS VOLUME (cu. m)	MASS (kg)	POWER (watts)
	BIOINSTRUMENTATION & PHYSIOLOGICAL MONITORING FACILITY (3)				
	PULMONARY ANALYSIS GROUP (3A)				
56	Bag Assembly	S	0.01	1	0
57	Bag-in-Box	S	0.15	19	0
58	Doppler Recorder	E	0.01	1	0
59	Electronics Control Assembly	S	0.08	13	100
60	Mask/Regulator System	S	0.01	3	30
61	Mass Spectrometer	S	~~0.02~~ .087	~~10~~ 40.7	~~100~~ 200
62	Pulmonary Function Equipment Stowage Assembly	S	~~0.39~~ .051	20	0
63	Pulmonary Gas Cylinder Assembly	S	0.09	30	0
64	Rebreathing Assembly	S	0.02	1	0
65	Spirometry Assembly	S	0.01	1	0
66	Syringe (3 Liter Calibration)	S	0.01	2	0
	PHYSICAL MONITORING GROUP (3B)				
67	Accelerometer And Recorder	S	0.04	16	35
68	Anthropometric Measurement System	S	0.02	~~TBD~~ 1	0
69	Cameras	W	0.15	50	150
70	Compliance Volumometer	S	~~0.06~~ .015	~~TBD~~ 16	~~TBD~~ 130
71	Electroencephalomagnetogram (EEMG)	S	0.06	~~TBD~~ 2	TBD
72	Electromyograph (EMG)	E	0.01	2	20
73	Force Measurement Device	E	0.01	1	10
74	Force Resistance System	S	0.40	70	~~100~~ 220
75	Fundus Camera	S	~~0.03~~ .003	~~TBD~~ 2	~~TBD~~ Bat. of
76	Goniometer And Recorder	E	0.01	2	25

source codes: C=1.8 CFP, S=SBI, E=EDCO, W=WP-01

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS VOLUME (cu. m)	MASS (kg)	POWER (watts)
	BIOINSTRUMENTATION & PHYSIOLOGICAL MONITORING FACILITY (con't)				
	PHYSICAL MONITORING GROUP (3B) (con't)				
77	Hard Tissue Imaging System	S	0.29	136	300
78	Mass Calibration Unit	S	0.01	2	0
79	Mass Measurement Device-Body	E	0.65	35	15
80	Mass Measurement Device-Micro	W	0.08	17	15
81	Mass Measurement Device-Small	W	0.08	17	15
82	Motion Analysis System	S	0.05	20	100
83	Plethysmograph Measuring System	S	0.01	3	30
84	Soft Tissue Imaging System	S	0.96	300	800
85	Tonometer	S	~~0.01~~ .0002	~~TBD~~ -.06	~~0~~ Bat OP
86	Video System	E	0.10	30	300
	NEUROPHYSIOLOGICAL ANALYSIS GROUP (3C)				
87	EEG Cap	S	0.01	.2	0
88	EEG Signal Conditioner	S	0.01	2	20
89	Electrode Impedance Meter	E	0.01	1	0
90	Electro-oculograph (EOG)	E	0.01	2	20
91	Neurovestibular ECDI	E	0.09	11	120
92	Neurovestibular Helmet Interface Box	E	0.01	2	20
93	Neurovestibular Helmet Assembly	E	0.04	13	110
94	Neurovestibular Helmet Restraint	E	0.01	2	20
95	Neurovestibular Optokinetic Stimulus	E	0.01	2	20
96	Neurovestibular Rotating Chair	E	0.12	38	220
97	Subject Restraint System	E	0.05	18	0
98	Visual Tracking System	S	0.01	2	20

source codes: C=1.8 CFP, S=SBI, E=EDCO, W=WP-01

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS VOLUME (cu. m)	MASS (kg)	POWER (watts)
	BIOINSTRUMENTATION & PHYSIOLOGICAL MONITORING FACILITY (con't)				
	CARDIOVASCULAR GROUP (3D)				
99	Animal Biotelemetry System	S	0.05	20	100
100	Blood Pressure And Flow Instrumentation	S	0.06	20	200
101	Cardiodynamic Monitor	S	0.02	4	150
102	Electrocardiograph (ECG)	S	0.01	2	20
103	Holter Recorder	S	0.01	2	0
104	Human Biotelemetry System	E	0.05	17	140
105	LBNP Device	E	0.16	20	55
106	~~(Neck Baro-Cuff)~~ CAROTID SINUS BARORECEPTOR STIMULATOR	S	~~0.10~~ .132	~~TBD~~ 45.2	~~TBD~~ 145
107	Physiological Hemodynamic Assess Device	E	0.05	18	100
108	Ultrasonic Imaging System	W	0.20	70	600
109	Venous Pressure Transducer/Display	S	0.05	20	100
	PLANT MONITORING GROUP (3E)				
110	Plant Gas Chromatograph/Mass Spectrometer	S	0.20	25	100
111	Plant Gas Cylinder Assembly	S	0.09	19	0
112	Plant HPLC Ion Chromatograph	S	0.12	40	200

source codes: C=1.8 CFP, S=SBI, E=EDCO, W=WP-01

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS		
			VOLUME (cu. m)	MASS (kg)	POWER (watts)
	ANALYTICAL INSTRUMENTS FACILITY (4)				
	BIOLOGICAL SAMPLE ANALYSIS GROUP (4A)				
113	Blood Gas Analyzer	S	0.13	45	250
114	Chemistry Analysis System	E	0.10	30	200
115	Chemistry System	S	0.08	23	100
116	Continuous Flow Electrophoresis Device	S	0.06	TBD	TBD
117	ELISA Reader	E	0.02	6	100
118	Gas Chromatograph/Mass Spectrometer	W	0.20	25	100
119	Gas Cylinder Assembly	S	0.09	19	0
120	High Performance Liquid Chromatograph	W	0.12	40	100
121	Incubator (35-65 deg C Copy 1 of 2)	W	0.16	50	400
122	Osmometer	E	0.02	5	20
123	pH Meter/Ion Specific Analyzer	W	0.02	7	5
124	Qualitative Reagent Strip And Reader	S	0.03	·10	100
125	Radioimmunoassay	E	0.05	20	0
126	Scintillation Counter	S	0.24	90	500
127	Spectrophotometer (UV/VIS/NIR)	W	0.11	40	300
128	Urine Analysis System	E	0.16	55	400
	CELL ANALYSIS GROUP (4B)				
129	Cell Handling Accessories	S	0.05	20	50
130	Cell Harvestor	S	0.06	19	50
131	Cell Perfusion Apparatus	S	0.06	TBD	TBD
132	Centrifugal Incubator (5% CO2 @37 deg C Copy 1 of 2)	E	0.16	40	300
133	Centrifugal Incubator (5% CO2 @37 deg C Copy 2 of 2)	E	0.16	40	300

source codes: C=1.8 CFP, S=SBI, E=EDCO, W=WP-01

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS VOLUME (cu. m)	MASS (kg)	POWER (watts)
	ANALYTICAL INSTRUMENTS FACILITY (4) (con't)				
	CELL ANALYSIS GROUP (4B) (con't)				
134	Centrifuge Hematocrit	S	0.01	2	20
135	Chromosomal Slide Preparation Device	S	0.01	2	20
136	Fluoromeasure Probe	S	0.05	TBD	TBD
137	Flow Cytometer	E	0.24	36	500
138	Hematology System	S	0.07	23	200
139	Image Digitizing System	S	~~0.25~~ .03	~~70~~ 11.4	500
140	Microscope System (Optical & Stereo Macroscope Subsets)	W	0.40	100	400
141	Mitogen Culture Device	E	0.01	2	20
142	Skin Window Device	S	0.01	2	0
143	Slide Preparation Device	E	0.01	2	20

source codes: C=1.8 CFP, S=SBI, E=EDCO, W=WP-01

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS VOLUME (cu. m)	MASS (kg)	POWER (watts)
	LAB SUPPORT EQUIPMENT FACILITY (5)				
	ENVIRONMENTAL MONITORING & CONTROL GROUP (5A)				
144	Accelerometer Subsystem	W	0.10	30	200
145	Automated Microbic System	S	0.20	70	~~500~~ 110
146	Dosimeter, Passive	W	0.09	35	0
147	Head/Torso Phantom	S	0.12	~~TBD~~ 32	0
148	Incubator (35-65 deg C Copy 2 of 2)	W	0.16	50	400
149	Microbial Preparation System	S	0.01	2	~~20~~ 110
150	Radiation Shielded Locker (Copy 2 of 2)	W	0.20	80	0
151	Reuter Microbiology Air Sampler	S	~~0.01~~ .005	~~1~~ 1.45	0
152	Solid Sorbent Air Sampler	S	0.01	5	0
153	Spectrometer (Proton/Heavy Ion)	S	0.03	10	20
154	Tissue Equivalent Proportional Counter	S	~~0.01~~ .001	~~TBD~~ 2	0
155	Total Hydrocarbon Analyzer	S	0.20	70	250
	HARDWARE MAINTENANCE GROUP (5B)				
156	Battery Charger	W	0.03	10	100
157	Camera Locker	W	0.30	100	0
158	Cleaning Equipment	W	0.20	70	500
159	Digital Multimeter	W	0.06	20	50
160	General Purpose Hand Tools	W	0.10	30	0
	LOGISTICS CONTROL GROUP (5C)				
161	Inventory Control System	S	0.20	70	500
162	Lab Materials Packaging & Handling Equipment	S	0.20	70	500
163	Test/Checkout/Calibration Instrumentation	S	0.20	70	200

source codes: C=1.8 CFP, S=SBI, E=EDCO, W=WP-01

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS VOLUME (cu. m)	MASS (kg)	POWER (watts)
	CENTRALIZED LIFE SCIENCES COMPUTER FACILITY (6)				
	LIFE SCIENCES DATA GROUP (6A)				
164	Digital Recording Oscilloscope	W	0.03	10	100
165	Experiment Control Computer System	S	0.05	20	400
166	Multichannel Data Recorder	E	0.09	30	150
167	Voice Recorder	S	~~0.01~~ .003	~~1~~ .26	~~0~~ Bat CF
	CLOSED ECOLOGICAL LIFE SUPPORT FACILITY (7)				
	FEAST GROUP (7A)				
168	CELSS Test Facility	S	1.92	1000	1300
	EXOBIOLOGY FACILITY (8)				
	GAS/GRAIN GROUP (8A)				
169	Gas Grain Simulator	S	1.92	800	1500

source codes: C=1.8 CFP, S=SBI, E=EDCO, W=WP-01

From Neal Jackson 3/21/89

LIFE SCIENCES HARDWARE LIST FOR THE SPACE STATION FREEDOM ERA

Baselined: December 1988

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS VOLUME (cu. m)	MASS (kg)	POWER (watts)	UNIT HARDWARE PARAMETERS UPDATED: 3-Mar BY:DRP VOLUME (cu. m)	MASS (kg)	POWER (watts)	RESP
16	Animal Tissue Biopsy Equipment	S	0.03	8	0				A
17	Blood Collection System	S	0.02	1	0				J
22	Electrolusion Device	S	0.06	TBD	TBD				J
23	Fixation Unit	S	0.02	4	0				A'J
28	Muscle Biopsy Equipment	S	0.01	1	0				'A
29	Perfusion & Fixation Unit	S	0.01	2	0				A
30	Plant Care Unit	S	0.05	10	50				A
31	Plant Harvest/Dissection Unit	S	0.01	4	20				A
33	Saliva Collection Unit	S	0.01	1	0	0.001	0.2	0	J
34	Sample Preparation Device	S	0.17	22	150				J'A
38	Sweat Collection Device	S	0.01	TBD	0	0.005	5.05	15	J
39	CO2 Administration Device	S	0.01	3	0				A
40	Rodent Blood Collection System	S	0.03	10	50				A
41	Rodent Caudal Vertebrae Thermal Device (CVTD)	S	0.01	2	50				A
42	Rodent Guillotine	S	0.01	4	0				A
43	Rodent Restraint	S	0.01	3	0				A
44	Rodent Surgery Platform	S	0.01	3	0				A
45	Rodent Surgery/Dissection Unit	S	0.01	3	0				A
46	Rodent Urine Collection System	S	0.03	10	50				A
47	Rodent Veterinary Unit	S	0.03	10	0				A
48	Primate Blood Collection System	S	0.05	2	140				A
49	Primate Handling Equipment	S	0.01	1	0				A
50	Primate LBNP Device	S	0.05	3	140				A
51	Primate Surgery Platform	S	0.04	5	0				A
52	Primate Surgery/Dissection Unit	S	0.02	5	0				A
53	Primate Urine Collection System	S	0.01	10	14				A
54	Primate Veterinary Unit	S	0.03	10	0				A
55	Small Primate Restraint	S	0.05	2	0				A
56	Bag Assembly	S	0.01	1	0				J
57	Bag-In-Box	S	0.15	19	0				J
59	Electronics Control Assembly	S	0.08	13	100				J
60	Mask/Regulator System	S	0.01	3	30				J
61	Mass Spectrometer	S	0.02	10	100	0.087	40.7	200	J
62	Pulmonary Function Equipment Stowage Assembly	S	0.39	20	0	0.051	20	0	J
63	Pulmonary Gas Cylinder Assembly	S	0.09	30	0				J
64	Rebreathing Assembly	S	0.02	1	0				J
65	Spirometry Assembly	S	0.01	1	0				J
66	Syringe (3 Liter Calibration)	S	0.01	2	0				J
67	Accelerometer And Recorder	S	0.04	16	35		16.06		J

A=ARC, J=JSC, '=Prime

Updated: 3/22/89

LIFE SCIENCES HARDWARE LIST FOR THE SPACE STATION FREEDOM ERA

Baselined: December 1988

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS VOLUME (cu. m)	MASS (kg)	POWER (watts)	UNIT HARDWARE PARAMETERS UPDATED: 3-Mar BY:DRP VOLUME (cu. m)	MASS (kg)	POWER (watts)	RESP
68	Anthropometric Measurement System	S	0.02	TBD	0		1		J
70	Compliance Volumometer	S	0.06	TBD	TBD	0.0152	16	130	J
71	Electroencephalomagnetogram (EEMG)	S	0.06	TBD	TBD		2		J
74	Force Resistance System	S	0.40	70	100			220	J
75	Fundus Camera	S	0.03	TBD	TBD	0.003	2	Battery Op	J
77	Hard Tissue Imaging System	S	0.29	136	300				J
78	Mass Calibration Unit	S	0.01	2	0				J
82	Motion Analysis System	S	0.05	20	100				J
83	Plethysmograph Measuring System	S	0.01	3	30				J
84	Soft Tissue Imaging System	S	0.96	300	800				J
85	Tonometer	S	0.01	TBD	0	0.000226	0.06	Battery Op	J
87	EEG Cap	S	0.01	2	0				J
88	EEG Signal Conditioner	S	0.01	2	20				J
98	Visual Tracking System	S	0.01	2	20				J
99	Animal Biotelemetry System	S	0.05	20	100				A
100	Blood Pressure And Flow Instrumentation	S	0.06	20	200				AJ'
101	Cardiodynamic Monitor	S	0.02	4	150				J
102	Electrocardiograph (ECG)	S	0.01	2	20				J
103	Holter Recorder	S	0.01	2	0				J
106	Neck Baro-Cuff	S	0.10	TBD	TBD	0.132	45.2	145	J
109	Venous Pressure Transducer/Display	S	0.05	20	100				J
110	Plant Gas Chromatograph/Mass Spectrometer	S	0.20	25	100				A
111	Plant Gas Cylinder Assembly	S	0.09	19	0				A
112	Plant HPLC Ion Chromatograph	S	0.12	40	200				A
113	Blood Gas Analyzer	S	0.13	45	250				J
115	Chemistry System	S	0.08	23	100				J
116	Continuous Flow Electrophoresis Device	S	0.06	TBD	TBD				J
119	Gas Cylinder Assembly	S	0.09	19	0				J
124	Qualitative Reagent Strip And Reader	S	0.03	10	100				J
126	Scintillation Counter	S	0.24	90	500				J
129	Cell Handling Accessories	S	0.05	20	50				A'J
130	Cell Harvestor	S	0.06	19	50				A'J
131	Cell Perfusion Apparatus	S	0.06	TBD	TBD				AJ'
134	Centrifuge Hematocrit	S	0.01	2	20				AJ'
135	Chromosomal Slide Preparation Device	S	0.01	2	20				J
136	Fluoromeasure Probe	S	0.05	TBD	TBD				J
138	Hematology System	S	0.07	23	200				J
139	Image Digitizing System	S	0.25	70	500	0.03	11.4		J
142	Skin Window Device	S	0.01	2	0				J

Updated: 3/22/89

A-ARC, J-JSC, '-Prime

H/W ITEM #	HARDWARE ITEM NAME	SOURCE CODE	UNIT HARDWARE PARAMETERS VOLUME (cu. m)	MASS (kg)	POWER (watts)	UNIT HARDWARE PARAMETERS UPDATED: 3-Mar BY:DRP VOLUME (cu. m)	MASS (kg)	POWER (watts)	RESP
145	Automated Microbic System	S	0.20	70	500	0.2	70	110	J
147	Head/Torso Phantom	S	0.12	TBD	0		32		J
149	Microbial Preparation System	S	0.01	2	20	0.01	2	110	J
151	Reuter Microbiology Air Sampler	S	0.01	1	0	0.005	1.45		A J'
152	Solid Sorbent Air Sampler	S	0.01	5	0				J
153	Spectrometer (Proton/Heavy Ion)	S	0.03	10	20				J
154	Tissue Equivalent Proportional Counter	S	0.01	TBD	0	0.001	2	0	J
155	Total Hydrocarbon Analyzer	S	0.20	70	250				J
161	Inventory Control System	S	0.20	70	500				A J'
162	Lab Materials Packaging & Handling Equipment	S	0.20	70	500				A' J
163	Test/Checkout/Calibration Instrumentation	S	0.20	70	200				A J'
165	Experiment Control Computer System	S	0.05	20	400				J' A
167	Voice Recorder	S	0.01	1	0	0.003	0.26	Battery Op	J
168	CELSS Test Facility	S	1.92	1000	1300				A
169	Gas Grain Simulator	S	1.92	800	1500				A

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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SBI01	Kozarsky, D.	MUS Inputs		Lockheed Life Sciences Program Office	Lockheed Memo	Washington, DC	01/19/89
SBI02	Kozarsky, D.	Latest Space Station Rack Studies		NASA MSFC		Huntsville, AL.	02/02/89
SBI03	Holt, A.	PMWG-SS Freedom Assly. Seq. Trial Pyl. Manifest		Payload Manifest Working Group (PMWG)		Reston, VA.	12/09/88
SBI04	Shannon, J.	Business Practice Low Cost System Activity		NASA JSC		Houston, TX.	11/12/75
SBI05	NASA	Off-the-Shelf Hardware Procurement		NASA JSC	NASA MEMO HB/73-M286	Houston, TX.	05/16/73
SBI06	NASA	OTS Technology Use For Space Shuttle Program		NASA JSC	NASA MEMO	Houston, TX.	11/20/73
SBI07	NASA	Proposed Space Shuttle Directive On OTS HW.		NASA JSC	NASA MEMO NB/74-L149	Houston, TX.	06/20/74
SBI08	NASA	Cancellation Of Space Shuttle Directive On OTS		NASA JSC		Houston, TX.	10/01/74
SBI09	NASA	Agency Balloon Pyl. Util. of Avail. Equip. & Exper		NASA JSC	NASA PLAN 323-50-XX-71	Houston, TX.	05/25/76
SBI10	NASA	Space Shuttle Program DTO/DSO Noncritical Requirements Document		Flight Support Equipment Office - JSC	NSTS 21096	Houston, TX.	08/01/88
SBI11	NASA	Reference Mission Operational Analysis Document (RMOAD) For The Life Sciences Research Facilities.		NASA JSC	NASA TM 89604	Houston, TX.	02/01/87
SBI12	Breiling, R.	Cost Risk Analysis Using Price Models		RCA Price Systems		Mooreston, NJ.	09/01/87
SBI13	Fogleman, G.Schwart, D.Fonda, M.	Gas Grain Simulation Facility: Fundamental Studies of Particle Formation And Interactions	1	NASA Ames Research Center	NASA ARC/SSS 88-01	Moffet Field, CA.	08/31/87

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SBI14	JPL	Flight Projects Office Payload Classification Product Assurance Provisions		JPL	JPL D-1489 Rev. A	Pasadena, CA.	04/30/87
SBI15	PRC Systems	Cost Estimate For The Search for Extraterrestrial Intelligence (SETI) Revised		PRC Systems Services		Huntsville, AL.	06/15/87
SBI16	NASA SSPO	Space Station Commonality Process Requirements Rev.B		NASA SSPO	SSP 30285 Rev. B	Reston, Virgina	09/15/88
SBI17	Webb, D.	Technology Forecasting Using Price - H		Rockwell International		Anaheim, CA.	04/17/86
SBI18	NASA	Classification Of NASA Office Of Space Science And Applications (OSSA) Space Station Payloads		NASA JSC		Houston, TX.	/ /
SBI19	NASA	Life Science Research Objectives And Representative Experiments For The Space Station (Green Book)		NASA Ames Life Science Division		Moffet Field, CA.	01/01/86
SBI20	NASA	Medical Requirements Of An In-Flight Medical System For Space Station		NASA JSC	JSC 31013	Houston, TX.	11/30/87
SBI21	TRW	A Study Of Low Cost Approaches To Scientific Experiment Implementation For Shuttle Launched And Serviced Automated Spacecraft		TRW Systems Group	Contract NASW - 2717	Redondo Beach, CA.	03/19/89

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SBI22	LMSC	Low-Cost Program Practices For Future NASA Space Programs		LMSC	LMSC-D387518	Sunnyvale, CA.	05/30/74
SBI23	Steward, GMiller, L	Biomedical Equipment Technology Assesment For The Science Laboratory Module		Management and Technical Services Company		Houston, TX.	08/01/86
SBI24	General Electric	WP-3 Commonality Plan		General Electric	NAS5-32000	Philadelphia , PA	04/22/88
SBI25	NASA	Microbiology Support Plan For Space Station		NASA JSC	JSC-32015	Houston, TX.	09/01/86
SBI26	NASA	Concepts And Requirements For Space Station Life Sciences Ground Support And Operations		NASA JSC	LS-70034	Houston, TX.	04/11/88
SBI27	NASA	Spacelab Mission 4 Integrated Payload Requirements Document		NASA JSC	SM-SE-03	Houston, TX.	06/01/83
SBI28	General Dynamics	Life Sciences Payload Definition And Integration Study	IV	General Dynamics	CASD-NAS-74-046	San Diego, CA.	08/01/74
SBI29	General Dynamics	Life Sciences Payload Definition and Integration Study - Executive Summary	1	General Dynamics	CASD-NAS-74-046	San Diego, CA.	08/01/74
SBI30	NASA	SL-3 Ames Research Center Life Sciences Payload Familiarization Manual		Ames Research Center	ADP-81-50-001	Moffet Field, CA.	02/01/81
SBI31	Rockwell Intl.	EMS Data Data Package 2.3A S4200.2 Methodology Definition - Commonality Analysis Trade Study		Rockwell Internation	SSS 85-0168	Downey, Ca.	10/04/85

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SBI32	Rockwell Intl.	EMS Data Data Package 2.2B S4201.2, Module Commonality Analysis		Rockwell International	SSS 85-0137	Downey, CA	09/06/85
SBI33	General Electric	Space Station Work Package 3 Definition And Preliminary Design Commonality Candidates		General Electric Space Systems Division	DRD - 19	Philadelphia, PA	05/10/85
SBI34	Rockwell Intl.	EMS Data Data Package 2.3A S4203.2, Module Outfitting/System Commonality Analysis		Rockwell International	SSS 85-0158	Downey, CA	10/28/85
SBI35	NASA JSC	Space Station Freedom Human-Oriented Life Sciences Research Baseline Reference Experiment Scenario		JSC- Medical Sciences Space Station Office	Blue Book	Houston, TX.	10/01/88
SBI36	NASA SSPO	Space Station Approved Electrical Electronic, And Electromechanical Parts List		Space Station Program Office	SSP 30423 Rev. A	Reston, Virgina	11/15/88
SBI37	NASA SSPO	Space Station Program Design Criteria and Practices		Space Station Program Office	SSP 30213 Rev. B	Reston, Virgina	07/30/88
SBI38	MDAC	Manufacturing Management Plan		McDonnel Douglas	DR MU-01	Houston, TX	/ /
SBI39	NASA JSC	July 1988 Pogress Report On Experiment Standard User Interfaces Study		JSC - Life Sciences Project Division		Houston, TX.	07/01/88
SBI40	Rockwell Intl.	EMS Data Data Package 2.3A S4207.2, GSE Commonality Analysis		Rockwell International	SSS 85-0099	Downey, CA	10/04/85
SBI41	NASA OSSA	Life Sciences Space Station Planning Document: A Reference Payload For The Life Sciences Research Facility		Office of Space Science and Applications	NASA TM 89188	Washington, D.C.	01/01/86

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SBI42	Buroni, A.Pascucci, B	The OBDH test equipment and its goals		ESA		Milan, Italy	10/01/78
SBI43	Shiokari, A.	Standarization and Program Effect Analysis - Final Report	111	Aerospace Corporation		El Segundo, CA	01/01/75
SBI44	Huffstetler, W.	Skylab Biomedical Hardware Development		AIAA 20th Annual Meeting		Los Angeles, CA	08/22/74
SBI45	Powell, A.	Commonality Analysis For The NASA Space Station Common Module - 36 IAF Meeting, October 7-12 1985		Pergamon Press		New York, NY	10/07/85
SBI46	Anderson, A.	Progressive Autonomy - For Space Station Systems Operation		AIAA		New York, NY	06/05/84
SBI47	NASA JSC	Life Sciences Research Laboratory (LSRL) Human Research Facility forSpace Station Initial Operating Configuration (IOC) Science Reqts.		NASA JSC	JSC 20799	Houston, TX	10/01/85
SBI48	MDAC	Crew Health Care System (CHec) Development Plan		Mcdonnell Douglas Space Station Co.		Houston, TX.	01/28/89
SBI49	Minsky, M.	Engines of Creation		Anchor Press		New York, NY	01/10/86
SBI50	MDAC	Crew Health Care	1	MDAC	MDC H3924	Houston, Texas	11/01/88
SBI51	NASA JSC	Columbus Reference Configuration Report		NASA JSC	RP 1213800000	Houston, TX.	05/31/88
SBI52	NASA HQ	Shuttle/Payload I/F Definition Document for Middeck Accomodations		NASA HQ	NSTS 21000	Washington, DC	03/01/88

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SBI53		Rack Accomodations Users Manual					/ /
SBI54	NASA JSC	Mission Integration Plan		NASA JSC	SSP 30000 Appendix D	Houston, TX.	04/30/86
SBI55	Pacheo	Analyzing Commonality in a System		Boeing	NASA STI Facility	Baltimore, MD.	03/01/88
SBI56	NASA MSFC	Spacelab Configurations					/ /
SBI57	Rockwell Intl.	Space Shuttle Management Proposal	II	Rockwell Intl.	SD 72-SH-50-2		05/12/72
SBI58	LMSC	Space Shuttle Management Proposal	II	LMSC	LMSC-D157364		05/12/72
SBI59	MDAC	Space Shuttle Program Management Proposal		MDAC	E0600		05/12/72
SBI60	MSFC	MSFC Space Station CER's Report		MSFC	PRC D-2185-H		12/01/82
SBI61	NASA JSC	CERV Target Costs for Benchmark and Reference Configurations		JSC CERV Office		Houston, TX.	06/15/88
SBI62	CBO	Cost Estimating For Air Missles		Congressional Budget Office		Washington, D.C.	01/01/83
SBI63	Evans, Jim	Meeting with Jim Evans Technical Assistant, NASA Space and Life Sciences		Eagle Engr.		Houston, TX.	04/19/89
SBI64	Whitlock, R.	JSC Cost Analysis Office		Eagle Engr.		Houston, TX.	04/11/89
SBI65	PRICE	PRICE Users Newsletter	12				10/01/88
SBI66	General Electric	PRICE H Reference Manual					01/01/88
SBI67	NASA JSC	Satellite Services Workshop	1&2	NASA JSC	JSC 20677	Houston, TX.	11/06/85

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SB168	Hamaker, Joe	Telephone interview relating to MSFC history and techniques for cost estimating.		Cost Analysis Branch Chief MSFC		Huntsville, Al.	04/27/89
SB169	Booker, Clef	Personal Interview		Man-Systems Division JSC		Houston, TX.	04/04/89
SB170	Evans, Jim	Personal Interview		Life Science Project Division JSC		Houston, TX.	04/19/89
SB171	Heberlig,Jac k	Telephone interview relating to make-or-buy lessons learned from Apollo		International Business Machines (IBM)		Houston, TX.	03/10/89
SB172	Loftus, Joe	Telephone interview relating to make-or-buy history		Assistant Director (Plans) JSC		Houston,TX.	03/14/89
SB173	Christy, Neil	Telephone interview relating to hardware development student experiments, and make-or-buy				Houston, TX.	03/15/89
SB174	McAllister,F red	Telephone Interview		Man-System Division, JSC		Houston,TX	03/14/89
SB175	Trowbridge, John	Interview relating to CHeC make-or-buy		McDonnell Douglas		Houston,TX.	03/17/89
SB176	Trowbridge, John	Personal interview relating CHeC experience to miniaturization, modularity and make-or-buy		McDonnell Douglas		Houston, TX.	03/29/89
SB177	Nagel, John	Personal Interview relating to LSLE make-or-buy experience		Eagle Technical Services		Houston, TX	03/27/89
SB178	McFadyen, Gary	Personal Interview relating to life science hardware background at JSC		Southwest Research Institute		Houston, TX.	04/10/89

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SBI79	Booker, Clef	Personal Interview - Minaturization on amplifiers, computers and modularity		NASA JSC/SP 341 Man-System Division		Houston, TX.	04/04/89
SBI80	McFadyen	Bioengineering on SBI hardware		Southwest Research Institute		San Antonio, TX.	04/06/89
SBI81	Allen, Joe	Personal interview - S.S. Life Science AIAA Meeting		Space Industries		Houston, TX.	04/07/89
SBI82	Averner, Maurice	Personal interview on CELSS		NASA HQ. CELSS Coordinator		Washington, DC.	04/07/89
SBI83	Fogleman, G. PhD	Personal interview relating to Gas Grain Simulation Facility		NASA AMES		Moffet Field, CA.	04/06/89
SBI84	White. Bob	Personal Interview relating to modularity and commonality		NASA JPL		Pasadena, CA.	04/10/89
SBI85	Grumm, Richard	Personal interview relating to SBI hardware		NASA JPL		Pasadena, CA.	04/11/89
SBI86	Boeing	U.S. Lab Review Workshop					/ /
SBI87	McGillroy,B.	Personal Interview on CELSS		NASA AMES		Moffet Field, CA	05/05/89
SBI88	NASA JSC	Life Science Flight Experiments Program Life Sciences Laboratory Equipment (LSLE) Descriptions		NASA JSC	JSC-16254-I	Houston, TX.	09/01/86
SBI89	Boeing	Space Station Program Commonality Plan Draft 3		Boeing	D683-10112-1		10/31/88
SBI90	GE Govt.Services	Life Sciences Hardware List for the Space Station Freedom Era - Baselined December 1988 Updated 3/22/89		GE Government Services		Houston, TX.	03/22/89

Appendix B - Complete SBI Trade Studies Bibliography

ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SBI91		NASDA Standard Rack Envelope Study Status		NASDA			/ /
SBI92		Spacelab Payloads Accomodations Handbook		NASA MSFC	SLP/2104	Huntsvillle, Al.	08/16/85
SBI93		Station Interface Accomodations for Pressurized and Attached Payloads		NASA			02/01/89
SBI94		Life Sciences Study for the Space Station		Management and Technical Services Co.		Houston, TX.	08/01/84
SBI95	Crenshaw, John	Personal Interview with John Crenshaw - Discussion of standarized avoins (mounted on racks) in airlines.				Houston, TX.	05/16/89
SBI96	Juran, J.M.	The Non-Pareto Principle Mea Culpa					/ /
SBI97	Arabian, D.	Beware Off-the-Shelf Hardware		NASA JSC		Houston, TX.	10/17/73
SBI98	SBI98NASA JSC	Experimenting with Baroceptor Reflexes	12	NASA Tech Briefs	No. 11	New York, NY	12/01/88

Appendix C - Cost Assessment Techniques Summary

1.0 Introduction

1.1 Relative Cost Impact Analysis Task

JSC and GE Government Services are developing the SBI hardware cost estimate to be presented to NASA Headquarters. The cost related task in these trade studies is to develop and present factors which assist the cost estimators in using tools to develop the effect of the trade study specialty area (miniaturization, modularity and commonality, and Modified COTS) on SBI cost estimates. The life cycle costs are most important in judging the long term benefits of a new project. However, consideration of life cycle costs requires knowledge of the probable project life, operational use time lines, maintenance concepts, and logistics relationships. These data are not available at the time of these initial trade studies. Therefore, the trade studies address primarily the relative cost impact analysis of the design and development phase of the SBI. Life cycle costs are dealt with on a comparative, subjective basis in order to illustrate the influence of life cycle cost factors on the various trade study subjects.

1.2 Documentation Approach

The application of cost methods as applied to SBI trade studies involves some methods common to all of the studies and others that apply uniquely to a specific trade subject. Therefore, the selected approach to the problem is to deal with cost methods and cost trends in this appendix that is to be a part of each study report. In the cost appendix, subsequent sections of Section 1.0 deal with various methods examined for the trade studies, Section 2.0 defines the cost estimating relationship (CER's) and their factors and sensitivities, and Section 3.0 deals with specific variations and parameters of interest with respect to each trade study. Sections 4, 5 and 6 provide brief discussions of testing, SE&I and project management costs, Section 7.0 life cycle effects, and Section 8.0 summarizes the conclusions.

1.3 Cost Method Overview

Cost methods considered and evaluated in the course of this effort include the basic types listed below:

a. Detailed cost build-up method. The detailed cost estimate is compiled using estimates from specialists in the various design disciplines and is constructed from a spread of hours required in design, labor rates, overhead and other factors affecting the cost of DDT&E.

b. General Electric PRICE. The PRICE H model is a sophisticated cost modeling program requiring a variety of inputs including weight, manufacturing complexities, and design complexity plus secondary factors.

c. Cost estimating relationship (CER's). The simplest cost estimating tools are empirical relationships based primarily on system weight and derived to match past experience on previous programs.

d. Cost impact analysis methods. Parametric studies to establish and/or to quantify cost drivers and cost trend effects.

The choice between the foregoing alternatives was narrowed to options c and d which are used in combination as described in the balance of this report. Initial SBI cost estimates will be developed in a separate effort using PRICE H. Therefore, the task in the trade studies is to provide data and/or factors which will be helpful in assisting cost estimators in the use of the tools from which the actual estimates will be formulated. A secondary purpose is to develop parametric trend data that will help the reader understand the potential impact of the various trade study subjects on cost, i.e. miniaturization, commonality, and the use of commercial products (COTS) in lieu of new design.

Empirical cost relationships use system weight as the primary factor in deriving development and theoretical first unit (TFU) costs. A series of such relationships can be used to reflect the inherent complexity of different types of space-borne systems, i.e., one relationship for structural or mechanical systems, a second for packaged electronics, and a third for complex distributed hybrid systems. This approach has its roots in past program experience in that the end results are usually compared with past program actual costs and the relationships adjusted to match what has happened on similar system development during their life cycle. References SBI No. 60 and SBI No. 61 were used as a data source for CER's. Also, a discussion was held with the cost analysis specialist at JSC and MSFC (ref. SBI No. 64 and No. 68) as part of the effort to determine whether or not other cost work has been accomplished on the SBI trade study subjects.

As will be seen in the ensuing sections and in the trade studies proper, the results and trends also employ second order effects such as the amount of new design required, the impact of sophisticated technology and alternate materials.

Regardless of how one approaches the subject of cost development or cost trends there are three fundamental principles are involved in evaluating costs, cost drivers and cost trends (ref. SBI No. 65). These are as follows:

1. Estimates require reasoned judgments made by people and cannot be automated.

2. Estimates require a reasonably detailed definition of the project hardware that must be acquired or developed before estimates can be made.

3. All estimates are based upon comparisons. When we estimate, we evaluate how something is like or how it is unlike things we have seen before.

The SBI Program estimates are particularly challenging because the definition of the hardware items and the data that will permit comparisons is not detailed and complete. We are dealing with some items in their earliest conceptual phase of definition.

A couple of study principles should also be mentioned because they may help us understand the validity of the results we obtain. These are:

1. The sensitivity that study results show to variations in assumption provides an indication as to the fundamental nature of the assumption. If results are highly sensitive to variations in assumption then the assumption should be used with caution. Extrapolations are particularly hazardous in such instances. On the other

hand if results are not highly sensitive, then scaling over a wide range may be feasible, although extrapolations of cost values can yield misleading results in any event and should always be applied carefully.

2. Parametric approaches may be necessary in order to understand trends due to the absence of specific data for use in the study. Parametric in the sense used here means the arbitrary variation of a given parameter over a range of expected values, while holding other values constant.

The costing relationships used in SBI trade studies are applicable to space systems and are founded on past programs as described in references SBI No. 60 and No. 61. The only questions, therefore, are whether or not they can be used on SBI hardware (which does use subsystems similar in nature to other manned space systems) and how accurately they can be scaled to fit the range of SBI sizes. Insofar as practical, these questions have been circumvented by means of reporting cost trends in lieu of cost values.

2.0 General Development Cost Methods

2.1 Empirical Methods

As stated in Section 1.3 CER's are empirical cost estimating relationships that express expected costs on the basis of past program experience. Empirical cost estimating requires some sort of systems definition plus good judgement in the selection of the constants, and exponents. The nature of a system element or assembly, and the size/weight of the item are primary cost drivers. The most predominant variable is the exponent of the weight term in the following generalized equation:

$$\text{Cost} = df * (C_1 (Wt)^n) + C_2 (Wt)^n$$

Where

wt = weight of the system, module or assembly

n = an exponent selected on the basis of system complexity

df = a factor reflecting the amount of new design required (design factor)

C_1 = constant selected to establish the cost trend origin

C_2 = a constant to reflect special requirements such as tooling - can be zero

Adjustments to the weight exponent and the constants yields values which show dramatic cost increases as a function of weight but decreasing cost per pound as the weight is increased. Cost relationships always show these trends when applied to launch vehicles, spacecraft, or payloads. Therefore, it is assumed that they apply to biology equipment (for space) as well. Economies of scale are present in all such systems. The larger the system, assembly, or component, the lower its cost per pound. There is, however, a limitation to the applicability of CER's to SBI hardware due to size limitations. All CER's have a range of applicability and produce consistent results in terms of cost per pound over that range. The limitation comes into play when extrapolating outside the range of applicability, particularly where the size is small. Unfortunately, this limitation may be a factor in SBI hardware elements and assemblies due to their size being relatively small compared to manned spacecraft systems. Therefore, when a CER yields costs in a very high range, on the order of $100,000/lb. or $220,000/Kg, or higher, caution and judgement are necessary to avoid the use of misleading results.

2.2 System Complexity Exponents (n)

Past experience in estimating costs with empirical methods suggests that the exponent, n, increases with increasing system complexity and as a function of the degree to which a system is distributed. For example, relatively simple, structure or packaged power modules may be represented by n = 0.2. The cost of more complex mechanical systems and structures which are comprised of a variety of components and assemblies can be represented by an exponent, n = 0.4 and the most complex distributed electronics call for an exponent on the order of 0.5 to 0.6. Inasmuch as the SBI systems involve all the foregoing elements plus sophisticated sensors, it may be necessary to use exponents that are as high as 0.8 or 1.0 to represent cost trends of parts of the SBI systems. Reference No. 60 uses an exponent, n, equal to .5 for development when historical data are not available. This value has been used in SBI Reference No. 60 for displays and controls, instrumentation and communications, all of which are comprised of distributed electronics and is consistent with the range recommended here (.5 to .6).

The dramatic effect of the system complexity exponent is illustrated by Figure 2-1. Figure 2-1 is a plot of cost per pound vs. complexity exponent, n, for a range of values of n between 0.1 and 1.0. As can be seen from the figure, 1000 units of weight costs 0.2% per unit weight as much at n = 0.1 compared to the cost at n = 1.0. The point is that care must be exercised in making a proper selection of exponent in order to achieve reasonable accuracy in estimating actual costs.

The historical use of lower exponents for simple, packaged systems, and the use of higher values for complex distributed systems matches common sense expectations. To express it another way, one can safely assume that the cost of a system will be influenced dramatically by the number of different groups involved in the design, by the number of interfaces in the system, and by the complexity of the design integration effort required. Distributed power and data systems invariably cost more (per pound) to develop than do packaged elements. However, the degree to which this applies to SBI is not clear due to the fact that biological systems tend to be more packaged and less distributed than do other space systems.

2.3 Design Factors (df)

Figure 2-2 defines the design factors that represent the degree of new design required in a development. On the low side is the factor representing the use of existing designs that require very little modification, integration or testing. For all new current state-of-the-art designs which involve no new technology, the design factor is 0.9 to 1.0. The factor for new design requiring advancement in technology is expressed as greater than unity and can be as high as 2 or 3 for efforts that dictate a multiple design path approach to achieve the desired goals. Price H refers to this type of factor as the engineering complexity factor and uses design values similar to those in Figure 2-2. However, Price H varies the experience of the design team as well as the complexity and the difficulty of the design.

2.4 Method Summary

The SBI trade studies will all require a definition of system element size, complexity and degree of new design. These factors may have to be varied over a range of probable values to evaluate trends, but they will all come into play in costing comparisons.

FIGURE 2-1
Effect of Exponent "n" on Cost

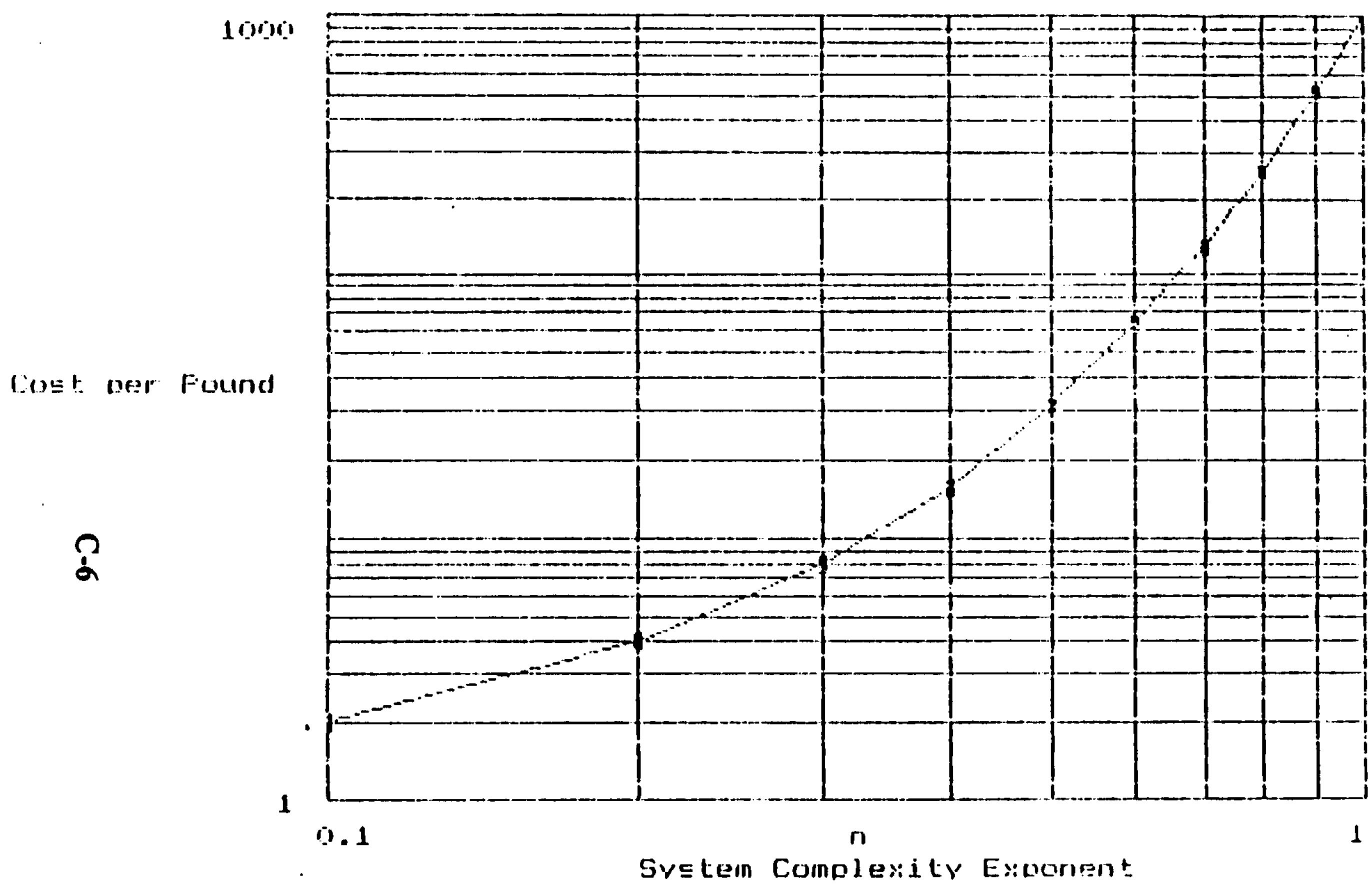


Figure 2-2 Design Factors

Design Factor	Description of the Design Task
.1 to .2	Off-The-Shelf. Minor design modifications and little or no qualification testing required
.3 to .4	Design Exists. Some new design drawings required Minimum integration costs involved
.5 to .6	Design exists but requires significant modification. On the order of 40% to 50% to existing drawings.
.7 to .8	Similar designs exist but mostly new drawings required No new technology involved in electronics, structure etc.
.9 to 1.0	New design with all new drawings. Little or no new technology required
1.0 to 3.0	All new design, new technology required. May require multiple attack on new technology problems

3.0 Cost Methods Applicable to Specific Trade Studies

Three of the four studies are discussed separately in this section although there are common elements associated with them that were not covered in Section 2.0. The intent is to examine the prime cost drivers that come into play with the subjects of miniaturization, modularity and commonality, use of COTS, and compatibility between spacecraft. Rack compatibility is covered in Section 7.4 under life cycle costs.

3.1 Hardware Miniaturization Cost Drivers

Fundamentally the variables of system (or component) weight, system complexity, and difficulty of design all influence miniaturization cost trends. For the purposes of this section weight and design difficulty will be varied, while system complexity will be treated as a series of constants, each being evaluated separately. Materials changes will not be dealt with even though it is valid to assume that the use of titanium, graphite, steel or composites will adversely affect cost. In fact, the dense materials (titanium and steel) will adversely affect cost due to weight and cost due to manufacturing complexity as well.

Given the foregoing exclusions, the miniaturization cost trends have been dealt with by parametric variation of the system size, and the degree of new design needed to achieve a given degree of miniaturization. The selected values of miniaturization vary between 10% and 90% in increments of 10%. In other words, if an unminiaturized system size is treated as 100%, Tables 3-1 through 3-4 show the effect on cost of weight reduction between zero and 90% on the first line. In order to include the effect of system complexity, Tables 3-1 through 3-4 are provided for values of n = 0.2, 0.4, 0.6, and 0.8.

The columns in the tables vary the design difficulty between a minimum change (.1 to .2 on Figure 2-2) and an all new design (0.9 to 1.0 on Figure 2-2). However, Tables 3-2 through 3-4 show the minimum design change as unity for reasons of simplifying the numbers. Thus the minimum design change number becomes 1.0 in lieu of 0.15 and the all new design becomes 6.0 which represents a relative value, compared to the minimum change value, i.e. 0.90 /0.15 = 6.0.

The use of Tables 3-1 through 3-4 is simple. Numbers less than 1.0 indicate a cost reduction and the degree of same, while numbers above 1.0 represent cost increases and the relative size of the increase. For example, using a 50% size reduction, and miniaturization requiring an all new design (df = 6) for n = 0.4, table 3-2 shows that the cost will be on the order of 4 1/2 times the cost for an unmodified item that is not miniaturized. In like manner, one can deduce that the cost of an all new design that achieves a 90% reduction in size (was 20 lbs., is 2.0 lbs.) will cost approximately 2 1/2 (2.4 from Table 3-2) the amount of an unmodified design.

Figure 3-1 is included to illustrate the cost trends for various systems complexity factors between n = .2 and n = .8. The curves all use a design factor df = 1.0 and all have been normalized so that the unminiaturized weight is unity. The purpose of Figure 3-1 is to show the effect of complexity factors on cost as weight is reduced. No design modification effects are included in Figure 3-1 so the curves indicate complexity trends only. To generate an estimate of the relative cost of miniaturization including redesign effects, one must multiply the cost factor (Figure 3-1) by a design factor as is done in Tables 3-1 through 3-4.

Table 3-1
Miniaturization Guide Chart
n=.2

df \ % Miniat.	0	10	20	30	40	50	60	70	80	90
Design Integration Only	1.00	.98	.96	.93	.90	.87	.83	.79	.73	.63
Significant Modification Req'd (30%)	2.00	1.96	1.92	1.86	1.80	1.74	1.66	1.58	1.46	1.26
Major Modification Req'd (50%)	3.00	2.94	2.88	2.79	2.70	2.61	2.49	2.37	2.19	1.89
All New Design	6.00	5.88	5.76	5.58	5.40	5.22	4.98	4.74	4.38	3.78

Table 3-2
Miniaturization Guide Chart
n=.4

df \ % Miniat.	0	10	20	30	40	50	60	70	80	90
Design Integration Only	1.00	.96	.92	.87	.82	.76	.69	.62	.53	.40
Significant Modification Req'd (30%)	2.00	1.92	1.84	1.74	1.64	1.52	1.38	1.24	1.06	.80
Major Modification Req'd (50%)	3.00	2.88	2.76	2.61	2.46	2.28	2.07	1.86	1.59	1.20
All New Design	6.00	5.76	5.52	5.22	4.92	4.56	4.14	3.72	3.18	2.40

Table 3-3
Miniaturization Guide Chart
n=.6

df \ % Miniat.	0	10	20	30	40	50	60	70	80	90
Design Integration Only	1.00	.94	.86	.81	.74	.66	.58	.49	.38	.25
Significant Modification Req'd (30%)	2.00	1.88	1.72	1.62	1.48	1.32	1.16	.98	.76	.50
Major Modification Req'd (50%)	3.00	2.82	2.58	2.43	2.22	1.98	1.74	1.47	1.14	.75
All New Design	6.00	5.64	5.16	4.86	4.44	3.96	3.48	2.94	2.28	1.50

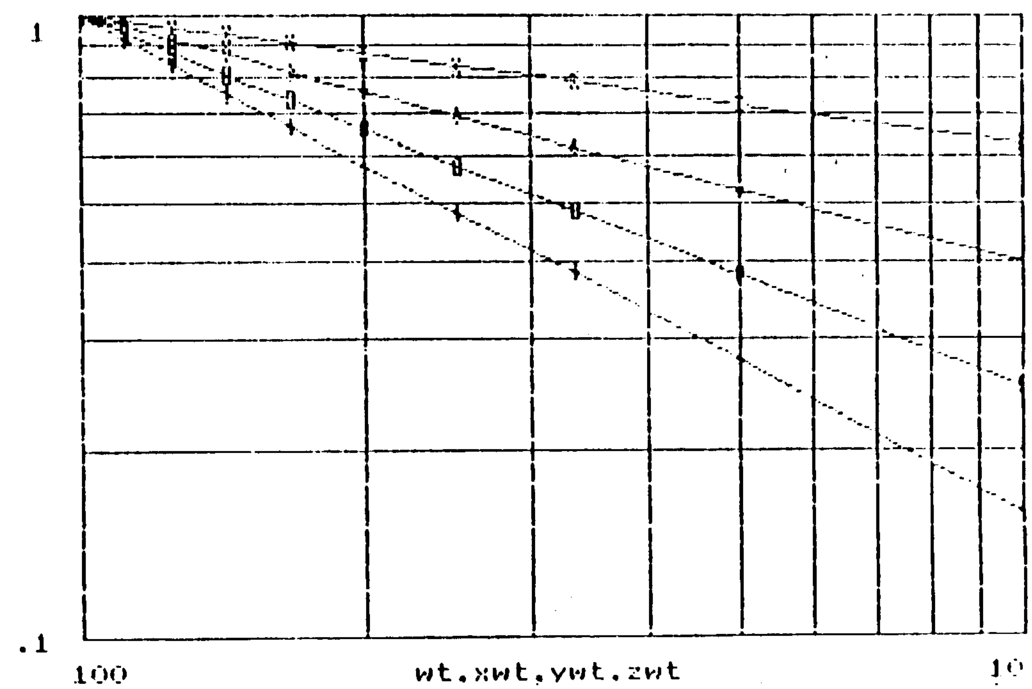
Table 3-4
Miniaturization Guide Chart
n=.8

df \ % Miniat.	0	10	20	30	40	50	60	70	80	90
Design Integration Only	1.00	.92	.84	.75	.67	.57	.48	.38	.28	.16
Significant Modification Req'd (30%)	2.00	1.84	1.68	1.50	1.34	1.14	.96	.76	.56	.32
Major Modification Req'd (50%)	3.00	2.76	2.52	2.25	2.01	1.71	1.44	1.14	.84	.48
All New Design	6.00	5.52	5.04	4.50	4.02	3.42	2.88	2.28	1.68	.96

Cost Factor from Tables 3-1 thru 3-4
cost(wt,xwt,ywt,zwt)=df*(wt)^n/wt

Figure 3 -1

Variation of Cost as a Function of Weight



X = Normalized Cost for n =.2
Y = Normalized Cost for n =.4
O = Normalized Cost for n =.6
+ = Normalized Cost for n =.8

The examples are not meant to suggest that certain combinations of miniaturization and design difficulty are more rational than others, but were selected simply to demonstrate table usage. It is conceivable that a modest degree of miniaturization is achievable with modest design (df = 2).

Caution is advised! for several reasons:

1. Some items cannot be reduced in size.

2. Some items should not be reduced in size.

3. Significant size reductions may require technology breakthroughs in materials, electronics, displays, etc. that could complicate the SBI development task.

4. Substitute materials will often negate weight reductions and raise costs even higher than estimated by the tables.

Notwithstanding all the adverse possibilities, one could conceivably reduce size and cost by miniaturizing an item or an assembly.

3.2 Modularity and Commonality

Common system modules, assemblies or components can have a profound impact upon development cost because of the potential savings associated with the use of a common module in more than one SBI hardware item. The following examples serve to illustrate this fact.

Table 3-5 shows the impact of using learning to reduce costs. For example, consider the case where sixteen units are to be constructed for a given SBI application of a system rack or drawer, but the item in question can be used in four applications rather than in only a single place. If the system is to be produced in small quantities, exotic tools and automation are not cost effective and the item is normally assembled using piece parts. Such systems usually have learning factors of 80%, i.e., each time the number of units is doubled (SBI Ref. No. 68), the cost of the nth unit is 80% of the previous cycle's end product cost. To be specific, the 2nd unit costs .8 times the first unit, the 4th unit .8 times the second, etc. See Table 3-5. In the case of a built-up drawer or rack which is used in four places, 16 units for prototypes, test, flight hardware, etc., becomes 64. As can be seen from Table 3-5, the cost of the 64th unit is 26.2% of the 1st unit and 64% of the 16th unit. The average cost for 64 items is reduced to 37.4% of the first unit cost compared to 55.8% of the first unit cost for 16 items. The lower the learning, the less dramatic the unit cost reduction, but for any item that is fabricated by other than completely automated processes, there is a cost reduction to be realized by common use in more than one application.

If one considers the programmatic input of multiple applications, there also exists the opportunity to avoid duplicate design and development efforts. For the sake of simplicity, we will confine this discussion to D&D plus fabrication and assume that four separate developments each require a test program. This being the case, we can treat a single, dual, triple and quadruple application in terms of the D&D effort and include the effect of reduced costs due to learning as well.

D&D = Design and Development Cost
TFU = Theoretical First Unit Cost
L.F. = .80
Number of articles required per application = 16

Then:

Let CP_1 = Cost of a single program,
Let 35% D&D = TFU Cost

$$C.P_1 = 1.0\ D\&D_{cost} + [.35\ D\&D * L.F.]\ 16$$

$$= 1.0\ D\&D + [.35\ D\&D * .558]\ 16$$

$$C.P_1 = 1.0\ D\&D + 3.1248\ D\&D = 4.1248\ D\&D$$

$$\text{Normalized cost} = C.P./4.1248\ D\&D$$

In a similar manner, the cost of 2, 3 and 4 applications can be calculated which yields the data in Table 3-6.

TABLE 3-5
Learning Factor Table
All First Articles are 100%

Quantity / Learning Factor		2	4	8	16	24	32	64
0.95	N^{th}	95.0%	90.3%	85.7%	81.5%	79.0%	77.4%	73.5%
	Aver.	97.5%	94.4%	90.8%	87.0%	84.65	83.0%	79.1%
0.90	N^{th}	90.0%	81.0%	72.9%	65.6%	61.7%	59.0%	53.1%
	Aver.	95.0%	88.9%	82.2%	75.2%	71.3%	68.5%	62.0%
0.85	N^{th}	85.0%	72.3%	61.4%	52.2%	47.5%	44.4%	37.7%
	Aver.	92.5%	83.6%	74.2%	64.9%	59.7%	56.2%	48.3%
0.80	N^{th}	80.0%	64.0%	51.2%	41.0%	35.9%	32.8%	26.2%
	Aver.	90.0%	78.6%	69.3%	55.8%	49.8%	45.9%	37.4%

Notes:

1. N^{th} refers to the 2^{nd}, 4^{th} etc article in the fabrication of identical articles by the same process

2."Aver.", refers to the average cost of the 1^{st} through the N^{th} article under the same conditions

3. The External Tank learning factor has been estimated at 80% (0.80) due to the relatively large amount of manual labor that goes into the fabrication process. In general the more manual the process, the greater the learning and the smaller is the number from the table that applies.

4. As the learning factors approach unity the reduction in cost for each succeeding cycle is reduced and 1.0 represents a fully automated process wherein the first article and the N^{th} article cost is the same.

5. For the purposes of the SBI trade studies we can use the guidelines that the manual fabrication and assembly processes of sheet metal have learning factors of 80% to 90% while the more automated and repetitive processes range between 90% and 95% or even as high as 97%. There probably won't be any automated processes where the costs of a number of articles remains the same as the first article cost.

Table 3-6
Cost of Multiple Applications

Applications	D&D Cost	Production Cost	Normalized Total Cost Per Application
1	1.0 (D&D)	3.1248 (D&D)	1.00
2	.50 (D&D)	5.1408 (D&D)	.744
3	.33 (D&D)	6.7704 (D&D)	.628
4	.25 (D&D)	8.3776 (D&D)	.568
5	.20 (D&D)	9.785 (D&D)	.523

Figure 3-2 is a linear plot of the foregoing information based upon a theoretical first unit (TFU) cost of 35% * (DD), Figure 3-3 is based on a TFU of 15% * (DD). Figures 3-2 and 3-3 illustrate two facts. The first is that a significant cost reduction result from the use of hardware in more than a single application. The second is that the point of diminishing cost return occurs rapidly beyond the third application.

Modularity, although similar to commonality in some respects, offers other advantages as well. However, one must acknowledge that modular designs may cost more initially than non-modular designs due to the tendency for them to require added weight for packaging and more design integration due to an increase in the number of interfaces present in the system. Nevertheless, such systems have lower life cycle costs because of simplicity in assembly, repair, replacement, problem diagnosis and upkeep in general. Also there are the advantages of being able to upgrade individual modules with new technology and/or design improvements without impacting the rest of the system and without complicated disassembly and assembly to affect a module changeout.

Thus, if modules can be made common, the system possesses the attributes of modularization and offers potential cost savings from the multiple use of various system modules. The long and short of it is that the system cost can be reduced and the system flexibility and life cycle attributes improved. Common elements in modular designs should be a major, high priority goal in all SBI systems.

3.3 Modification of Existing Hardware (COTS) vs. New Hardware Build

Commercial off-the-shelf (COTS) hardware has been used for space applications sporadically since the early days of manned space flight and it poses the same cost-related challenges today as it did 25 years ago. The variables involved are the cost of the item, the cost of modification to meet space flight requirements, and the cost of demonstrating the hardware's reliability in qualification testing.

Past experience indicates that the cost of hardware modification is normally the primary cost factor of the cost elements listed. In an effort to assign an order of magnitude to modification costs, the weight of the COTS, the degree of modification (design factor, df), and the nature of the system (weight and system complexity, n) are used as prime cost drivers. Table 3-6 and 3-7 show the cost of modification against size (wt), and for systems with complexity factors (n) of .2 and .4. The higher order complexity factors are assumed to be not applicable on the basis that COTS is usually procured as modules or assemblies and then integrated into a larger system as necessary.

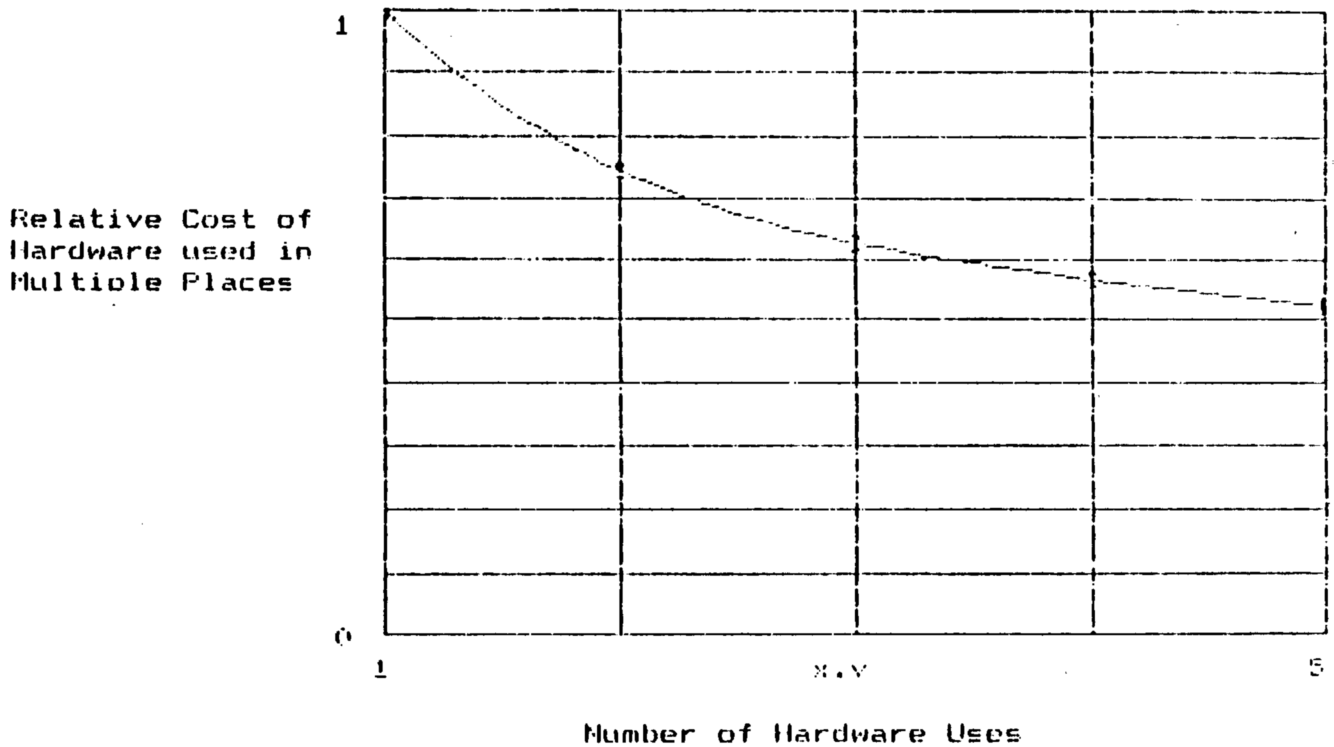
The costs shown in Tables 3-7 and 3-8 are based upon the assumption that COTS modifications are approximately the same cost as are redesigns to existing systems. The degree of modification (or redesign) is reflected in the design factor, df. The degree of system complexity is reflected by the system complexity factor, n. The range of weights over which these parameters are varied was selected on the basis that few items to be modified would be heavier than 50 Kg and that the small items less than 5 Kg would be procured as components or small assemblies which would be used in the design of a new system. The assumed size limit can be modified if necessary but were made to keep the number of weight variables in a reasonable size range with modest increments between each one. Here, again, caution is needed when applying CER type relationships to small items and to items where the portion of a hardware element being modified is small. See paragraph 2.1 for a discussion of scaling limitations.

Specific modifications to COTS may be simple enough to invalidate the assumption that modifications and redesign costs are similar. If so, alternate COTS modification cost methods will be required and will reflect greater savings. Thus, the foregoing assumption degrades gracefully because it is conservative from a cost point of view.

A popular viewpoint today is that modified COTS is always less costly than is a new design. This belief is reflected in the emphasis on "make or buy" in recent NASA RFP's and also in recent cost seminars held by major aerospace companies. Nonetheless, some cost specialists express the opinion that modifications to COTS greater than 30-35% probably makes a new design preferable. The COTS vs. new design trade study deals with these subjects so this part of the report will be confined to cost trends only. From the viewpoint of modification costs alone it appears straightforward that COTS has great cost reduction potential and should be seriously considered whenever a commercially available system element exists that can be utilized in SBI.

In order to illustrate the cost trends for modification costs and modification cost per pound, Figure 3-4 and 3-5 are included. Figure 3.4 represents minor modifications (df = .15) and n = .2, and, therefore, shows the lowest cost per pound of any of the cases in Tables 3-7 and 3-8. Figure 3-5 is for the case of substantial modifications and n = .4, df = .55 and thus represents a high side cost case. The figures both show the trends that are typical for the values presented in the tables.

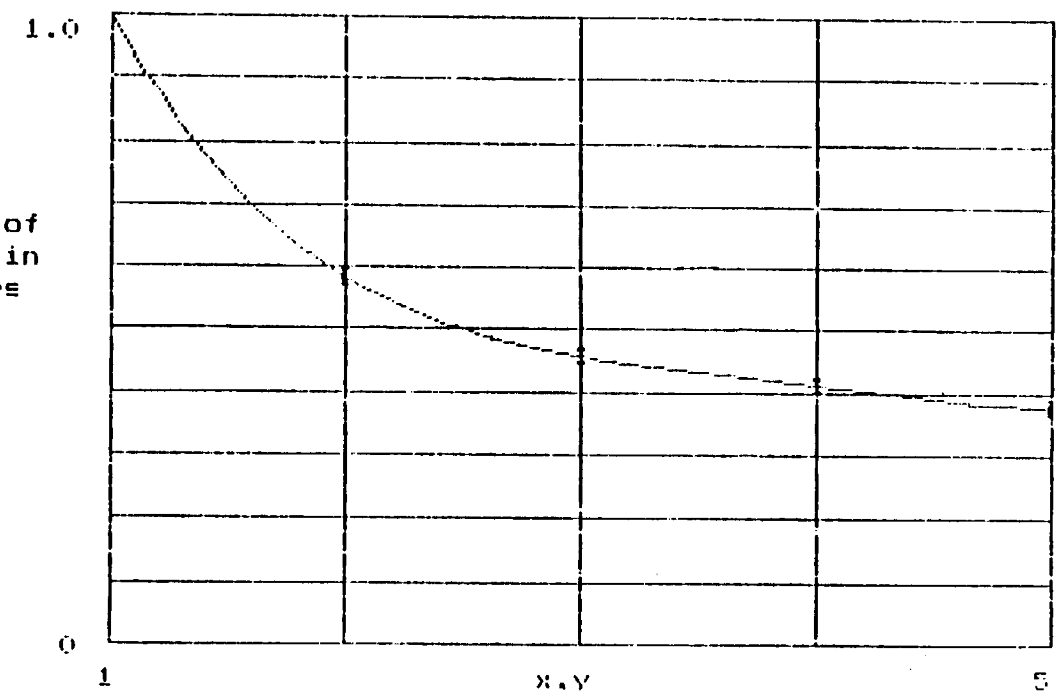
Figure 3-2
Effect on Cost of Multiple
Applications of Hardware



First Unit Cost (TFU) = .35*(Dev. Cost)

Learning Factor = 80%

Figure 3-3
Effect on Cost of Multiple
Applications of Hardware



Relative Cost of
Hardware Used in
Multiple Places

Number of Hardware Uses

First Unit Cost (TFU) = .15*(Dev.Cost)

Learning Factor = 80%

Table 3-7 Cost of Modifying Commercial Off-the Shelf Hardware

System Complexity Factor (n) =.2

Design Factor / Weight of Part Modified	Minor Mods df=.15		Modest Mods df=.35		Substantial Mods df=.55		Major Mods df=.75	
	Mod. Cost	Cost/kg	Mod. Cost	Cost/kg	Mod. Cost	Cost/kg	Mod. Cost	Cost/kg
Weight =5 kgs	242.3	48.46	565.4	113.1	888.5	177.7	1212	242.3
Weight = 10 kgs.	278.3	27.83	649.5	64.95	1021	102.1	1392	139.2
Weight = 20 kgs.	319.7	15.99	746.0	37.3	1172	58.62	1599	79.93
Weight = 30kgs.	346.7	11.56	809.1	26.97	1271	42.38	1734	57.79
Weight = 40 kgs.	376.0	9.182	857.0	21.42	1347	33.67	1836	45.91
Weight = 50 kgs.	384.0	7.681	896.1	17.92	1408	28.16	1920	38.40

Notes: 1) All costs are in thousands of dollars

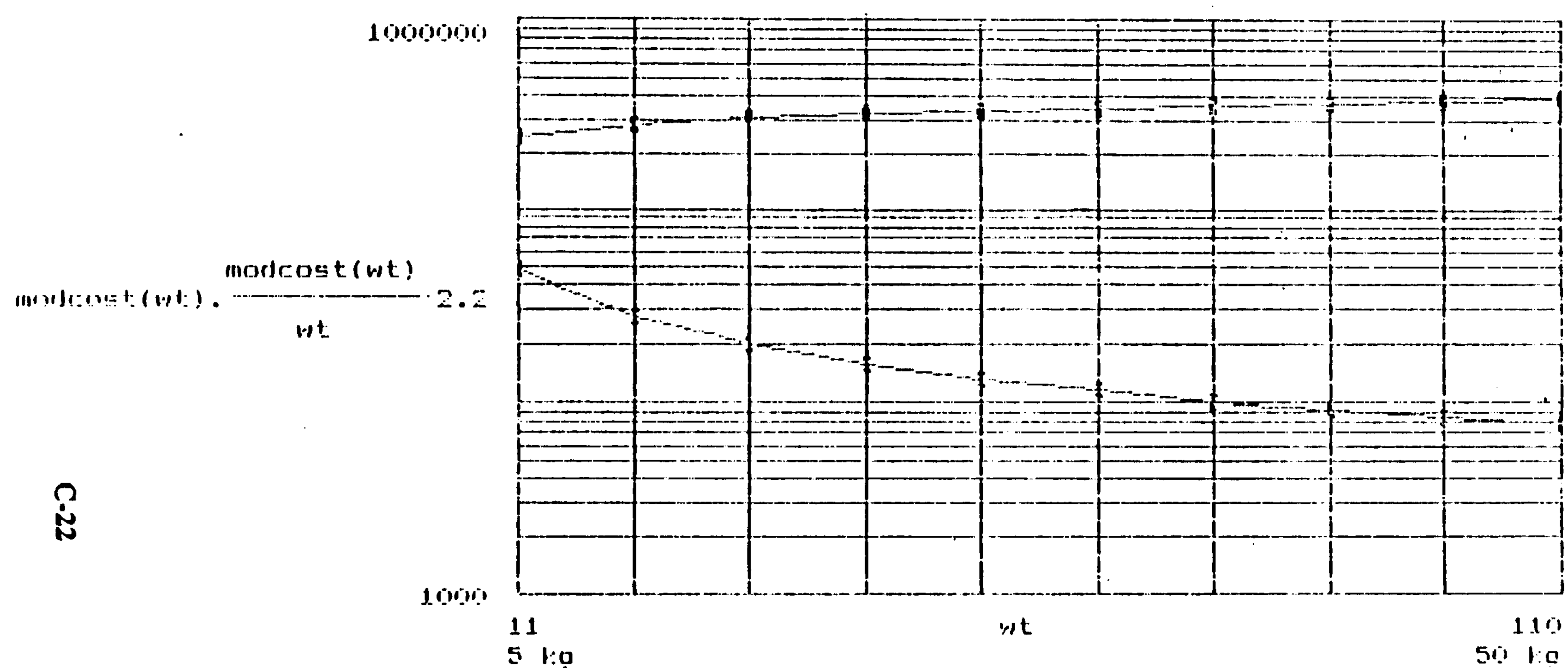
Table 3-8 Cost of Modifying Commercial Off-the Shelf Hardware

System Complexity Factor (n) =.4

Weight of Part Modified \ Design Factor	Minor Mods df=.15		Modest Mods df=.35		Substantial Mods df=.55		Major Mods df=.75	
	Mod. Cost	Cost/kg	Mod. Cost	Cost/kg	Mod. Cost	Cost/kg	Mod. Cost	Cost/kg
Weight =5 kgs.	391.4	78.28	913.3	182.7	1435	287.0	1957	391.4
Weight = 10 kgs.	516.5	51.65	1205	120.5	1894	189.4	2582	258.2
Weight = 20 kgs.	681.5	34.08	1590	79.51	2499	148.5	3408	170.4
Weight = 30 kgs.	801.5	26.72	1870	62.34	2939	97.96	4008	133.6
Weight = 40 kgs.	899.3	22.48	2098	52.46	3297	82.43	4496	112.4
Weight = 50 kgs.	983.2	19.66	2294	45.88	3605	72.10	4916	98.32

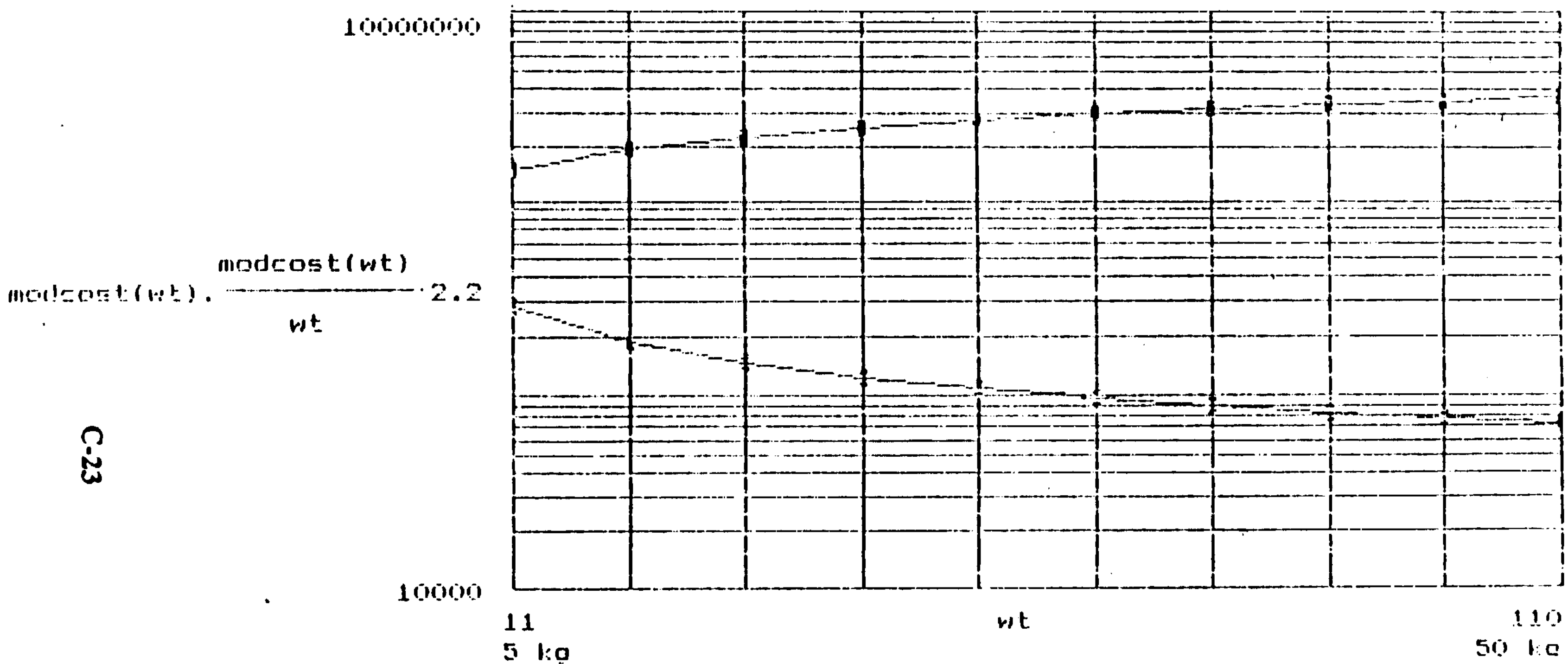
Notes: 1) All costs are in thousands of dollars

Figure 3 - 4
Variation of Cost & Cost/kg for COTS Mods
df=.15 n=.2



O = Cost of Modifications
X = Cost of MODS/kg. of COTS

Figure 3 - 5
Variation of Cost & Cost/kg for COTS Mods
df=.55   n=.4



O = Cost of Modifications
X = Cost of MODS/kg. of COTS

4.0 Testing Costs

A cursory treatment of testing costs is presented so as to make the cost picture as complete as possible. However, the applicability of test costs to SBI has not been validated and the guidelines presented should be applied with care only where a similarity exists between SBI elements and/or subsystems; and other manned spacecraft systems.

4.1 Test Hardware

Test hardware costs in past manned programs have included the cost of labor and materials for major test articles used to verify design concepts. However, test hardware cost relationships exclude element tests, component tests, qualification and certification tests. The cost of labor and material for the design, procurement, installation, checkout and operation of the instrumentation system on major test articles is included and as one might expect, these factors drive the cost of test hardware up to a value greater than the first unit cost.

The CER's examined put the cost of test hardware at 30% more than the theoretical first unit (TFU) cost, i.e. 1.3 * TFU. It should be noted that this cost is to demonstrate and to verify the operation of the designed hardware and should not be construed to include experimentation and testing to acquire biological information of an experimental or research character.

4.2 Integration Assembly and Checkout (IACO)

This factor is most commonly estimated as a function of TFU costs or test hardware costs. It will generally run on the order of 10 - 20% of test hardware costs for manned systems, but care must be exercised in applying such a rough rule of thumb to SBI. Therefore, a simple CER is suggested in cases where PRICE H estimates have not yet been formulated. The CER is as listed below:

$$IACO = .3\,(1.3\ TFU)^{0.7}$$

The resulting estimate can only be generated when all other hardware costs are available.

4.3 Test Operations

Test operations CER's indicate that costs generally run on the order of 20% to 30% of the cost of test hardware plus integration, assembly and checkout costs. However, as is the case with other test related items of cost, the applicability to SBI hardware has not been validated. Nonetheless, the order of magnitude could be used for SBI estimates pending specific definition of test requirements for the various experiments.

Examination of the SBI hardware list (Ref.SBI No. 87) and the Life Science Laboratory Equipment description (Ref. SBI No.88) suggests that test operations could vary from little or nothing all the way up to the level indicated in CER's and approximated above.

5.0 SE&I Costs

SE&I cost for the design and development phase are generally expressed as a function of the DDT&E + Systems Test Hardware + IACO + Test Operations + GSE costs. However, the lower end of the validity range is almost $1.0 billion of DDT&E costs and the applicability to SBI is extremely doubtful. For that reason, it is recommended that the preliminary SBI SE&I cost be taken as 10% to 15% of the SBI total system development cost until a detailed estimate or a PRICE H value is generated.

6.0 Program Management Costs

Program management costs usually run 5% of the total of all other costs, i.e., 5% of the sum of DDT&E + IACO + Test Hardware + Test Operations + GSE + SE&I (for DDT&E) costs. Inasmuch as there is no basis to assume that SBI program management cost is any more or any less than other types of programs, it seems reasonable to use a very preliminary value of this order of magnitude for budgetary estimating purposes.

7.0 Life Cycle Costs

As noted previously in this appendix, life cycle cost information is not available and therefore only a subjective treatment of the subject is possible. Nonetheless, Table 7-1 provides some worthwhile insights concerning all the SBI trade study subjects being addressed by Eagle. Taken singly, these subjects reveal the following probable life cycle impacts.

7.1 Study No. 3 - Miniaturization

The possible reduction of cost due to the impact of weight reduction is more theoretical than achievable. Indications are fairly clear that most attempts to miniaturize will cost rather than save money. Therefore, one must conclude that the reason for attempting size reductions is other than cost savings. It is beyond the scope of this write-up to postulate or to speculate further.

7.2 Study No. 4 - Modularity and Commonality

If the SBI program-wide support can be mobilized to support modular design and the development of hardware for common application to a number of SBI experiments and/or facilities, the cost benefit should be very significant. All the factors noted in Table 7-1 tend to substantiate this conclusion and only the programmatic direction and support has any identifiable cost or problem related to it.

Modular designs and common equipment should be a top priority requirement, goal and objective of SBI effort.

7.3 Study No. 5 - COTS vs. New Hardware

COTS should be regarded as a slightly trickier subject than commonality due to the potential pitfalls and cost penalties that can be incurred in its application to spaceflight. Nonetheless, the potential cost savings are large enough so that judicious use of COTS where it fits with the SBI program appears to be a cost-wise approach which could yield tremendous cost benefits for only nominal technical risk. Technical risk which can be offset by care in selecting, testing, and screening the procured items.

The use of modified COTS in lieu of a new design appears to pay off until the modification cost approaches the cost of an optimized new piece of hardware. The cut-off point has not been defined but would make an interesting and worthwhile follow-on study. Intuitively one would expect to find a series of cut-off points that are a function of the hardware complexity, and therefore, the cost and complexity of the modification program.

7.4 Study No. 6 - Rack Compatibility

To a greater degree than the other SBI trade studies, this subject seems to defy analysis that could give cost trend indications or life cycle cost indicators. Nevertheless, if one assumes that the inter-program coordination of rack compatibility can be accomplished with a reasonable effort, there exists the possibility to lower cost, to reduce the cost of data normalizing and comparison, and improved scientific data return might possibly be a companion benefit to lower experimentation costs.

The entire spectrum of life cycle costs beyond the design and program management phase that would accrue due to compatibility all appear to be very positive and beneficial. Logistics, ground processing, pre-flight checkout, operations, repair and replacement all would be impacted in a beneficial way by this approach. A comparable achievement that comes to mind is the establishment of standard equipment racks by the International Air Transport Association (IATA). The benefits apply to a large number of items (commercial transports) and of course the impact is greater, but the concept has been a true bonanza to all the world's commercial airlines. Rack compatibility is potentially a smaller sized cousin to IATA's achievement.

Table 7 -1 Life Cycle Cost

Phase / Study	Study No. 3 Hardware Miniaturization	Study No. 4 Modularity and Commonality	Study No. 5 COTS vs. New Hardware	Study No. 6 Rack Compatibility
Design	Design change always required. Cost of redesign may be partially offset by size & weight reduction.	Requires programmatic support and some allowance for increased weight and cost in design phase.	Dependent upon availability and suitability of commercial modules and/or elements for SBI system application.	Requires inter-program coordination/communication and direction which is very difficult to achieve.
Development	Fabrication may be complicated due to size reduction.	Development, manufacture or procurement is facilitated by modularity. Commonality cost impacts all positive.	Modified COTS appears to have significant potential advantage. Requires sound make or buy anlysis & eval.	Common source would be highly desireable but will be hard to do due to specification differences & organiz. barriers
Test and Evaluation	Test costs may increase due to difficulty in set-up and trouble shooting.	Module testing, integrated testing and test trouble shooting are simplified and cost savings result.	Testing impact appears to be negative due to need for extra qualification tests and periodic retest (screening).	Should have only minor impact which stems from differences in test requirements.
Sustaining Engineering	No significant impact pro or con is apparent.	Individual engineering groups can operate with less sytems integration effort.	Should be automatically supported by vendor's program. Generally positive. Mods could pose problems.	Responsibility may be difficult to establish and to identify. Problem potential is small due to type of hardware.
Technology Upgrade	May be less likely due to absence of alternate hardware availability.	Facilitated and made easier by modular design.	Not predictable. Experience indicates that it can vary from easy and to very painful and awkward.	Should be possible within a rack or module. Compatibility will reduce the overall cost of inserting new tech. upgrades.
Maintenance and Operations	Possible adverse impact on maintenance due to small size. Operation should not be affected.	Common module impacts on maintenance, logistics and operations are all positive & highly significant.	Maintenance of unmodified portion could pose problem. Operation not affected if reliability is adequate.	Design for long life should mean small scale preventive maintenance is all that is required.
Replacement	May be less costly due to size and favorable impact on logistics.	Can be accomplished in planned phases and/or steps with minimum disruption to system operation.	COTS use suggests that low cost replacements are available. Advantage can erode with age.	Standard interfaces can only work to reduce the cost of replacement. Fewer spares, standard procedures etc.
Overall Life Cycle Cost Impact	Tends to look negative. The need to miniaturize must be based upon reasons other than cost.	Life cycle cost impacts are all highly favorable except for design phase coordination & possible weight penalties.	Very significant life cycle cost advantage inherent in COTS. However, initial selection and mod program must be prudent.	Whatever the cost of inter-program coordination, ICD's etc., the impact on overall NASA cost is very beneficial

8.0 Recommendations

1. Perform a follow-on effort to generate a designer's "John Commonsense" manual for cost avoidance and/or reduction. The manual should be a series of simple groundrules and guidelines to help reduce Space Biology Initiative Program costs. Where possible, a series of tables or curves to help assess the potential cost gain should be included.

2. Mount an effort to accumulate an SBI historical cost data base. The objective should be at least two-fold. First, identify the breakpoint for various cost trade-offs. Examples are presented in Figures 3-2 and 3-3 which show that commonality soon reaches a point of diminishing return insofar as it pertains to development and manufacturing. Given such breakpoints, explore the possibility of additional life cycle cost benefits which result from reduced sparing, simplified logistics, reduced maintenance, etc. Second, obtain enough historical cost information to permit the development of CER's that are properly scaled for the range of sizes in question. Existing CER's have limitations that may invalidate their use on SBI. Therefore, actual cost data from ongoing SBI efforts would provide a valuable asset to future work of a similar nature.

3. Consider a follow-on program to develop a rule-based or expert system that could be used for quick cost estimates and cost comparisons. Such an effort can only proceed in parallel with item 2, above, but the development time is such that it should begin as soon as practical.

4. Generate a comprehensive compendium of cost estimating relationships and apply them to SBI. Subsequently, make comparisons with other cost estimating methods in an attempt to remove the existing programmatic skepticism about the voodoo and black magic of cost predictions.

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Appendix D - Database Definition

Appendix D - Database Definition

The database files for the SBI trade Studies were developed using dBASE IV. The database files consist of dbf, ndx, and frm files. The dbf files are dBASE IV database files. NDX files are the index files for the dbf (database) files. The frm files are report files for the trade study candidate and bibliography reports. The SBI trade study database consist of 4 database files with 78 fields of information. A complete listing of the database structure and dictionary is included in this database definition.

Database Structure For SBI Trade Studies

Structure for database: W:hardware.dbf
Number of data records: 93
Date of last update : 05/30/89

Field	Field Name	Type	Width	Dec
1	HW_ID	Character	3	
2	HW_NAME	Character	50	
3	HW_DESCRTN	Character	254	
4	HW_FACILIT	Character	55	
5	INFO_SOURC	Character	250	
6	HW_MASS	Numeric	6	3
7	HW_VOLUME	Numeric	8	6
8	HW_POWER	Numeric	4	
9	HW_VOLTAGE	Numeric	6	
10	HW_HEIGHT	Numeric	6	
11	HW_WIDTH	Numeric	6	
12	HW_DEPTH	Numeric	8	
13	REMARKS	Character	50	
14	RECORD_DAT	Date	8	
15	GROUP	Character	50	
16	CATEGORY	Character	50	
17	FUNCTION	Character	60	
18	FAC_ID	Character	4	
19	GROUP_ID	Character	4	
20	MIN_LEVEL	Character	5	
21	CONFIDENCE	Character	5	
22	SUFFIC_DAT	Character	4	
23	PRIORITY	Character	2	
24	MIN_LV_POT	Character	6	
25	MIN_EST_CF	Character	6	
26	MOD_LV_POT	Character	6	
27	MOD_EST_CF	Character	6	
28	COM_LV_POT	Character	6	
29	COM_EST_CF	Character	6	
30	SYS_COMPLX	Character	6	
31	DSN_COMPLX	Character	6	
32	BUY_LV_POT	Numeric	4	
33	BUY_MOD_LV	Numeric	4	
34	BUY_EST_CF	Character	4	
35	BUY_OTS_PT	Numeric	4	
36	BUY_DAT_AV	Character	4	
37	MOD_CAN	Logical	1	
** Total **			968	

Structure for database: W:biblo.dbf
Number of data records: 98
Date of last update : 05/26/89

Field	Field Name	Type	Width	Dec
1	BB_ID	Character	5	
2	AUTHOR_NO1	Character	16	
3	AUTHOR_NO2	Character	12	
4	AUTHOR_NO3	Character	12	
5	ART_TITLE	Character	135	
6	BOOK_TITLE	Character	100	
7	VOLUME_NO	Character	3	
8	PUBLISHER	Character	42	
9	PUBL_LOC	Character	32	
10	DATE	Date	8	
11	PAGE_NOS	Character	4	
12	ABSTRACT	Character	100	
13	ACQUIRED	Character	20	
14	COST	Numeric	6	
15	LOANED	Character	4	
16	REP_DOC_NO	Character	22	
17	MOD	Logical	1	
18	MIN	Logical	1	
19	COTS	Logical	1	
20	RACK	Logical	1	
** Total **			526	

Structure for database: W:rack_com.dbf
Number of data records: 166
Date of last update : 05/26/89

Field	Field Name	Type	Width	Dec
1	IF_ITEM	Character	38	
2	UNITS	Character	8	
3	UNIT_SYS	Character	1	
4	ITEM_TYPE	Character	12	
5	VALUE	Character	50	
6	MODULE	Character	25	
** Total **			135	

Structure for database: W:comm_mod.dbf
Number of data records: 153
Date of last update : 05/30/89

Field	Field Name	Type	Width	Dec
1	HW_ID	Character	3	
2	COMM_MOD	Character	30	
3	COUNT	Numeric	1	
4	COST_DECSC	Numeric	4	2
5	MASS	Numeric	4	2
** Total **			43	

Appendix D - Database Dictionary for Space Biology Initiative Trade Studies

Hardware.dbf This is the database file for SBI hardware.

Field 1	HW_ID	Unique identification number for each hardware item
Field 2	HW_NAME	Hardware name
Field 3	HW_DESCRTN	Hardware description
Field 4	HW_FACILIT	Facility where SBI hardware is used
Field 5	INFO_SOURC	Information source for SBI hardware data
Field 6	HW_MASS	Hardware mass
Field 7	HW_VOLUME	Hardware volume
Field 8	HW_POWER	Hardware power requirement
Field 9	HW_VOLTAGE	Hardware voltage requirements
Field 10	HW_HEIGHT	Hardware height
Field 11	HW_WIDTH	Hardware width
Field 12	HW_DEPTH	Hardware depth
Field 13	REMARKS	Remarks concerning SBI hardware equipment
Field 14	RECORD_DAT	Update of last record
Field 15	GROUP	Hardware group
Field 16	CATEGORY	Hardware category
Field 17	FUNCTION	Hardware function
Field 18	FAC_ID	Hardware facility ID number
Field 19	GROUP_ID	Hardware group ID number
Field 20	MIN_LEVEL	Miniaturization level for hardware
Field 21	CONFIDENCE	Confidence level for miniaturization
Field 22	SUFFIC_DAT	Is there sufficient data to make a decision of hardware miniaturization?
Field 23	PRIORITY	Priority level for hardware item based on mass
Field 24	MIN_LV_POT	Miniaturization level potential for the hardware item
Field 25	MIN_EST_CF	Confidence level for miniaturization
Field 26	MOD_LV_POT	Modularity potential for hardware item
Field 27	MOD_EST_CF	Confidence level for modularity estimate
Field 28	COM_LV_POT	Commonality potential for hardware item
Field 29	COM_EST_CF	Confidence level for commonality estimate
Field 30	SYS_COMPLX	System complexity for hardware item
Field 31	DSN_COMPLX	Design complexity for hardware item
Field 32	BUY_LV_POT	Percent Buy for Hardware Item
Field 33	BUY_MOD_LV	Percent modification to Buy Hardware Item
Field 34	BUY_EST_CF	Confidence Level for Make-or-Buy Estimate
Field 35	BUY_OTS_PT	Percentage of COTS hardware that does not require modification
Field 36	BUY_DAT_AV	Is sufficient data available for make-or-buy estimate
Field 37	MOD_CAN	Logical field can the hardware item be modularized Y or N

PROTOTYPE UTILIZATION IN THEDEVELOPMENT OF SPACE BIOLOGY HARDWARE

TRADE STUDIES

JOHNSON SPACE CENTER
HOUSTON, TEXAS
77058

SPACE BIOLOGY

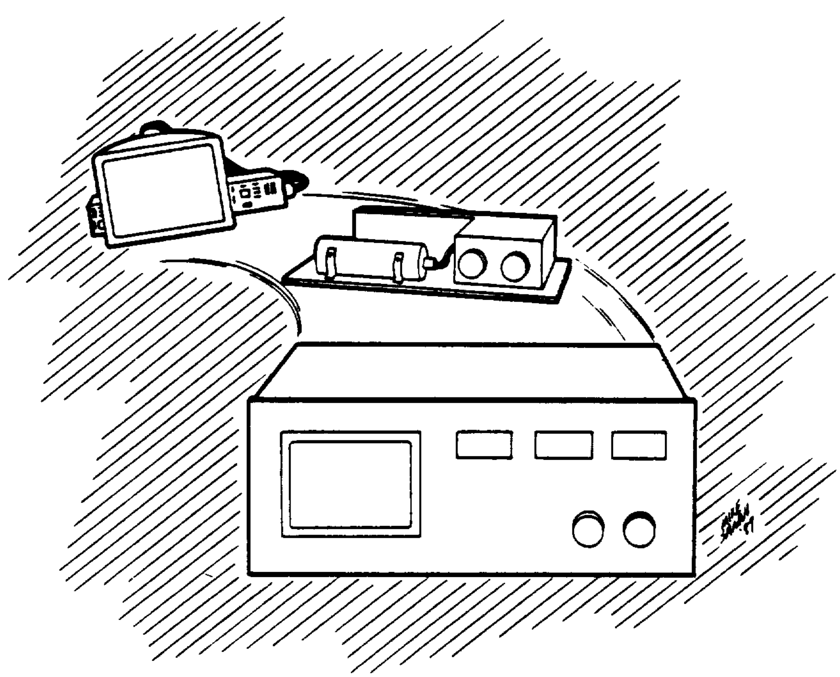
INITIATIVE

Space Biology Initiative
Program Definition Review

Lyndon B. Johnson Space Center
Houston, Texas 77058

HORIZON AEROSPACE

Prototype Utilization in the Development of Space Biology Hardware



FINAL REPORT

June 1, 1989