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TRADE STUDIES

JOHNSON SPACE CENTER
HOUSTON, TEXAS
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SPACE BIOLOGY

INITIATIVE

VOLUME II

HARDWARE MINIATURIZATION VS COST

TRADE STUDIES

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SPACE BIOLOGY

INITIATIVE

Space Biology Initiative
Program Definition Review

Lyndon B. Johnson Space Center
Houston, Texas 77058

HORIZON
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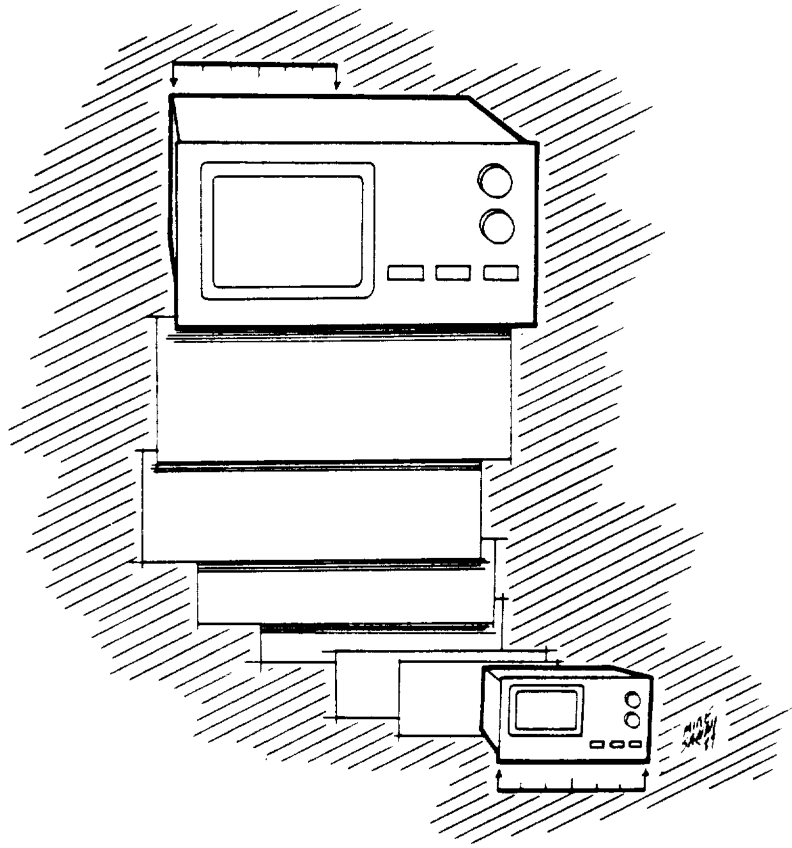
Hardware Miniaturization vs. Cost



FINAL REPORT

June 1, 1989

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SPACE BIOLOGY INITIATIVE
PROGRAM DEFINITION REVIEW

TRADE STUDY 3

HARDWARE MINIATURIZATION
vs.
COST

FINAL REPORT

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Foreword

The "Hardware Miniaturization Versus Cost 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 to NASA Headquarters, Code B, scheduled for the June-July, 1989 time period. The task personnel researched, acquired, recorded, and analyzed information relating to miniaturization of space biology equipment. The study data provides parametric information indicating the factors which influence the cost and design for categories and functions of SBI hardware.

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:	Mr. Frank J. Herbert
Cost Analysis Techniques Leader:	Mr. James W. Bilodeau (Jim)
Visual Materials Support:	Mr. J.M. Stovall (Mike)
Information Management Leader:	Mr. Terry Sutton (Eagle Technical Services)

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List of Abbreviations and Acronyms

AI	Artificial Intelligence
ARC	Ames Research Center
BmRP	Biomedical Research Project (Human/Crew Members)
BRP	Biological Research Project (Non Human/Rodents, primates or plants)
BPMF	Bioinstrumentation & Physiological Monitoring Facility
BSHF	Biological Specimen Holding Facility
CAD	Computer Aided Design
CDR	Critical Design Review
CELSS	Closed Ecological Life Support System
CHeC	Crew Health Care
COTS	Commercial Off-The-Shelf
CR	Change Request
DDT&E	Design, Development, Test and Evaluation
DMS	Data Management System
DRI	Denver Research Institute
ECF	Exercise Countermeasure Facility
ECLSS	Environmental Control and Life Support System
EDCO	Extended Duration Crew Operations
EHS	Environmental Health System
EPDS	Electrical Power Distribution System
FEAST	Flight Early Acquisition Systems Test
FSU	Functional Support Unit
GGS	Gas Grain Simulator
HMF	Health Maintenance Facility
HPLC	High Performance Liquid Chromatography
HQUL	Hardware Quantity and Usage List
HRF	Human Research Facility
JSC	Johnson Space Center
KSC	Kennedy Space Center
LAN	Local Area Network
LSE	Laboratory Support Equipment
LSLE	Life Sciences Laboratory Equipment
LSRF	Life Science Research Facility
MDE	Mission Dependent Equipment
MDU	Medical Development Unit
MLI	Multi-Layer Insulation
MRDB	Mission Requirements Data Base
MSK	Major Subcontractor
NASA	National Aeronautics and Space Administration
NSTS	NASA Space Transportation System
OTS	Off-The-Shelf
PI	Principal Investigator
PMC	Permanent Manned Capability
PMS	Pulmonary Monitoring System
POCC	Payload Operations Control Center

RMOAD	Reference Mission Operational Analysis Document
SAIS	Science & Applications Information System
SBHB	Space Biology Hardware Baseline
SBI	Space Biology Initiative
SSF	Space Station Freedom
SSFP	Space Station Freedom Program
SSIS	Space Station Information Systems
TDRSS	Tracking and Data Relay Satellite System
TFU	Theoretical First Unit
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.

Orbit 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 must be adjusted in scope and schedule to be complete for the SBI Definition (Non-Advocate) Review.

1.2 Task Statement

The objective of this study is to determine the optimum hardware miniaturization level with the lowest cost impact for space biology hardware. Space biology hardware and/or components/subassemblies/assemblies which are the most likely candidates for application of miniaturization are to be defined and relative cost impacts of such miniaturization are to be analyzed. The study will provide a mathematical or statistical analysis method with the capability to support development of parametric cost analysis impacts for levels of production design miniaturization.

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 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. The trade study results are planned to be produced in the form of factors, guidelines, rules of thumb, and technical discussion which provide insight on the effect of miniaturization on the relative cost of the SBI hardware. The SBI cost estimators are required to define input parameters to the PRICE model which control the cost estimating algorithms. These trade study results can be used as a handbook of miniaturization cost effects by the SBI cost estimators in developing and defining the required PRICE input parameters.

1.4 Scope

The space biology hardware to be investigated has been defined and baselined in Appendix A which is titled 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 requirements may be stable in the early program phases, hardware end item specifications are evolving and may change many times during the design process. For this reason, the trade study analyses have focused on the category and function of each hardware item (Table 1.4) 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 Miniaturization 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 analysis; and, finally, the payoff phase where candidate items and implementation factors are identified.

1.5.1 Data And Documentation Survey

A literature review and database search were conducted immediately upon study initiation. Information pertaining to the miniaturization of commercial and space flight research hardware was considered for applicability to the study task.

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 Costing Techniques Summary

Costing techniques used in previous projects were surveyed and historical cost factors were collected for review of applicability to this trade study. The applicable data were identified for use in cost analysis to demonstrate relative cost impacts of miniaturization for space biology technology hardware.

1.5.4 Survey Data Integration

The Space Biology Hardware Baseline was reviewed and the hardware that had potential for miniaturization was identified as candidates for miniaturization. The technical data collected from the survey was integrated with the Space Biology Hardware Baseline and an analysis of candidates, specifications, cost, and miniaturization applications was performed.

The initial survey data analysis was performed to select a sample of the SBHB items which could be potential candidates for miniaturization. With limited study time and a SBHB of 93 items, a method was needed to separate the items which could have the most cost impact and were worthy of study resource application. The "vital few and trivial many" method (SBI #96) was used. This method applies the principle that in any population which contributes to a common effect (cost), a relative few of the contributors account for the bulk of the effect (cost). All SBHB items were listed in descending order of probable acquisition cost. Weight was used as an indication of probable acquisition cost based on historical experience in previous space programs. It was found that 34 percent of the items (32 items) accounted for 93 percent of the mass or probable cost (Table 5.2). Therefore, consideration was immediately limited to these 32 items. The miniaturization candidate sample set was chosen from Table 5.2 based on amenability to miniaturization.

The sample set was then subjected to a more detailed analysis to determine important factors relative to miniaturization and to select the most representative candidate for final analysis. By this process, a reasonable effort could be devoted to analyze one example case more thoroughly.

1.5.5 Cost Analysis

Analyses were performed to demonstrate the relative cost impact to miniaturize the candidate items. Additional study was dedicated to the final selected item. Based on this analysis, the relative relationship of miniaturizing space biology hardware to cost was assessed.

1.6 Definition of Miniaturization

1.6.1 Size Reduction

The miniaturization of a hardware item will be designated in terms of percentage. The range of percentage miniaturization will normally vary between 10% and 90% in increments of 10%. The miniaturization in this trade study will deal with weight reduction as the size of a hardware item is reduced. That is a 10% miniaturization means a 100 kg item will be reduced to 90 kg. We will also assume that volume will be reduced 10% (i.e. 100 M^3 would be reduced to 90 M^3).

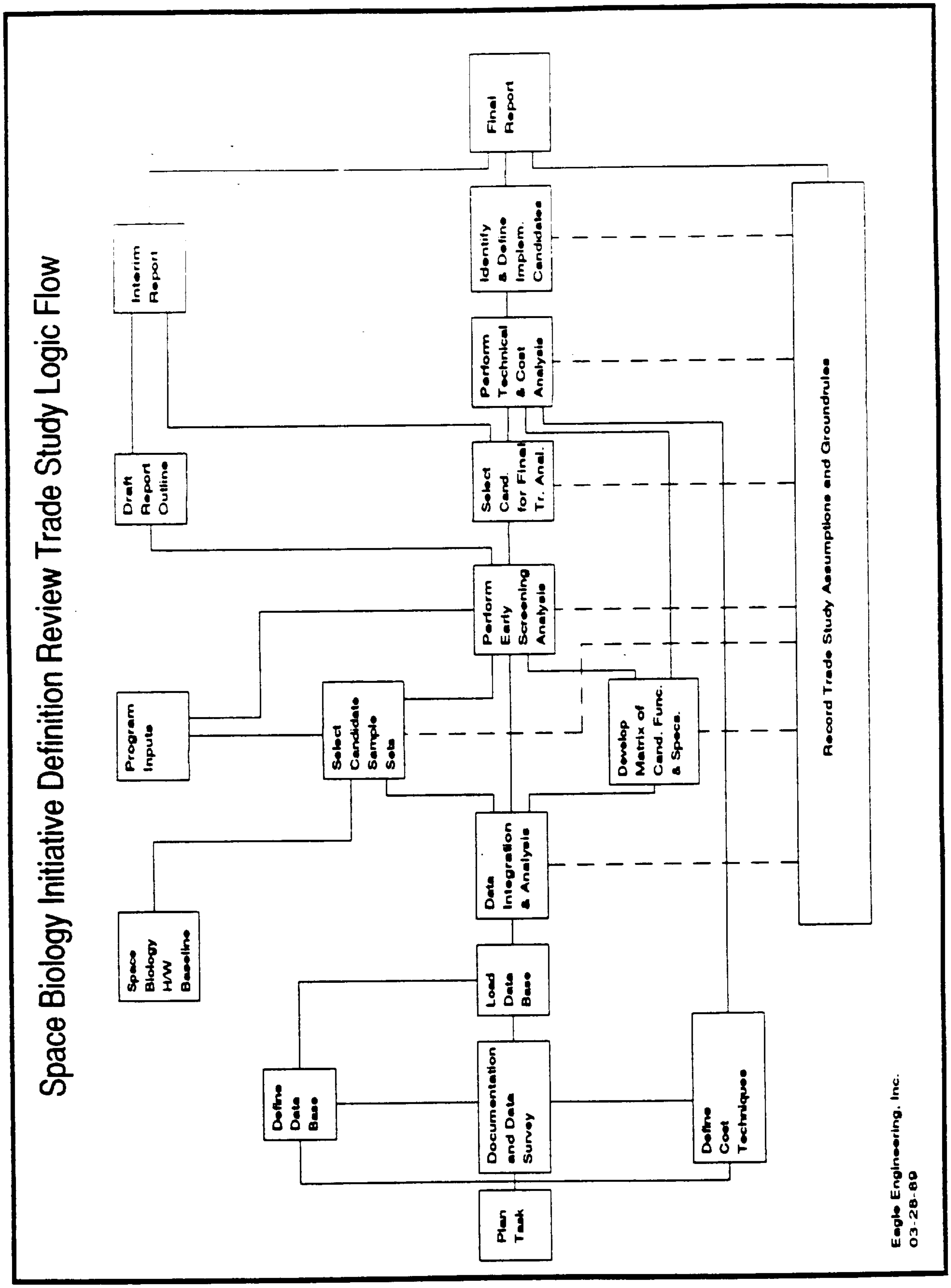
1.6.2 Performance

The SBI hardware item, after miniaturization, (10% or 90%) must meet or exceed the original performance requirements as set by the Principle Investigator (PI). There may be a new technological development that reduces the size of the various parts within a hardware item. However, if the hardware fails to be compatible with other units or in providing accurate results then the miniaturization is of no benefit.

Table 1.4 SBI Hardware Categories and Functions

SBI HARDWARE CATEGORIES	FUNCTIONS (Applicable to each Category)
Cardiovascular	Analysis
Cytology	Calibration
Environmental Monitoring	ELSS
Exobiology	Collection
Hematology	Health Maintenance
Histology	Measurement
Logistics	Preparation
Miscellaneous	Stowage
Neurophysiology	
Plant Sciences	
Pulmonary	
Surgical Science	
Urology	

Figure 1.5-1 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 a 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 a list common to all of the studies (Table 2.1-1). The assumptions which primarily affect the miniaturization study are documented in a separate list (Table 2.1-2).

2.2 SBI Candidate Hardware Items For Miniaturization

The baseline candidate list of 93 SBI hardware items is shown in Appendix A with an "S" by each item. Space flight history has established that project costs are most significantly affected by space equipment weight. To determine which SBI hardware warranted the most study resources, the SBI hardware list was prioritized by mass (Table 2.2-1 repeated from Table 5.2-1) showing the top 32 items which represent 93% by mass, 87% by volume and 85% by power (watts) of the total 93 items. The 32 hardware items in Table 2.2-1 were reviewed and selective judgments were recorded on the potential for miniaturization (Table 2.2-2 repeated from Table 5.2-2). The list in Table 2.2-2 was then reviewed and reduced by dropping those items with insufficient definition and those items which may only have a potential for being reduced in size by 0 - 10%. The miniaturization candidate sample set listing the best possible 20 candidates for miniaturization is provided in Table 2.2-3 (repeated from Table 5.2-3).

2.3 Miniaturization Cost Impacts

The gas grain simulator (hardware item 169) was selected from the candidate sample set for an indepth analysis. Using Appendix E and the gas grain simulator (GGS) information as shown in Section 5, a relative cost impact factor was developed for each of the 8 assemblies of this GGS (Table 5.3). The relative cost factors (design factor and complexity are discussed in Appendix C) shown in Table 5.3 are subjective and a small change in these factors has a profound change on the relative cost factor for miniaturization. For example, the GGS assembly III, Aerosol, and assembly V, Spectrometry, have the same mass and the same amount of miniaturization. However, due to a difference in factors (n and df) the relative cost for miniaturization is totally different. Assembly III, is a 13% increase while assembly V is a decrease of .03% in relative cost for miniaturization.

Table 2.3 shows the final analysis of the GGS along with the other 3 top SBI hardware items. The GGS was chosen for detailed analysis due to the total mass and the availability of data. The mass percent column was added to this Table 2.3 to show the method of calculating the prorated cost percent. (Mass Percent times the cost factor % equals the cost prorata %.) Those subsystems with less than 10% miniaturization were not considered in this calculation and, therefore, do not show up in the cost prorata. The overall cost increase as shown in Table 2.3 and 5.3 indicates that the GGS would have a 5.16% increase in cost for miniaturizing some of the individual subsystems.

The results of this trade study, though somewhat limited in scope, indicate that miniaturization will almost invariably increase cost. The greater the degree of change required to achieve miniaturization, the greater will be the cost. However, a large degree of the redesign cost increase for miniaturization can be offset by virtue of weight reduction.

2.4 Performance Assessment

The groundrule has been established that the equipment performance specifications must be satisfied with any method chosen for hardware implementation. Therefore, the performance and accuracy of the equipment should not be an issue. The various components within the subsystems of the GGS may not be compatible with being miniaturized without affecting performance. There is always a risk with new technology and new equipment that the final performance would be degraded with miniaturization. The components of the subsystem as well as the performance of the entire hardware unit must be compatible.

2.5 Future Work

The analysis shown in Table 2.3 for the GGS can be done for all the hardware items to estimate the cost impact for miniaturization.

The life cycle cost relationship was not addressed in this trade study; however, future trade studies should address the effects.

The hardware items that have common components and the feasibility of miniaturizing a common component would be a tremendous cost savings.

Future trade studies should look at all related medical/science programs (i.e. CHeC, etc.) for miniaturization.

2.6 Conclusion Summary

Miniaturization of SBI hardware that is complex will generally add to the cost of development. The heavier items (Mass) will give the greatest potential return for miniaturizing. Miniaturizing may allow more experiments to be placed on-board SSF than had previously been planned. Life cycle cost impacts were not added in this trade study, but should be for future studies. Weight restrictions for the total SSF payload may require miniaturization to reduce the weight and volume of a specific hardware item or it will not be flown.

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 Miniaturization Trade Study Assumptions and Groundrules

1) Availability of data on hardware definition was a factor in selecting the best possible miniaturization candidates.

2) Absence of specific equipment historical data required using empirical data for cost analysis.

Item Prioritized by Mass	Hardware Item #	Hardware Item Name	Mass		Power		Volume	
			Kg	Accumul.	(Watts)	Accumul.	M^3	Accumul.
1	168	CELSS	1000	1000	1300	1300	1.92	1.92
2	169	Gas Grain Simulator	800	1800	1500	2800	1.92	3.84
3	84	Soft Tissue Imaging System	300	2100	800	3600	.96	4.80
4	77	Hard Tissue Imaging System	136	2236	300	3900	.29	5.09
5	126	Scintillation Counter	90	2326	500	4400	.24	5.33
6	74	Force Resistance System	70	2396	100	4500	.40	5.73
7	145	Automated Microbic System	70	2466	110	4610	.20	5.93
8	155	Total Hydrocarbon Analyzer	70	2536	250	4860	.20	6.13
9	161	Inventory Control System	70	2606	500	5360	.20	6.33
10	162	Lab Materials Pack & Hand. Equip.	70	2676	500	5860	.20	6.53
11	163	Test/Ckout/Calibration Instrumentation	70	2746	200	5860	.20	6.73
12	106	Neck Baro-Cuff	45	2791	145	6205	.13	6.86
13	113	Blood Gas Analyzer	45	2836	250	6455	.13	6.99
14	61	Mass Spectrometer	41	2897	200	6655	.09	7.08
15	112	Plant HPLC Ion Chromatograph	40	2917	200	6855	.12	7.2
16	147	Head Torso Phantom	32	2949	0	6855	.12	7.32
17	63	Pulmonary Gas Cylinder Assem.	30	2979	0	6855	.09	7.41
18	110	Plant Gas Chromatograph/Mass Spectrometer	25	3004	100	6955	.20	7.61
19	115	Chemistry System	23	3027	100	7055	.08	7.69
20	138	Hematology	23	3050	200	7255	.07	7.76
21	34	Sample Preparation Device	22	3072	150	7405	.17	7.93
22	165	Experiment Control Computer System	20	3092	400	7805	.05	7.98
23	62	Pulmonary Function Equip Stor. Assem.	20	3112	0	7805	.05	8.03
24	82	Motion Analysis System	20	3132	100	7905	.05	8.08
25	99	Animal Biotelemetry System	20	3152	100	8005	.05	8.13
26	100	Blood Pressure & Flow Instrumentation	20	3172	200	8205	.06	8.19
27	109	Venous Pressure Transducer/Display	20	3192	100	8305	.05	8.24
28	129	Cell Handling Accessories	20	3212	50	8355	.05	8.29
29	57	Bag-in-Box	19	3231	0	8355	.15	8.44
30	111	Plant Gas Cylinder Assem.	19	3250	0	8355	.09	8.53
31	119	Gas Cylinder Assembly	19	3269	50	8405	.09	8.62
32	130	Cell Harvester	19	3288	50	8455	.06	8.68

93 SBI H/W Items 89 Items have 3535 kg mass 10.0M³ of volume 10,359 watts of power 4 Items are TBD (all are small)

Table 2.2-1 List of SBI Hardware Vital to Program Cost Impact Analysis

Item # Prioritized by Mass	Hardware Item #	Hardware Item Name	Sufficient Data Available	Miniaturization Level (Percent)				Assessment Confidence Level	
				0-10	10-20	20-50	50+	Low	High
1	168	CELSS				X			X
2	169	Gas Grain Simulator Facility				X			X
3	84	Soft Tissue Imaging System	No						
4	77	Hard Tissue Imaging System	No						
5	126	Scintillation Counter			X			X	
6	74	Force Resistance System			X			X	
7	145	Automated Microbic System				X			X
8	155	Total Hydrocarbon Analyzer	No						
9	161	Inventory Control System				X			X
10	162	Lab Materials Pack & Hand. Equip.		X				X	
11	163	Test/Ckout/Calibration Instrumentation				X		X	
12	106	Neck Baro-Cuff				X			X
13	113	Blood Gas Analyzer	No						
14	61	Mass Spectrometer			X			X	
15	112	Plant HPLC Ion Chromatograph	No						
16	147	Head Torso Phantom			X				X
17	63	Pulmonary Gas Cylinder Assem.		X				X	
18	110	Plant Gas Chromatograph/Mass Spec			X			X	
19	115	Chemistry System			X			X	
20	138	Hematology			X			X	
21	34	Sample Preparation Device		X					
22	165	Experiment Control Computer System				X			X
23	62	Pulmonary Function Equip Stor. Assem.		X					X
24	82	Motion Analysis System				X			X
25	99	Animal Biotelemetry System			X				X
26	100	Blood Pressure & Flow Instrumentation	No						
27	1^9	Venous Pressure Transducer/Display			X			X	
28	129	Cell Handling Accessories				X			X
29	57	Bag-In-Box			X			X	
30	111	Plant Gas Cylinder Assem.	No						
31	119	Gas Cylinder Assembly							X
32	130	Cell Harvester				X		X	

Table 2.2-2 Miniaturization Assessment Review for Sample Selection

Item # Prioritized by Mass	Hardware Item #	Hardware Item Name	Miniaturization Level (Percent)			Assessment Confidence Level	
			10-20	20-50	50+	Low	High
1	168	CELSS		X			X
2	169	Gas Grain Simulator Facility		X			X
5	126	Scintillation Counter	X			X	
6	74	Force Resistance System	X			X	
7	145	Automated Microbic System		X			X
9	161	Inventory Control System		X			X
11	163	Test/Ckout/Calibration Instrumentation		X		X	
12	106	Neck Baro-Cuff		X			X
14	61	Mass Spectrometer	X			X	
16	147	Head Torso Phantom	X				X
18	110	Plant Gas Chromatograph/Mass Spec	X			X	
19	115	Chemistry System	X			X	
20	138	Hematology	X			X	
22	165	Experiment Control Computer System		X			X
24	82	Motion Analysis System		X			X
25	99	Animal Biotelemetry System	X				X
27	109	Venous Pressure Transducer/Display	X			X	
28	129	Cell Handling Accessories		X			X
29	57	Bag-In-Box	X			X	
32	130	Cell Harvester		X		X	

Table 2.2-3 Miniaturization Candidate Sample Set

H/W Item #	Priority # by Mass	H/W Item Name	Lowest Assembly Component Level Possible	Mass (kg)	Mass Percent	Percent Miniaturization	Relative Cost Factor %	Cost Pro-rated %
168	1	CELSS*						
			Modified Plant Growth	27.				
			Gas & Liquid Handling	27.				
			Water Condensation	27.				
			Nutrient Delway	27.				
			Crop Research	635.				
			Chamber-seed Germ.	7.				
		TOTAL		750.				
169	2	GGS	Chamber	200.	25.	<10	-	-
			Environment Mont.	80.	10.	30	+16	1.6
			Aerosol Gen.	150.	18.75	30	+13	2.43
			Optics/Imaging	80.	10.	<10	-	-
			Spectrometry	150.	18.75	30	(-.03)	(-.56)
			Particle	50.	6.25	10	+15	.93
			Computer	50.	6.25	30	+13	.81
			Storage	40.	5.	10	(-.01)	(-05)
		TOTAL		800.	100.			5.16
84	3	Soft Tissue Imaging TOTAL		300.				
77	4	Hard Tissue Imaging TOTAL		136.				

Notes: * Revised mass figures as of 5/5/89

Table 2.3 Miniaturization Cost Impact Analysis

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

An extensive survey was made to collect all the latest information pertaining to miniaturization and associated cost experience. Library searches were made using titles, authors, key words, acronyms, phrases, synonyms, time periods and any possible activities related to miniaturization. Interviews with personnel (both in-person and by telephone) having knowledge of the study subject were made 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 EEI SBI reference index number has been assigned to each information source.

4.1.2 Trade Study Bibliography For Miniaturization

Particular reference information from Appendix B that is of special importance to miniaturization is repeated in Table 4.1.2. All references were used to gain background information for the final analysis of the candidate selection and for the degree of miniaturization.

4.2 Documentation Data

The Physiological Monitoring System (PMS) used on Skylab had unique monitoring sensors. These sensors had built-in microminiaturized amplifiers that were developed by the Denver Research Institute (DRI). These amplifiers were developed under the management of NASA JSC and were microminiaturized specifically for the PMS. These same basic sensors with the microminiaturized amplifiers are to be used for the SBI Bioinstrumentation & Physiological Monitoring Facility (BPMF) (Group 3 in Appendix A). See reference SBI-69 & 70. However, no cost information was available to indicate the cost required to accomplish the PMS miniaturization. No documentation could be located that dealt directly with miniaturization and the related relative cost of miniaturizing. The literature did not reveal any reference to cost factors nor did any of the interviews reveal any reference to cost factors.

Table 4.1-2 Bibliography for Miniaturization Trade Study

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
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
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

Table 4.1-2 Bibliography for Miniaturization Trade Study

ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
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 Implementa- tion For Shuttle Launched And Serviced Automated Spacecraft		TRW Systems Group	Contract NASW - 2717	Redondo Beach, CA.	03/19/89
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

Table 4.1-2 Bibliography for Miniaturization Trade Study

ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SB126	NASA	Concepts And Requirements For Space Station Life Sciences Ground Support And Operations		NASA JSC	LS-70034	Houston, TX.	04/11/88
SB127	NASA	Spacelab Mission 4 Integrated Payload Requirements Document		NASA JSC	SM-SE-03	Houston, TX.	06/01/83
SB128	General Dynamics	Life Sciences Payload Definition And Integration Study	IV	General Dynamics	CASD-NAS-74-046	San Diego, CA.	08/01/74
SB129	General Dynamics	Life Sciences Payload Definition and Integration Study - Executive Summary	1	General Dynamics	CASD-NAS-74-046	San Diego, CA.	08/01/74
SB130	NASA	SL-3 Ames Research Center Life Sciences Payload Familiarization Manual		Ames Research Center	ADP-81-50-001	Moffet Field, CA.	02/01/81
SB131	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
SB132	Rockwell Intl.	EMS Data Data Package 2.2B S4201.2, Module Commonality Analysis		Rockwell International	SSS 85-0137	Downey, CA	09/06/85
SB133	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
SB134	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

Table 4.1-2 Bibliography for Miniaturization Trade Study

ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SB135	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
SB139	NASA JSC	July 1988 Pogress Report On Experiment Standard User Interfaces Study		JSC - Life Sciences Project Division		Houston, TX.	07/01/88
SB140	Rockwell Intl.	EMS Data Data Package 2.3A 64207.2, GSE Commonality Analysis		Rockwell International	SSS 85-0099	Downey, CA	10/04/85
SB141	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
SB144	Huffstetler, W.	Skylab Biomedical Hardware Development		AIAA 20th Annual Meeting		Los Angeles, CA	08/22/74
SB146	Anderson, A.	Progressive Autonomy - For Space Station Systems Operation		AIAA		New York, NY	06/05/84
SB147	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
SB148	MDAC	Crew Health Care System (CHec) Development Plan		Mcdonnell Douglas Space Station Co.		Houston, TX.	01/28/89
SB149	Minsky, M.	Engines of Creation		Anchor Press		New York, NY	01/10/86
SB150	MDAC	Crew Health Care	1	MDAC	MDC H3924	Houston, Texas	11/01/88

Table 4.1-2 Bibliography for Miniaturization Trade Study

ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
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					/ /
SBI68	Hamaker, Joe	Telephone interview relating to MSFC history and techniques for cost estimating.		Cost Analysis Branch Chief MSFC		Huntsville, Al.	04/27/89
SBI69	Booker, Clef	Personal Interview		Man-Systems Division JSC		Houston, TX.	04/04/89
SBI70	Evans, Jim	Personal Interview		Life Science Project Division JSC		Houston, TX.	04/19/89
SBI76	Trowbridge, John	Personal interview relating CHeC experience to miniaturization, modularity and make-or-buy		McDonnell Douglas		Houston, TX.	03/29/89
SBI78	McFadyen, Gary	Personal Interview relating to life science hardware background at JSC		Southwest Research Institute		Houston, TX.	04/10/89
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

Table 4.1-2 Bibliography for Miniaturization Trade Study

ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
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

5.0 Trade Study

5.1 Relative Cost Analysis of Previous Hardware

The microminiaturized amplifier that was used in the Skylab PMS and will also be used in the SBI BPMF was developed and miniaturized by the Denver Research Institute (DRI). This organization no longer exists and no cost data can be found related to this development. NASA JSC who contracted DRI to do the work does not have the cost data (Ref. SBI#70, personal interview with Jim Evans NASA JSC SE).

There may be other historical data concerning miniaturization and related cost information, but this data was not found in the time frame of this study.

5.2 SBI Hardware Sample Selection

The Space Biology Hardware Baseline list is shown in Appendix A. This list has 169 hardware items, however, only 93 of these items are categorized for SBI functions. This list was based-lined December 1988 and then updated 23 March 1989. Many of these items are in the conceptional phase; however, some are existing hardware items that are in existence today. There will more than likely be future additions and deletions to this baseline list.

The initial survey data analysis was performed to select a sample of the SBHB items which could be potential candidates for miniaturization. With limited study time and a SBHB of 93 items, a method was needed to separate items which could have large cost impact and were worthy of study resource application. The following methods was used. All SBHB items were listed in descending order of probable acquisition cost. Weight was used as an indication of probable acquisition cost based on historical experience in previous space programs. It was found that 34 percent of the items (32 items) accounted for 93 percent of the mass or probable cost (Table 5.2-1). The accumulated volume ($8.68M^3$) of the 32 items represents 87% of the total volume. The accumulated power (8455 watts) represents 82% of total power requirements

The prioritized list of "vital" hardware items was considered for miniaturization. This list was further examined for those items that can be considered as a sample set of candidates for possible miniaturization (Table 5.2-2). This list showing the possible level of miniaturization was developed using all available resources within the constraints of this trade study. This assessment of possible candidates for miniaturization is based upon the best knowledge of the SBI hardware items at the time of this study. There will be additions and deletions from this list as new developments and techniques become known. The items for which miniaturization estimates were left blank in this table ("No" under Sufficient Data) indicates they are new developments still in the conception phase. Selected items from Table 5.2-2 are listed in Table 5.2-3 as the set of best possible candidates for some degree of miniaturization. The candidate sample set in Table 5.2-3 does not include those items where the degree of miniaturization was considered to have low potential at this time (0-10%) or items for which sufficient data was not available for assessment.

5.3 SBI Miniaturization Candidate Selection

Within the candidate sample set (Table 5.2-3) there is one item which was selected as the best candidate to be analyzed in greater detail. The Gas Grain Simulator (GGS) was selected for detailed analysis due to the availability of data (Ref. Appendix E), cooperation of the personnel at ARC (Ref. SBI #83), and the fact that the GGS is the heaviest of all the SBI hardware items (Ref. SBI #87 info on CELSS updated Mass).

The GGS is the only item in the baseline list (Appendix A) for Exobiology. The GGS consists of eight assemblies/subsystems as shown in Table 5.3. There are 21 major hardware subassemblies for the GGS shown in Table 5.3 and Figure 5.3. The percentage (%) of possible miniaturization for each of these 21 hardware subassemblies is shown in Table 5.3 (Ref. SBI#83, telephone interview with Guy Fogleman - Ames). The amount of miniaturization (percentages) selected for the eight subsystems was estimated by projecting the operational use and future development of the hardware. Complexity, hybrid systems, function of each unit, interrelated functions, and overall compatibility, were some of the factors considered in making the final decision of the amount of miniaturization. The GGS hardware has not been built nor have (RFP) gone out at the time of this study. The estimates made for miniaturization are highly subjective and may or not be feasible when more is understood concerning the overall GGS.

5.4 Miniaturized SBI Hardware Performance Impact Analysis

5.4.1 On Orbit Crew Utilization

Most of the experiments using SBI hardware are being conceived to have minimum crew interface. There will be some time required for initial setup and calibration for the individual experiments. These programs and time lines have not been worked out at the time of this report. Miniaturization which violated any operational human factor parameters or ergonomics would not be allowed. Therefore, The possible miniaturization of various hardware items should not effect the utilization of crew time.

5.4.2 Hardware Diagnostics/Repair

Miniaturization of the SBI hardware will not effect the reliability of the components/assemblies. Any design or redesign that includes miniaturization must maintain the original hardware integrity for accurate experiment results. However, the methods of implementing miniaturization and modularity may often be in conflict. Miniaturization uses maximum component integration and packaging efficiency. Modularity may comprise these aspects to allow modular construction. A modular concept would allow a faulty unit to be replaced with a spare unit aiding in hardware diagnostics and repair. Extensive repairs such as replacing individual components within a unit are not in the present design concept. Since miniaturization objectives could deter the implementation of modularity, hardware diagnostics and repair performance could be reduced.

5.4.3 Equipment Accuracy

By groundrule direction, all SBI hardware must be implemented to satisfy the required performance specifications whether constructed using miniaturization or not. Therefore, any miniaturization of assemblies/components can not jeopardize the accuracy of the hardware.

5.5 Relative SBI Miniaturization Cost Impact Analysis

5.5.1 Empirical Cost Relationships

Cost estimating relationships (CERV's) use systems weight and a complexity, n, as the principle factors in deriving design and development (DD) and theoretical first unit (TFU) costs. The exponent, n, increases as complexity increases being on the order of .2 for simple packaged systems, on the order of .4 for mechanisms or simple packaged electronics, and on the order of .6 for distributed complex systems. See Appendix C for a detailed treatment of cost estimating methods including cost estimating relationships.

In the process of analyzing the cost impact of miniaturizing an SBI hardware element, both weight and complexity come into play. Also, one must consider the design factor, df, in cases where more design effort is required or where a redesign is required in order to miniaturize a piece of hardware. As explained in Appendix C, the reduction in weight due to miniaturizing an element and the cost of the redesign effort needed to do so tend to offset each other. The relationship below is used in Appendix C to perform a parametric analysis of cost impact due to miniaturization (weight change and cost change due to redesign necessary to make an item smaller):

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

Where:

w = weight of a module or assembly or part
n = a complexity exponent
df= a design factor reflecting the amount of new design required
C_1= constant, taken as unity for comparative purposes.

To understand the relative impact of these factors, several items that can be miniaturized have been identified and the cost impact of miniaturization calculated using the foregoing factors. No actual cost data will be presented in this trade study.

5.5.2 GGS Miniaturization Cost Analysis

Table 5.3 gives the assumptions (design factors and system complexity factors) that were used with the empirical equation from Section 5.5.1. To read Table 5.3 left to right:

Roman numbers are the subsystems mass/weight in kilo grams.

Amount of miniaturization has three columns showing percentages. The components listed under the subsystems were analyzed for miniaturization and then the entire subsystem was given a percentage figure.

The design factor (df) without miniaturization was not considered and therefore a 1.0 was used for this column.

The complexity factor (n) was varied according to the proposed design of that subsystem.

The new design factor(df) is the factor for the anticipated new design or redesign of that subsystem.

The mass percent column is the percent of the subsystem mass to the total mass.

The relative cost factor percent is the percent increase in cost for that subsystem using the factors and analysis described in section 5.5.1.

The last column is the percent of each subsystem prorated. The mass percent times the relative cost factor percent equals the prorate percent.

The appropriate totals are shown at the bottom.

The results from this analysis indicates that there would be a increase in cost of 5 percent for the overall GGS.

The amount of miniaturization shown and the amount of cost increase for each assembly is shown in the last two columns of Table 5.3. These figures are dependant upon the subjective assumptions that were made for df and n factors. The number III and V assemblies have identical weight and miniaturization, but because the df and n factors are different, assembly III shows an increase in cost while V shows a decrease. The total cost increase for miniaturization of this particular hardware item was 5.16%. Most of the SBI hardware items are complex hybrid systems that will require a new or redesign for miniaturization. A large redesign or new design would increase the design factors which would in turn increase the cost. This would also have an effect on the overall design. The miniaturization cost increase percentages are shown in the last column of Table 5.3. The sum of the assembly percentages can be used to estimate a relative cost increase or decrease for the total SBI hardware item based on the amount of miniaturization of each assembly. Miniaturization will generally increase the cost as shown in this analysis. Qualified life cycle cost reduction has not been addressed in the miniaturization cost impact analysis. See appendix C Section 7.0 for a subjective assessment of miniaturization life cycle costs.

Table 5.2-1 Database Listing of SBI Hardware Vital to Program Cost Impact Analysis

ITEM # PRIORITIZED BY MASS	HW ITEM #	HARDWARE ITEM NAME	ACCUM % OF ITEMS	MASS (kg)	ACCUM MASS	ACCUM MASS PERCENT	ACCUM POWER PERCENT	ACCUM VOLUME PERCENT
1	168	CELSS Test Facility	1	1000.0	1000	28	13	19
2	169	Gas Grain Simulator	2	800.0	1800	51	27	33
3	84	Soft Tissue Imaging System	3	300.0	2100	59	35	46
4	77	Hard Tissue Imaging System	4	136.0	2236	63	38	51
5	126	Scintillation Counter	5	90.0	2326	66	42	53
6	74	Force Resistance System	6	70.0	2396	68	45	57
7	145	Automated Microbal System	8	70.0	2466	70	46	59
8	155	Total Hyrdocarbon Analyzer	9	70.0	2536	72	48	61
9	161	Inventory Control System	10	70.0	2606	74	53	63
10	162	Lab Materials Packaging & Handling Equipment	11	70.0	2676	76	58	65
11	163	Test/Checkout/Calibration Instrumentation	12	70.0	2746	78	60	67
12	106	Neck Baro-Cuff	13	45.2	2791	79	61	69
13	113	Blood Gas Analyzer	14	45.0	2836	80	63	70
14	61	Mass Spectrometer	15	40.7	2877	91	65	71
15	112	Plant HLPC Ion Chromatograph	16	40.0	2917	83	67	72
16	147	Head/Torso Phantom	17	32.0	2949	83	67	73
17	63	Pulmonary Gas Cylinder Assembly	18	30.0	2979	84	67	74
18	110	Plant Gas Chromatograph/Mass Spectrometer	19	25.0	3004	85	68	76
19	115	Chemistry System	20	23.0	3027	86	69	77
20	138	Hematology System	22	23.0	3050	86	71	78
21	34	Sample Preparation Device	23	22.0	3072	87	73	79
22	165	Experiment Control Computer System	24	20.1	3092	87	77	80
23	62	Pulmonary Function Equipment Stowage Assembly	25	20.0	3112	88	77	80
24	82	Motion Analysis System	26	20.0	3132	89	77	81
25	99	Animal Biotelemetry System	27	20.0	3152	89	78	81
26	100	Blood Pressure and Flow Instrumentation	28	20.0	3172	90	80	82
27	109	Venous Pressure Transducer/Display	29	20.0	3192	90	81	82
28	129	Cell Handling Accessories	30	20.0	3212	91	82	83
29	57	Bag-in-Box	31	19.0	3231	91	82	84
30	111	Plant Gas Cylinder Assembly	32	19.0	3250	92	82	85
31	119	Gas Cylinder Assembly	33	19.0	3269	92	82	86
32	130	Cell Harvestor	34	19.0	3288	93	82	87

NOTES:

1. Total number of SBI hardware items = 93.
2. 89 items have 3535 kg mass, 10,359 Watts power, and 10 cubic meters volume.
3. 4 items are not currently defined, but all are small.

Table 5.2-2 Database Listing for Miniaturization Sample Selection Assessment

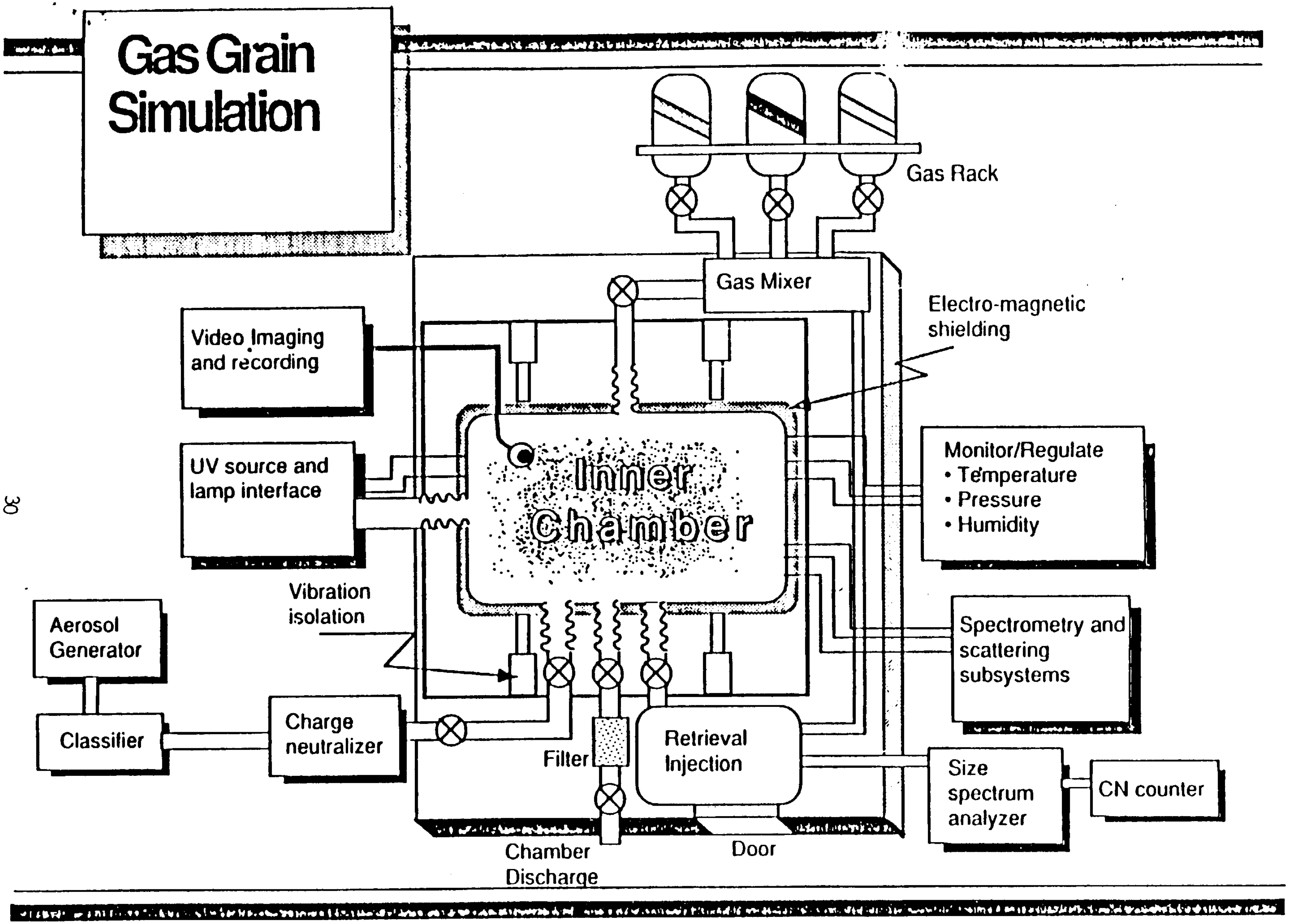
Priority # of Items by Mass	HW Item Number	HARDWARE NAME	SUFFICIENT DATA	MINIATURIZATION LEVEL (Percent)	CONFIDENCE LEVEL
1	168	CELSS Test Facility	Yes	20-50	High
2	169	Gas Grain Simulator	Yes	20-50	High
3	84	Soft Tissue Imaging System	No		
4	77	Hard Tissue Imaging System	No		
5	126	Scintillation Counter	Yes	20-50	Low
6	74	Force Resistance System	Yes	10-20	Low
7	145	Automated Microbal System	Yes	20-50	High
8	155	Total Hyrdocarbon Analyzer	No		
9	161	Inventory Control System	Yes	20-50	High
10	162	Lab Materials Packaging & Handling Equipment	Yes	0-10	Low
11	163	Test/Checkout/Calibration Instrumentation	Yes	20-50	Low
12	106	Neck Baro-Cuff	Yes	20-50	High
13	113	Blood Gas Analyzer	No		
14	61	Mass Spectrometer	Yes	10-20	Low
15	112	Plant HLPC Ion Chromatograph	No		
16	147	Head/Torso Phantom	Yes	10-20	High
17	63	Pulmonary Gas Cylinder Assembly	Yes	0-10	Low
18	110	Plant Gas Chromatograph/Mass Spectrometer	Yes	10-20	Low
19	115	Chemistry System	Yes	10-20	Low
20	138	Hematology System	Yes	10-20	Low
21	34	Sample Preparation Device	Yes	0-10	Low
22	165	Experiment Control Computer System	Yes	20-50	High
23	62	Pulmonary Function Equipment Stowage Assembly	Yes	0-10	Low
24	82	Motion Analysis System	Yes	20-50	High
25	99	Animal Biotelemetry System	Yes	10-20	High
26	100	Blood Pressure and Flow Instrumentation	No		
27	109	Venous Pressure Transducer/Display	No	10-20	Low
28	129	Cell Handling Accessories	Yes	20-50	High
29	57	Bag-in-Box	Yes	10-20	Low
30	111	Plant Gas Cylinder Assembly	No		
31	119	Gas Cylinder Assembly	Yes	0-10	High
32	130	Cell Harvestor	Yes	20-50	Low

Table 5.2-3 Database Listing of Miniaturization Candidate Sample Set

Priority # of Items by Mass	HW Item Number	HARDWARE NAME	MINIATURIZATION LEVEL (Percent)	CONFIDENCE LEVEL
1	168	CELSS Test Facility	20-50	High
2	169	Gas Grain Simulator	20-50	High
5	126	Scintillation Counter	20-50	Low
6	74	Force Resistance System	10-20	Low
7	145	Automated Microbal System	20-50	High
9	161	Inventory Control System	20-50	High
11	163	Test/Checkout/Calibration Instrumentation	20-50	Low
12	106	Neck Baro-Cuff	20-50	High
14	61	Mass Spectrometer	10-20	Low
16	147	Head/Torso Phantom	10-20	High
18	110	Plant Gas Chromatograph/Mass Spectrometer	10-20	Low
19	115	Chemistry System	10-20	Low
20	138	Hematology System	10-20	Low
22	165	Experiment Control Computer System	20-50	High
24	82	Motion Analysis System	20-50	High
25	99	Animal Biotelemetry System	10-20	High
27	109	Venous Pressure Transducer/Display	10-20	Low
28	129	Cell Handling Accessories	20-50	High
29	57	Bag-in-Box	10-20	Low
32	130	Cell Harvestor	20-50	Low

Gas-Grain Simulator Hardware	Mass (kg) 800	Miniaturization Possible Potential Percentage Reduce 0-10%	10%	30%	df Without Minial.	Complexity Exponent n	New Design Factor df	Mass Percent	Relative Cost Factor Percent	Cost Prorate Percent
I. General Purpose Experiment Chamber/Containment Subsystem	200	-			-	-	-	25	-	-
1. Chamber		X								
2. Vibration isolation, chamber support and containment		X								
II. Chamber Environment Regulation/Monitoring Subsystem	80			30%	1.0	.2	1.25	10	+16%	+1.6
3. Temp., pressure, and humidity monitor				X						
thermocouple		X								
pressure diaphram				X						
leak detectors			X							
4. Gas handling										
III. Aerosol Generation/Measurement Subsystem	150			30%	1.0	.4	1.30	18.75	+13%	+2.43
5. Aerosol generator, dryer, charge neutralizer				X						
6. Size analyzers				X						
7. CN counter				X						
8. Electrostatic classifer				X						
IV. Chamber Illumination, Optics, and Imagining Subsystem	80	-			-	-	-	10	-	-
9. Fiber optics system		X								
10. Continuous spectrum light source (UV source)		X								
11. Camera, lenses		X								
V. Spectrometry/Optical Scattering Subsystem	150			30%	1.0	.6	1.20	18.75	-03%	-.56
12. Monochromater				X						
13. Photodetectors				X						
14. Spectrometer		X		X						
15. Required Lamps										
VI. Particle Manipulation and Positioning Subsystem	50		10%		1.0	.4	1.20	6.25	+15%	+.93
16. Acoustic levitator		X								
17. Particle injection mechanism			X							
18. Particle retrieval mechanism			X							
VII. Computer Control and Data Acquisition Subsystem	50			30%	1.0	.4	1.30	6.25	+13%	+.81
19. Computer				X						
20. User interface		X								
CRT										
Keyboard										
Joy stick										
Mouse										
VIII. Storage Locker	40		10%		1.0	.1	1.0	5	-.01%	-.05
21. Storage locker			X							
Total for GGS	800							100		+5.16

Table 5.3 Exobiology Facility/GGS - Miniaturization Analysis



Gas Grain Simulation
Gas Rack
Gas Mixer
Electro-magnetic shielding
Video Imaging and recording
UV source and lamp interface
Inner Chamber
Monitor/Regulate
• Temperature
• Pressure
• Humidity
Vibration isolation
Spectrometry and scattering subsystems
Aerosol Generator
Classifier
Charge neutralizer
Filter
Retrieval Injection
Size spectrum analyzer
CN counter
Chamber Discharge
Door

Figure 5.3

6.0 Conclusion

6.1 Discussion

The items selected for miniaturization (Table 5.2-3) are the best possible candidates based upon their mass, complexity, anticipated use, and information known at the time of this trade study. The results of the cost analysis indicates that miniaturization will generally increase cost. Each assembly/component must be considered separately. It can generally be said that the more complex a system, the greater the cost for miniaturization. This would indicate that some of these items may not be adaptable to miniaturization due to the high increase in cost even when life cycle costs are factored into the analysis.

Life cycle costs were not considered in this trade study; however, miniaturization of payload items could be expected to reduce life cycle costs.

If there were a fixed payload allowable mass assigned to SBI, the use of miniaturization would allow more experiment items per unit of mass. The net result would be that miniaturization would enable the accomplishment of more science within the fixed assigned SBI mass. This benefit could be equated to a cost benefit which might compensate for the additional development expense required for miniaturized hardware. This cost benefit analysis could not be performed in this trade study because of a lack of information.

It would appear that miniaturizing the heaviest items would provide the greatest return on the investment since any cost reduction is a function of the absolute amount of mass eliminated. That is, a 100 kilogram item reduced 20 percent would save 20 kilogram, whereas a 20 percent reduction of a 5 kilogram items would only save 1 kilogram.

A final consideration is that, in the future, some significant SBI hardware item could be excluded from consideration due to a very large mass normally associated with the item. In a case of this nature, it would have to be reduced through miniaturization or not included at all.

6.2 Important Guidelines

- Miniaturization will generally add development cost to the SBI hardware.
- The more complex hybrid systems will add the greatest cost for miniaturization.
- The miniaturization of larger (heavier) items will give a greater return in weight savings than the smaller items.
- Miniaturization is more likely to be cost beneficial when life cycle cost are factored into the overall analysis.
- There may be additional benefits to the science program by increasing the science hardware item (more Experiments) when reducing individual items through miniaturization.

- Not all items can be miniaturized.

6.3 Other Considerations

The interrelationship of these trade studies has not been considered. There could be considerable cost savings with an overall trade study of miniaturization, modularity, commonality, modified COTS versus new build items and other hardware items (Not SBI). See Section 2.6 for other recommendations for future work.

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

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)				
	SAMPLE COLLECTION AND PROCESSING GROUP (2C)				
16	Animal Tissue Biopsy Equipment	S	0.03	8	0
17	Blood Collection System	S	0.02	1	0
18	Centrifuge Refrigerated	W	0.15	40	450
19	Centrifuge Standard Lab	E	0.09	26	200
20	Digital Thermometer	W	0.01	2	34
21	Drug Administration Equipment	E	0.01	1	0
22	Electrofusion Device	S	0.06	TBD	TBD
23	Fixation Unit	S	0.02	4	0
24	Fluid Handling Tools/System	W	0.48	80	100
25	Laboratory Sciences Workbench	W	0.96	300	700
26	Life Sciences Glove Box (Copy 2 of 2)	W	0.96	350	800
27	Microscope System (Stereo Macroscope Subset, Copy 2	W	0.25	80	200
28	Muscle Biopsy Equipment	S	0.01	1	0
29	Perfusion & Fixation Unit	S	0.01	2	0
30	Plant Care Unit	S	0.05	10	50
31	Plant Harvest/Dissection Unit	S	0.01	4	20
32	Radioimmunoassay Prep Device	E	0.01	2	0
33	Saliva Collection Unit	S	~~0.01~~ .001	~~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~~ .505	~~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	CAROTID SINUS BARORECEPTOR STIMULATOR (Neck Baro-Cuff)	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 CEP, 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 OP
	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 Jac'on 3/23/89

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	Electrofusion 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				J
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	0.087	40.7	200	J
61	Mass Spectrometer	S	0.02	10	100	0.051	20	0	J
62	Pulmonary Function Equipment Stowage Assembly	S	0.39	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

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

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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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
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, BSE 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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SBI68	Hamaker, Joe	Telephone interview relating to MSFC history and techniques for cost estimating.		Cost Analysis Branch Chief MSFC		Huntsville, Al.	04/27/89
SBI69	Booker, Clef	Personal Interview		Man-Systems Division JSC		Houston, TX.	04/04/89
SBI70	Evans, Jim	Personal Interview		Life Science Project Division JSC		Houston, TX.	04/19/89
SBI71	Heberlig,Jack	Telephone interview relating to make-or-buy lessons learned from Apollo		International Business Machines (IBM)		Houston, TX.	03/10/89
SBI72	Loftus, Joe	Telephone interview relating to make-or-buy history		Assistant Director (Plans) JSC		Houston,TX.	03/14/89
SBI73	Christy, Neil	Telephone interview relating to hardware development student experiments, and make-or-buy				Houston, TX.	03/15/89
SBI74	McAllister,Fred	Telephone Interview		Man-System Division, JSC		Houston,TX	03/14/89
SBI75	Trowbridge, John	Interview relating to CHeC make-or-buy		McDonnell Douglas		Houston,TX.	03/17/89
SBI76	Trowbridge, John	Personal interview relating CHeC experience to miniaturization, modularity and make-or-buy		McDonnell Douglas		Houston, TX.	03/29/89
SBI77	Nagel, John	Personal Interview relating to LSLE make-or-buy experience		Eagle Technical Services		Houston, TX	03/27/89
SBI78	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

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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

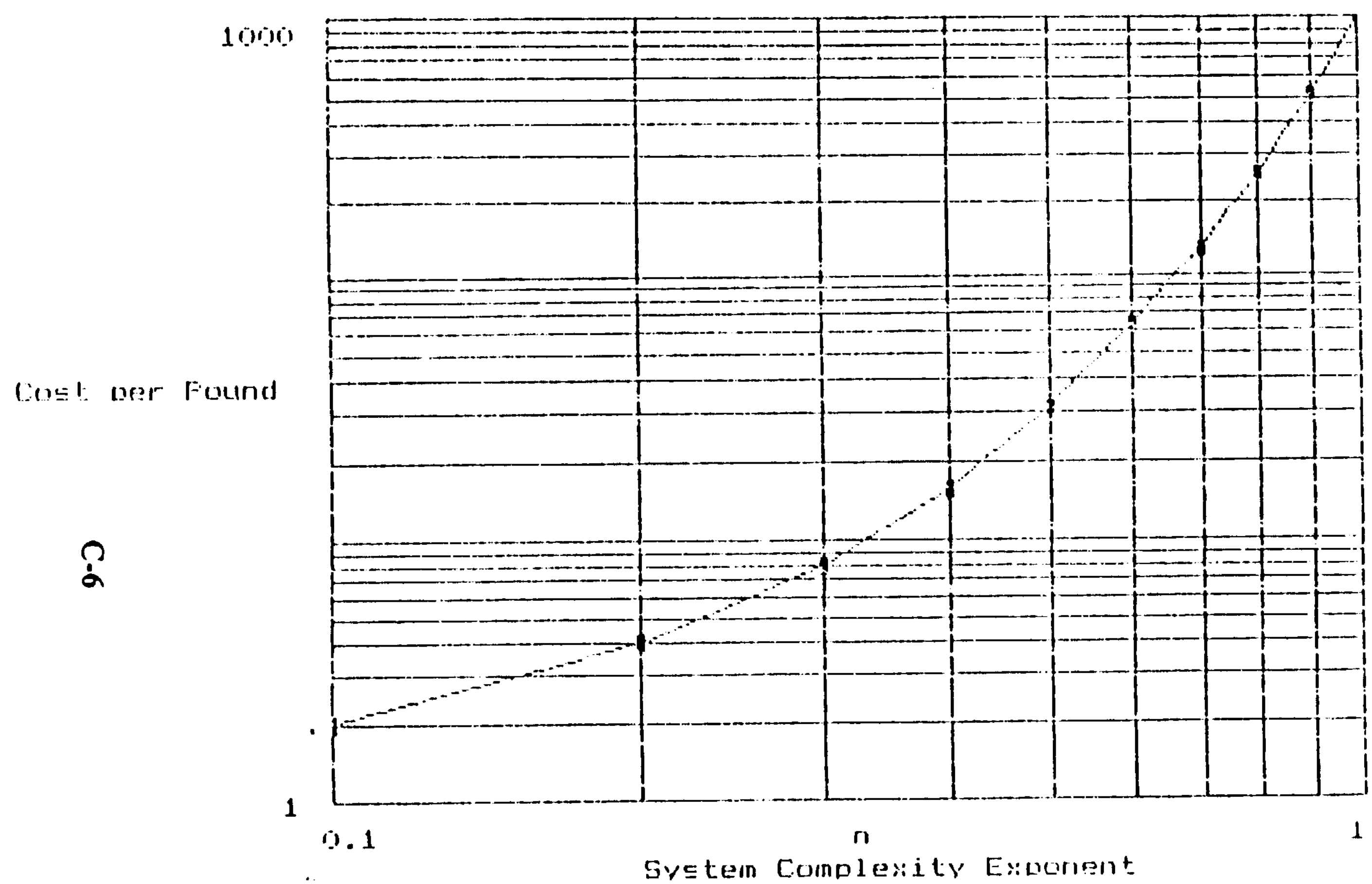


Figure 2-2 Design Factors

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

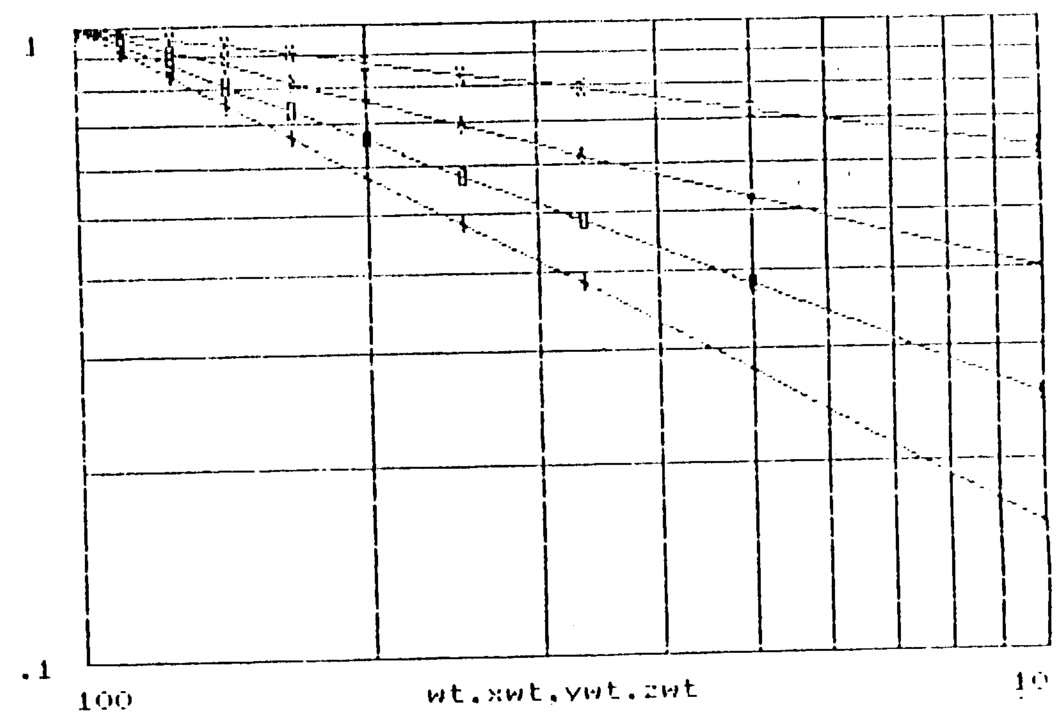
Table 3-4
Miniaturization Guide Chart
n=.8

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
0 = 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

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

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

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

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%

Learning Factor	Quantity	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.

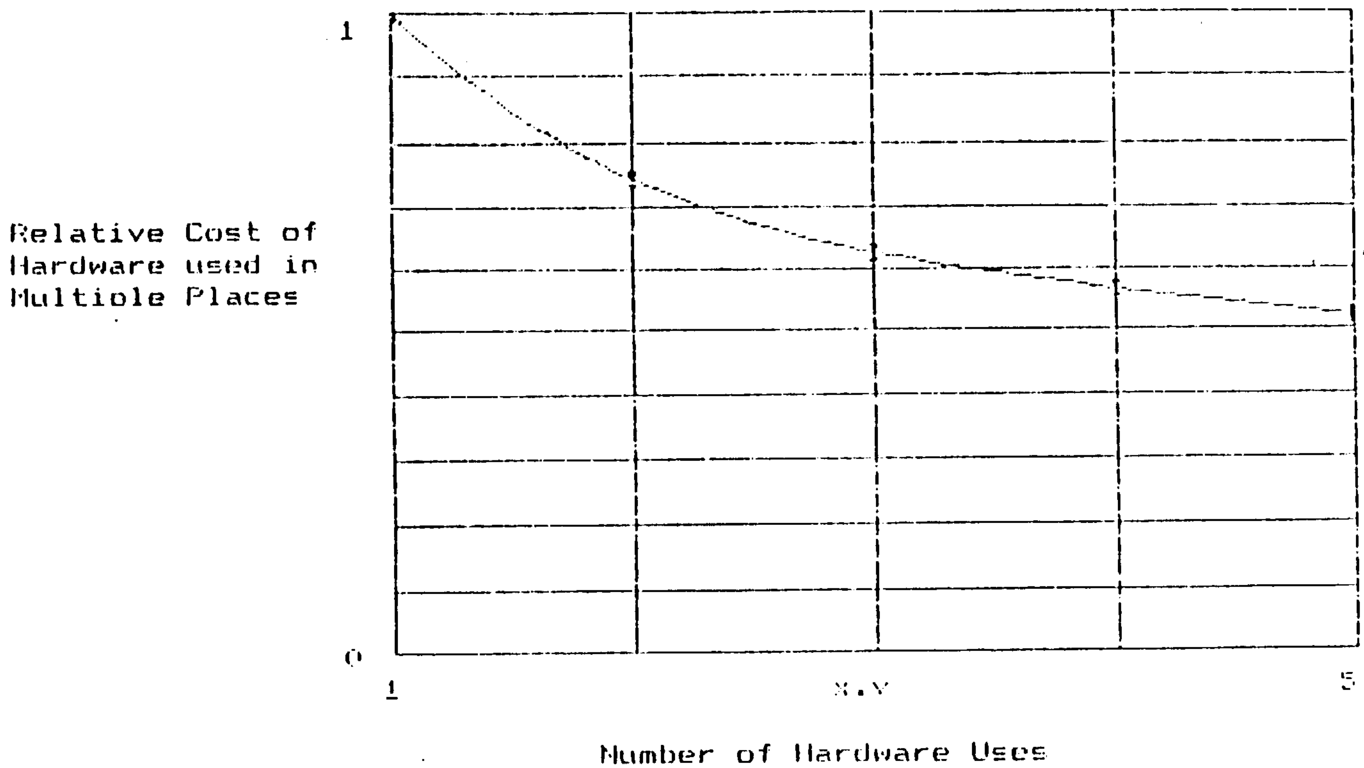
The costs shown in Tables 3-7 and 3-8 are based upon the assumption that COTS modifications are approximately the same cost as are redesigns to existing systems. The degree of modification (or redesign) is reflected in the design factor, df. The degree of system complexity is reflected by the system 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.

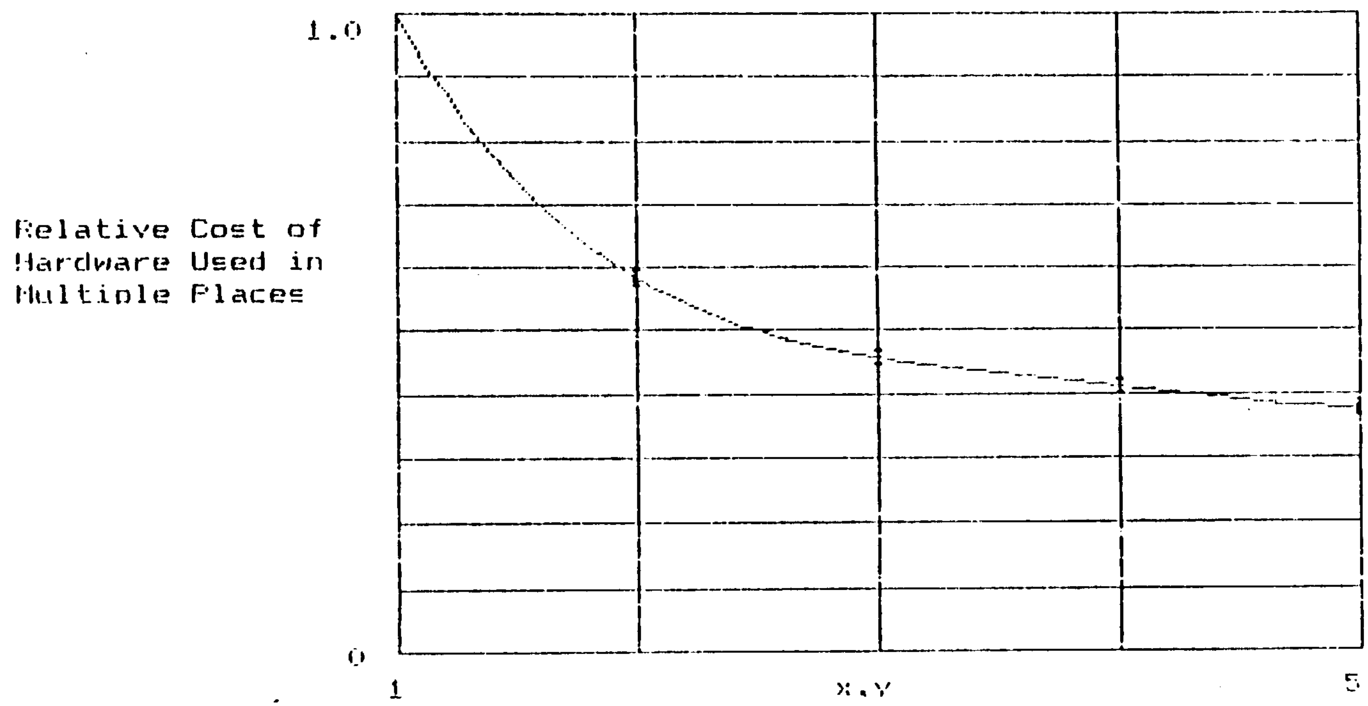
Figure 3-2
Effect on Cost of Multiple
Applications of Hardware



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

Learning Factor = 80%

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



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

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	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

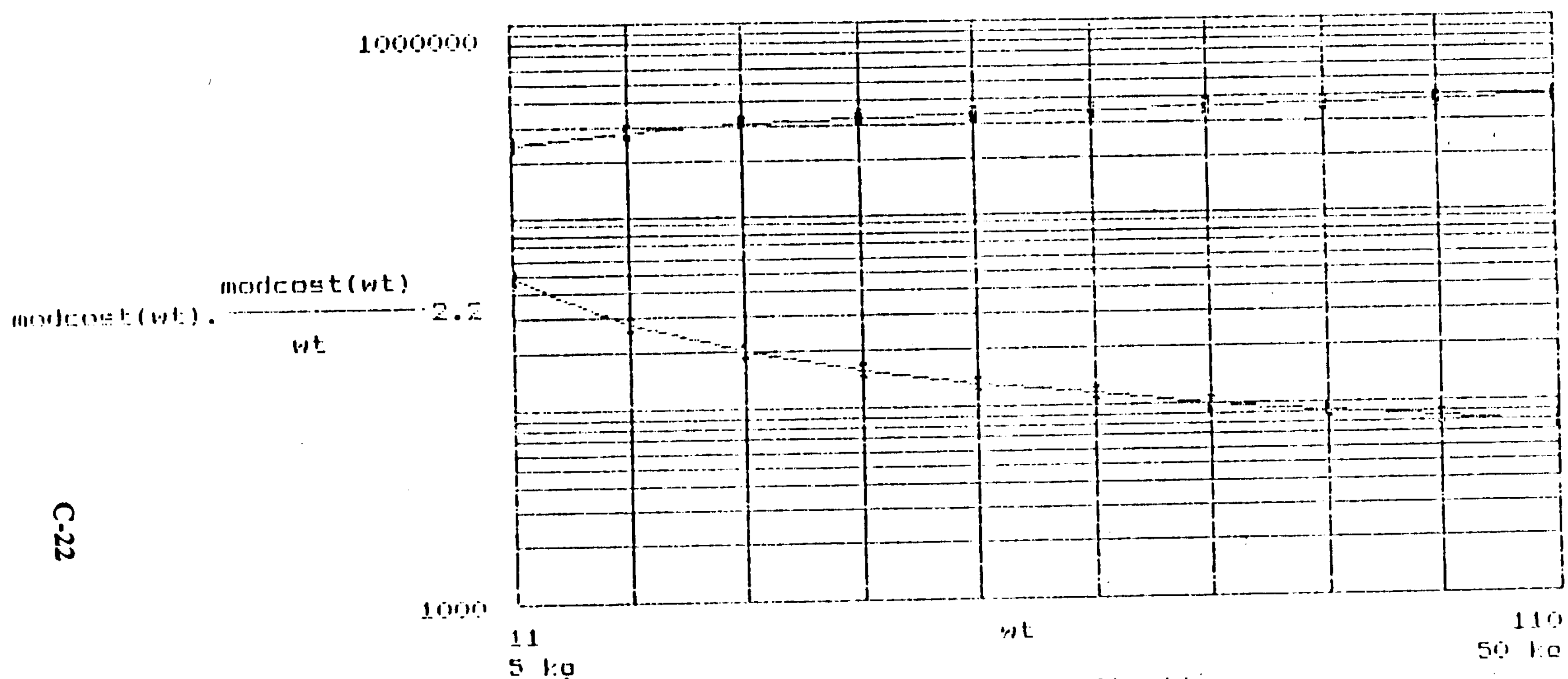
Table 3-8 Cost of Modifying Commercial Off-the Shelf Hardware

System Complexity Factor (n) =.4

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.	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

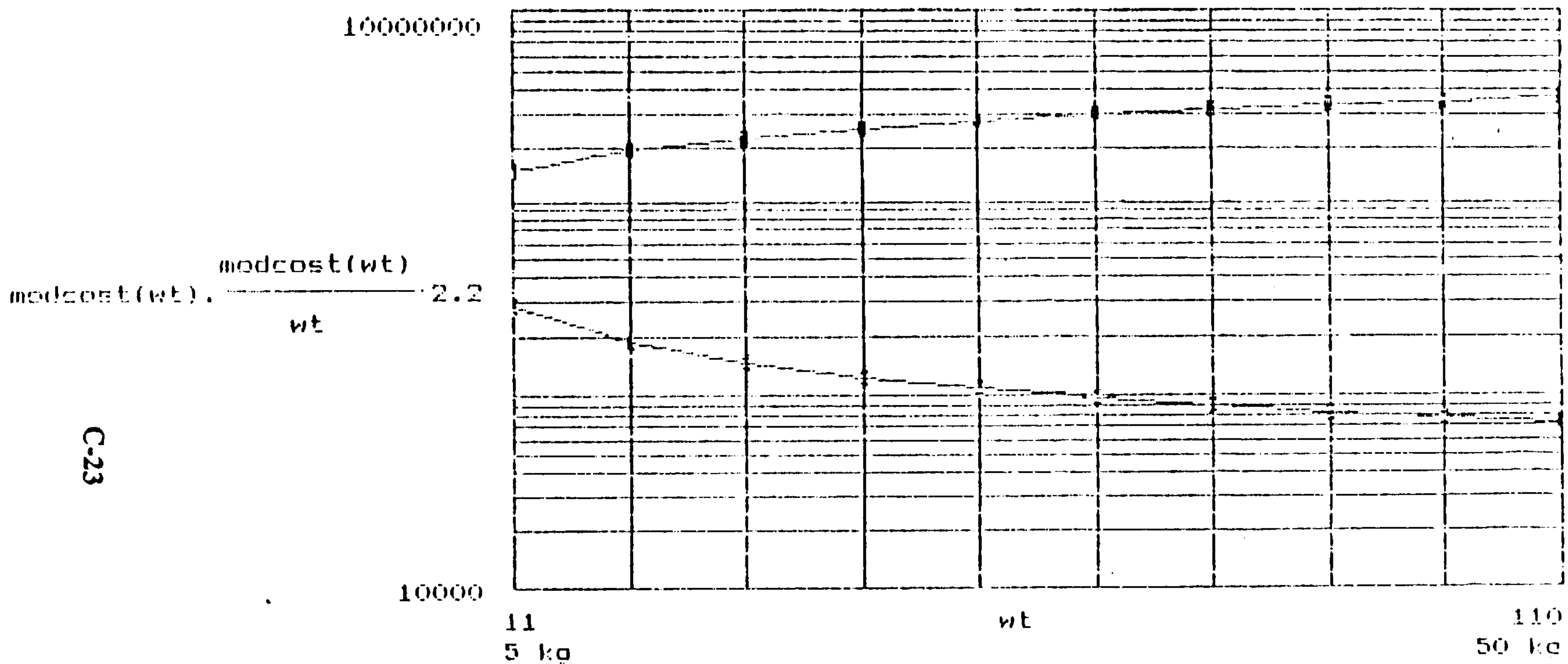
Notes: 1) All costs are in thousands of dollars

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



0 = 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.

Bibliography

A. MSFC Space Station CER's Report PRC D-2185-H, Contract NAS8-33789, December, 1982.

B. CERV Target Costs for Benchmark and Reference Configurations - JSC CERV Office Presentation, June 15, 1988.

C. PRICE Users Newsletter, Volume 12, Number 3, October, 1988.

D. Cost Estimating for Air to Air Missiles, Congressional Budget Office, January, 1983.

E. PRICE H™ Reference Manual, General Electric Company, 1988.

F. SBI Team Contact Report - Joe Hamacke, April 27, 1989.

G. SBI Contact Report - Richard Whitlock, April 11, 1989.

H. Report No. MSC-01248, ASSCAS Cost Handbook, Contract NAS 9-9018, January, 1970.

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

biblo.dbf **This is the database for bibliography information.**

Field 1	BB_ID	Identification number for the reference
Field 2	AUTHOR_NO1	First author
Field 3	AUTHOR_NO2	Second author
Field 4	AUTHOR_NO3	Third author
Field 5	ART_TITLE	Title of article
Field 6	BOOK_TITLE	Title of book
Field 7	VOLUME_NO	Volume number
Field 8	PUBLISHER	Publisher
Field 9	PUBL_LOC	Publisher's address
Field 10	DATE	Date of publication
Field 11	PAGE_NOS	Page number of reference
Field 12	ABSTRACT	Abstract
Field 13	ACQUIRED	Where the reference was acquired
Field 14	COST	Cost of reference
Field 15	LOANED	Where the reference was loaned from
Field 16	REP_DOC_NO	Report or document number
Field 17	MOD	Was this reference used on the modularity trade study? y or n
Field 18	MIN	Was this reference used on the miniaturization trade study? y or n
Field 19	CUTS	Was this reference used on the make-or-buy trade study? y or n
Field 20	RACK	Was this reference used on the rack compatibility trade study? y or n

rack_com.dbf **This is the database file for the rack comparison study.**

Field 1	IF_ITEM	I/F item being compared, i.e. power converters
Field 2	UNITS	Units of comparison, i.e. inches
Field 3	UNIT_SYS_	Unit system, i.e. metric
Field 4	ITEM_TYPE	Functional Grouping of IF Item i.e. Data Mgmt.
Field 4	VALUE	Value of the comparison
Field 5	MODULE	Module, i.e. U.S. Lab

comm_mod.dbf **This is the design modularity and commonality database**

Field 1	HW_ID	Unique identification number for each hardware item
Field 2	COMM_MOD	Modularity function/assembly
Field 3	COUNT	Used to total hardware items in COMM_MOD Field
Field 4	COST_DECSC	Cost description
Field 5	MASS	Mass of hardware item

Appendix E Detailed Hardware Description

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CELSS/FEAST Hardware Data Sheet

Report Date . 4/5/89

Controlled Ecological Life Support System

CELSS

Title	Germination Experiment Kit
Element No 1	**Revision** A
Project	FEAST

Hardware Status	Mod existing
Revision Date	Apr 4, 1989

Hardware Description

Modified Plant Growth Unit.

Objective

1.) Provide a means for initial screening of plant cultivars in terms of their ability to germinate in μ-g.
2.) Determine root-shoot orientation under μ-g conditions.

Desired Features/Functions

1. Lighting : LED @ >180 μmol/sq.m/s
2. Basic nutrient delivery
3. Video recording and/or downlink capability

Hardware Specifications

Weight (Kg) 27.3 **Height (m)** .253 **Width (m)** .440

Depth (m) .516 **Temp Range** Ambient

Peak Power (Kw) .300 **Cont Power (Kw)** .150

Power Source

STS Mid-deck.

Item Specific Support Equipt

Plant Growth Module

Data Downlink Reqs

1.5 MBPS Video; 1.6 KBPS Voice

Rack Mounted/Stowed STS Middeck

Hardware Specifications

Design Status

Modification to PGU required.

Development Cost ($K)	5,700
Development Time (months)	12
Anticipated Launch Date	1992 & 1996
Risk Category	1

CELSS/FEAST Hardware Data Sheet

Report Date 4/5/89

Germination Experiment Kit
Science Justification
Identified Experiments CELSS Germination Studies.
History Utilizes existing PGU design with modification for germination studies.
Problem/Issues&Concerns none
Vendor Source List
Interface Requirements STS Mid-deck.
Special Considerations none
Safety Issues none
Flight Opportunity USML-1 (3/92) & USML-4 (5/96)
Notes 1.) Two flights needed : Possible flights are USML-1 and USML-4. REV A : Revised cost 4/4/89 from $5250K to $2700K to reflect changes in Cost Estimates.

CELSS/FEAST Hardware Data Sheet

Report Date 4/5/89

Controlled Ecological Life Support System

Hardware Status Planned

Revision Date Apr 4, 1989

Title Gas/Liquid Handling Experiment H/W

Element No 2 **Revision** A

Project FEAST

Objective

1.) To evaluate and demonstrate fundamental physical principles of gas and liquid handling, mixing and separation under μ-g environment as applied to CELSS technology development.
2.) To demonstrate concept design for gas/liquid handling systems in μ-g.

Hardware Description

An experiment package for KC-135, STS (GAS or Mid-deck) or Spacelab for evaluating physical principles pertaining to gas and liquid handling, mixing and separation under μ-g conditions.

Desired Features/Functions

1. Video recording and/or downlink capability
2. Capable of mixing and separation tests of a variety of gas/liquid combinations common to CELSS (water/air, nutrient solution/air,etc)
3. Thermal and shock isolation
4. Liquid and gas containment
5. Various gas and liquid reservoirs
6. Mixing and separation chamber
7. Simple PLC control with control valves.

Hardware Specifications

Weight (Kg) 27.3 **Height (m)** .253 **Width (m)** .440

Depth (m) .516 **Temp Range** Ambient

Peak Power (Kw) .3 **Cont Power (Kw)** .15

Power Source

Standard KC-135, Spacelab or NSTS source.

Item Specific Support Equipt

none

Data Downlink Reqs

.05 KBPS Command; 1.5 KBPS Digital; 1.5 MBPS Video; 1.6 KBPS Voice

Rack Mounted/Stowed NSTS:Mid-deck Stowage
SL : Rack Mounted

Hardware Specifications

1. Mid-deck locker size, may be partial SL rack size.

Design Status

New Design

Development Cost ($K)	1,500
Development Time (months)	24
Anticipated Launch Date	1993
Risk Category	3

CELSS/FEAST Hardware Data Sheet

Report Date 4/5/89

Gas/Liquid Handling Experiment H/W
Science Justification Evaluation of physical principles for FEAST.
Identified Experiments
History Existing liquid/gas transfer, mixing and separation technologies for μ-g from previous space flight vehicles and payloads.
Problem/Issues&Concerns none at present
Vendor Source List none at present
Interface Requirements Standard KC-135, NSTS or SL.
Special Considerations Containment of liquids and gases.
Safety Issues none
Flight Opportunity USML-2 (8/93)
Notes REV A : Revised cost 4/4/89 from $3000K to $1500K. Changed Unit No. from 3 to 2 to reflect Cost Estimate categorization; added misc data to various categories.

CELSS/FEAST Hardware Data Sheet

Report Date : 4/5/89

Controlled Ecological Life Support System

Hardware Status	Planned
Revision Date	Apr 4, 1989

Title Water Condensation & Re-cycling Exp H/W

Element No 3 **Revision** A

Project FEAST

Objective

1.) To determine problems associated with water condensation technologies under μ-g.
2.) Demonstrate and prove-out conceptual designs.

Hardware Description

Spacelab, NSTS middeck or KC-135 size experiment package for water condensation studies.

Desired Features/Functions

1. Video recording and/or downlink capability
2. Water vapor source and water reservoir
3. Condensation chamber with cooling
4. Stream processing capability at various rates
5. Monitoring capability of : relative humidty, liquid volume, process rates

Hardware Specifications

Weight (Kg) 27.3 **Height (m)** .253 **Width (m)** .440

Depth (m) .516 **Temp Range** Ambient

Peak Power (Kw) .300 **Cont Power (Kw)** .150

Power Source

Standard platform source.

Item Specific Support Equipt

none

Data Downlink Reqs

Rack Mounted/Stowed Rack Mounted or Stowed.

Hardware Specifications

Design Status

New Design

Development Cost ($K)	2,900
Development Time (months)	
Anticipated Launch Date	1995
Risk Category	4

A

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CELSS/FEAST Hardware Data Sheet

Report Date 4/5/89

Water Condensation & Re-cycling Exp H/W
Science Justification
Identified Experiments
History
Problem/Issues&Concerns
Vendor Source List
Interface Requirements
Special Considerations
Safety Issues
Flight Opportunity USML-3 (1/95)
Notes 1.) Two flights may be required. 2.) May only require KC-135 flight to validate. 3.) REV A : Revised cost 4/4/89 from $5800K to $2900K. Changed Unit No. from 2 to 3 to reflect Cost Estimate categorization.

CELSS/FEAST Hardware Data Sheet

Report Date 4/5/89

Controlled Ecological Life Support System

Title Nutrient Delivery Test H/W

Element No 4 **Revision** A

Project FEAST

Objective

1. To evaluate plant nutrient delivery concepts under μ-g conditions for CELSS technology development.

Hardware Specifications

Weight (Kg) 27.3 **Height (m)** .253 **Width (m)** .440

Depth (m) .516 **Temp Range** Ambient

Peak Power (Kw) .300 **Cont Power (Kw)** .150

Power Source

Standard mid-deck power source or equivalent

Data Downlink Reqs

.05 KBPS Command; 1.5 KBPS Digital; 1.5 MBPS Video; 1.6 KBPS Voice

Rack Mounted/Stowed Stowed

Hardware Specifications

Hardware Status Planned

Revision Date Apr 4, 1989

Hardware Description

Size of two middeck lockers on STS to study basic μ-g nutrient delivery systems.

Desired Features/Functions

1. Video recording and/or downlink capability.
2. Capability for testing a number of nutrient delivery concepts
3. Liquid and gas containment

Item Specific Support Equipt

none

Design Status

New Design

Development Cost ($K)	3,475
Development Time (months)	24
Anticipated Launch Date	1992 & 1996
Risk Category	4

CELSS/FEAST Hardware Data Sheet

Report Date 4/5/89

Nutrient Delivery Test H/W
Science Justification Provides test and demonstration of nutrient delivery systems for CELSS technologies.
Identified Experiments
History None
Problem/Issues&Concerns
Vendor Source List None
Interface Requirements
Special Considerations
Safety Issues
Flight Opportunity SLS-2 (7/92) & IML-4 (3/96)
Notes REV A : Revised cost 4/4/89 from $6850K to $3475K.

CELSS/FEAST Hardware Data Sheet

Report Date 4/5/89

Controlled Ecological Life Support System

Hardware Status Planned

Revision Date Apr 4, 1989

Title CELSS Test Facility

Element No 5 | **Revision** A

Project FEAST

Objective

1.) To provide a facility for conducting plant productivity studies from seed to maturity (in some instances seed to seed) with mixed crops and in mixed maturities under µ-gravity conditions.

2.) Assess system reliability and maintainability for CELSS technologies.

Hardware Description

Crop growth research facility for seed-to-seed crop studies under µ-gravity. IOC Station Freedom implementation.

Desired Features/Functions

1. Modular subsystem elements to allow for design evolution.
2. LED lighting system
3. Standard double rack size.
4. Complete control of inputs and outputs to Station ambient atm.
5. Implements automation and expert systems.
6. Full complement DAS.
7. Maximized degree of closure

Hardware Specifications

Weight (Kg) 634.7 **Height (m)** 1.89 **Width (m)** 1.05

Depth (m) 0.91 **Temp Range** S.S. Ambient

Peak Power (Kw) 2.0 **Cont Power (Kw)** 1.5

Power Source

Standard Rack power

Item Specific Support Equipt

CTF Germination and Storage Chamber.

Data Downlink Reqs

.05 KBPS Command, 1.5 KBPS Digital, 1.5 MBPS Video, 1.6 KBPS Voice

Rack Mounted/Stowed Rack Mounted

Hardware Specifications

1. Lighting : 0 - 3000 µmol/sq.m/s
2. Modular nutrient delivery system
3. Sealed enclosure w/ access and windows
4. Fully controllable HVAC
5. Pressure compensation system
6. Water condensation & re-cycling capability
7. Control of internal gaseous environment (O_2, CO_2, N_2)
8. Microbial monitoring capability
9. Monitoring, control and data acquisition systems
10. Automated specimen handling
11. Growing Area: 0.71 sq.m, max growing height : 0.85 m
12. Self-contained with modular subsystems
13. Fuill control of parameters withing specified ranges

Design Status

New Design

Development Cost ($K)	42,050
Development Time (months)	72
Anticipated Launch Date	1998
Risk Category	3

CELSS/FEAST Hardware Data Sheet

Report Date 4/5/89

CELSS Test Facility
Science Justification Hardware is mandatory for developement of future CELSS technologies and advanced life support systems.
Identified Experiments Hardware to be used in meeting CELSS Project FEAST objectives.
History Major design elements derived from non-flight Crop Growth Research Chamber (CGRC) requirements.
Problem/Issues&Concerns Nutrient dlivery system, lighting, & power.
Vendor Source List None at present.
Interface Requirements Standard Space Station Freedom rack interfaces.
Special Considerations None
Safety Issues None
Flight Opportunity PMC S.S. Freedom
Notes 1. Establish reliability baseline for CELSS hardware 2. Needs maintenance scenario and possibly S/E for same. 3. Current crop candidates are : Potatoes, soybeans, wheat, tomato, lettuce, radish, rice, onion, legume & spinach. REV A : Revised cost 4/4/89 from $15,000K to $42,050K to reflect incorporation of CROP elements into CTF. Revised growing area from 1.5 - 2.0 sq.m to 0.71 sq.m, power from 1.8kW to 2.0 Kw peak and 1.2 - 1.3 kW cont to 1.5kW, mass changed from 1000 kg to 634.7 kg.

CELSS/FEAST Hardware Data Sheet

Report Date 4/5/89

Controlled Ecological Life Support System

Title CTF Germination Chamber

Element No 6 **Revision** NR

Project FEAST

Objective

1. To provide environment for germinating seeds prior to planting in the CTF.

2. To provide seed storage.

Hardware Specifications

Weight (Kg) 6.8 **Height (m)** .253 **Width (m)** .440

Depth (m) .516 **Temp Range** S.S. Ambient

Peak Power (Kw) .300 **Cont Power (Kw)** .150

Power Source

none required

Data Downlink Reqs

none

Rack Mounted/Stowed Stowed

Hardware Specifications

Approximately the size of a NSTS Middeck Locker.

Hardware Status Planned

Revision Date

Hardware Description

Provides germination environment for seed germination proir to planting in the CELSS Test Facility, Approx. the size of STS Middeck Locker

Desired Features/Functions

1. Air-tight chamber
2. Humidity controlled
3. Heat, shock and vibration isolated

Item Specific Support Equipt

none

Design Status

New Design

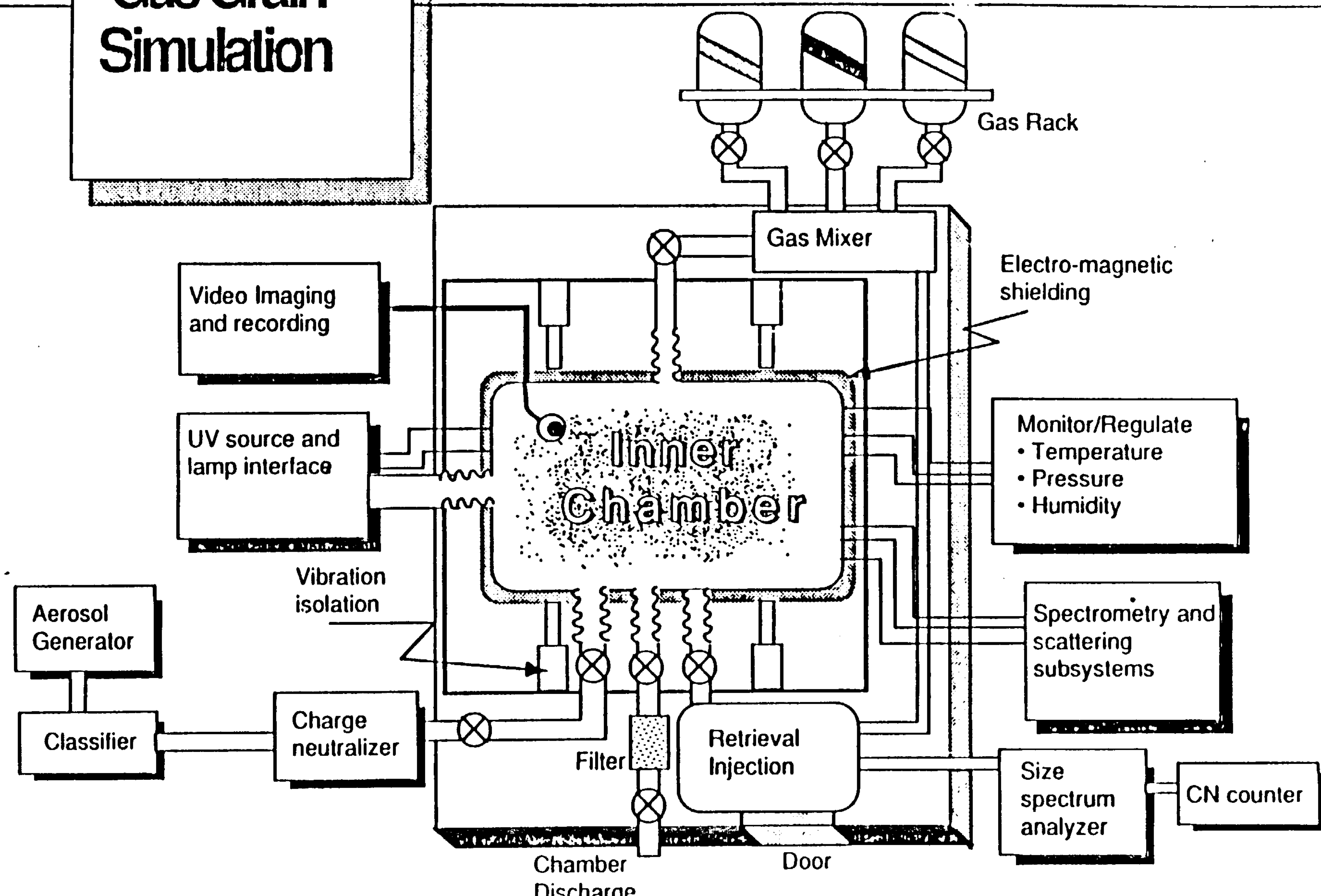
Development Cost ($K)	800
Development Time (months)	12
Anticipated Launch Date	1998
Risk Category	1

CELSS/FEAST Hardware Data Sheet

Report Date 4/5/89

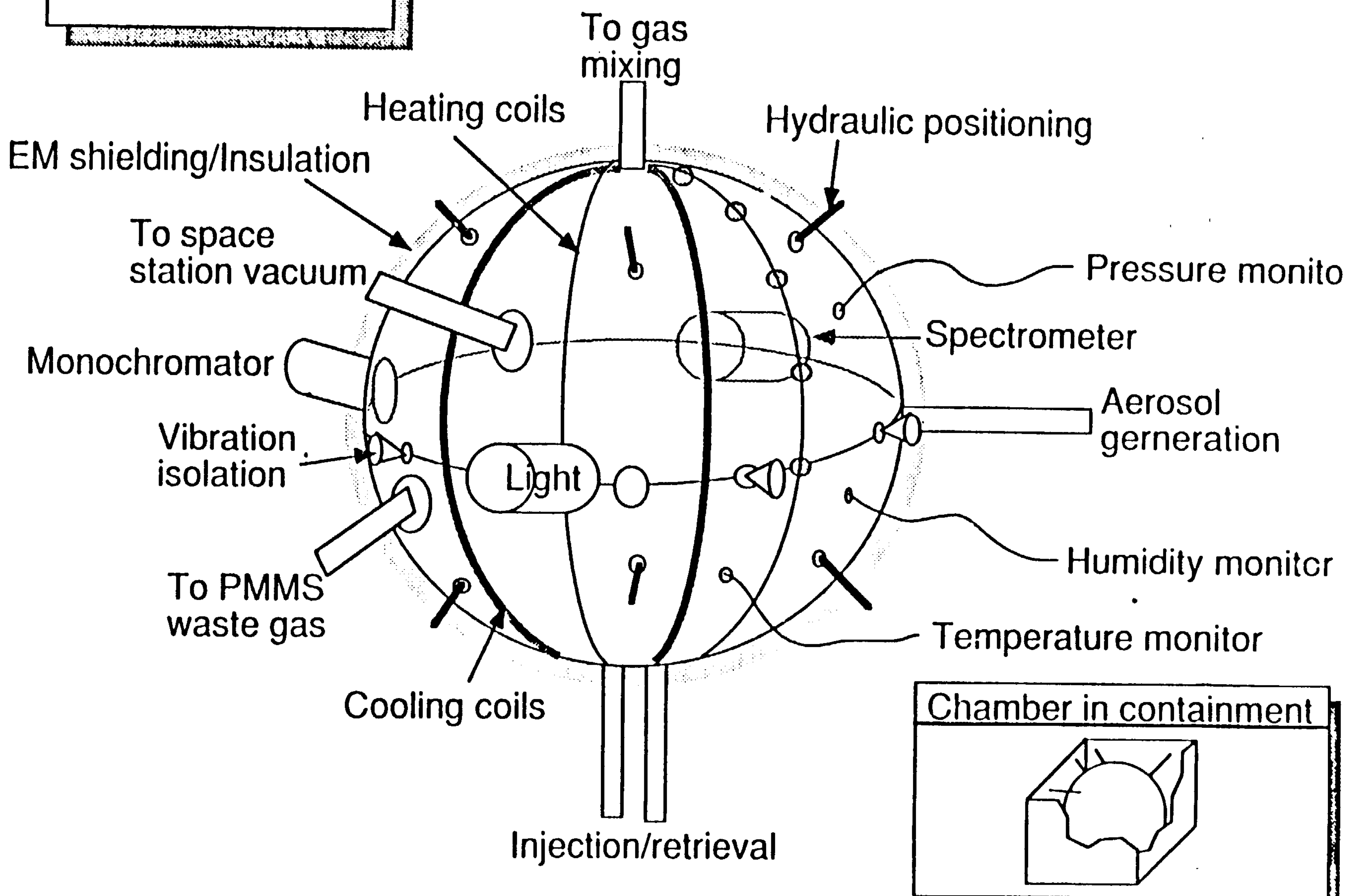
CTF Germination Chamber
Science Justification Provides germination of seeds prior to planting in the CTF. Reduces operational power demand on CTF. Provides seed storage.
Identified Experiments none
History Plant Growth Unit.
Problem/Issues&Concerns none
Vendor Source List none
Interface Requirements
Special Considerations
Safety Issues
Flight Opportunity PMC Space Station Freedom
Notes 1. Provides for two separate and independent compartments: a.) Seed storage compartment and b.) Germination compartment. 2. Seed compartment could also be used for misc. equipment stowage

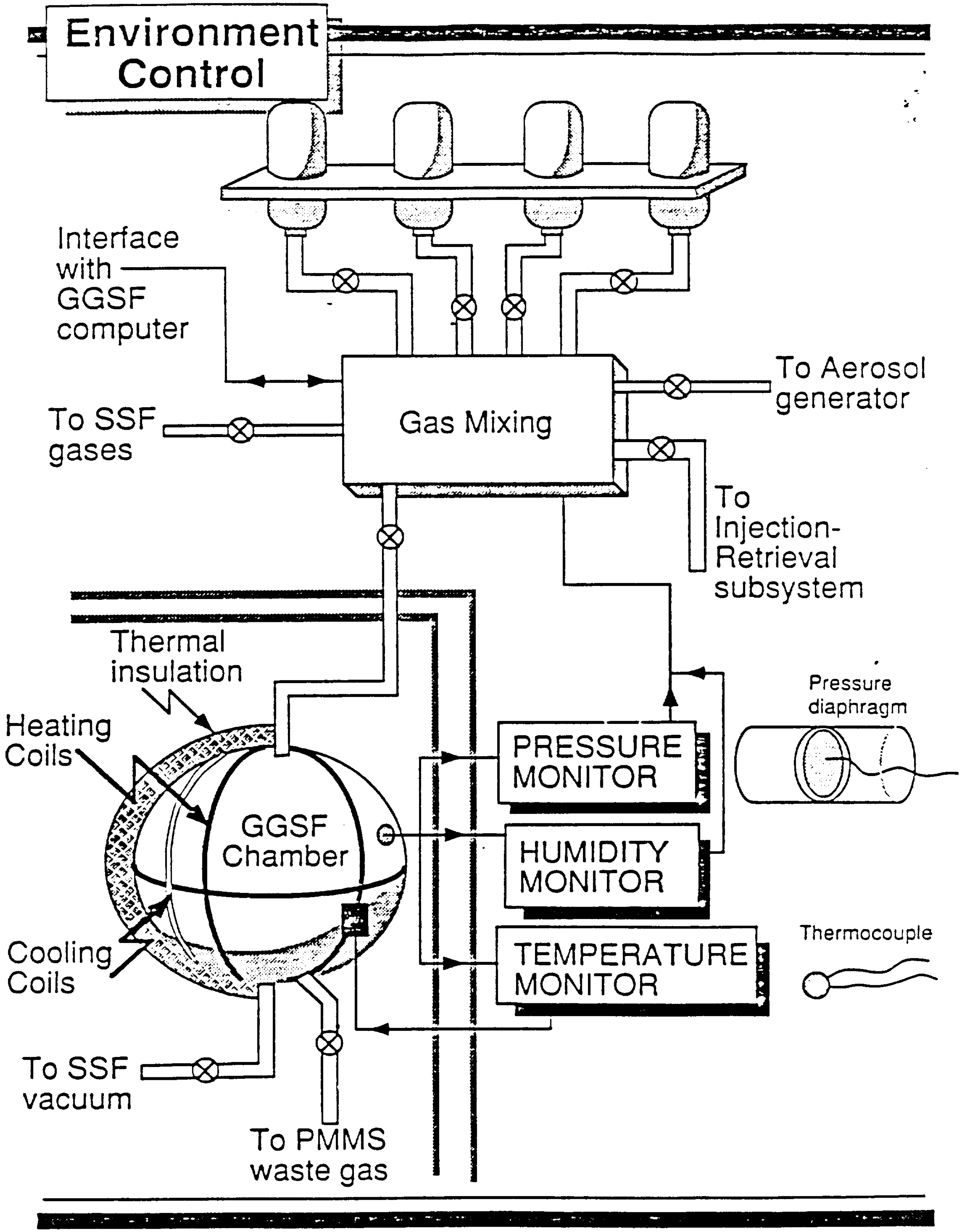
Gas Grain Simulation



GGSF Chamber

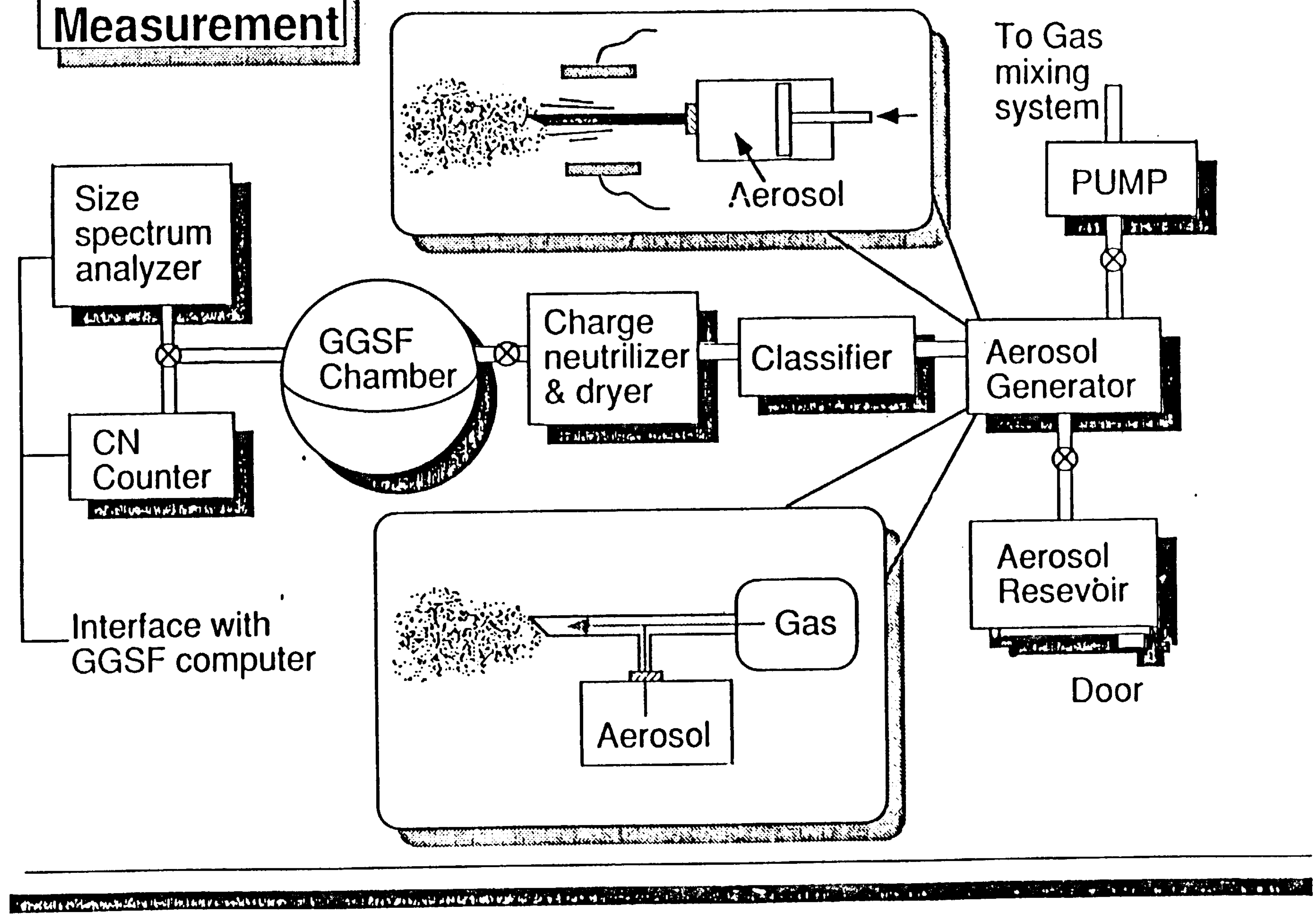
Ports and component connections indicated



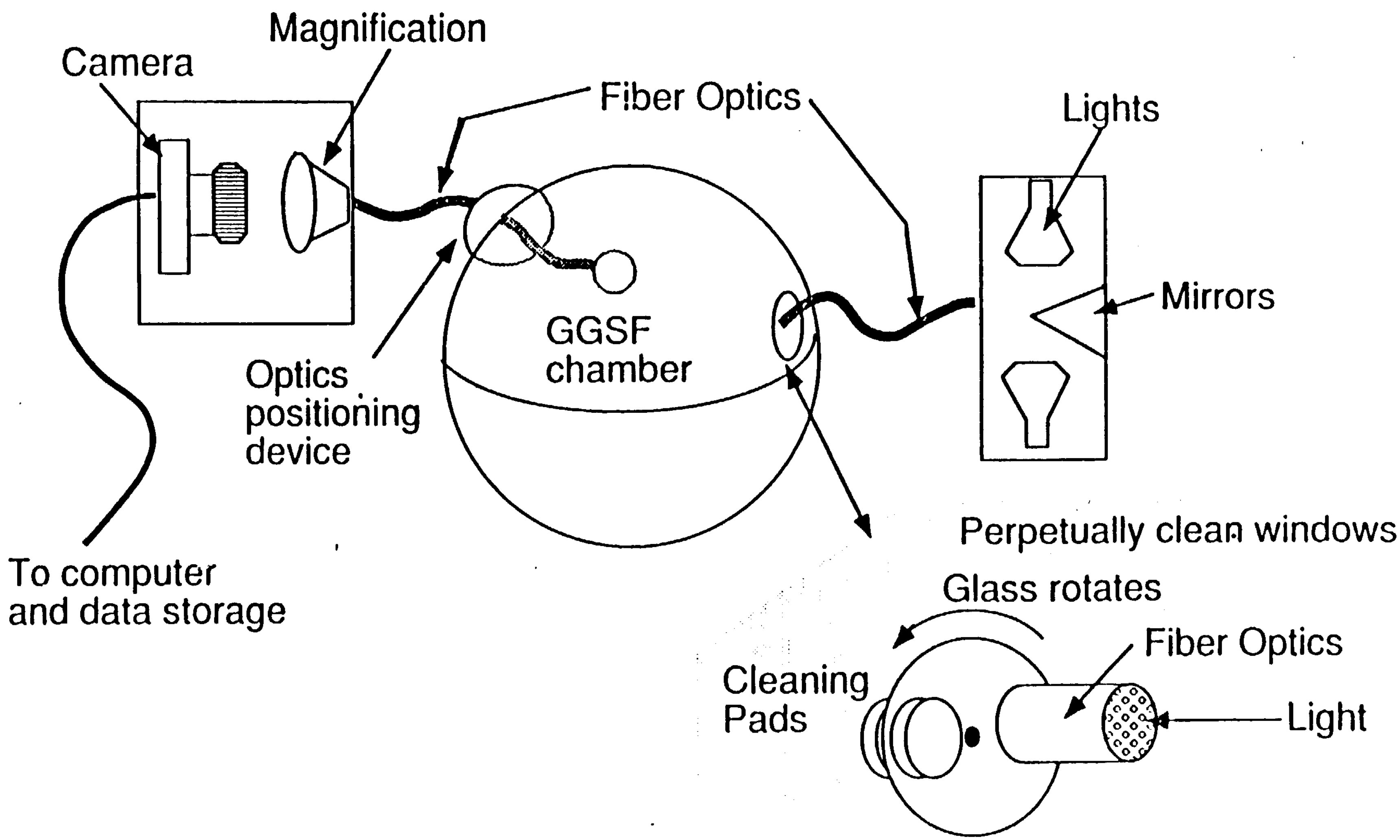


Environment Control
Interface with GGSF computer
To SSF gases
Gas Mixing
To Aerosol generator
To Injection-Retrieval subsystem
Thermal insulation
Heating Coils
GGSF Chamber
Cooling Coils
PRESSURE MONITOR
HUMIDITY MONITOR
TEMPERATURE MONITOR
Pressure diaphragm
Thermocouple
To SSF vacuum
To PMMS waste gas

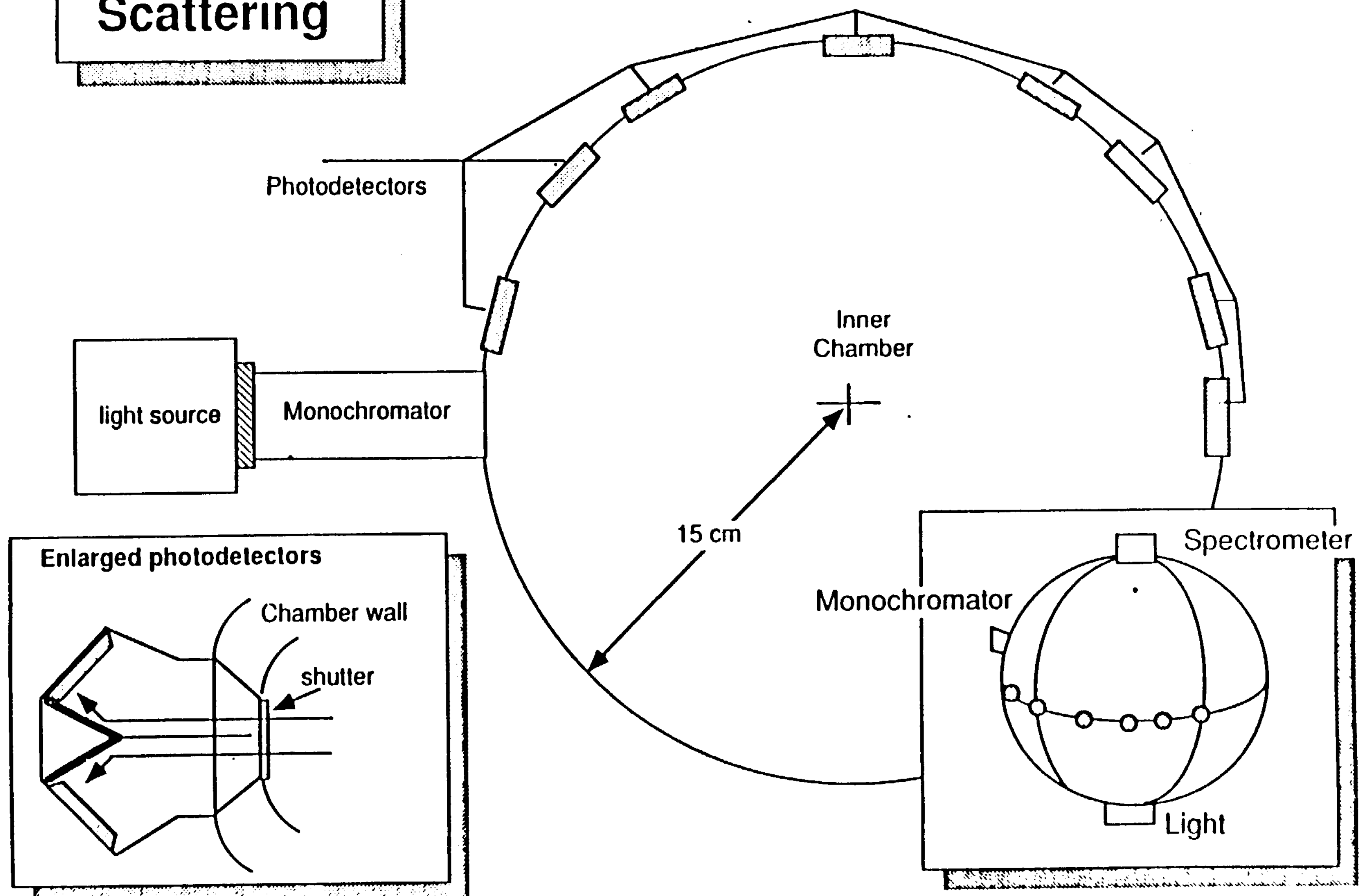
Aerosol Generation-Measurement



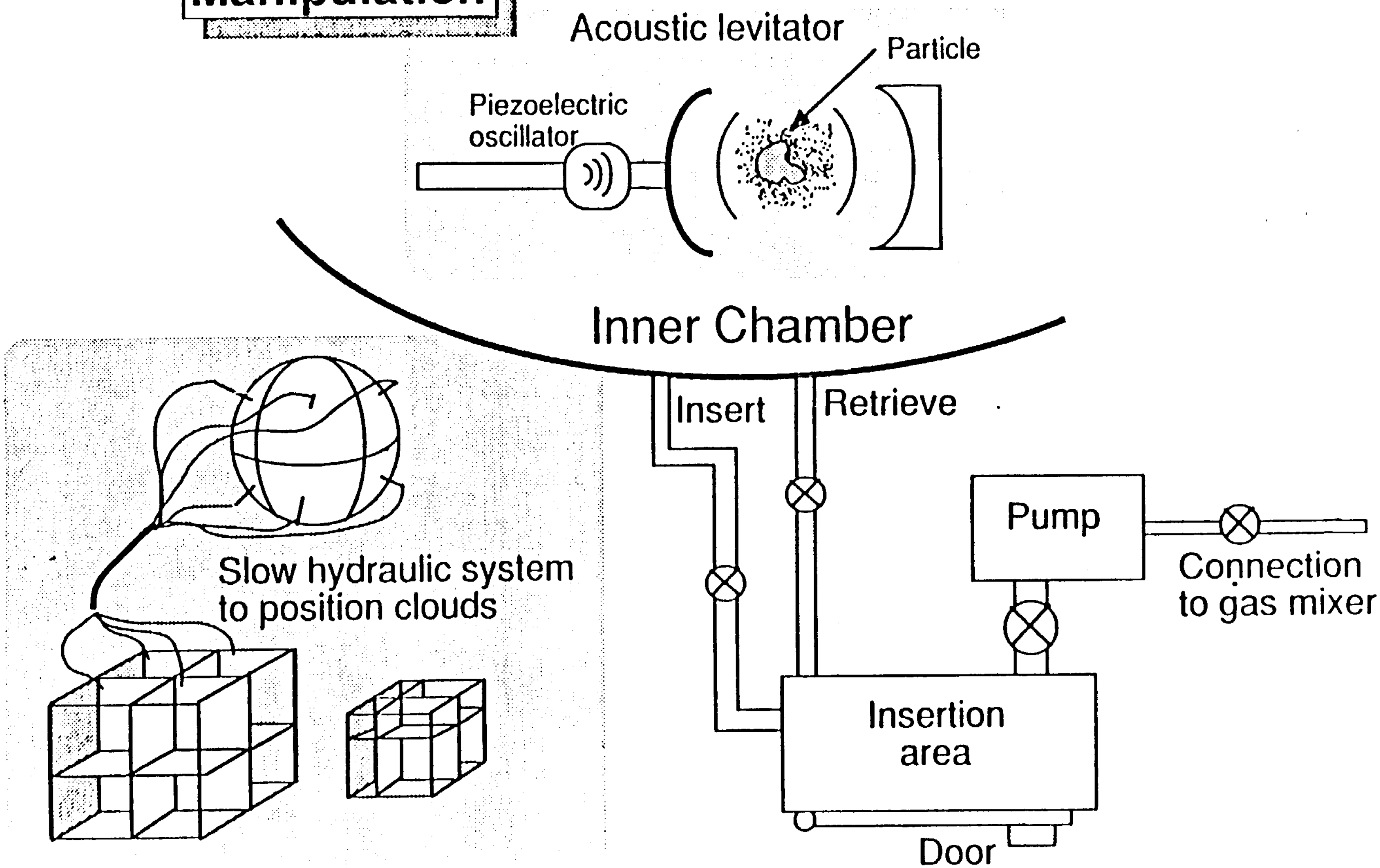
Imaging Systems



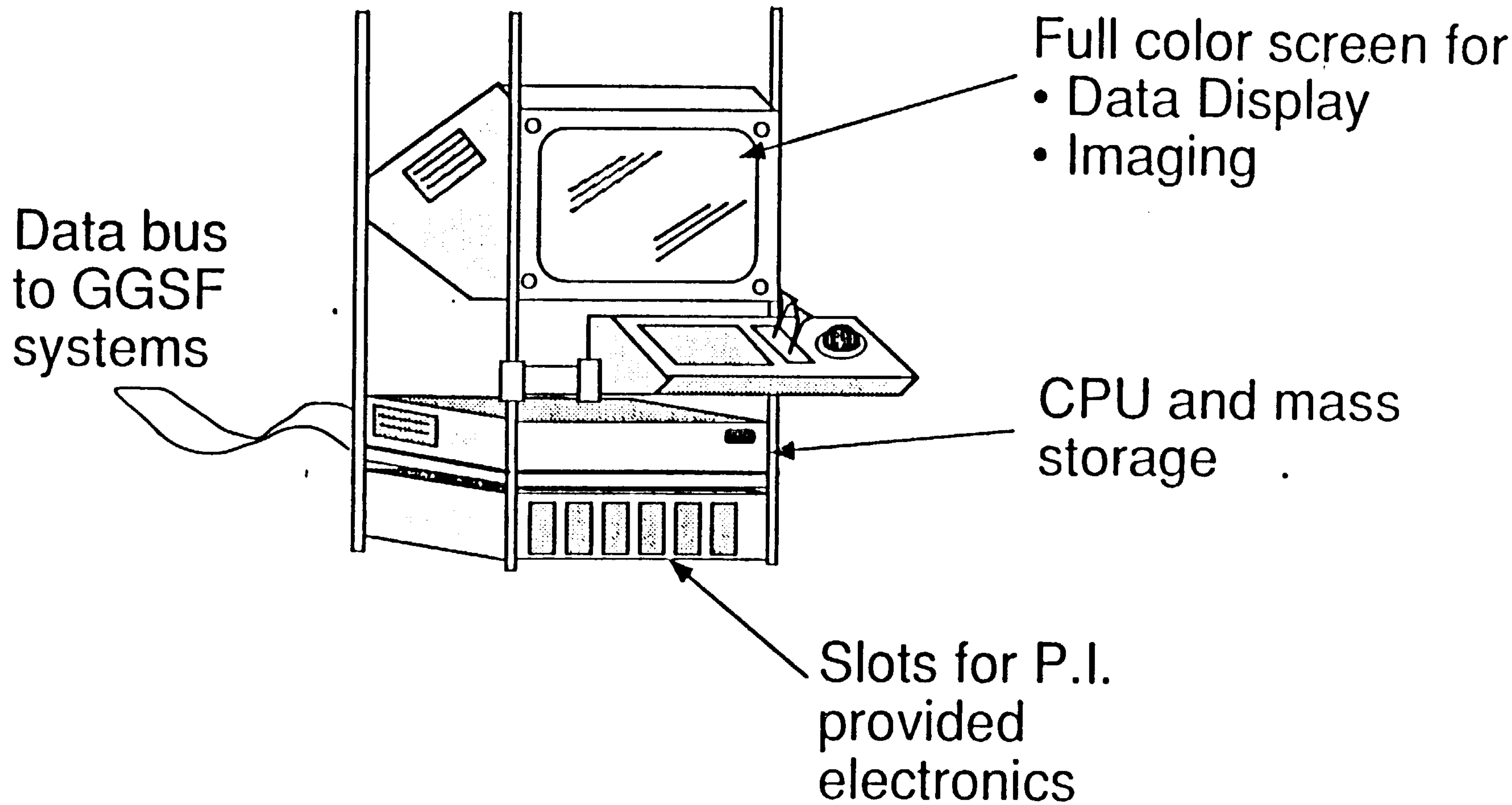
Spectrometry and Scattering



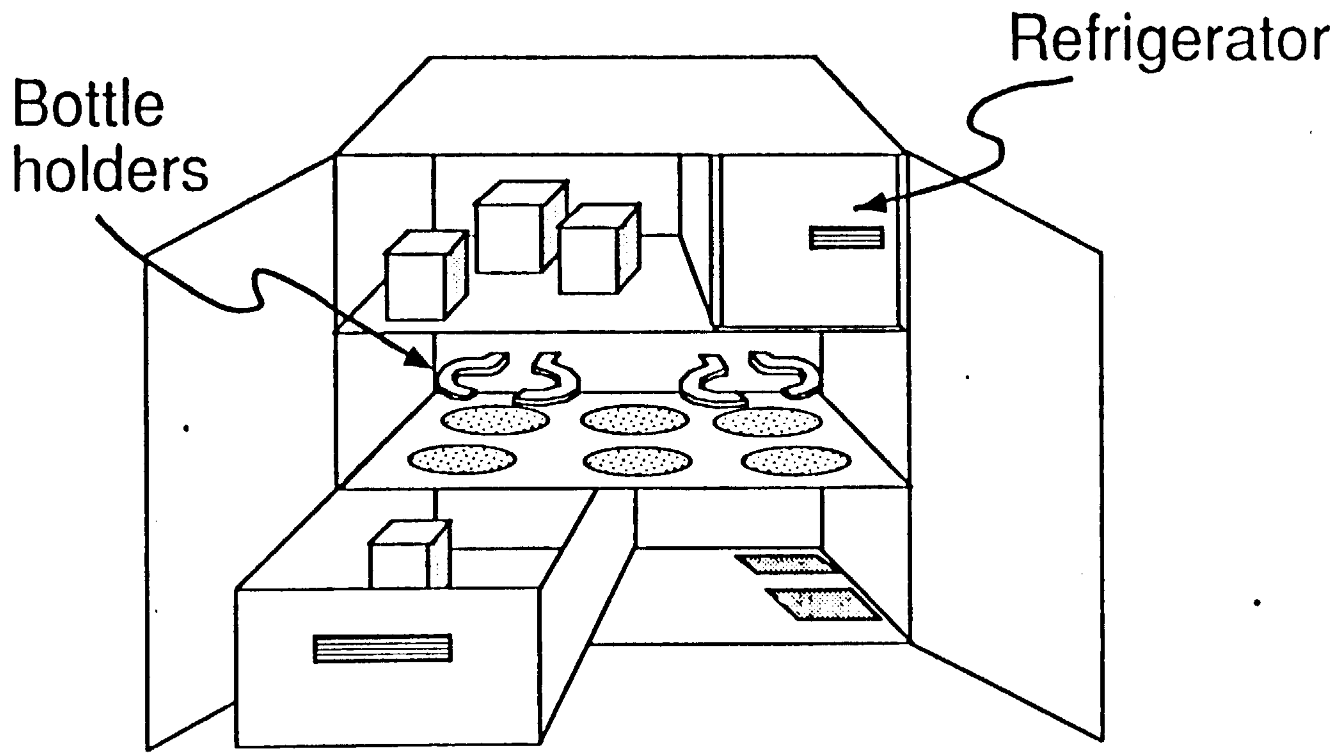
Retrieval Injection Manipulation



Computer Control



Storage Locker



Gas-Grain Simulation Facility: Description

The Gas-Grain Simulation Facility (GGSF), currently under development by the Exobiology Flight Experiments Program at Ames Research Center, is a facility-class payload proposed for the Space Station. The GGSF will be used to simulate and investigate fundamental chemical and physical processes such as the formation, collision and interaction of droplets, grains and other particles.

The Gas-Grain Simulation Facility will occupy a Space Station double rack. It will consist of several subsystems supporting an adaptable 10 liter experiment chamber. Subsystems will provide environmental control (e.g., temperature, pressure, gas mixture and humidity), measurement equipment (e.g., video cameras, optical particle counters, spectrometers, and photometers), and energy sources. Subsystems will also furnish: command and control capability; mechanisms for producing, injecting, and removing particles and clouds of particles; and levitation devices for positioning particles and keeping them in fixed positions away from the chamber walls. GGSF mass and power requirements are estimated to be 700 to 800 Kg and 1500 W peak (750 W average) respectively.

The GGSF will be modular in design; that is, it will have an adaptable configuration allowing subsystem components to be connected in a number of ways. Modularity will also allow the GGSF to evolve. At an early stage, the GGSF would be capable of supporting those experiments which promise high scientific yield and require only a few subsystems. Further, modularity will allow outdated subsystems to be replaced. New experiment chambers will be brought to the Space Station once a year so the GGSF will have a very long, useful lifetime (i.e., 10 years).

The facility's computer will control all operations of the facility during an experiment and have an autonomous decision making capability. Data exchange requirements, estimated at 20 to 40 kilobytes per day, are modest. Data/command uplinks will occur about twice per week. Aside from time needed for the initial set-up and calibration of experiments, crew time requirements will be minimal.

One possible GGSF operational sequence is as follows: A chamber designed for a series of experiments is "plugged in" to the GGSF and subsystems are attached in the configuration necessary for the first experiment. A command is then given to begin the execution of preprogrammed instructions for performing the experiment. After the first experiment is completed, the system may be reconfigured for the second experiment. When the sequence of experiments associated with the first chamber is completed, the chamber is removed and stored for return to Earth and a second chamber is attached for the next sequence of experiments.

Since many of the suggested GGSF experiments require gravitational accelerations of 10^{-4} to 10^{-5} g, it will be necessary to consider the background gravitational gradient when deciding where in the Space Station to place the GGSF. The GGSF will take advantage of some of the user support systems supplied by the Space Station such as the 10^{-3} torr "house" vacuum and data from the accelerometer system. Also, given the delicate physical and chemical properties of some particles generated in the GGSF, some preliminary sample analysis on the Space Station may be desirable. Such analysis will require special sample handling equipment and analytical tools. For example, some GGSF experiments will use a Scanning Electron Microscope, a Gas Chromatograph, a Mass Spectrometer, a (micro) mass measurement system, and/or a High Pressure Liquid Chromatograph if they are available.

Gas-Grain Simulation Facility: Science Rationale/Objectives

In many astrophysical and geological systems (atmospheric clouds, interstellar clouds, planetary rings, Titan's organic aerosols, Martian dust storms, etc.), processes involving small particles significantly contribute to the overall behavior of the system. Grain nucleation and aggregation, low velocity particle collisions, and charge accumulation are a few of the processes that influence such systems. Particles undergoing these processes include interstellar grains, protoplanetary particles, atmospheric aerosols, combustion products, and pre-biotic organic polymers.

The ability to simulate and investigate these types of systems and processes would present an exciting opportunity to answer long-standing scientific questions concerning the life and death of stars, the formation of the Solar System, and the connection between the Solar System's evolution and the appearance of life. These investigations would also increase our understanding of processes of immediate concern such as acid rain formation, ozone depletion, and climatic change on Earth. Furthermore, investigation of particle systems is essential to the achievement of NASA's scientific goal to attain a deep understanding of the Solar System, Earth, and the origin of life.

Many particle systems are not well understood because parameters relevant to these systems are poorly determined or unknown. Examples of such parameters are the coagulation rate of aerosol particles, the size distribution of particles nucleated from a gas, and the dependence of aggregation efficiency on material properties. Due to rapid particle settling in a 1g environment, these parameters are difficult and in many cases impossible to measure in experimental simulations on Earth.

In the study of small particle processes relevant to scientific issues mentioned above, the demands on experiment design are severe. Two common requirements are low relative velocities between particles and long time periods during which the particles must be suspended. Generally, the suspension times required are substantially longer than can be attained in 1g. Furthermore, for many studies, Earth's gravity can interfere directly with the phenomenon under study (e.g., weak inter-particle forces) or preclude the establishment of proper experimental conditions (e.g., a convection-free environment). Consequently, many processes are not amenable to experimentation in 1g.

However, in the Earth-orbital environment, the effects of gravity are reduced by a factor of as much as one million. In this environment, previously impractical or impossible experiments become feasible. Small-particle processes which cannot be studied on Earth can be investigated in Earth-orbit with a general-purpose microgravity particle research facility such as the Gas-Grain Simulation Facility (GGSF).

The GGSF, a facility-class payload proposed for the Space Station, will be used to simulate and investigate fundamental chemical and physical processes such as the formation, collision and interaction of droplets, grains and other particles. Scientific issues that can be addressed with the Gas-Grain Simulation Facility are relevant to the disciplines of exobiology, planetary science, astrophysics, atmospheric science, biology, and physics and chemistry. To date, twenty candidate GGSF experiments have been identified and described in detail. The candidate experiments are as follows:

1. Low-Velocity Collisions Between Fragile Aggregates

2. Low-Energy Grain Interaction/Solid Surface Tension

3. Cloud Forming Experiment

4. Planetary Ring Particle Dynamics

5. Aggregation of Fine Geological Particulates in Planetary Atmospheres

6. Condensation of Water on Carbonaceous Particles

7. Optical Properties of Low-Temperature Cloud Crystals

8. Ice Scavenging and Aggregation

9. Synthesis of Tholin in Microgravity and Measurement of its Optical Properties

10. Metallic Behavior of Aggregates

11. Investigations of Organic Compound Synthesis on Surfaces of Growing Particles

12. Crystallization of Protein Crystal-Growth Inhibitors

13. Dipolar Grain Coagulation and Orientation

14. Titan Atmospheric Aerosol Simulation

15. Surface Condensation and Annealing of Chondritic Dust

16. Studies of Fractal Particles

17. Emission Properties of Particles and Clusters

18. Effect of Convection on Particle Deposition and Coagulation

19. Growth and Reproduction of Microorganisms in a Nutrient Aerosol

20. Long Term Survival of Human Microbiota in and on Aerosols

The GGSF will be sufficiantly flexible to accommodate the above as well as many other scientifically important investigations without compromising the requirements of any particular investigation. By extending the range of conditions in which experiments can be performed, the GGSF will be a powerful tool for studying the physics of small particles and grains. Important advances in our understanding of the many small-particle phenomena should follow from the new ability to study subtle small-particle effects and interactions.

Gas-Grain Simulation Facility: Hardware

The Gas-Grain Simulation Facility (GGSF) consists of eight subsystems which are complimentary and interdependent. All of the subsystems are necessary for meeting the facility science requirements. The GGSF subsystems and hardware are as follows:

1. General Purpose Experiment Chamber/Containment Subsystem
   (Includes ports, feed-throughs, subsystem interfaces, double- or triple-containment, vibration isolation, EM shielding, etc.)

2. Chamber Environment Regulation/Monitoring Subsystem
   (For regulation and monitoring of temperature, pressure, and humidity. Includes gas-handling system, filters, etc.)

3. Aerosol Generation/Measurement Subsystem
   (Includes aerosol generators, size spectrum analyzers, CN counter, electrostatic classifier, dryer, charge neutralizer, etc.)

4. Chamber Illumination, Optics, and Imaging Subsystem
   (Includes UV sources, camera with optics, various lamps, photometer, etc.)

5. Spectrometry/Optical Scattering Subsystem
   (Includes spectrometers, lasers, photodetectors and other support equipment for light scattering measurements, etc.)

6. Particle Manipulation and Positioning Subsystem
   (Includes acoustic levitator, particle injection mechanisms, particle retrieval mechanisms, etc.)

7. Computer Control and Data Acquisition Subsystem
   (Includes microcomputer and console, data bus, data storage, control electronics, etc.)

8. Storage Locker
   (For storing special gas mixtures, fluids for aerosol generators, interfaces and adaptors, PI-provided hardware, samples produced in experiment runs, film, etc.)

LIFE SCIENCES FLIGHT PROGRAMS CHANGE REQUEST

Reference Documentation:

Life Sciences Hardware List for the Space Station Freedom Era. R-0006

Description of Change:

Change the **Exobiology Facility** section to reflect the following:

EXOBIOLOGY FACILITY (8)

		Volume (cu. m)	Weight (kg)	Power (watts)
Gas-Grain Simulation Facility Hardware Group (8A)		**2.40**	**800**	**1500**
1.	General Purpose Experiment Chamber/Containment Subsystem	0.48	200	0
2.	Chamber Environment Regulation/Monitoring Subsystem	0.23	80	200
3.	Aerosol Generation/Measurement Subsystem	0.45	150	300
4.	Chamber Illumination, Optics, and Imaging Subsystem	0.20	80	200
5.	Spectrometry/Optical Scattering Subsystem	0.20	150	300
6.	Particle Manipulation and Positioning Subsystem	0.16	50	200
7.	Computer Control and Data Acquisition Subsystem	0.20	50	300
8.	Storage Locker	0.48	40	0

Justification/Rationale:

This Change Request identifies the component subsystems of the Gas-Grain Simulation Facility (8A) and includes the volume, weight and power estimates for each subsystem. The additional 0.48 cubic meters of volume indicated in this Change Request is required for storage of items such as special gas mixtures, fluids for aerosol generators, experiment-produced samples to be returned to Earth, and film. These changes reflect further refinement of the Gas-Grain Simulation Facility requirements.

3/3/89

Gas-Grain Simulation Facility: Hardware Definitions

General Purpose Experiment Chamber/Containment Subsystem: The Gas-Grain Simulation Facility (GGSF) experiment chamber for studying small-particle processes and interactions in microgravity.

Chamber Environment Regulation/Monitoring Subsystem: A Gas-Grain Simulation Facility (GGSF) subsystem that establishes, regulates, and removes the gas-mixture in the GGSF chamber as well as monitors and regulates the chamber/gas temperature, pressure, and humidity.

Aerosol Generation/Measurement Subsystem: A Gas-Grain Simulation Facility (GGSF) subsystem that generates and introduces into the GGSF chamber aerosol clouds of various concentration, particle-size, and dispersion and monitors the cloud size-distribution and total concentration.

Chamber Illumination, Optics, and Imaging Subsystem: A Gas-Grain Simulation Facility (GGSF) subsystem that provides optical imaging of processes occurring in the GGSF chamber and provides various light/energy sources.

Spectrometry/Optical Scattering Subsystem: A Gas-Grain Simulation Facility (GGSF) subsystem that measures light-scattering and extinction properties of aerosol/dust clouds and single grains.

Particle Manipulation and Positioning Subsystem: A Gas-Grain Simulation Facility (GGSF) subsystem that mechanically and/or aerodynamically injects particles into the chamber, manipulates them by acoustic and/or aerodynamic levitation, and retrieves samples from the chamber.

Gas-Grain Simulation Facility Computer Control and Data Acquisition Subsystem: A Gas-Grain Simulation Facility (GGSF) subsystem which provides computer and electronic control of experiments, data acquisition and storage.

Gas-Grain Simulation Facility Storage Locker: A locker to store Gas-Grain Simulation Facility (GGSF) support materials such as PI-provided equipment and special dust or aerosol mixtures for a planned suite of experiments and to store samples for return to Earth.

SPACE STATION FREEDOM / SPACELAB MODULE COMPATIBILITY

TRADE STUDIES

JOHNSON SPACE CENTER
HOUSTON, TEXAS
77058

SPACE BIOLOGY

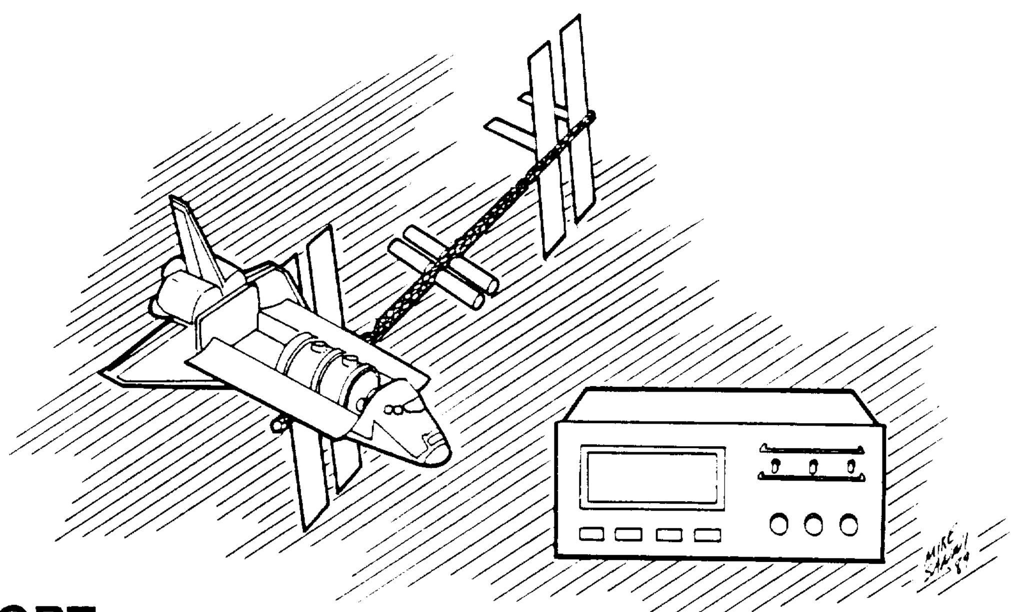
INITIATIVE

Space Biology Initiative
Program Definition Review

Lyndon B. Johnson Space Center
Houston, Texas 77058

HORIZON AEROSPACE

Space Station Freedom/ Spacelab Modules Compatibility



FINAL REPORT

June 1, 1989

HORIZON AEROSPACE

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• HOUSTON, TEXAS, USA 77058 • (713) 333-5944
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SPACE BIOLOGY INITIATIVE PROGRAM DEFINITION REVIEW

TRADE STUDY 6

SPACE STATION FREEDOM / SPACELAB MODULES COMPATIBILITY

FINAL REPORT

Prepared by:

HORIZON AEROSPACE

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T. Sutton

Prepared for:

GE GOVERNMENT SERVICES
Houston, Texas
Contract No. G966016-J45

June 1, 1989

Space Station Freedom/Spacelab Modules Rack Compatibility
Space Biology Initiative (SBI) Definition Review Trade Study
Trade Study Number 6

Prepared under Horizon Aerospace Purchase Order No. HAG 966016-J45-EAGLE
in Support of
GE Government Services Tasks for
NASA JSC Life Sciences Project Division

By
Eagle Engineering, Inc. (EEI)
Houston, Texas
EEI Contract TO-89-32

Trade Study 6 Report
EEI Report 89-236
Final Report
May 31, 1989

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
Cost Analysis Techniques Leader:	Mr. James W. Bilodeau (Jim)
Visual Materials Support:	Mr. J.M. Stovall (Mike)
Information Management Leader:	Mr. Terry Sutton (Eagle Technical Services)

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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

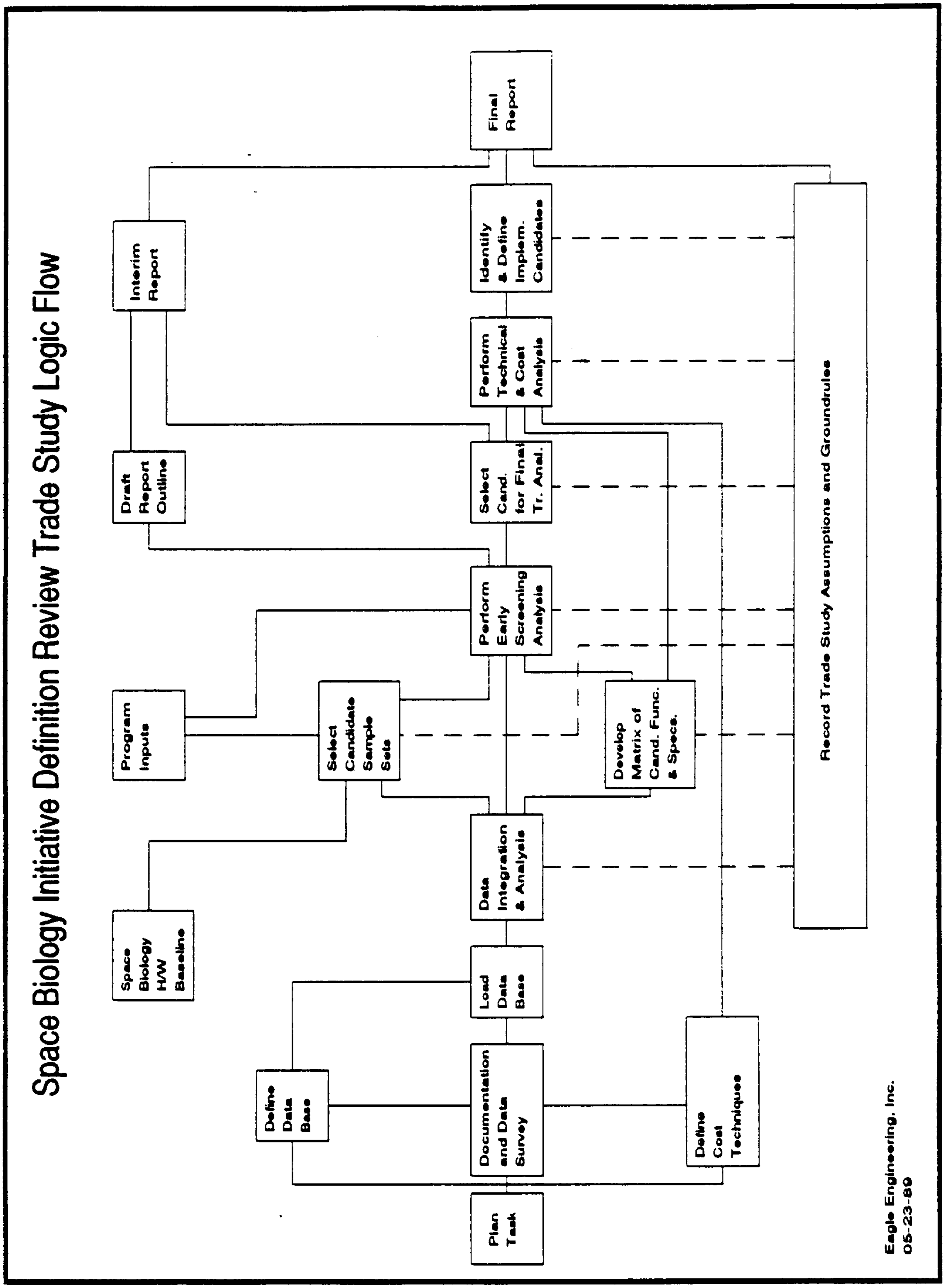
An analysis of the trade study data needs was performed to provide an understanding of the logical database design requirements. Based on the knowledge gained in the database analysis, the trade study data structures were developed and implemented on a computer system. The pertinent information collected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

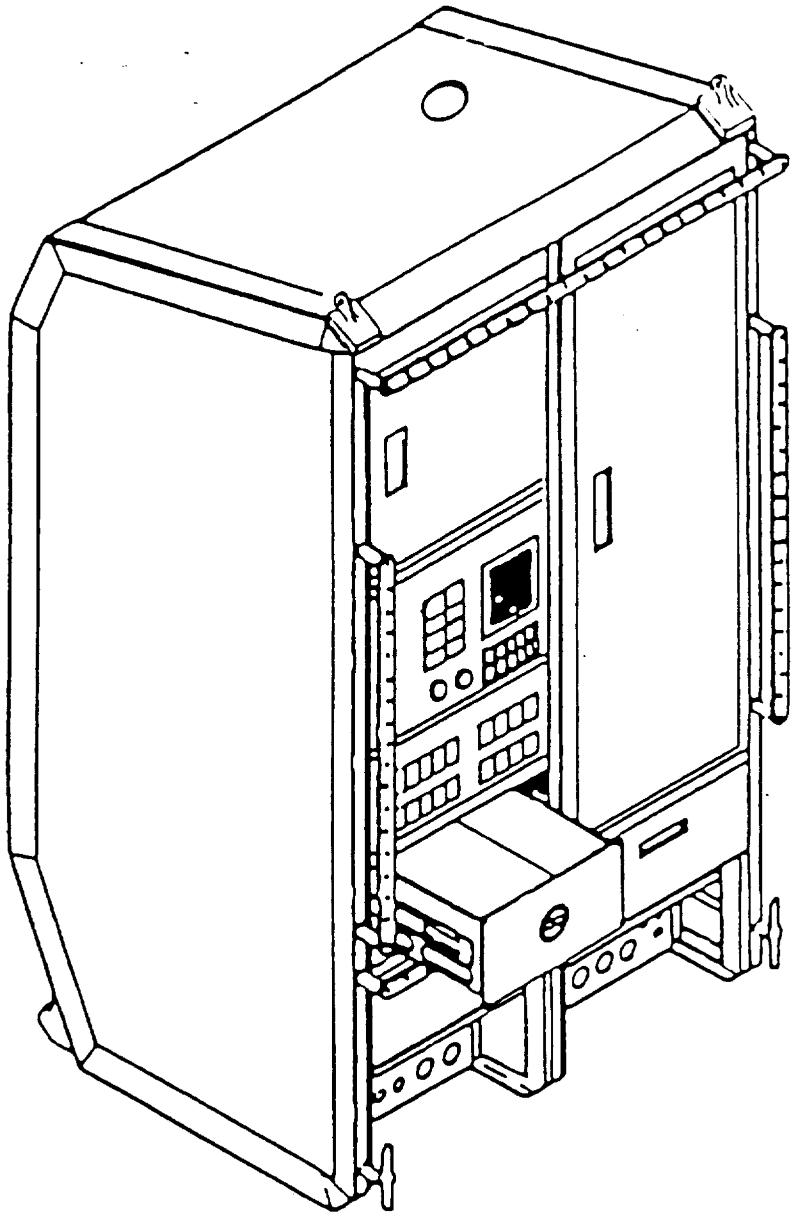


Figure 4.2.2-1 Payload/Experiment Racks as Distributed in the ESA Laboratory

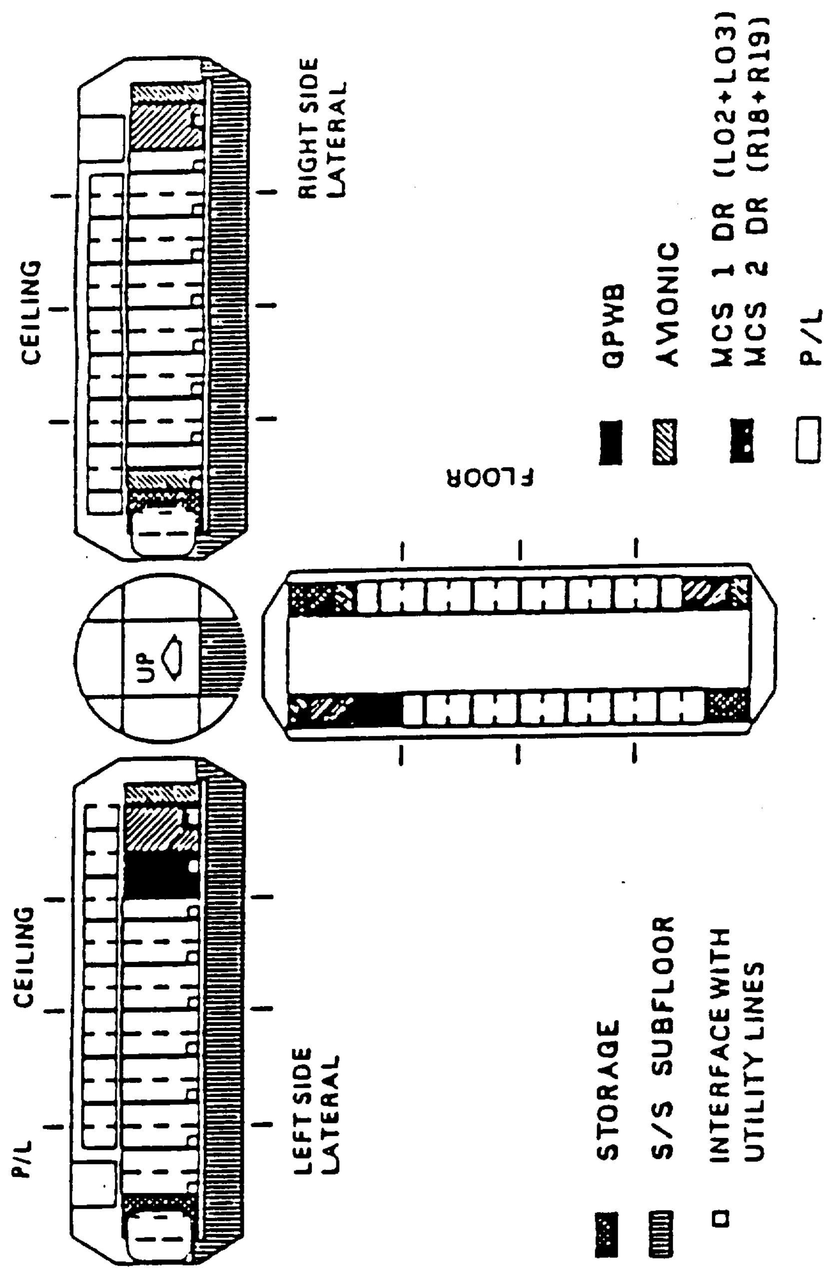


Figure 4.2.3-1 JEM Pressurized Module Internal Layout

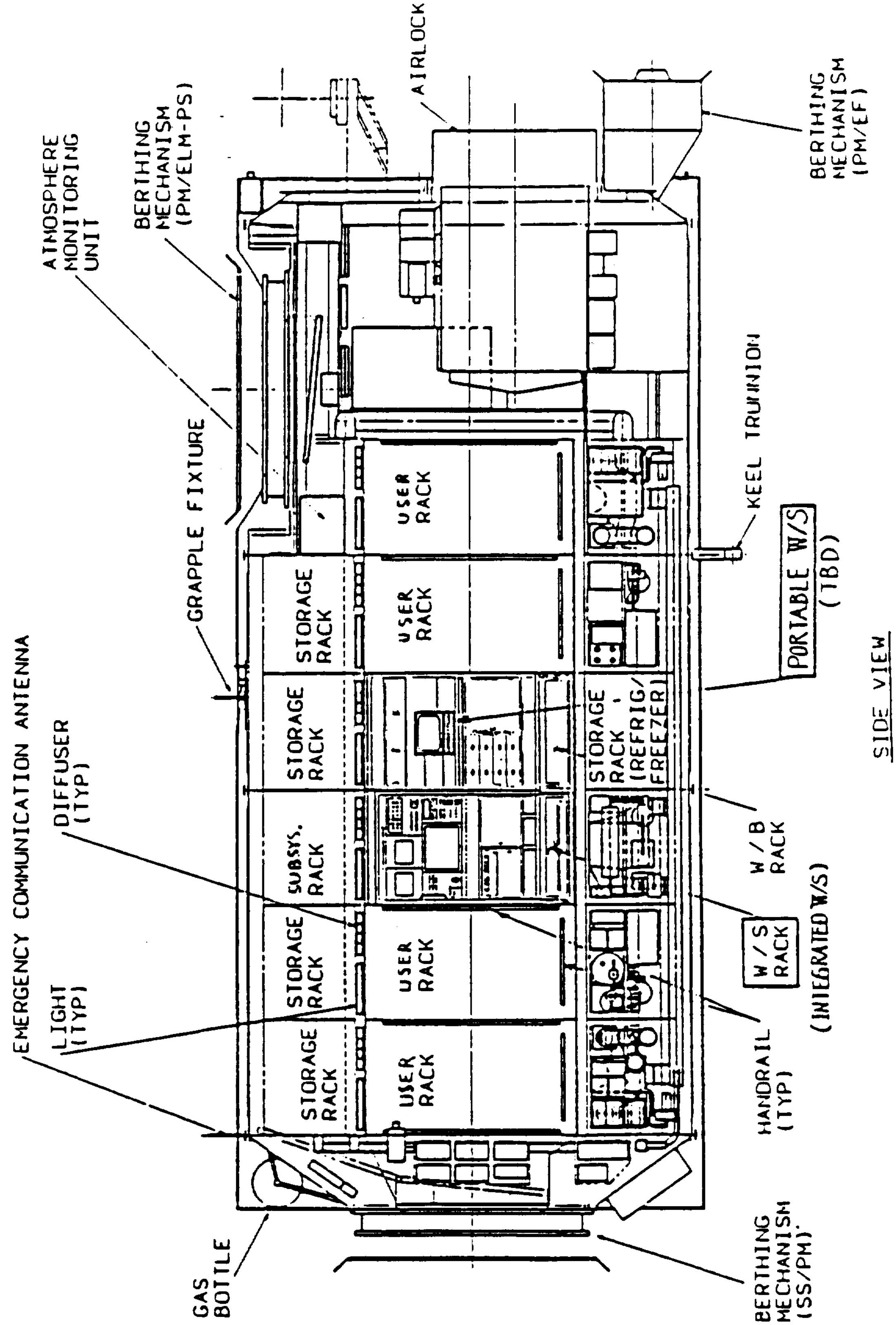


Figure 4.2.4-1 Spacelab Segments

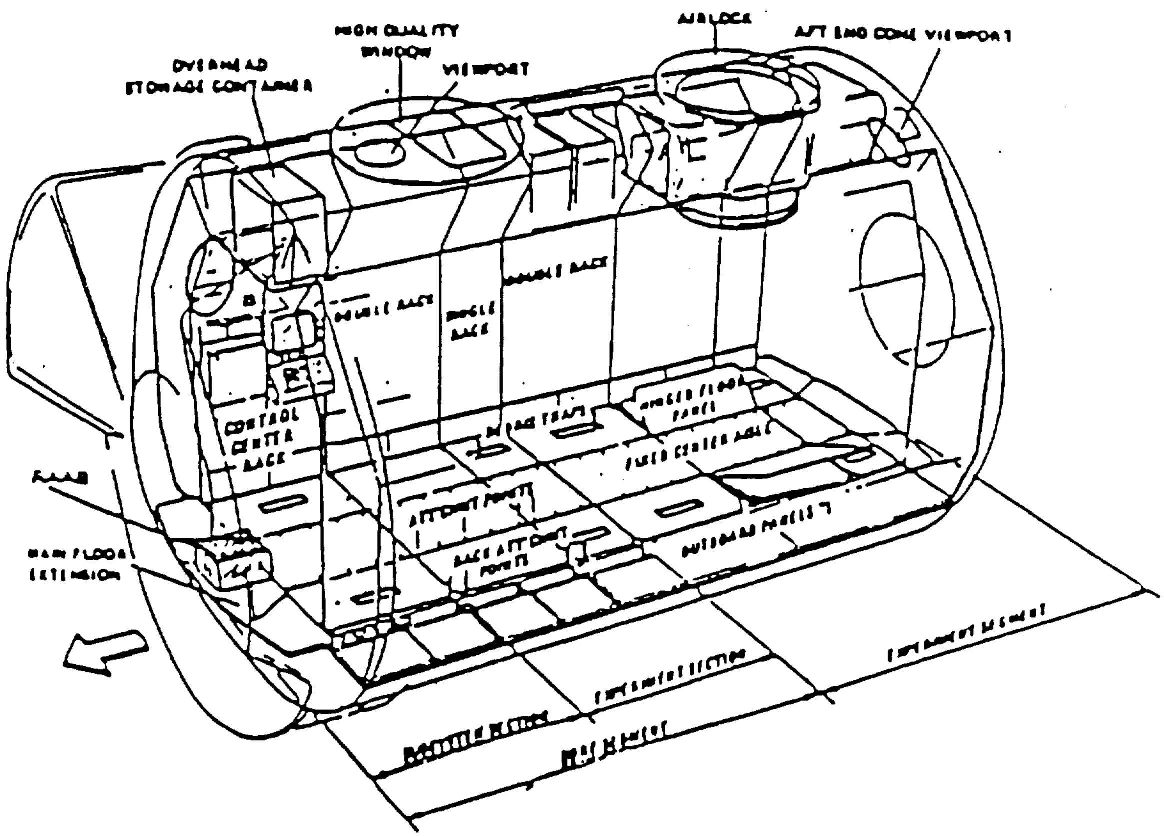
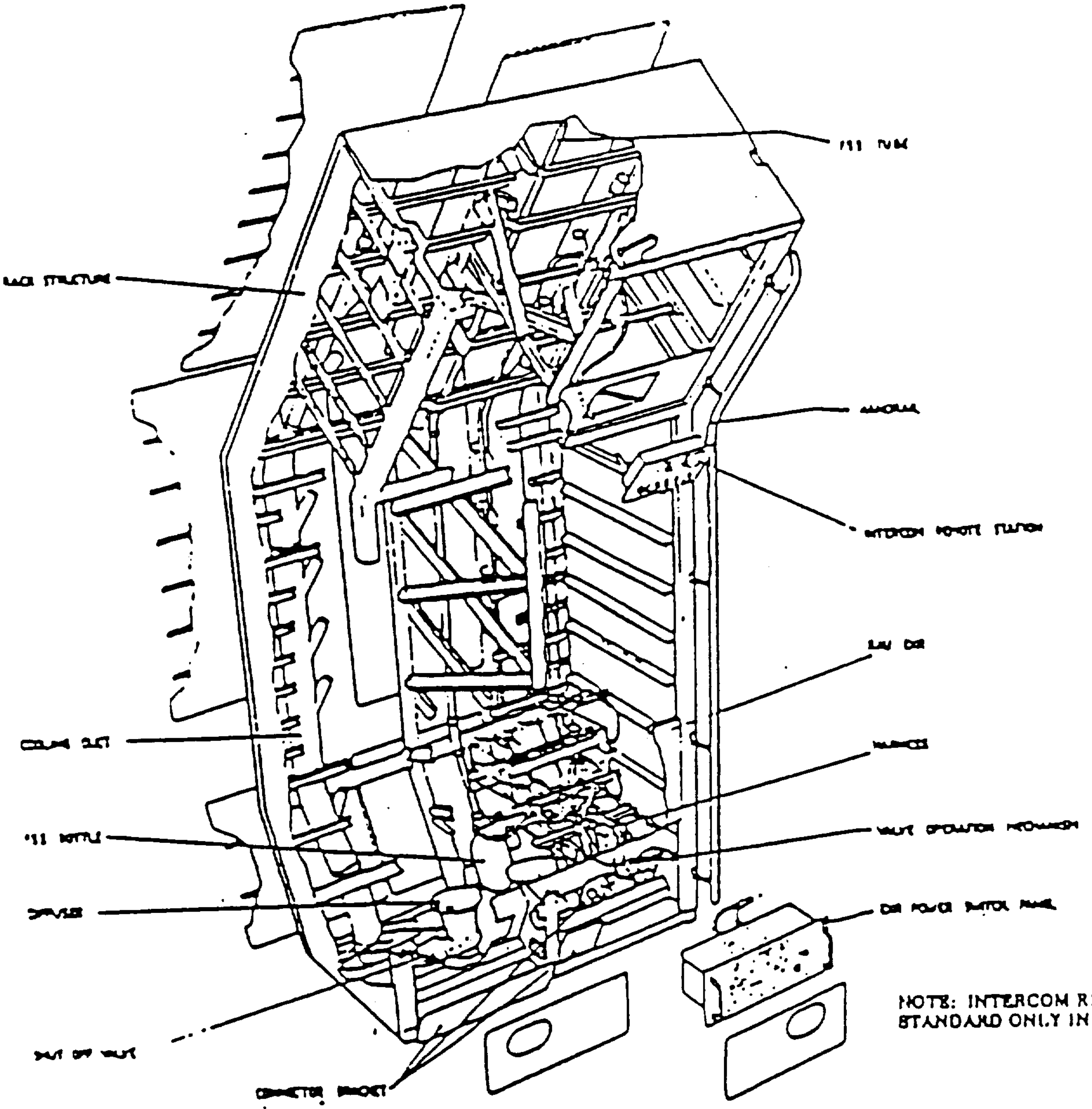


Figure 4.2.4-2 Spacelab Standard Double Rack



NOTE: INTERCOM REMOTE STATION IS STANDARD ONLY IN RACKS 4, 7 AND 10.

Figure 4.2.4-3 Spacelab Rack Numbering System

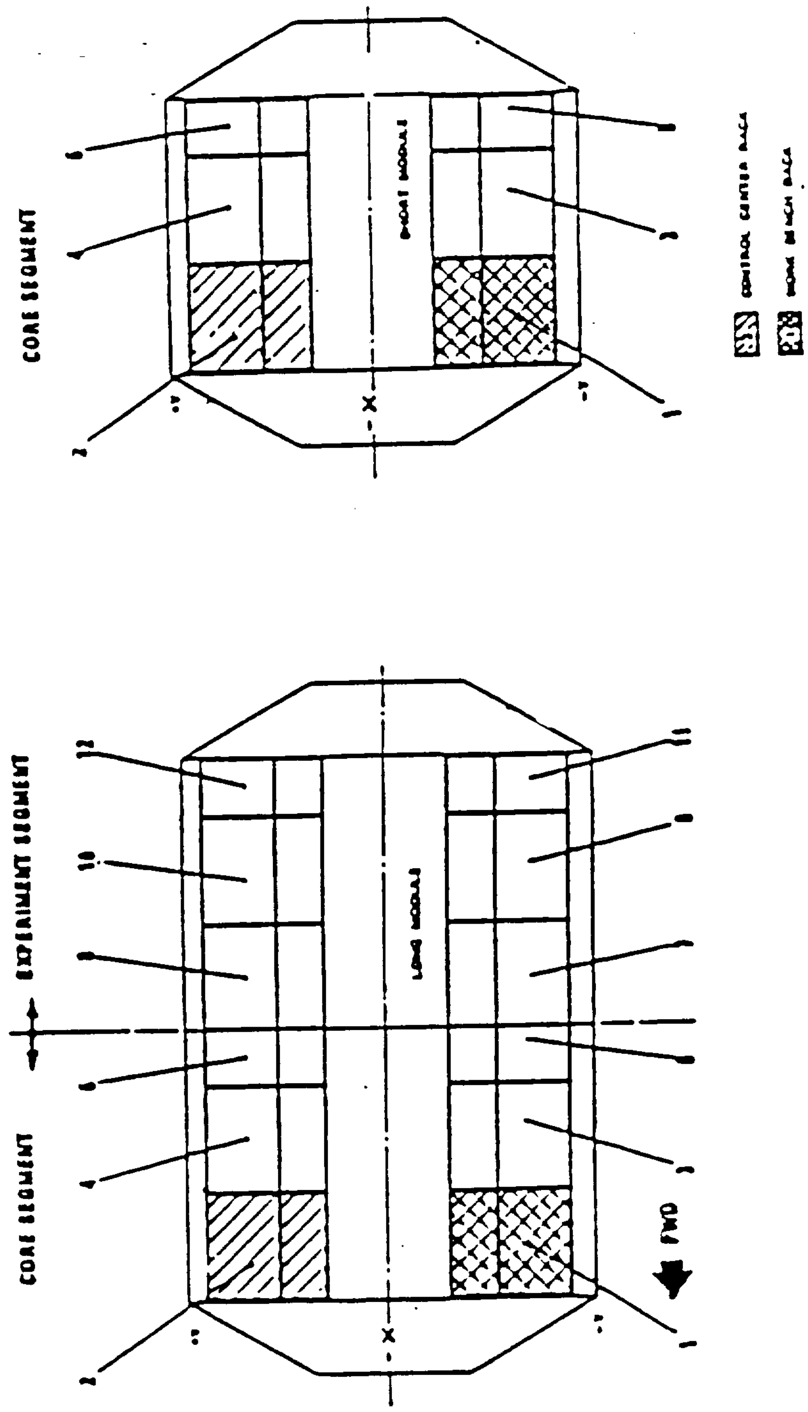


Figure 4.2.5-1 Orbiter Middeck Locker Layout

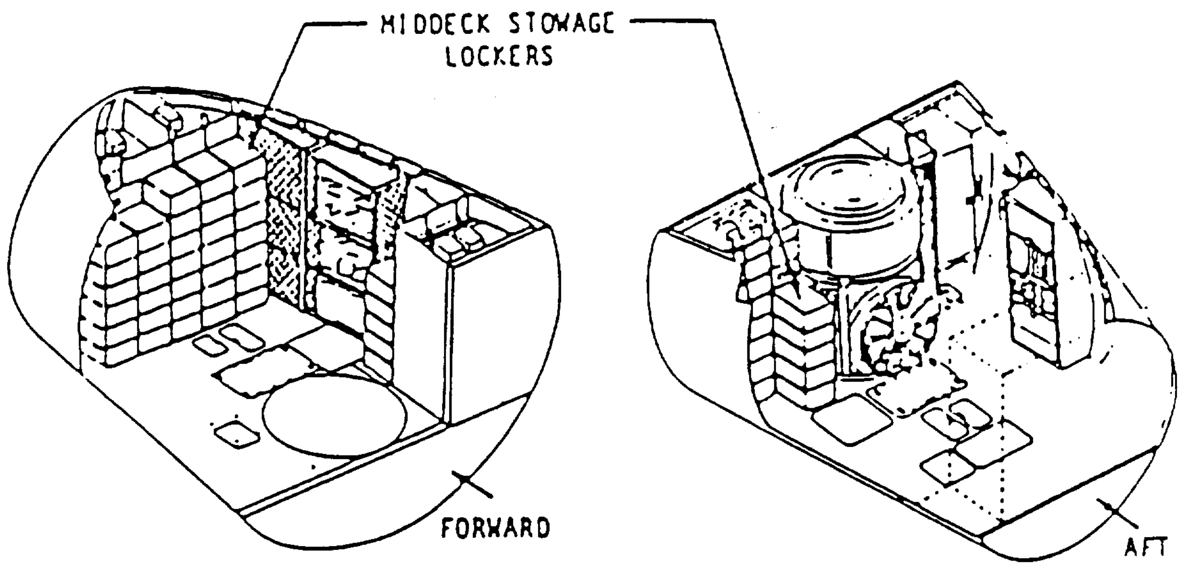


Figure 4.2.5-2 Middeck Locker and Typical Stowage Packaging

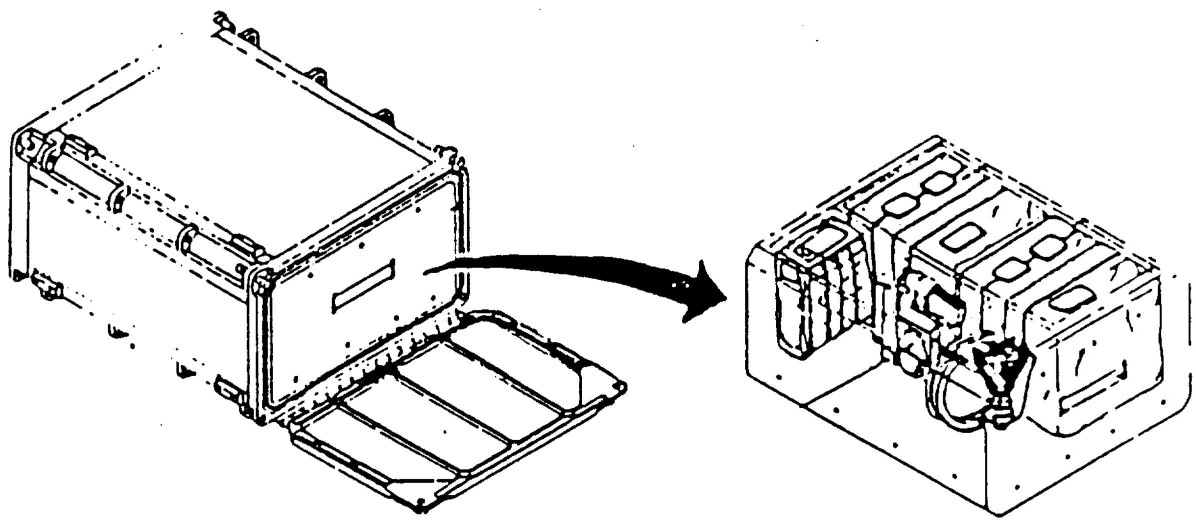
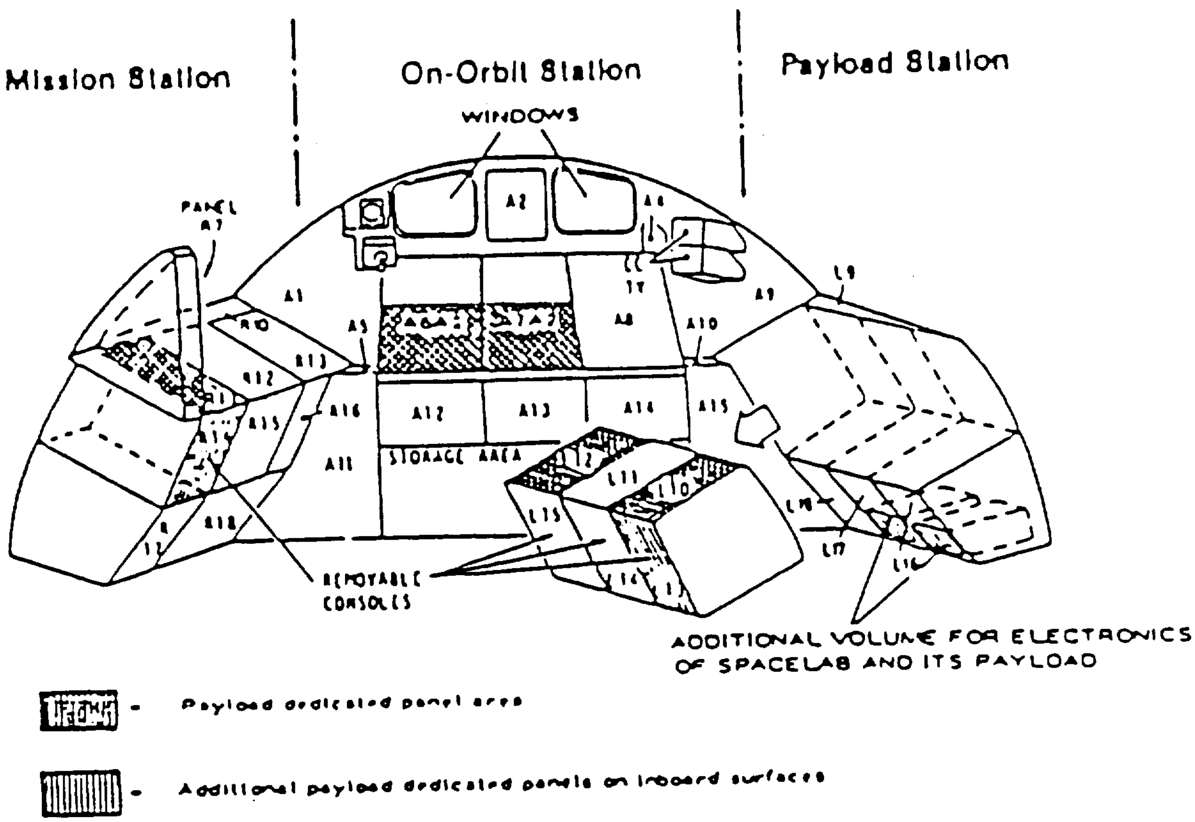


Figure 4.2.5-3 Orbiter Aft Flight Deck



C-3

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

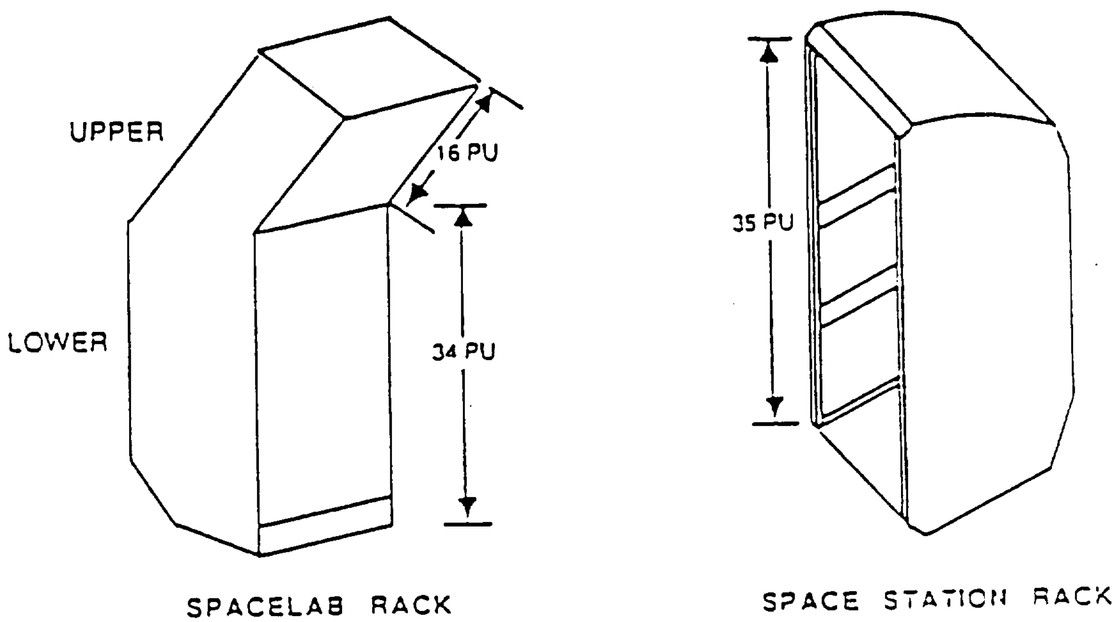
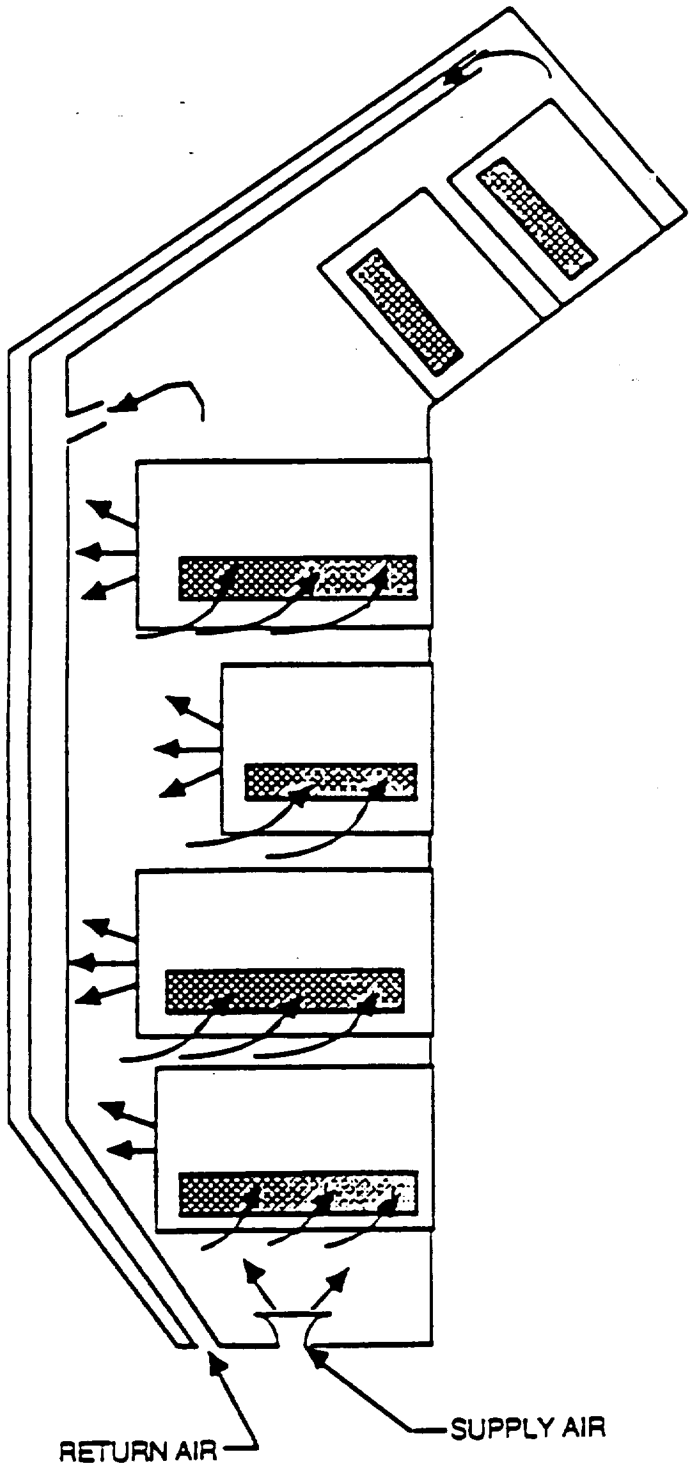


Figure 5.2.3-1 Spacelab Rack Cooling Concept



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
Up Dated 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

				UNIT HARDWARE 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
				~~1~~ .2	0
34	Sample Preparation Device	-		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	0.96	300	800
84	Soft Tissue Imaging System	S	~~0.01~~ .0002	~~TBD~~ -.06	~~0~~ Bat op
85	Tonometer	E	0.10	30	300
86	Video System				
	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	CAROTID SINUS BARORECEPTOR STIMULATOR (Neck Baro-Cuff)	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 3/23/89

Baselined: December 1988

LIFE SCIENCES HARDWARE LIST FOR THE SPACE STATION FREEDOM ERA

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	Electrofusion 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

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

A-ARC, J-JSC, '-Prime

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
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

Appendix B - Complete SBI Trade Study Bibliography

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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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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
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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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
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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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
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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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
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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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
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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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SBI68	Hamaker, Joe	Telephone interview relating to MSFC history and techniques for cost estimating.		Cost Analysis Branch Chief MSFC		Huntsville, Al.	04/27/89
SBI69	Booker, Clef	Personal Interview		Man-Systems Division JSC		Houston, TX.	04/04/89
SBI70	Evans, Jim	Personal Interview		Life Science Project Division JSC		Houston, TX.	04/19/89
SBI71	Heberlig,Jack	Telephone interview relating to make-or-buy lessons learned from Apollo		International Business Machines (IBM)		Houston, TX.	03/10/89
SBI72	Loftus, Joe	Telephone interview relating to make-or-buy history		Assistant Director (Plans) JSC		Houston,TX.	03/14/89
SBI73	Christy, Neil	Telephone interview relating to hardware development student experiments, and make-or-buy				Houston, TX.	03/15/89
SBI74	McAllister,Fred	Telephone Interview		Man-System Division, JSC		Houston,TX	03/14/89
SBI75	Trowbridge, John	Interview relating to CHeC make-or-buy		McDonnell Douglas		Houston,TX.	03/17/89
SBI76	Trowbridge, John	Personal interview relating CHeC experience to miniaturization, modularity and make-or-buy		McDonnell Douglas		Houston, TX.	03/29/89
SBI77	Nagel, John	Personal Interview relating to LSLE make-or-buy experience		Eagle Technical Services		Houston, TX	03/27/89
SBI78	McFadyen, Gary	Personal Interview relating to life science hardware background at JSC		Southwest Research Institute		Houston, TX.	04/10/89

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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
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

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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

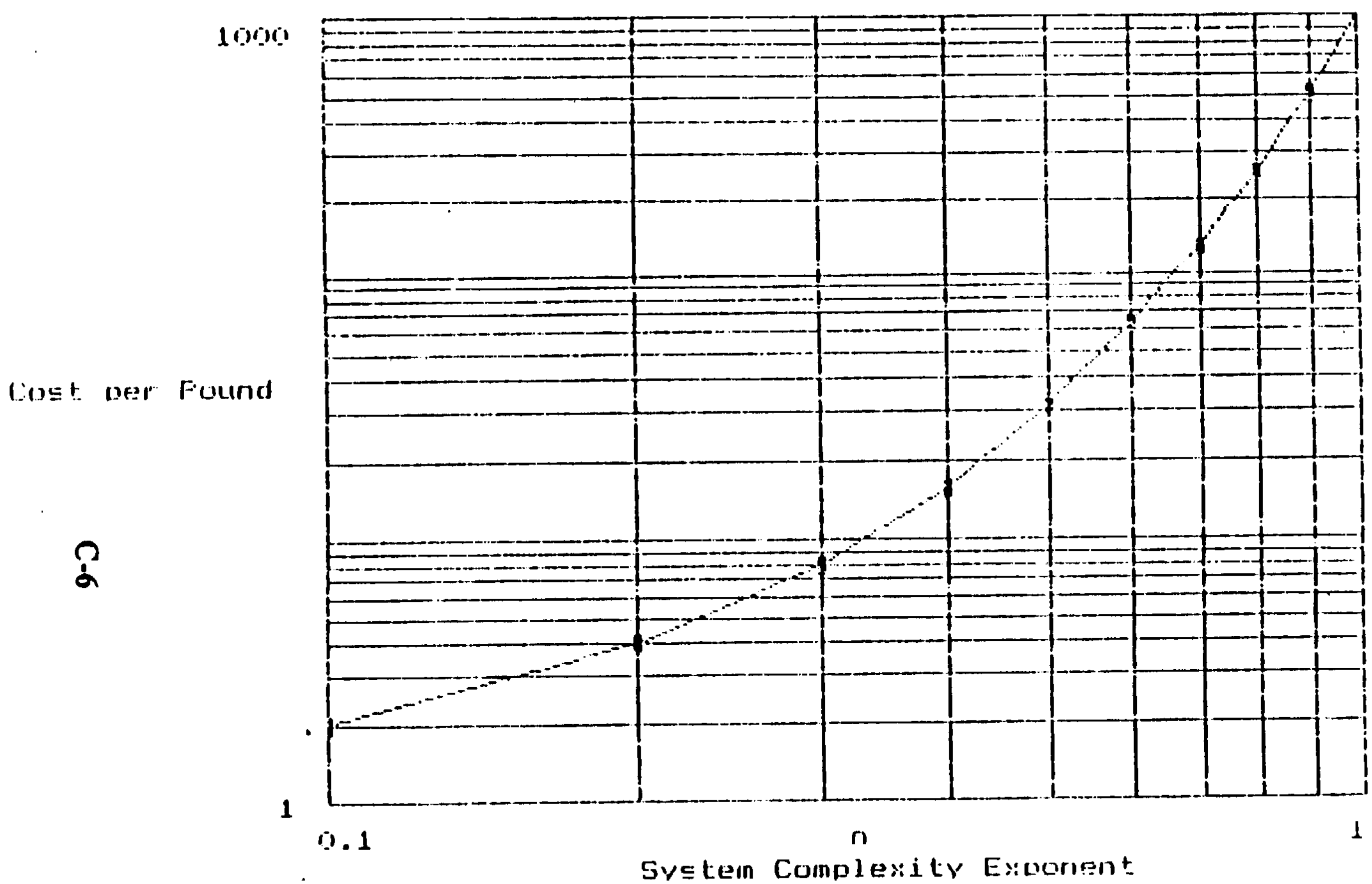


Figure 2-2 Design Factors

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

dl \ % 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

dl \ % 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

% Miniat. / df	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

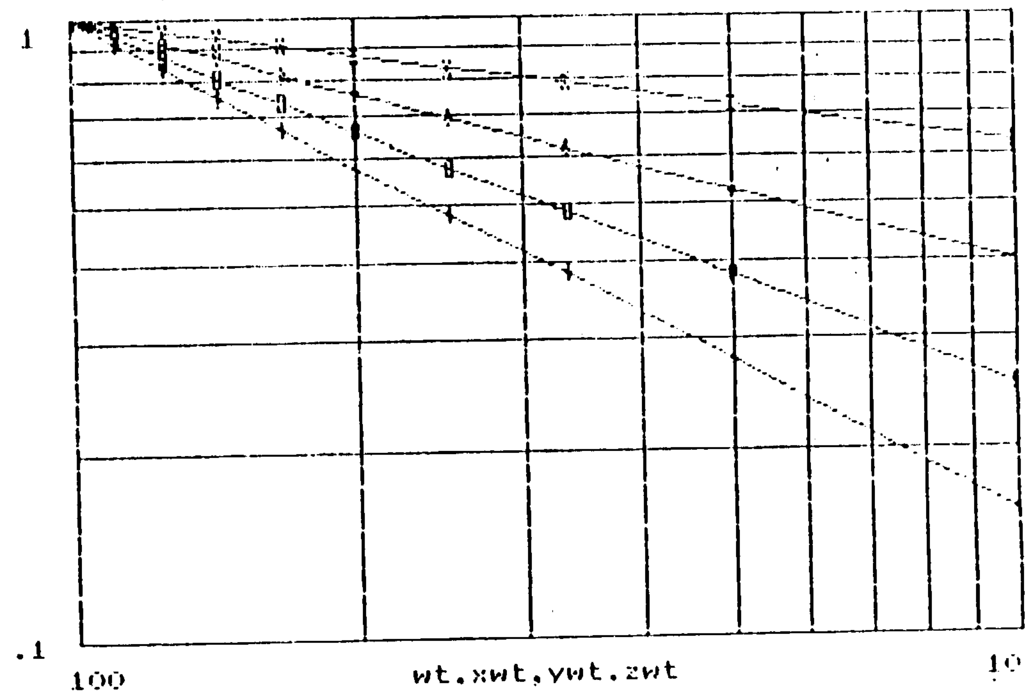
Table 3-4
Miniaturization Guide Chart
n=.8

% Miniat. / df	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
0 = 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

$$C.P._1 = 1.0\, D\&D_{cost} + [.35\, D\&D * L.F.]\, 16$$

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

$$C.P._1 = 1.0\, D\&D + 3.1248\, D\&D = 4.1248\, D\&D$$

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.

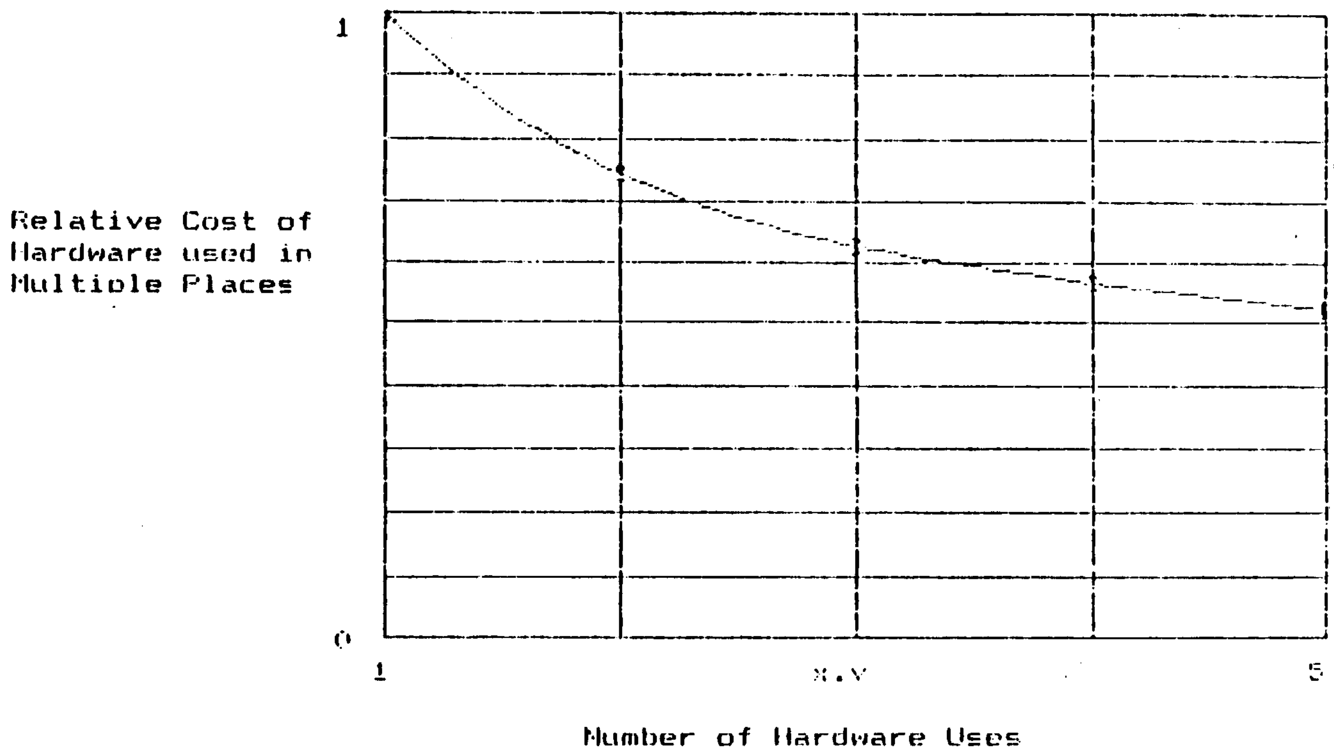
The costs shown in Tables 3-7 and 3-8 are based upon the assumption that COTS modifications are approximately the same cost as are redesigns to existing systems. The degree of modification (or redesign) is reflected in the design factor, df. The degree of system complexity is reflected by the system 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 SB1.

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.

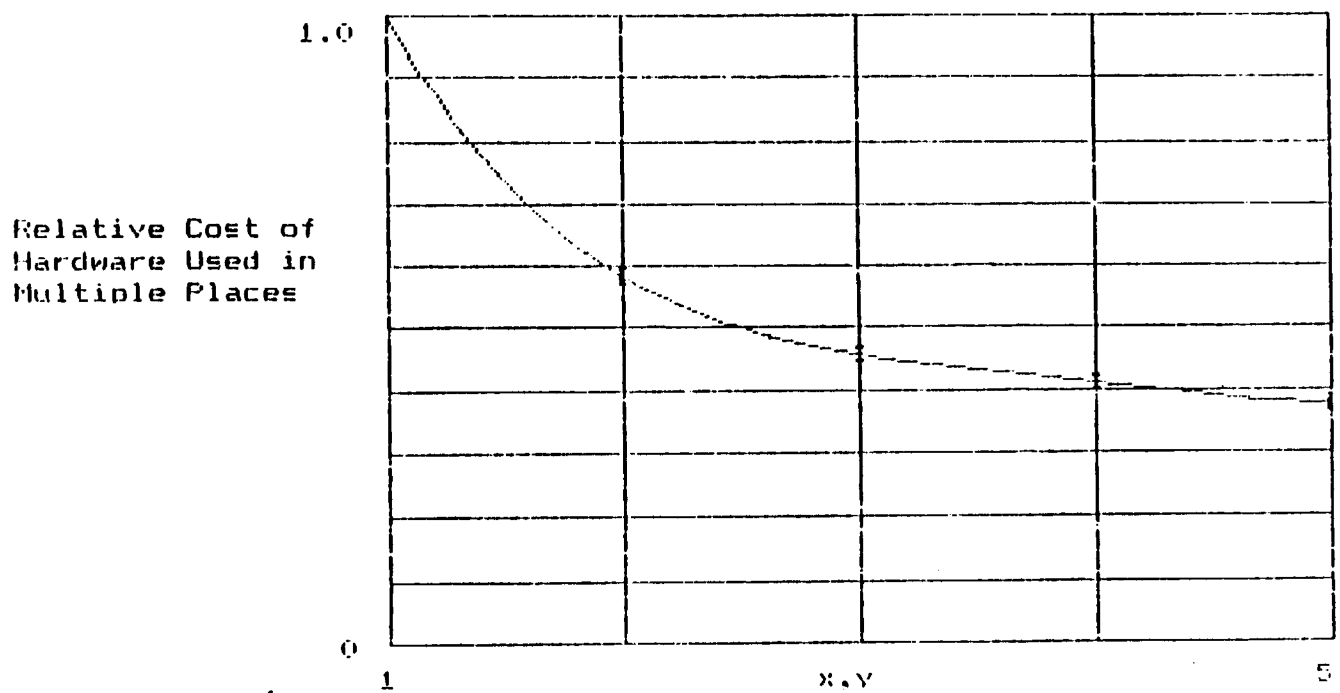
Figure 3-2
Effect on Cost of Multiple
Applications of Hardware



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

Learning Factor = 80%

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



Number of Hardware Uses

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

Learning Factor = 00%

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

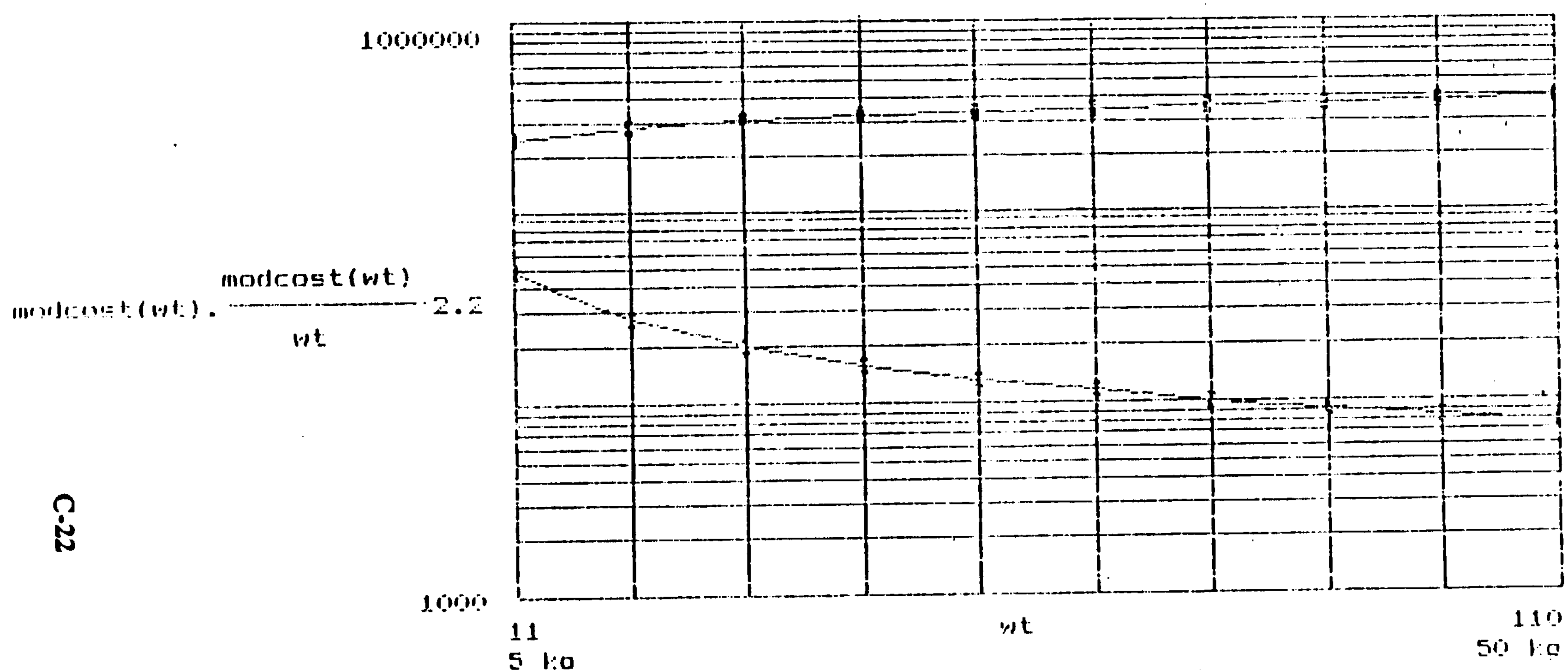
Table 3-8 Cost of Modifying Commercial Off-the Shelf Hardware

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

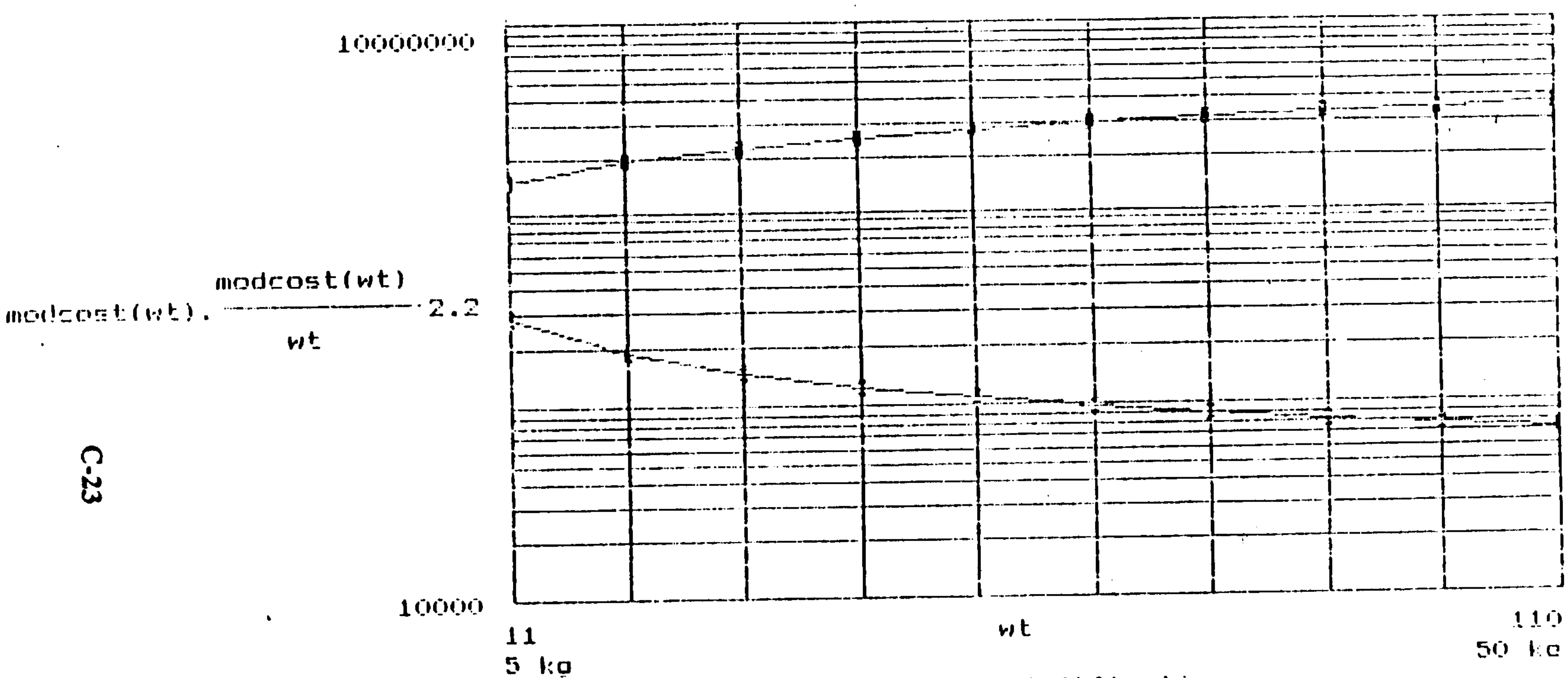
Notes: 1) All costs are in thousands of dollars

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.

Bibliography

A. MSFC Space Station CER's Report PRC D-2185-H, Contract NAS8-33789, December, 1982.

B. CERV Target Costs for Benchmark and Reference Configurations - JSC CERV Office Presentation, June 15, 1988.

C. PRICE Users Newsletter, Volume 12, Number 3, October, 1988.

D. Cost Estimating for Air to Air Missiles, Congressional Budget Office, January, 1983.

E. PRICE H™ Reference Manual, General Electric Company, 1988.

F. SBI Team Contact Report - Joe Hamacke, April 27, 1989.

G. SBI Contact Report - Richard Whitlock, April 11, 1989.

H. Report No. MSC-01248, ASSCAS Cost Handbook, Contract NAS 9-9018, January, 1970.

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

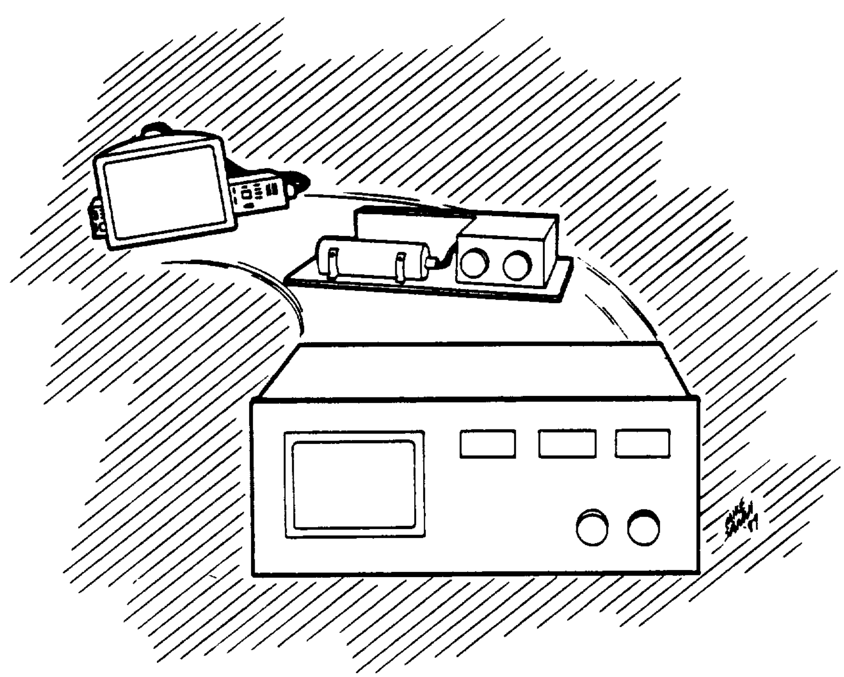
INITIATIVE

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

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SPACE BIOLOGY INITIATIVE
PROGRAM DEFINITION REVIEW

TRADE STUDY 2

PROTOTYPE UTILIZATION IN THE DEVELOPMENT OF SPACE BIOLOGY HARDWARE

FINAL REPORT

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GE GOVERNMENT SERVICES
Houston, Texas
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June 1, 1989

FOREWARD

This study, entitled "Prototype Utilization in the Development of Space Biology Hardware", was performed under a subcontract to Horizon Aerospace. It is one of six studies performed as a part of the NASA Space Biology Initiative (SBI) Definition Review Trade Studies Contract.

The study was performed under the direction of Mr. Neal Jackson and Mr. John Crenshaw of Horizon Aerospace and was conducted by Mr. H. J. Wood, Jr. and Mr. Arthur E. Schulze of the Biomedical Technologies Division of Lovelace Scientific Resources, Inc., Houston, Texas.

Management and engineering review were provided by the staff at Lovelace in Albuquerque, New Mexico.

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ACRONYMS AND ABBREVIATIONS

AI	Artificial Intelligence
BIT	Built In Test
BITE	Built In Test Equipment
BMMD	Body Mass Measurement Device
BPMS	Blood Pressure Measuring System
BPMU	Blood Pressure Measuring Unit
CFE	Contractor Furnished Equipment
CDR	Critical Design Review
CDTR	Cassette Data Tape Recorder
CHeCS	Crew Health Care System
COTS	Commercial Off-The-Shelf
DFI	Development Flight Instrumentation
DMS	Data Management System
DPA	Destructive Physical Analysis
DVTU	Design Verification Test Unit
ECF	Exercise Countermeasure Facility
ECG	Electrocardiograph
EDCO	Extended Duration Crew Operations
EEE	Electrical, Electronic and Electromechanical
EM	Engineering Model
EMG	Electromyograph
EMI	Electromagnetic Interference
ESA	European Space Agency
FMEA	Failure Modes & Effects Analyses
FRR	Flight Readiness Review
GAMS	Gas Analyzer Mass Spectrometer
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
HMF	Health Maintenance Facility
ISO	International Standard Organization
JSC	Johnson Space Center
KSC	Kennedy Space Center
LBNPD	Lower Body Negative Pressure Device
LSE	Laboratory Support Equipment
LSLE	Life Sciences Laboratory Equipment
LSRF	Life Science Research Facility
MIL-STD	Military Standard
MCOTS	Modified Commercial Off the Shelf
NASA	National Aeronautics and Space Administration
NSTS	National Space Transportation System

OSSA	Office of Space Science and Applications
OTS	Off-The-Shelf
PDR	Preliminary Design Review
PFM	Protoflight Model
PI	Principal Investigator
PMS	Physiological Monitoring System
Qual.	Qualification
R&QA	Reliability and Quality Assurance
RF	Radio Frequency
RMS	Remote Manipulator System
SBI	Space Biology Initiative
SEU	Single Event Upset
Spec.	Specification
SRM&QA	Safety, Reliability, Maintenance & Quality Assurance
SSAEPL	Space Station Approved EEE Parts List
SSF	Space Station Freedom
SSP	Space Station Program
STS	Space Transportation System
TBD	To Be Determined
TU	Training Unit
VOCC	Venous Occlusion Cuff and Controller

Glossary and Definitions

From JSC 31000, Vol. 1, Rev. D, Appendix B

ACCEPTANCE TEST: Formal testing conducted to determine whether or not an item satisfies its acceptance criteria and to enable the user to determine to accept or reject same. Required on an end item where quantitative data is a prerequisite to demonstrate compliance of the item with design/procurement specifications.

ACCEPTANCE TESTING: 1) Formal tests conducted to assure equipment meets contracted or design requirements. Includes performance demonstrations and environmental exposures to screen out manufacturing defects, workmanship errors, incipient failures, and other performance anomalies not readily detectable by normal inspection techniques or ambient functional tests. 2) Tests to determine that a part, component, subsystem, or system is capable of meeting performance requirements prescribed in the purchase specification or in other documents specifying adequate performance capability for the item in question. Anomalies not readily detectable by normal inspection techinques or through ambient functional tests.

ADVANCED DEVELOPMENT PROGRAM: A program which focuses emerging generic technologies toward a space station application, builds and integrates prototype components into subsystems for demonstration in ground-based test bed facilities, and conducts flight experiments using the Shuttle as necessary.

ALGORITHM: Mathematical steps used in the process of solving a problem. The objectives of the algorithm is to produce a desired result (output) from specified input.

ARTIFICIAL INTELLIGENCE: 1) A subfield of computer science dealing with concepts and methods of symbolic inference by a computer and the symbolic representation of knowledge used in making inferences to make a machine behave in ways humans recognize as "intelligent" behavior. 2) A discipline devoted to developing and applying computational approaches to intelligent behavior. Also referred to as machine intelligence or heuristic programming.

ASSEMBLY: A number of parts, or subassemblies and/or any combination thereof, joined together to perform a specific function and capable of disassembly. The distinction between an assembly and a subassembly is determined by the individual application. An assembly in one instance may be a subassembly in another, where if forms a portion of an assembly.

COMMERCIAL PART OR ITEM: A part or item which is manufactured primarily for the commercial rather than the government market and having both commercial and government applications. Commercial parts also include parts which are manufactured in accordance with normal commercial quality controlled production runs which meet or exceed the requirements of government specifications or standards.

COMMON ELEMENTS: Equipment items or subsystems that are interchangeable.

COMMON EQUIPMENT: Any equipment that can be utilized at more than one operational site.

COMPONENT: 1) A major functional entity within a susbystem which can contain both hardware and software subcomponents which can be either collocated or physically distributed within the Space Station Program element. 2) A particular hardware item within a system (e.g., a pump, valve within pump, electrical power distribution box). 3) A combination of parts, devices and structures, usually self-contained, which performs a distinctive function in the operation of the overall equipment or system (e.g., transmitter, cryogenic pump, encoder).

CONTRACTOR: The supplier of the end item and associated support items to the Government under the terms of a specific contract.

CONTRACTOR-FURNISHED EQUIPMENT (CFE): CFE is equipment provided to NASA by a prime contractor whose activities are monitored directly by a NASA program or project office.

DELIVERABLE: An item of hardware, software, or documentation which the contractor is required to deliver to the government.

DESTRUCTIVE PHYSICAL ANALYSIS: Analysis of EEE parts to assure that the internal construction, quality, and condition of samples do not vary from lot to lot.

DEVELOPMENT TESTS: Tests performed with minimum rigor and controls to substantiate a design approach. Includes tests performed to minimize technical risks and to assist design engineering activities. They encompass material selection, design tolerance verification, and identification of operational characteristics.

ENVIRONMENTAL TEST: Any test performed under environmental conditions other than ambient for the primary purpose of verifying the quality of the GSE.

EXPERIMENT: The system of hardware, software, and procedures for performance of a scientific or applications investigation undertaken to:

--Discover unknown phenomena
--Establish the basis of known laws
--Evaluate applications processes and/or equipment

FAILURE MODES AND EFFECTS ANALYSIS (FMEA): Identification and evaluation of what items are expected to fail and the resulting consequences of failure.

FAULT TOLERANCE: 1) The ability to continue to operate in the presence of anomalies or failures. 2) The number of failures which can be allowed without disruption of nominal functional performance.

GOVERNMENT-FURNISHED EQUIPMENT: Equipment in the possession of or acquired by the Government, and delivered or made available to a non-government organization.

LIFE CYCLE COSTS: A process and technique for predicting and considering the entire cost of a program or project from inception to ultimate disposition.

LIMITED LIFE: An equipment item or system is designated as having a limited useful life in relation to its application. Limited life includes operating time or cycles and age life.

LIMITED-SHELF-LIFE ITEM: Any item which deteriorates with the passage of time and thus requires periodic replacement, refurbishment, retesting, or operation to assure that its operating characteristics have not degraded beyond acceptable limits. This includes installed as well as stored components.

LONG LEADTIME ITEMS: Those items which because of their complexity of design, complicated manufacturing processes, or limited production, may cause production or procurement cycles which would preclude timely or adequate delivery, if not ordered in advance of normal provisioning.

OFF-THE-SHELF DESIGN: An existing design for equipment with known characteristics and proven history that has not been manufactured for which product enhancement changes could be incorporated into its production.

OFF-THE-SHELF EQUIPMENT: Equipment of an existing design that has already been completely manufactured and is already for delivery.

OFF-THE-SHELF HARDWARE: Production or existing design hardware (black box, component) used in or for NASA, military, and/or commercial programs.

OPERATING LIFE: The maximum operating time or cycles which an item can accrue replacement or refurbishment without risk of degradation of performance beyond acceptable limits.

PART: One or more pieces joined together which are not normally subject to disassembly; it maybe deviated, EEE, or substituted.

Deviated Parts--Parts deviating to some degree from their controlling specifications.

EEE Parts--Devices such as transistors, diodes, microcircuits, resistors, capacitors, relays, connectors, switches, transformers and inductors which are in compliance with the NASA Standard Parts List MIL-STD-975.

Nonstandard EEE Parts-- A EEE part not listed in MIL-STD-975, NASA Standard EEE Parts List or SSAEPL.

Grade 1.--The classification used for higher quality standard parts intended for applications that the responsible NASA project office has determined to be critical.

Grade 2--The classification used for inclusion within the applicable standard and are intended for applications not requiring Grade 1 parts.

Substitute Parts-- Parts differing from those specified in the approved equipment design.

PROTOFLIGHT: A verification activity using flight hardware and software for ground qualification in lieu of a dedicated test article. The approach includes the use of reduced test levels and/or durations and post-test hardware refurbishment where required.

PROTOFLIGHTING: The programmatic process of manufacturing a singular item, using it for verification and limited (nondestructive) testing, refurbishing it as required, and then using it as a flight article.

PROTOTYPE: A hardware item having essential features of a production unit, but differing in certain respects, such as packaging and weight. It is used to support test activities, and to demonstrate manufacturing techniques, but is not used for flight.

QUALIFICATION TESTS: Tests conducted as part of the certification program to demonstrate that design and performance requirements are realized under specified conditions.

REDUNDANCY: The existence of more than one means for performing a given function.

RELIABILITY: The probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified operating conditions.

REPAIR PARTS: Individual parts or assemblies required for the maintenance or repair of equipment, systems, or spares. Such repair parts may also be repairable or nonrepairable assemblies, or one-piece items. Consumable supplies used in maintenance or repair such as wiping rags, etc., are not considered repair parts.

RISK: 1) The probability of suffering harm or loss. 2) The chance (qualitative) of loss of personnel, loss of system or damage to, or loss of equipment or property.

SOFTWARE VALIDATION: Tests and/or analyses to determine that software design meets requirements:

A. Validation by Testing-- The process of conducting tests to prove the software design meets established design requirements.

B. Validation by Analysis--1) Analysis performed to show a software article previously validated is reused or recovered (modified) to perform a similar function. 2) Analysis performed to satisfy validation objectives when testing under simulated mission conditions is not feasible or cost-effective or the need exists to extrapolate test data beyond the performed points.

SPARE PARTS: Components, assemblies, and equipment that are completely interchangeable with like items installed or in use which are or can be used to replace like items removed during maintenance and overhaul.

SPARE(S): An item or items whose fit, form and functions are completely interchangeable with another or like item or items. Types of spares for the SSFP are identified as: (1) development spare parts, (2) initial spare parts, and (3) replenishment spare parts.

SPARING: The act of quantifying and identifying spares and associated parts required to support an item or total system (e.g., control moment gyros--two spares).

SPECIFICATION: Document or combination of documents controlling the design parameter (i.e., materials used, physical and electrical characteristics.

SUBASSEMBLY: Two or more parts which form a portion of an assembly or a component replaceable as a whole, but having a part or parts which are individually replaceable (e.g., telephone dial, mounting board with mounted parts, etc.).

SUBSYSTEM: A specific set of hardware and/or software functional entities and their associated interconnections, which perform a single category of functions (e.g., data storage and retrieval subsystem, video subsystem). The functional level immediately below the "system" level.

VERIFICATION: A process which determines that Space Station hardware and software systems meet all design, performance, and safety requirements. The verification process includes analysis, test, inspection, demonstration, or a combination thereof.

The two levels of verification activities include:

A. Hardware/Software Verification Activities--A process to ensure specific hardware/software is built in accordance with the design, meets established performance requirements and is free of manufacturing and workmanship defects.

B. Design Verification Activities--A process to ensure design of the Space Station, subsystems, or components as designed and meets requirements defined in contractual specifications. They include both formal certification and system-level verification activities (including hardware/software and interface compatibility). Where verification is not accomplished by testing, analysis is to be performed.

EXECUTIVE SUMMARY

TECHNICAL FACTORS: Examination of the past and present prototype hardware development activities has disclosed that there are a number of valuable lessons to be learned from NASA's experience as well as from that of a number of other industry and government groups. In addition to the outlined approaches to the construction and use of protytypes and the identification of the driving factors, major findings are related to the impact of component and system obsolescence, shortened time of support by part manufacturers, the reduced number of part manufacturers, and the resulting non-availability of replacement parts. These findings all impact the planning for SBI Hardware prototypes.

It is shown that adaptation of modified commercial off-the-shelf hardware has distinct advantages over new starts in the areas of reduced cost and greater design maturity. Experience shows that the adaptation must be done methodically and with great skill by persons having extensive previous experience.

Many technical details for successfully implementing prototype development programs are presented. They cover full hardware development from a new start as well as development based on modification of commercial off-the-shelf hardware.

The possible applications of each type of prototype article are examined and the major program value of each identified. The limits to apparent cost advantages and the increased risk of the "protoflight" hardware approach are discussed as well as the continued need for an engineering unit within the program.

PROCEDURES: The various methods of developing prototype hardware have been combined and simplified into an integrated sequence of steps which define a recommended approach for each set of circumstances. Using the flow chart procedure presented, one determines a reference set of required hardware units. Then, by considering the parameters identified in a family of "drivers", the starting quantities are driven down or up to match them with the particular programmatic application.

RECOMMENDATIONS: A number of items are identified and discussed which, if uncorrected, will drive up costs and reduce the number of potential prototype hardware suppliers supporting NASA.

Ten major areas of concern are highlighted in the Recommendations (Section 3.0) of this report.

CONCLUSIONS: The major conclusions of this trade study are summarized in Section 4.0.

1.0 INTRODUCTION

1.1 BACKGROUND

The factors that should be used by designers and planners of space hardware to determine the number and types of prototypes required to successfully conduct a biomedical research program are overwhelmingly numerous. Organized decision-making requires subdivision of the problem such that it can be attacked in reasonable, digestible pieces.

The prototyping activities to be considered in this study range from no prototypes where a single unit serves as a flight unit, often called a "protoflight", to multiple prototypes for each function; i.e., concept unit, reliability unit, DVTU unit, training unit, back-up unit, etc. Prototyping fits into a phase of system engineering which can nominally be called "evaluation." (Machol, 1965)

The evaluation phase should determine whether the performance of a system is adequate to fulfill the operational mission assigned to the system. In a well-managed development program, the evaluation is conducted throughout the design phase and is "largely completed before the prototype is constructed." "It therefore follows that evaluation should be largely completed before the really expensive phases of prototype construction and test are undertaken." (Machol, 1965)

The following definitions apply to the various terms as used in this study:

ENGINEERING PROTOTYPE: "A hardware item having essential features of a production unit, but differing in certain respects such as packaging and weight." Prototypes are "used to support test activities and to demonstrate manufacturing techniques, but are not used for flight."

PROTOFLIGHTING: "The programmatic process of manufacturing a single item, using it for verification and limited (nondestructive) testing, refurbishing as required, and then using it as a flight article." (For purposes of this study, a protoflight unit is considered a flight unit and not a prototype).

RELIABILITY: "Distribution of failures in the time domain"

QUALITY CONTROL: "Distribution of defects in a population"

OPERATION: "Activity resulting from the use of systems."

Some of the terms commonly used to refer to prototypes of aerospace subsystems are as follows:

1. Breadboard
2. Proof of Concept Model
3. Brassboard
4. Pre-Production Model
5. Mock-Up (Not necessarily a "prototype")
6. Design Verification and Test Unit (DVTU)
7. Training Unit
8. Qualification Test Unit
9. Engineering Model
10. Thermal Test Article

These items are often semantically intertwined and mock-up units are not necessarily operational prototypes--the need for mock-ups is usually independent of the need for prototypes. Mock-ups are usually non-functioning units used for a multitude of purposes. Generalized drivers to define the number and types of mock-ups are uniquely programmatic and are not a part of this study.

Analyses of the naming of prototypes have shown that the fundamental categories might be listed in the order of increasing fidelity as follows:

1. Breadboard ("Commercial Off The Shelf Unit")
2. Brassboard (Proof of Concept Model)
3. Design Verification and Test Unit (DVTU) (Engineering Model)
4. Training Unit
5. Qualification Unit (Pre-Production Unit)

Even these fundamental prototypes can have double and triple uses; e.g., a DVTU might be used as a Qualification Unit and/or Back-Up Flight Unit. Obviously, computer simulation might even be used for some hardware to eliminate the need for the lower level prototypes. (Hopcroft, 1988)

Definitions and conventional uses for these units are as follows:

BREADBOARD: A breadboard is the first experimental combination of hardware, and in some cases software, developed in a sequence of progressively more complex prototype units. It may consist of a group of standard test equipment, together with various experimental circuits. It is used to demonstrate a concept and to investigate or optimize various functions. Most digitial and some analog circuit development is suitable for computer simulation rather than hardware experimentation.

BRASSBOARD: A brassboard is a hand-crafted prototype unit which usually incorporates all electronic elements of the final article. Its configuration allows assessment of effects such as mutual circuit interactions and distributed capacitance. Realistic computer simulation of this evaluation unit is difficult to achieve. This prototype is particularly useful in the evolution of radio-frequency and high speed digital systems. It is often the first opportunity to confirm anticipated interface compatibility.

DESIGN VERIFICATION TEST UNIT (DVTU) OR ENGINEERING MODEL (EM): This prototype may be called either name. It is essentially identical, both mechanically and electrically, to the flight article except that it is assembled with commercial, rather than high-reliability, parts. All design changes should be incorporated and evaluated on this unit. Compatibility, software performance, and all functional tests should be accomplished with this prototype. It should also be subjected to extensive environmental tests. One of the most valuable aspects of the DVTU or EM is that it normally allows methodical analysis of the device and completion of all design changes prior to the activation of rigorous formal SRM&QA documentation procedures necessary for all subsequent activities.

QUALIFICATION UNIT: A qualification unit is the highest quality prototype. It is absolutely identical to the flight hardware and software in every respect. Ideally, it is reserved for formal testing which verifies that the system or device meets all requirements and specifications. Normally this system is not flown since it has been exposed to higher than flight environmental test levels. The exception is in a protoflight program where only one flight-configured article is built, qualification tested, and flown. Every aspect of the life of this unit is under strict procedural and documentation control.

MOCKUP: Mockup units are not operational prototypes but they demonstrate some particular attribute of the flight article and thereby provide valuable support in design and application testing. Typical evaluation activities include thermal and cooling tests, mass distribution tests, mechanical interface tests, and human factors evaluations.

PROTOFLIGHT MODEL: (PFM) Under the protoflight concept, only one unit is built using flight standard high-reliability parts. This protoflight model combines the normal prototype and flight models in some cost-critical applications. The protoflight model should be preceded by a development/engineering model in order to allow completion of all changes and engineering tests prior to fabrication of the qualification/flight unit.

TRAINING UNIT: A training unit is a prototype article which is normally dedicated to flight crew training. It should be physically and functionally like the flight articles. In some cases, the engineering model is used for this purpose. Nominal control procedures apply to the unit unless it is designated a flight or spare unit, in which case stringent SRM&QA procedures will apply.

The overriding reason for constructing engineering prototypes is to provide "early warning of potential operational problems." (Machol, 1965). Other primary reasons are as follows:

1. Verify that operational performance meets design specific specifications
2. Determine the effects of extreme environments
3. Assess reliability for extended periods of operation
4. Determine the effects of component tolerance and variability on overall system performance

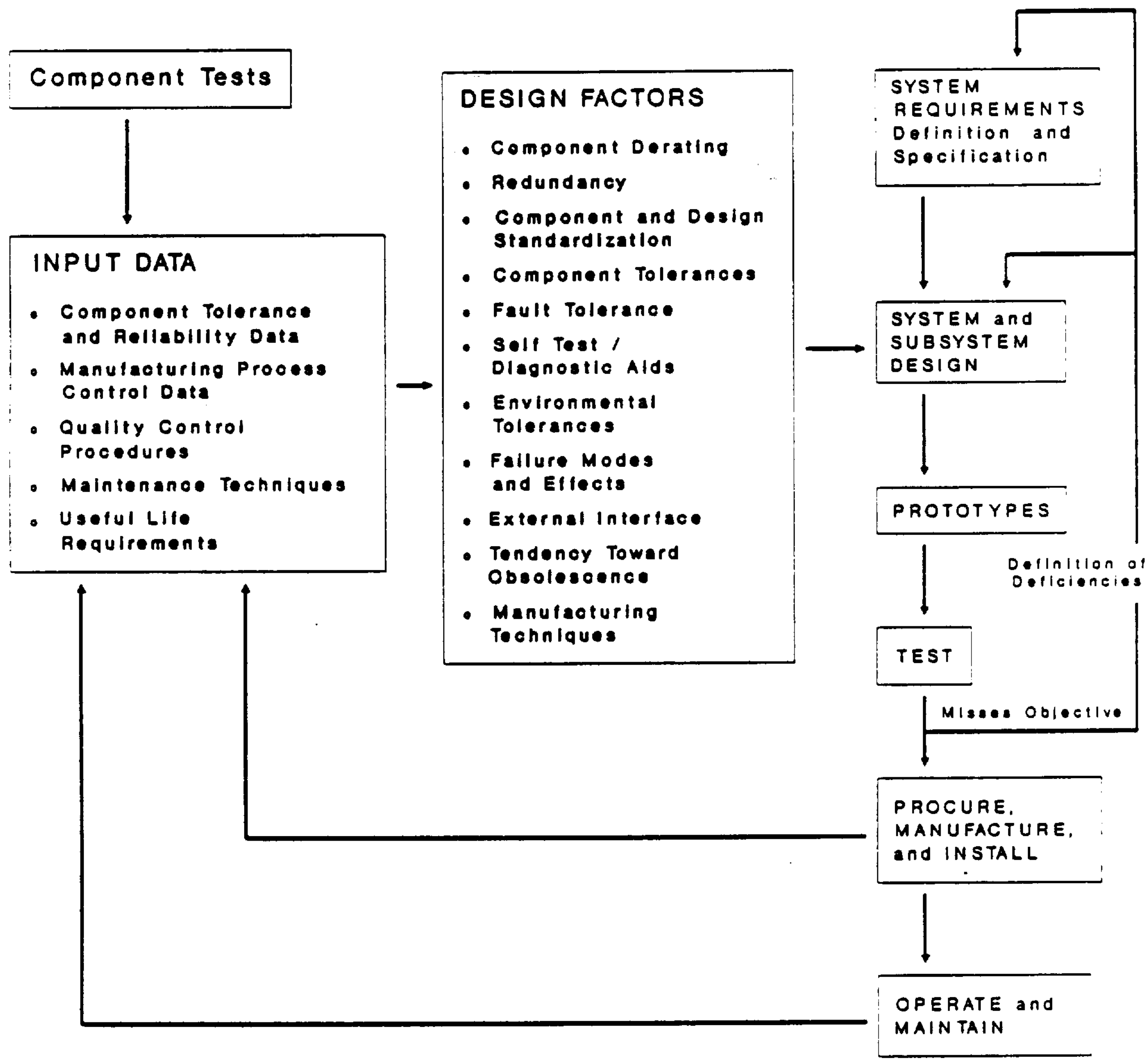
Some of the secondary uses of prototypes are as follows:

1. Train operators and maintenance personnel
2. Demonstrate system performance to users and management
3. Debug system interfaces and software
4. Evaluate the EMI emission and susceptibility

Figure 1.1-1 is a diagram which illustrates the role of prototypes in the system disign process. The importance of a strong prototyping program to the successful completion of an iterative design program is obvious.

Figure 1.1-1

ROLE OF PROTOTYPES IN THE SYSTEM DESIGN PROCESS



[From Machol, 1965]

1.2 PURPOSE

The objective of this study was to define the factors which space flight hardware developers and planners should consider when determining:

1. Number of hardware units required to support program
2. Design level of the units
3. Most efficient means of utilization of the units

The analysis considered technology risk, maintainability, reliability, and safety design requirements for achieving the delivery of highest quality flight hardware. Relative cost impacts of the utilization of prototyping were identified.

1.3 METHODOLOGY

Numerous sources of information on the utilization of prototypes for the development of commercial hardware, space flight, research hardware, and industrial hardware have been surveyed by literature searches, personal interviews, and telephone interviews. The following sources provided a significant input for this study:

1. NASA past experience (Skylab, Spacelab, etc.)
2. Similar Shuttle requirements/experience
3. Experience of other programs (JPL Deep Space, communications satellites, DOE, etc.)
4. Industrial experience (medical implants, downhole instrumentation, etc.)
5. Space Station requirements already defined
6. Software development experience of similar programs

Case studies of past and present NASA hardware development experience have supplied considerable information describing the proper use of prototypes in the research hardware development process. The following NASA Life Sciences hardware programs provided insight into the prototype development process:

Blood Pressure Measuring Unit	(BPMU)	
Blood Pressure Measuring System	(BPMS)	(Skylab)
Physiological Measuring System	(PMS)	

Electromyograph Signal Conditioner	(EMG)
Electrocardiograph Signal Conditioner	(ECG)
Minicentrifuge	
Body Mass Measuring Device	(BMMD)
Gas Analyzer Mass Spectrometer	(GAMS)
Cassette Data Tape Recorder	(CDTR)
Skylab Refrigerator/Freezer	
Orbiter Refrigerator/Freezer	
Baro Experiment Neck Cuff	
LSLE Microcomputer	

Large quantities of telecommunications equipment have been developed by NASA/JSC and supplied as GFE to the manned space flight programs. This equipment is similar in many respects to the SBI hardware and the experience of these engineers and managers in GFE hardware should be of direct applicability to SBI. The following representative samples of this hardware were considered from the prototype development standpoint:

Hardware	Program	Proto. Method
DFI Telemetry	Apollo GFE	Shelf & Dev.
Lunar Comm Ry	Apollo GFE	New Dev.
AF Tape Player	Apollo GFE	Mod. Off-Shelf
TV Systems	Apollo & STS GFE	New Dev.
Signal Process	STS GFE	New Dev.
Teleprinter	STS GFE	Mod. Off-Shelf
Text & Graph	STS GFE	Dev/Shelf Tech.
Cabin Leak Det	STS GFE	Off-Shelf
Sir-C Payload	STS GFE	Off-Shelf Mod/ Internat'l. Dev.

Representative personnel from the following fields were contacted and supplied data and opinions for the study:

1. Manned space flight
2. Deep space flight
3. Geosynchronous communications satellites
4. Military satellites and undersea electronic devices
5. Military missile nuclear war heads
6. Medical electronic implants
7. Commercial communications satellites
8. Commercial undersea telephone electronics

9. Commercial nuclear power instrumentation
10. Oil industry deep hole instrumentation

The current NASA documents related to STS flight hardware and Space Station Freedom hardware were reviewed. Various electronic engineering databases were searched using combinations of key words; e.g., prototyping, modelling, simulation, systems, hardware, etc. The "Computer Database Plus" yielded the following numbers of citations for the listed key words:

Key Words	No. of Citations
Prototyping or Modelling	66
Simulation and Hardware	28
Computer/Simulation/Prototype	4
Systems and Modelling	8
Systems and Simulation	295
Systems/Simulation/Hardware	16

These citations were all too general for direct utility to this study, except as statistical background. Good, vigorous analysis work pertaining to the effectiveness of prototyping in the engineering design process is scarce.

Algorithms and decision flow charts were synthesized which reflect the analysis of all of the data that were collected. These "road maps" simplify and organize the decision making process, but the raw data and opinions as summarized in the appendices of this report are the supporting documentation with additional details which cannot be adequately summarized in a few charts. The study utilized a consensus approach to gather and compile pragmatic data rather than approaches which are more inherently theoretical. The names and dates in parentheses that are contained throughout this report refer to the references of Appendices B and C.

It was found in the course of the study that a strictly numerical rating system would cause the user to lose sight of the overall system aspects. Thus, the use of more subjective inputs can retain the "common sense" reality of the output. For example, the political realities of the program cannot easily be quantified. Initially, it was assumed that the quantity and quality of prototypes required for any piece of hardware might be determined by some formula starting from "none." As the study progressed, it became obvious that the interrelationships were too complex to model in a meaningful, yet simplistic, algorithm. Future studies of this type should consider the use of artificial intelligence (AI) techniques.

Thus, the methodology was revised to specify the ideal quantity and quality of prototypes required and then to identify the factors (or "drivers") which would cause an increase or decrease in the actual, required, prototyping activities. Attempts were made to separate engineering requirements from programmatic requirements; however, clear-cut distinctions could not always be made.

1.4 SCOPE

The development of Space Biology Initiative research hardware will involve intertwined hardware/software activities. Although the purpose of this study involved analyzing hardware, the software development impact must be considered and included in the analysis. Experience has shown that software development can be an expensive portion of a system design program. While software prototyping could imply the development of a significantly different end item, an operational system prototype must be considered to be a combination of software and hardware.

In the course of this study, hundreds of factors were identified that could be considered in determining the quantity and types of prototypes that should be constructed. In developing the decision models, these factors were combined and reduced by approximately ten-to-one in order to develop a manageable structure based on the major determining factors.

The Baseline SBI hardware list of Appendix D was examined and reviewed in detail; however, from the facts available it was impossible to identify the exact types and quantities of prototypes required for each of these items. Although the factors that must be considered could be enumerated for each of these pieces of equipment, the exact status and state of development of the equipment is variable and uncertain at this time.

2.0 FINDINGS

Examination of the SBI hardware development program and extensive discussions with experienced hardware developers both inside and outside NASA have disclosed a number of areas of concern common to all of the developers. The regularity with which the same problems surface in a variety of diverse programs indicates that they will recur during SBI hardware development. Solutions utilized by those interviewed are, in many cases, suitable for inclusion in this program from the beginning in order to preclude or minimize these predictable difficulties. The following sections discuss the identified problems relative to prototyping and their influence on hardware development. They also suggest solutions which are tailored to the SBI equipment development and procurement program. The findings of this study are presented as an assessment by consensus. Validation is also by consensus.

2.1 EQUIPMENT CATEGORIES

Previous programs have shown that SSF hardware systems will come from one of three sources: 1) Existing or modified flight rated hardware; 2) Adaptation of commercial off-the-shelf hardware; and 3) New design and development. Further, equipment will generally fall into one of two categories: 1) Experiment-unique, for scientific investigation; and 2) Operational, primarily for routine clinical tests, emergency usage, and some experiment support.

2.1.1 EXPERIMENT-UNIQUE EQUIPMENT

Equipment for experimental applications is intended to explore a particular phenomenon or group of objectives. Groups of standard operational equipment can be used, but customized special purpose equipment is more desirable in order to simplify configurations, increase probability of success, more efficiently use the crewperson's time, and increase precision.

With few exceptions, equipment in this class will be designed and developed specifically for its narrow field of investigaton. It is highly unlikely that any single piece of commercially available equipment can be adapted to perform the function, though several pieces of commercial hardware might be combined with new elements into a single, unique test system. Development of such a system, together with the other aspects of a research program, would normally be under the supervision of a scientist (Principal Investigator).

2.1.2 OPERATIONAL EQUIPMENT

This equipment is used, singly or in groups, for numerous applications which include vehicle/crew operations, health maintenance, emergencies, performance monitoring, or experiment support. It may be derived from modified flight or commercial off-the-shelf hardware or it may be custom designed. It will not normally be under the cognizance of a principal investigator but rather managed as a single item or group of instruments.

2.2 ADAPTATION OF COMMERCIAL OFF-THE-SHELF HARDWARE

In some cases commercial equipment exists which offers capability near that required for the space hardware. If a number of considerations related to the product and manufacturer are favorable, its adaptation can be a cost-effective and efficient method of obtaining the desired capability.

If executed or managed poorly, however, this approach can result in a very expensive, unreliable array of patches on top of patches. The preferred approach is to repackage as little as possible and to make fundamental mechanical or circuit redesigns only when absolutely necessary. If drastic changes are required, then the wrong unit has been selected for modification or a complete new design from "scratch" should be reconsidered. Since continuation of a modification program beyond a critical point leads so certainly to trouble, some mechanism should be built into the technical monitoring process which will trigger an automatic change to a new-design program. The inertia to continue such a program is tremendous. The management procedures should make it necessary to justify continuation rather than to justify a new start. The following cases, based on good and bad experiences, should be studied for their lessons in planning and implementing such a program.

Examples of very successful modifications are the Mini Oscilloscope (JOO1), which required a different power supply, and the Automatic Blood Pressure System (ABPS), which required repackaging. Both of these devices followed the rules of using highly qualified, modification-experienced, personnel and incorporating a minimum of fundamental system changes. Unsuccessful adaptation efforts are numerous. The adverse experience in NASA and industry has been so costly in dollars or reputation that some of those involved have either moved on to other activities or refuse to discuss the problems unless the project names are not mentioned. (Buckley,1989; Evans,1989; Richards,1989)

2.2.1 MCOTS POTENTIAL CONTRIBUTION TO RELIABILITY

Proper use of commercial, off-the-shelf hardware can contribute significantly to the operational reliability of that SBI hardware which properly fits into a MCOTS program. Hardware that has been manufactured and distributed in quantity over several years has accumulated huge numbers of operational hours of experience. This database allows the manufacturer to reduce marginal designs and to factor component tolerances and selection into the product. This type of experience is usually lacking in hardware uniquely designed for space flight. The operational reliability demonstrated in the automotive and appliance industries, for example, has never really been achieved in equipment designed for limited distribution. This difference in experience occurs in spite of the fact that high-reliability components and rigorous design procedures are followed in some of those limited-distribution industries. Perhaps, each of the units that were manufactured and distributed commercially might be considered a prototype. Thus, the customers/consumers became the testers of numerous prototypes. This huge experience base of information is difficult to capture or duplicate by building a total of only four or five units.

This seemingly enigmatic experience can also be elicited from the various companies that attempted to make commercial products from medical hardware developed for the space program in the decade of the 1970s. In general, these companies found that commercial versions of the high-reliability equipment designed for space flight demonstrated disappointing operational reliability when manufactured and distributed in quantity. The existing "lower state-of-the-art" medical monitoring equipment that had been on the market for several years was significantly more reliable on an operational basis than the new-technology, high-reliability designs which had been proven extensively in theory and had even undergone full qualification testing. It was only when this hardware was produced in quantities over several years that it established an operational reliability that was even of the same order of magnitude as the older commercial-off-the-shelf hardware.

Thus, one has to consider the subjective, informal prototype experience behind commercial-off-the-shelf equipment. A company that responds to its user's complaints and has mechanisms in place to change design, manufacturing ttechniques, procedures, and components based upon the ooperational experience of its customers can produce a superior product that is thoroughly "debugged." In evaluating commercial-off-the-shelf hardware, the huge numbers of "hidden prototypes" must not be forgotten or neglected. (Schulze, 1989)

2.2.2 MCOTS TECHNICAL SKILL REQUIREMENTS

The process of modifying commercial off-the-shelf equipment for use in a manned space program should be undertaken only by skilled engineers and technicians who have successfully performed this analysis and modification numerous times. There is a pronounced learning curve which is very demanding of newcomers to this activity. Well-developed engineering skills are required to determine the suitability of the existing system design, circuit implementation, component selection, interface compatibility, software design, etc. Related engineering experience is required to grasp fully the subtleties of a complex design, especially where the documentation is limited. Use of custom integrated circuits and sophisticated embedded computer functions add greatly to the skills required to identify the implications of modifying and applying a device in some way other than that intended by the original designer.

The use of COTS equipment generally requires careful assessment and evaluation of the following:

- Performance versus requirements
- Safety
- Capability to function in zero-g
- Materials compatibility (flammability, outgassing, shelf-life, etc.)
- Environmental qualification (vibration, shock, temperature, pressure, etc.)
- Weight and volume

In addition, special insight into the logic and procedures involved in FDA approval of medical equipment is needed to avoid invalidation of the extensive experience base inherent in commercially available medical products.

Practical experience and detailed knowledge of technical programmatic requirements is essential to assess the more mechanical attributes and limitations of a candidate for modification. The scope of experience required ranges across diverse technologies which include human factors, power sources, cooling, non-metallic materials, mechanical robustness, and potential impacts of extremes of thermal, shock, and vibration exposures.

Scientific and medical flight hardware will be used directly by the astronauts and should receive thorough human factors consideration. Hazards to the crew and demands on their time must be minimized. It is desirable for human factors experts to participate throughout the project. Personnel with extensive experience in training a variety of crew persons can be of immense benefit to the program. Continuous consideration of typical crew demands can prevent additional changes later in the program.

The variety and subtly of required skills approach those of an "art", implemented with extreme attention to detail. Miscalculation or under estimation can lead to a domino reaction of one change causing another--and then another. (Evans, 1989; Richards, 1989

2.2.3 MODIFICATION CANDIDATE SELECTION

Selection of a suitable candidate for a modification program requires much more than picking a good piece of hardware. Consideration must also be given to a series of other factors. These typically include the match between a product's performance and the required specifications, the factory's ability and interest in providing support, the extent of required modifications, the potential for repair/maintainability, and the total cost for modification, application, and lifetime support.

A selection process used successfully in the recent past by NASA for obtaining COTS medical and science related hardware incorporates the following steps:

1. Determine the useful performance features offered by each reasonable candidate unit available in the market.
2. Combine the most useful of these features into a composite-standard list of desired features.
3. Compare the capability of each candidate unit the optimum capability represented by the composite-standard list.

It is often useful to make a matrix which facilitates ranking the units numerically on each of the characteristics listed. This ranking, together with the evaluator's seasoned judgment, should provide a clear "best choice".

The single unit providing performance closest to the composite-standard becomes the prime candidate for selection. At this point, it is usually desirable to purchase the prime candidate and two or three close runners-up for further, detailed, examination.

Evaluation of each candidate should consider many factors, such as:

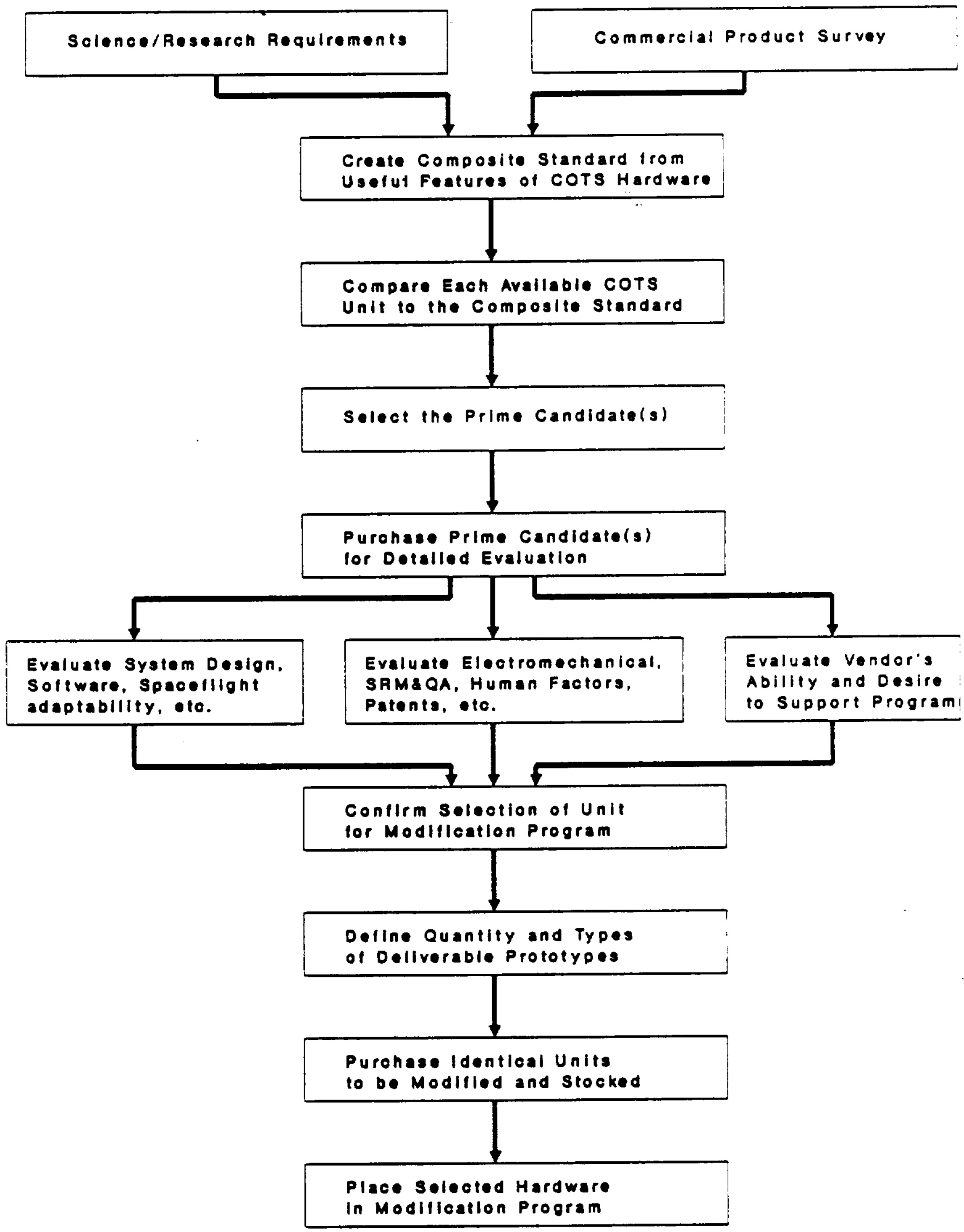
- Workmanship
- Robustness
- Internal element accessibility for repair/modification
- Human factors: location and feel of controls, displays, etc.
- Breakable glass or sharp edges
- Fundamental system engineering approach used
- Suitability of the circuit implementation
- Limits to fault propagation
- Test connectors or self diagnostic routines
- Quality, quantity, depth, and completeness of documentation for installation, operation and maintenance
- Software provided and availability of source codes and support
- Cooling technique and coldplate adaptability, if needed
- Power sources used and circuit overload protection
- Electrical, fluid, and gas interfaces
- Connector configuration
- Quantity and use or non-metallic materials
- Potential ignition sources, catalytic materials, etc.
- Hazardous materials - mercury, ethylene dioxide, etc.
- Nonstandard, unreliable, hazardous, or obsolete parts
- EMI emission or susceptibility
- Measured performance against advertised specifications
- Mechanical configuration: size, weight, shape, mounting, etc.
- Dependence on 1G for proper operation
- Electromechanical and data/computer interfaces

In addition to the detailed evaluation outlined above, discussions with the manufacturer and a visit to his factory should reveal his willingness and ability to support the product throughout the phases of modification and application. Chances of success increase with his degree of professionalism which is often reflected in the quality of his documentation. A lack of genuine interest and ability on his part should automatically disqualify the unit from further consideration. (Evans, 1989)

It is necessary to determine whether the essential documentation describing electrical, mechanical and software code designs is proprietary. The status of patent activity may make essential information unavailable or create disclosure limitations with which NASA cannot comply.

The proposed steps in a procedure for selecting and purchasing COTS hardware for modification are shown in the diagram of Figure 2.2-1.

Figure 2.2-1
Procedure for Selecting and Purchasing Commercial Off-The-Shelf Hardware for Modification



2.2.4 QUANTITY OF UNITS TO PURCHASE

The number of units required will normally include those for redesign, engineering test, interface compatibility test support, qualification testing, training, flight, and spares. Additional units should be purchased, and stored at this time, for cannibalization to provide unique parts and parts which will become obsolete and unavailable during the program life.

It is imperative that all units to be modified in a MCOTS program be identical before modification, both physically and electrically. Several actions may be taken in order to ensure that all units are the same. The units purchased should be from the middle of a single, stable, production run. They should have sequential serial numbers, unless one has been rejected for technical reasons. The total number of units ever to be purchased should be obtained at this time.

All documentation describing theory of circuit and mechanism operation, operation and repair procedures, software codes, and operational programming procedures should be obtained at the time of the purchase and should accurately describe any revisions or modifications incorporated in the product received. (Evans, 1989)

2.2.5 WHO SHOULD DO THE MODIFICATIONS?

It is very important for the modification team to possess expert ability in many areas. In-depth knowledge of the system, circuit, and software operation is essential. The original designer has an obvious advantage over any others in making design changes in these areas. It is, therefore, desirable for the designer to work with the NASA modification team if he or she is still employed by the manufacturer and if the manufacturer is cooperative.

Experience has shown, however, that manufacturers usually are not sufficiently familiar with many of the other requirements to be met for manned space flight. The experienced NASA modification team is in the best position to handle the engineering of other modifications beyond circuit and software changes.

Normally, a manufacturing facility is configured for production rather than for custom modification of hardware. While each situation must be judged separately, it might often be better to make the actual physical modifications in a NASA prototype shop or in a private facility specializing in custom modification and fabrication. Organizations which develop specialized equipment for the military often have the necessary facilities, organization, and space-oriented knowledge.

The Shuttle teleprinter development is an example of a combined effort by a manufacturer and NASA. The apparatus was derived from a production millitary device. Honeywell pulled partially completed units from the production line, and made mechanical modifications in their model shops. NASA/JSC personnel designed and fabricated specialized interface electronics. NASA model shops fabricated a mechanical interface to a standard spacecraft locker. Qualification testing was performed in JSC facilities.

The teleprinter project demonstrates the cost and time-saving potential of modified off-the-shelf hardware. This six-month program (time from authorization to flight) provided the selection, design, modification, testing, qualification, and delivery to KSC. The equipment involved were electronic breadboards, a DVTU, a qualification model, four flight articles, GSE, a ground terminal and interface boxes. The cost was perhaps 25% of a new development from "scratch." The program success can be attributed to the excellent military product history and a highly motivated team with a full-time, dedicated manager who was personally challenged. (Evans, 1989; Richards, 1989)

2.3 NEW DESIGN AND DEVELOPMENT

2.3.1 GENERAL FINDINGS

The alternative to adaptation of existing hardware is the design and development of a completely new device or system. This approach, typical for experiment-unique equipment, allows the configuration and performance to be matched exactly to the task. It affords the opportunity to automate test set-up or configuration, calibration, operating procedures, data acquisition, calculations, and interpretation of results. Comparisons must be made to determine the extent of automation appropriate in each case.

In new designs, use may be made of common, interchangeable, functional modules. If these elements are to be compatible with other hardware systems, then it is imperative that a systems engineering approach be applied to all hardware involved. Special care must be exercised in engineering, procurement, and technical management unless the common elements have been fully flight qualified before they are mandated for multiple usage.

Many tens of millions of dollars worth of GFE flight hardware has successfully been developed for manned space flight programs from Apollo through Shuttle using the following procedure as described by Sinderson (JSC,TCDD). The procedure is similar to that used for Life Sciences and other experimental and operational hardware.

A Representative Procurement, Qualification, and Maintenance Procedure

1. A document was generated which set down a preliminary set of requirements and interfaces.

2. A review was held including representatives of flight crew operations (users); project/program offices (funders); subsystem manager; supporting and interfacing groups such as hardware integration, payloads, and network communication (GSFC); reliability, safety, quality assurance, and integration/compatibility testing laboratories; and the engineering group designing and providing the hardware. Out of this review emerged a set of requirements which provided the best combination of capability, simplicity, cost effectiveness, SRM&QA, and potential for accommodating future needs. The resulting information was formalized in a document which became the basis for the subsequent engineering development, the specifications and the interface control document.

3. A buy-or-develop decision was made based on a thorough review of available hardware/techniques and in-house evaluations of candidate off-the-shelf devices.

4. If a suitable device was in production, the specification was adjusted and a MCOTS (modified commercial off-the-shelf) procurement program was initiated. Some modifications were accomplished within JSC while the manufacturer was willing and equipped to modify other products to accommodate special requirements such as selection or elimination of nonmetallic materials, reduction of weight, addition or elimination of some features, and incorporation of special testing.

5. If development was required, a program of in-house work was begun which included breadboarding critical elements, competitive evaluation of algorithms, system simulation, and extensive testing of candidate techniques in a fully integrated spacecraft and ground configuration. The in-house investigation and findings were completely documented and very detailed specifications and test criteria were prepared.

6. A competitive, often firm-fixed-price, procurement was initiated. Vendors were invited to propose implementations using the best and most cost-effective circuit and hardware techniques utilized in their facilities. The well-documented in-house NASA work eliminated vendors' concerns about potential expensive complications and produced a sufficiently high level of confidence to warrant minimum dollar, fixed-price proposals even where extensive development was involved.

7. The insight gained (and the definitive interface control documentation developed) during the in-house work provided an outstanding degree of integration compatibility of the delivered product.

8. Complete environmental test equipment was available in the JSC engineering laboratories, allowing qualification testing to be done either there or in the vendor's facility.

9. Complex maintenance and repair work was usually done at the vendor's facility. Spare parts and kits of parts for additional builds were maintained both in bonded storage at JSC and at the vendor's facility, since a limited number of units were produced and there was the possibility that critical components would become unavailable.

10. Hardware refurbishment and preparation for flight were accomplished at JSC while vehicle installation was done at KSC.

A highly successful variation of the above procedure involved a two-step approach. In the first phase, a contractor or in-house engineers researched the design prospects and built a proof of concept model which demonstrated the concept and its growth potential to management for programmatic approval. The second phase incorporated a separate hardware development program as described in steps 1-10 above. A highly successful example of such a two-phase program was the LCRU (Lunar Communication Relay Unit) which sent live television directly from the Moon to Earth under the real time command of an operator in the JSC Mission Control Center.

The following sections provide additional information related to the procedural steps above. The information is derived from a consensus of the individuals providing the experience data base.

2.3.2 REQUIREMENT DEVELOPMENT

There apparently exists some disagreement over the semantics of a requirement versus a specification. A reasonable understanding can be obtained by considering a "spectrum" of specificity. One end can be defined as a requirement and the other end as a specification. Although they deal with the same essential elements, they vary in degree of specificity. For the purposes of flight hardware development, it is appropriate to define a requirement as a broad statement of the need, one which describes the capability or the functions to be provided and the circumstances under which they will operate.

Conversely, a specification describes precisely the capability, the method of providing it, the exact details of the environment and resources, as well as the test methods and acceptable limits by which the performance will be confirmed.

A special challenge exists in the clarification of requirements in science and medical-related hardware development. There is a perception that many scientists and engineers view requirements, specifications, and developments so differently that there exists a fundamental communications problem. Deliberate action must be taken to bring the scientists (who have the need) and the engineers (who will fulfill it) together in a cooperative relationship which will foster creativity, productivity, and quality. Though the personnel may report to different organizations, it should be possible to create a spirit which bonds them as a team, stimulating communication while defining responsibilities and expectations. The result can be a synergism of creativity and energy which allows sharing successes as well as failures. The team, probably best moderated by a senior engineering manager, should scrub the requirements until clear statements exist which properly describe the need without "gold plating." (Evans, 1989; Sinderson, 1989)

2.3.3 TECHNIQUE AND APPROACH RESEARCH

With a clear statement of the requirements in hand, the team can methodically explore for the best theoretical and practical methods for solution of the basic problem. This may well include laboratory evaluation of various techniques, algorithms, etc.

A survey of the market place can reveal which of the theoretical methods are being used commercially. Examination of the equipment in use in the field will reveal the ease of application, reliability, accuracy as well as subtle problems in the man/machine interface.

A 'Phase A" study by specialized experts in the field has been productive in many instances. The refinement of in-house expertise which occurs in this process is invaluable in implementing the actual hardware development.

A well-defined approach, which utilizes the in-house information, perhaps augmented by experience with laboratory hardware, can be formulated. Good documentation from this work serves to inform management of technical details, to help secure funding, and to dispel apprehensions of potential bidders concerning the difficulties and unknowns in building the article. Experience has shown that the technique can sufficiently satisfy bidders to result in firm-fixed-price contracts, an excellent control of costs.

2.3.4 SPECIFICATION DEVELOPMENT

The ground work described above results in the insight and detailed information needed to generate a thorough, detailed, specification. Few things have more value in cost effectively obtaining excellent prototype hardware than a good specification. A major cost-cutting aspect of a well-developed specification is its ability to avoid technical changes and disputes over test methods and tolerances.

2.3.5 TECHNICAL MONITORING

The technical monitor should be a prime member of the NASA engineering team. He is the only person other than the procurement officer who can give direction to the contractor. All of his direction must be of a technical nature and must be within the scope of the contract. Changes of scope alter the contract's dollar value and must be negotiated by the contracting officer only.

The development of some medical experiment hardware for Skylab used a manufacturer's expertise to substitute for the Phase A and team activity described above. In these cases, the PI acted as the technical monitor. Breadboards were moved from the contractor's to JSC's laboratories where testing with human subject was done. A high degree of cooperation was achieved and high-quality equipment resulted. The need for JSC in-house work is greater now because there are very few appropriate manufacturers remaining with both medical and space flight hardware experience. NASA must take the technical lead in cultivating an industry support base.

2.3.6 ANALYSIS AND REVIEW

In addition to the pre-procurement analyses discussed above, many other areas of design analyses exist which may potentially add to the assurance that the prototype and flight system will be safe and reliable. The following list identifies many elemental analyses from the conceptual, preliminary, and final design phases. The size, criticality, sophistication, and specific end product of a development program determine which items are appropriate.

1 Conceptual design phase
   a. Preliminary hazards analysis
   b. Preliminary failure modes and effects analysis (FMEA)
   c. Reliability allocations
   d. Conceptual design review
2. Preliminary design phase
   a. Preliminary hazards analysis (update)
   b. Preliminary FMEA (update)
   c. Reliability allocation (update)
   d. Common cause failure analysis
   e. Redundancy techniques/standby
   f. Preliminary fault tree analysis (FTA)
   g. Stress/strength analysis
   h. Configuration optimization technique
   i. System design review (PDR)
3. Final design phase
   a. Hazards analysis
   b. FMEA
   c. Reliability predictions
   d. Breadboard, brassboard, mockup, & engineering modes tests
   e. Critical design review (CDR)

f. Qualification tests
g. Equipment design reviews
    • Changes
    • Data requirements
4. Post-Production phase
    a. Verification
    b. Certification
    c. Flight Readiness Review (FRR)

Obviously, guidance by an experienced technical monitor is essential to keep most manufacturers out of bureaucratic trouble. The need for some programmatic requirement simplification to achieve affordable reliability is addressed later in this report.

2.3.7 TEST AND EVALUATION OF ENGINEERING MODEL

This unit, similar to the flight unit except for its construction with commercial parts, is perhaps the most important of all prototypes. It receives all changes and every type of test, usually to levels exceeding flight and qualification. As a result, there should be no need to make any changes whatever to the qualification or flight units. There is more known about this unit than any other--ever. By subjecting it to higher than the qualification level in every test, it is possible to define the margins of physical and electrical performance for the flight articles. The engineering documentation developed on this unit should be complete. Under normal circumstances, the extremely rigorous SRM&QA documentation begins after this unit. With all problems solved using the engineering model, it should be possible for the qualification and flight units to move on through assembly and test without any negative documentation.

2.3.8 FABRICATION OF TRAINING AND QUALIFICATION UNITS

The training unit is normally the last of the units to be built under prototype conditions and controls. It should be configured and operated very much like the flight articles. The primary difference is that it is normally built with commercial quality parts. In some instances, there is a desire for it to serve as a flight spare. If that is the plan, it must be built identically to flight units and under the same controls and documentation. This arrangement can be undesirable since its primary training use would be very restricted and encumbered by operating limitations, required presence of inspectors, and documentation. The original objective, to reduce costs, could easily be lost in the "red tape."

The qualification unit is usually the first item off the flight article assembly line. This is desirable since it truly represents the flight article. However, if it does not pass qualification tests, the flight articles built along with it must receive the same modifications that it receives.

2.3.9 FLIGHT HARDWARE PRODUCTION

"Production", when used to describe flight hardware is perhaps a misnomer since there are so few units built. It does imply the correct impression that such units are the highest quality and best documented units available. Full SRM&QA (suitable for the criticality class) imposed.

2.3.10 SPARES, REPAIR AND MAINTENANCE PROGRAM

Information gained in the prototype analysis and testing program adds to the original criticality definition to confirm the planning basis for this activity. The specifics of the spare parts inventory are driven by the design and flight application. Detailed drawings, schematics, software source/debug codes, adjustment/allingment procedures and perhaps an "expert system" for trouble-shooting and repair are all forms of documentation which must be obtained at the time of design and fabrication. Shuttle experience has shown that economy here is very short-sighted. If it is possible at all, later reconstruction of this information is extemely expensive. (Sinderson, 1989; Richards, 1989)

2.4 DETERMINATION OF PROTOTYPE/FLIGHT QUANTITIES

2.4.1 CONCEPT OF DETERMINATION METHOD

The many factors which influence the required number of prototypes have been combined and arranged into a logic flow with three fundamental steps. The logic moves from an input of hardware requirement definition, through 1) risk classification, 2) implementation plan outline, and 3) quantity adjustment, to emerge as the quantity definition output, as shown below.

(INPUT)
HARDWARE REQUIREMENT DEFINITION

RISK CLASSIFICATION

IMPLEMENTATION PLAN OUTLINE

QUANTITY ADJUSTMENT BY DRIVERS

QUANTITY DEFINITION
(OUTPUT)

2.4.2 DEFINITION OF REQUIRED TERMS

A clear understanding of the quantity definition method requires that several terms be understood. They are:

PAYLOAD CLASSES:

- Class A payloads are those for which a minimum risk approach is clearly dictated by prohibitively high cost of consequence of failure, or by unacceptable combination of costs and intangible factors associated with failure. A full formal qualification and acceptance program is mandatory.

- Class B payloads are those for which an approach characterized by reasonable compromise between minimum risks and minimum costs is appropriate due to the capability to recover from in-flight failure by some means that is marginally acceptable. The qualification and acceptance program is less stringent than Class A.

- Class C payloads are those for which re-flight is a possibility. This class was originally established for certain STS payloads where manifesting can accommodate a re-flight in the event of an in-flight payload associated failure. Duration of payload operations for Space Station can be orders of magnitude greater than on STS, and the policies concerning routine re-flight on Space Station have not yet been established. On-orbit servicing may enable recovery from failure without the requirement for a separate flight opportunity. The qualification and acceptance program is less formalized than in Class B.

- Class D payloads are those that have objectives worth achieving at a cost not to exceed the amount required for a single, low-cost attempt. The qualification and acceptance program is limited to verifying safety and interface compatibility.

(From OSSA Classification Instruction, 1988)

PROTOTYPE UTILIZATION:

- Conventional Development: A development program using a sequence of progressively more complex prototype units for each step from concept through engineering development and on to qualification testing.

- Protoflight Development: A procedure in which only one flight model (PFM) is built to flight standards with high-reliability parts. Some use this unit for development, qualification testing, and flight, ESA and others include an engineering moder (EM).

EQUIPMENT SOURCES:

- Modified Commercial Off-The-Shelf (MCOTS): Equipment in commercial production which, with modification, can be adapted for flight.

- New Development: A development program starting from a "clean page", using either a conventional development or protoflight program, as appropriate.

2.4.3 OUTLINE OF PLANS

One of two development and prototype utilization plans is used. The plan selected depends on the class of the equipment (A and B or C and D). Each plan is designed around a different "reference" quantity of prototype equipment and a different degree of SR&QA rigor. Each plan is outlined below:

PLAN #1, a minimum cost approach for classes A & B:

- The number of units shown is the reference quantity and will be modified by the drivers. It is based on consensus.
- Analysis, reviews, SR&QA, and testing are rigorous.
- Engineering development is based on MCOTS or a new start.
- Use this reference quantity to support these functions:

Number of Units	Function Supported
1 - Brassboard	•Hardware and software design
1 - Engineering unit	•Design adjustments and tests •System interface compatibility tests •Software performance tests •Testing - through qualification level •All changes and fixes •Mechanical interface tests •EMI tests •Human factors integration •Confirmation of flight harness
1 - Qualification unit	•Qualification tests •Training
1 - Flight unit	•Flight (application may require more)
1 - Spare	•Flight

- Repair and Maintenance Program (Quantity depends upon whether equipment is built from new-start or is MCOTS)
  - If MCOTS . . . . Add 3 more units during purchase for cannibalization and/or for additional build.
  - If New Start . . . . .Buy parts for 2 complete kits plus buy selected critical parts. (a kit is all the parts, except chassis, required to build on unit)

PLAN #2, a minimum cost approach for classes C & D

- The number of units shown is the reference quantity and will by modified by the drivers. It is based on consensus.
- Analysis, reviews, SR&QA, and testing are less rigorous.
- Engineering development is based on MCOTS or a new start.
- Use this reference quantity to support these functions:

Number of Units	Function Supported
0 - Brassboard	•Use computer simulation to substi-ute for soft/hardware testing.
1 - Engineering unit	•Design adjustments and test •System interface compatibilty tests •Software performance tests •Testing - through qualification level •All changes and fixes •Mechanical interface tests •EMI tests •Human factors integration •Training (change from plan #1)
1 - Protoflight unit	•Qualification tests •Flight
0 - Spare	
0 - Training	

- Repair and Maintenance Program (Quantity depends upon whether equipment is built from new-start or is MCOTS)

If MCOTS:	Add 2 more units during purchase for cannibalization and /or for additional build.
If New Start:	Buy parts for one complete kit plus buy selected critical parts. (kit is all the parts, except for chassis, required to build one unit.)

2.4.4 QUANTITY DRIVERS

A large number of additional factors which influence the quantity of prototype units have been combined and grouped into the items on the following list. The reference quantities in each of the two plans should be adjusted down or up in response to the applicability of these factors for each design project.

PROTOTYPE QUANTITY DRIVERS

IMPACT OF FAILURE

This factor allows adjustment for extremes of safety, unusually expensive interfacing apparatus, critical timing of coordinated events, excessive media coverage, etc.

TECHNOLOGY MATURITY

If, for example, the apparatus has been derived from a high-quality commercial model which has been in broad use for a number of years, a brassboard might not be needed and less time might be spent refining the computer codes. On the other hand, a first-time application of a state-of-the-art technique will require the full complement of prototypes.

INTERFACE COMPLEXITY

Additional engineering models might be required for independent, simultaneous tests for a device with numerous complex interfaces.

DEGREE OF PROTOTYPE REUSE

In some cases, it is possible to use prototype hardware for more than a single purpose. For example, it might be possible to utilize the engineering model as a training unit for an application where the program timing, regulations, and simplicity are favorable. (See Figure 2.4-2)

FLIGHT USE AND DURATION

Requirements for multiple simultaneous uses of a device will obbiously require more flight articles as will very long-duration critical applications where sparing is a factor.

APPLICATION LEAD TIME

Additional prototype articles can be required when the development program is very short. Simultaneous engineering development of hardware and software, multiple interface tests, and training at multiple sites can readily increase the prototype and TU requirements.

2.4.5 QUANTITY SELECTION PROCEDURE

Figure 2.4-1 brings together graphically all of the sub-elements which have been explained in the previous sections. A hardware class determination is made from the hardware requirements and the flow chart is entered from the left. Classes A and B are implemented by Plan #1 which delineates a set of prototypes to start with. On the right, the quantity drivers are applied, altering quantities down or up as described.
In similar manner, classes C and D utilize Plan #2. The drivers are applied to the plan's standard quantity to derive the numbers to be built. Since there is only one flight article, it is impossible to reduce that element further.

2.4.6 PROTOTYPE USAGE MATRIX

Figure 2.4-2 identifies various ways in which multiple use can be made of prototype hardware. In some cases special permission must be obtained to use the units as indicated. Special precautions are needed to safeguard the equipment and to document its various exposures.

Figure 2.4-1

Procedure for Selecting Development/Procurement Plan

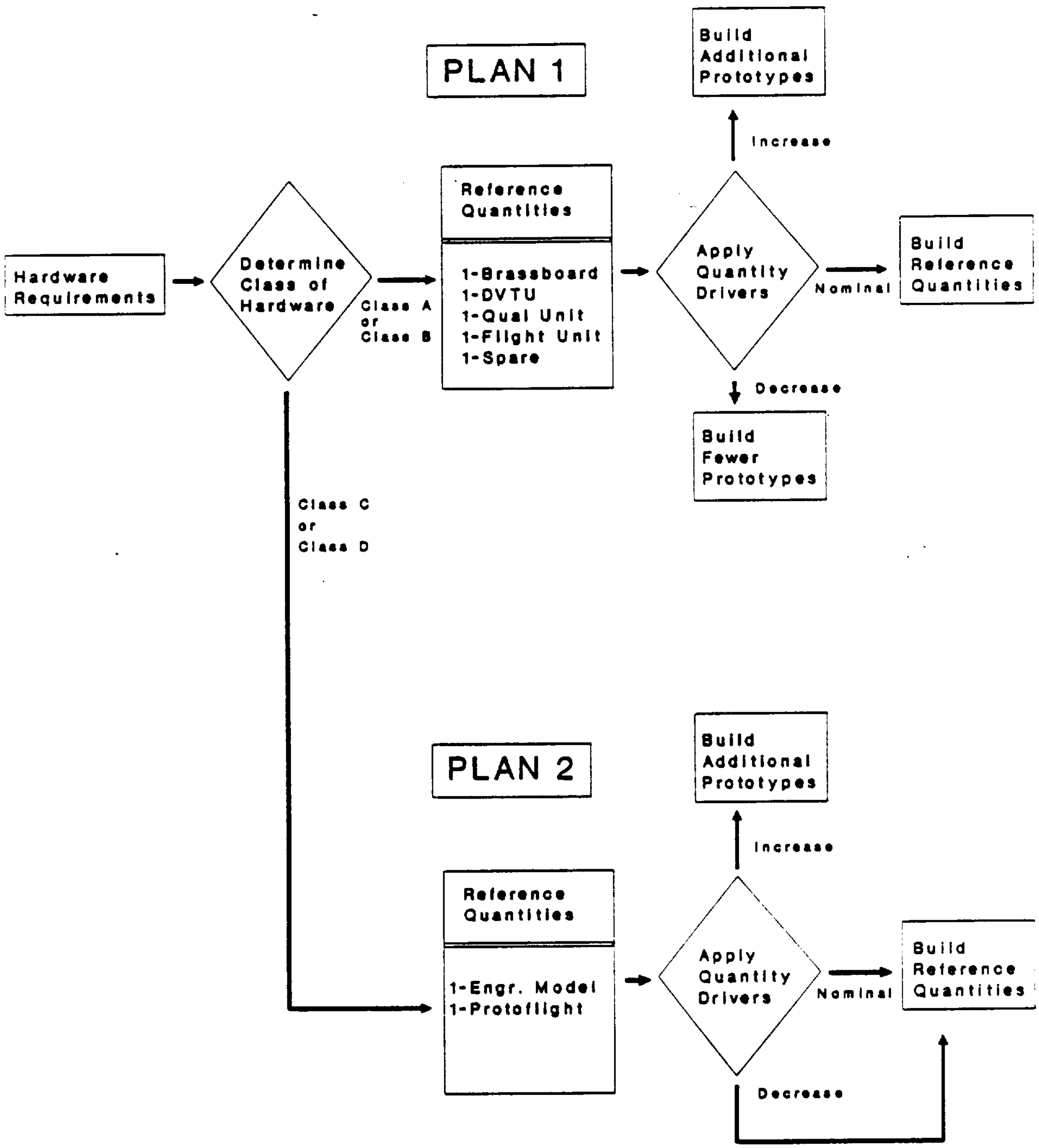


Figure 2.4-2

SUMMARY OF MULTIPLE USAGE OF HARDWARE

HARDWARE UNIT	APPLICATION					
	Devel-opment	Engr. Tests	Qual. Test	Spare	Training	Flight
Breadboard	X	X				
Brassboard	X	X				
Engineering Model	X	X			X	
Qual. Unit			X	(X)	(X)	(X)
Training Unit				(X)	X	
Flight Unit(s)						X
Back-Up Unit(s)				X	(X)	X

( ) Denotes special procedures and controls required.

Decisions regarding multiple uses are usually programmatic decisions which cannot be completely defined by technical factors. The cost savings in prototype deliverables is obvious if multiple uses can be made a part of the program plan.

2.5 RELATIVE COSTS

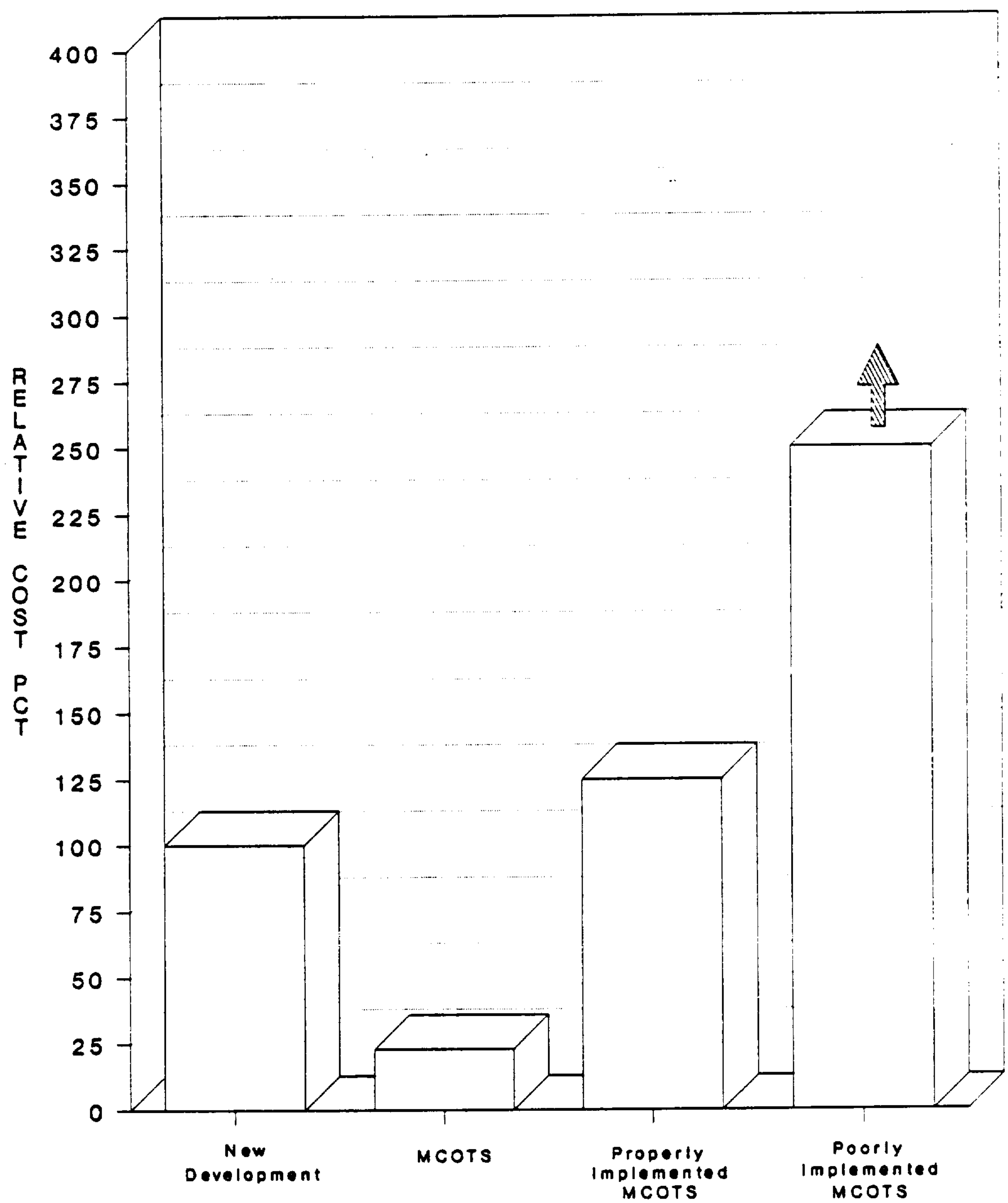
The relative costs (see Figure 2.5-1) of prototyping are dependent upon numerous and diverse factors. The major ractors impacting the incremental cost of the hardware development program are associated with the fidelity of the construction and the requirements for deliverabililty. The cost is influenced by such subtle factors as the accounting system used by the subcontractor; i.e., "Is engineering overhead or manufacturing overhead applied to the construction effort?" The expense to prepare and deliver prototypes on an expedited schedule can add to the cost of the program. If the prototype can be retained at the vendor's plant or if it can be built and delivered with other hardware, some cost savings can result from seemingly minor programmatic changes.

2.5.1 AFFECT OF PROTOTYPES ON PROGRAM COSTS

It is clear that each higher level of prototype is usually progressively more expensive. However, the managers of a number of programs have discovered (after the fact) that reducing the number of prototypes in a program does not necessarily reduce the program cost. In fact, there are numerous instances where the shortage of an engineering model has significantly increased the cost of R&QA documentation and manpower. Lost time in the engineering, environmental testing, and training areas can easily occur when equipment in not available when needed. A shortage of units for testing complex interfaces can easily cause testing delays in concurrent and adjacent projects where interface testing is scheduled.

The actual cost of <u>all</u> prototype hardware is very low when compared to the cost of the development program and the flight hardware. Numerous economies of construction are and can be practiced in the construction of prototypes, such as the use of commercial grade parts rather than expensive, high-reliability items. Breadboards and brassboards are also usually built without special enclosures and expensive connectors. The increased reliability associated with design maturity and the efficient utilization of design and test time

Figure 2.5-1
RELATIVE COSTS of DEVELOPMENT



made possible through assembly of adequate prototypes represent value to the program that can far exceed the cost of increased prototyping activity over the minimal amount required to deliver hardware.

If the technology is well-defined and a detailed end item specification can be written, then it is frequently possible to obtain a firm-fixed-price contract. In such a contract, there is normally no additional cost for some prototypes (such as breadboards), since these prototypes are an essential, inherent part of the design and development process. Thus, the cost of a breadboard does not necessarily represent and incremental cost to the program. This should be noted and accommodated by any cost models that use number of prototypes as an input.

2.5.2 COST OF MCOTS PROGRAM VERSUS NEW DEVELOPMENT

The relative costs of developoing equipment in a well-conducted MCOTS program may be kept to a total of about 15 to 25 percent of the cost of a full new development. It is possible that problems beyond the control of the engineering team will occur at some point during the program. If the MCOTS program is halted in a timely manner and a new development is efficiently initiated, the costs can be kept in the order of 125 percent of what a new development would have cost in the beginning. On the other hand, costs can ren several hundred percent of a new development if an MCOTS development is carried on for a long time beyond the optimum break point. These realtive costs are shown graphically in Figure 2.5-1. (Buckley, 1989; Evans, 1989, Land, 1989)

2.6 PARTS CONSIDERATIONS

Various component part problems in the U.S. have a major impact on the development of a prototyping strategy. They impact commercial, industrial, military, and NASA activities in many similar ways. Because of their complexity, the problems will be subdivided into those affecting high and then moderate reliability applications.

2.6.1 IDENTIFYING THE PROBLEMS

Maximum reliability applications: Criticality 1 and Class A applications demand that everything possible be done to ensure reliable operation. When the SBI equipment is deployed in conjunction with the Space Station Freedom, the problem is compounded by the extremely long operational life requirements. Clearly the best parts obtainable are required for this application. Three major factors impact the availablilty of the desired parts.

First, the electronic component industry in the United States appears to be deteriorating rapidly. Many part manufacturers have ceased manufacturing operations in the U.S. Others have been sold to foreign interests and still others have moved off-shore. There exists no U.S.-made source for many types of parts and for others there is no second source. Many uncertainties and unacceptable delays reduce the utility of foreign sources.

Second, the technology associated with many parts, especially integrated circuits, is changing very rapidly. New, improved products, are brought on-line continuously at a rapid rate. The older products are quickly dropped from inventory, as is the support for obsolete items. Typically, a new computer processor or memory chip now becomes obsolete in two to three years and support is dropped in another two. Some parts experts have observed that by the time an "S" part has been approved for NASA's qualified parts lists it is perhaps half way to obsolescnece and it will have been superseded by flight time. Many Shuttle systems contain parts which are obsolete and totally unavailable. Redesign is usually the only viable recourse. Electronics for the RMS arm, the main computers, the radar, and data recorders are but a few systems being redesigned at this time.

Third, NASA's quantity requirement is generally too small either to interest manufacturers in extending component availability or to warrant the expense of dedicated custom fabrication facilities. The high cost of qualifying a part for "S" rating, for example, tends to cause manufacturers to stretch availability.

Moderate reliability applications: The problems affecting high-reliability parts apply equally to moderate-reliability applications as well. Some consolation in this area can be derived from noting that the quality of military and commercial microcircuits and certain other components has increased markedly. The large production quantities of some of these parts tends to keep them on the market a little longer. The extremely long operational life required for use on SSF introduces many problems with availability of repair components, even for moderate reliability applications.

2.6.2 CANDIDATE SOLUTIONS

Although there are few good solutions to these problems, several candidate solutions are listed below:

Maximum reliability applications: Many experts consider the following actions to be appropriate in an effort to achieve maximum reliability. Some of these are not exactly component solutions but are strategically associated with the desired objective.

- Use components and circuit designs which have a maximum
- of maturity or heritage, but which are not approaching end of useful life
- Use the highest grade of parts available (S)
- Use highly integrated devices in order to minimize the parts count and the amount of circuitry outside the device packages
- Configure all custom designed circuitry to facilitate computer testing
- Use extensive assembly and fabrication controls
- Refine the design by the proper use of prototypes and design reviews
- Utilize adequate engineering models
- Use extreme caution in 100% incoming component test to avoid subtle damage to components due to static charge, humidity in temperature cycle, contamination of leads by chemical contact with skin, etc.
- Store spares in an inert environment
- Avoid devices which are not hermetically sealed
- Consider possible radiation hardening for high density memories in applications subject to SEU ("single event upset" associated with high energy particles in space)
- Always include a mild random shake test with tests imposed on 100% of flight articles
- Analyze performance signature during test
- Stockpile spares
- Monitor spares
- Consider component DPA (Destructive Physical Analysis - discussed below) with batch signature

Destructive Physical Analysis is the name given to a process which provides a complex signature for sectioned samples taken from a component production line. It detects subtle changes in the product generation process before more catastrophic problems develop. Allied-Signal Aerospace Company is one group who performs this test in conjunction with the Naval Weapons Support Center, Crane, Indiana. It is applied to components in various nuclear warheads and a broad variety of electronic devices and weapon systems.

The process allows detection of any change (induced by manufacturing variations) which has occurred in a device and which would cause it to be different in any way from the original qualification devices. "We have found this expecially useful with semiconductor products where the generating processes are complex and interrelated and initial changes in output performance are not readily detectable by other means. Once a semiconductor lot is qualified, destructive physical analysis samples are taken from all succeeding lots, which not only help detect subtle changes in the process, but also show lot-to-lot variations which make more visible the degree of vendor process control." (Wilson, 1989)

It is possible that the use of this or a related process could substitute for some of the testing and inspection involved in producing "S" level parts. The outcome might conceivably be equally reliable, but less expensive components, with much shorter delivery times. Information on the process is being provided to NASA/JSC and SR&QA for consideration.

Moderate reliability applications: The major reliability problems of custom-designed hardware, typical of that used in the space programs, are workmanship and design imperfections. In mass-produced products, where these problems have been gradually refined out, the problem of component part reliability becomes more obvious. Space hardware never has enough total operating time, with enough operational feedback, to reach this state. Therefore, while the reliabililty of components is important, the design and manufacturing techniques must be given an unusual amount of attention. These observations make it clear that commercial and military components are suitable for a great many SSF applications. The items listed below should receive attention when developing SSF flight hardware of moderate reliability:

- Achieve design maturity through use of proven circuits, devices, algorithms, and software together with extensive engineering testing.
- Use an adequate number of engineering prototypes

- Use proven fabrication techniques and controls
- Use burned and tested Mil-spec. parts
- Stockpile kits of components for repairs or additional builds (store in inert environment)
- If item is MCOTS, stockpile parts and unmodified units for cannibalization in an inert environment
- Provide a liberal quantity of flight spares
- Consider a shorter replacement life cycle

In view of the complex part situation, it is anticipated that repair will become a serious limitation to the long service life of each item. It is suggested that consideration be given to a shorter replacement life cycle of perhaps five years or less. Such a period seems more consistent with the present and expected component obsolescence cycle time. This possibility should be given much more detailed study by qualified experts, since its impact on design and parts selection in prototype and flight hardware is very significant. (Goeke, Holt, Hymer, Ramsey, Wilson, all 1989)

2.7 PROGRAMMATIC REQUIREMENTS

The Space Station Freedom is a very complicated project and there must necessarily be a great many rules and regulations which must be strictly followed. These rules, which are referred to here as programmatic requirements, are contained in hundreds of documents containing tens of thousands of pages of details.

The details which apply to the development of prototype and flight hardware are distributed throughout a large percentage of the documents. Many of the rules have not been completed and contain numerous TBDs. It is not yet possible to define absolutely which of the incomplete rules apply to prototyping. There is no known document which summarized which requirements the designers of equipment such as SBI hardware must meet. By comparison, the STS program has succeeded in compiling such summaries, though the one applying to DTO/DSO was signed as late as March, 1989.

A major impact on the SBI of not having summary requirements documents is high cost. Every designer/vendor must adhere strictly to these requirements. In order to do so, each must possess an immense set of ever-changing documents and have an operating understanding of which rules he must follow. At the beginning of a contract, a binding legal document defines his regulatory obligation.

This situation is generally like that in any Government contract, except it is unusually extensive and continually changing. It is necessary that planners and designers recognize the cost impact of the technical and legal staff each contractor must access. Completion of the TBDs and some simplifying and summarizing documentation is necessary before cost effective SBI prototype development can begin.

The designer's problem can be better appreciated by a review of Appendix A which is a partial list of applicable documents. Many are still incomplete and others will be added to the list as they are defined. A file drawer of these documents as they now exist can be intimidating to a small vendor of SBI hardware.

3.0 RECOMMENDATIONS

The following recommendations are based on extensive inputs from industry and NASA's Life Sciences and Engineering personnel. The recommendations might be applied essentially to most of the laboratory equipment which will be flown and operated on the Space Station Freedom. They apply directly to the SBI equipment and in particular to the cost-effective use of prototypes in development of that equipment. Their desired impact is to: 1) keep costs down, 2) provide the necessary degree of reliability, 3) provide the functional capability required, and 4) ensure that the vendors are able and willing to participate in the associated development and production programs.

1. Use a systems engineering approach to integrate and coordinage development programs for SBI devices which are expected to share common hardware element designs. It is essential that the designs incorporate the common requirements. Further, the development of common elements must be complete and qualified/verified prior to imposing their use on other system designs. Failure of a mandated common element design could cause failure of other systems in which it was used.

2. Automate functions requiring higher levels of operator knowledge. Education and skill training can be cost beneficial in many systems. Incorporation of automation in any SBI hardware development program may have an impact on prototype quantities and utilization and should, therefore, be considered in the very earliest stages of planning and development.

3. Establish shorter use/life expectations for SBI hardware. By initiating a replacement development program at the four-to-five year point, costly problems may be avoided. Such problems include hardware/software obsolescence, loss of developer engineering support capability, loss of component manufacturing sources, increased failure rate of hardware approaching the end of its useful life, and the expense of stocking and tracking critical and obsolete parts.

4. Stress risk-reduction, not low initial costs alone, in the development of hardware for long-duration applications on Space Station Freedom.

5. Incorporate ways productively to combine science and engineering personnel in teams for generation of detailed flight hardware requirements and specifications and for management of the development programs. These diverse talents, frequently located in different organizations, must fully cooperate to evolve efficiently the necessary hardware capability.

6. Re-establish long-term, in-house expertise in flight equipment engineering, modification, application, and support. It has been repeatedly shown that strong in-house capability is essential in obtaining good reliable flight equipment at the lowest possible cost.

7. Generate integrated technical requirements documents. Although excellent work has been done in the generation of the technical requirement documents which define SSF hardware development and its application, there are many TBDs remaining which must be clarified before SBI flight hardware contractors can begin their work. Serious consideration needs to be given to methods of simplifying the designers' task of properly applying these directives. Most manufacturers would be forced to incorporate a large staff, over a considerable period of time, to insure adherence to the thousands of applicable details. The cost for such a staff, (which must be added onto the actual hardware expense) would be significant. Small manufacturers, who comprehend the magnitude and seriousness of the problem, simply might not be able to bid on SBI development work for lack of staff experienced in reading and interpreting large stacks of specifications.

8. Examine the actual long-term reliability improvement due to the use of "S" level parts. Many factors in the U.S. component manufacturing industry have changed. Today's very rapid rate of electronic component obsolescence and the short period of availability (with technical support) demand careful attention to the effects on hardware development cycles, repair/maintenance, and logistics. Use of other MIL-specification levels, batch sample signature techniques, and more frequent redesign cycles are some factors which should be examined for potential solutions to long component procurement lead times and high program-life costs.

9. Develop mechanisms for indemnifying hardware and software development contractors. Rapid changes in U.S. litigation practices have made it almost impossible for small-to-medium-sized manufacturers of medical equipment to obtain reasonably priced

product liability insurance. Quoted insurance premiums may run several orders of magnitude more than the hardware costs. Large companies with an existing insurance "umbrella," covering many product lines, are able to obtain coverage at high, but manageable, costs. However, in many instances small specialized manufacturers are needed for their level of expertise, experience with development hardware, and their more acute interest in production of small quantities of customized prototype and flight hardware.

10. Standardize batteries and chargers. A recurring problem, obvious from a review of the SBI hardware list and common to adaptation of off-the-shelf hardware, is associated with the power source. Modern electronic hardware is frequently designed to utilize rechargeable batteries. More convenient and cost-effective use can be made of commercial off-the-shelf hardware if NASA can determine safe and acceptable methods which allow less restrictive use of rechargeable batteries. Utilizing conventional power sources can reduce the tests required in order to prove the performance of the power supply interfaces.

4.0 CONCLUSIONS

Prototype hardware development programs conducted by NASA and within various industries offer an experience knowledge-base which is very useful in establishing guidelines and procedures to be used by planners and developers providing future space biology research hardware. This study has been able to combine such knowledge with contemporary facts related to SSF regulations and component limitations to evolve information which should contribute to the success and cost efficiency of SBI hardware development. The following items summarize the major findings of this study for ease of application:

1. Prototype development programs may be subdivided according to: 1) type of application, 2) degree of reliability required (class), 3) availability of usable devices in the commercial market, and 4) the required useful life expectancy.

2. The numbers of required units and the development implementation methods may be determined using an algorithm described in Figure 2.4-1 and the associated text (Section 2.4) together with consideration of sets of "drivers."

3. There are two principal approaches to SBI hardware development that drive prototype development programs: 1) modification of commercial off-the-shelf equipment and 2) new development.

4. Each approach can be generalized with essential steps and hazards as identified in Sections 2.2 and 2.3.

5. Prototypes are needed to varying degrees in hardware and software development programs of every type.

6. Computer simulation can substitute, in some cases, for breadboard and brassboard prototypes.

7. Nothing can efficiently substitute for the design verification test unit (DVTU) or engineering model (EM) prototype.

8. The operational experience base of an MCOTS prototype program can enhance reliability due to product maturity and evolution from extensive user feedback.

9. Significant engineering design efforts and extensive prototype testing must be accomplished in a new-build development program in order to approach the maturity of an MCOTS development.

10. A MCOTS prototype development program can potentially provide a good flight article for a cost of 15 to 25% of a full new development program. If done poorly it can cost many times as much as a new development.

11. It is necessary to build a mechanism into an MCOTS program which will terminate the program and activiate a new build from "scratch" if problems exceed certain limits.

12. The actual cost of a full complement of prototype development hardware is very small compared to the development itself and the associated flight hardware. It is small also when compared to the impacts which can occur due to a shortage of prototype hardware.

13. For contracted development programs, some non-deliverable prototypes, such as breadboards, do not add cost directly to the program. However, additional <u>deliverable</u> units obviously add moderate cost the the program.

14. Currently, prototype development programs are impacted by the reduced availability of U.S. component manufacturers as well as the scarcity of potential subcontractorts experienced with both medical and space hardware.

15. Maintenance and repair of equipment in long-duration applications is severely impacted by the current high rate of component obsolescence, early elimination of inventory and termination of factory support. Thus, an abundance of component parts, spares, and prototypes should be purchased with the initial contract.

16. Because of the impact of parts obsolescence problems on SSF equipment, consideration should be given to a shorter planned useful life cycle of perhaps 5 years.

17. The major limitation to reliability in high-quality, mass-produced equipment is component quality and the stochastic features of component tolerances.

18. The major limitations to reliability in high-quality equipment, produced in small quantities, are design imperfections and assembly/workmanship problems.

19. Since space flight hardware quantities are always small, major attention must be paid primarily to design and workmanship imperfections and secondarily to parts problems.

20. Class A equipment requires the highest reliability attainable. Therefore, maximum care must be applied to design refinement, workmanship, and component quality. In this case, Destructive Physical Analysis techniques being pioneered by DOD and DOE offer a potential for ensuring greater component consistency during component production runs continuing over long periods of time.

21. Prototype hardware development programs beginning from a new start can potentially make excellent use of modularization and commonality techniques. Special safeguards must be observed to prevent propagation of technical, schedule, and lifetime availability problems of the mandated module into each development program.

22. Prototype hardware development programs beginning from a new start are better suited than MCOTS programs for incorporation of automation techniques.

23. Exceptional NASA in-house technical knowledge and hands-on experience will facilitate increasing success in flight prototype hardware development and evaluation while providing conditions which yield developments at the lowest cost.

24. The interrelationships between the quantity drivers and other factors that should be used for the determination of the ideal quantities and types of prototypes that should be required of SBI hardware are too complex to model in a meaningful, yet simplistic, algorithm.

APPENDIX A

A PARTIAL LIST OF DOCUMENTS APPLICABLE TO SSF HARDWARE PROTOTYPING

ANSI/MIL-STD-1815A	Ada Language Reference Manual 22 Jan, 1983
ISO 7498/4	International Standardization Org.
JPL 86-14	The NASA Aerospace Battery Safety Handbook, 15 July, '86
JSC 31000	Product Assurance Requirements Volume 4
JSC SPEC M1	Specification Marking and Requirements Volume 4 4.9.1.1
JSC TBD	Space Station/NSTS Safety Identification, Vol. 4 2.1.4.1,2
JSCM 1700D	JSC Safety Manual, Vol. 4, 2.3
JSC 20527	Space Station EVA User Interfaces Design Guidelines Documentor 19 Nov. '86
JSC 20793	Manned Space Vehicle Battery Safety Handbook, Sept '85
JSC 21053	Space Station Program Payload Integration Plan
JSC 30213	Space Station Program Design Criteria and Practices. 15 Apr. '86
JSC 30233	Space Station Requirements for Materials and Processes 26 Nov. '86

JSC 30237	Space Station Electromagnetic Emission and Susceptibility Requirements for Electromagnetic Compatibility, 1 Dec '86
JSC 30238	Space Station Electromagnetic Techniques (MIL-STD-462 amended)
JSC 30240	Space Station Grounding Standard
JSC 30242	Space Station Cable/Wire Design and Control Standard
JSC 30243	Space Station Specification, System Electromagnetic Compatibility Requirements (MIL-E-6051D amended)
JSC 30244	Space Station Software Standards Document
JSC 30245	Space Station Electrical and Electronic Material and Process Standard
JSC 30425	Space Station Systems Requirement, Natural Environment Definition for Design, 15 Jan '87
JSC 31000	Product Assurance Requirements Volume 4
JSC 31011	WP-2 Master Verification Plan November '86
JSC 31013	Medical Requirements of an Inflight Medical System for Space Station, Revision A 30 Nov. '87
JSC 31016	FSE/OSE General Design Requirements, Nov. '86

JSC 31019	JSC Software Management Plan
JSC 31025	Acquisition Logistics Support Requirements
JSC 32015	Microbial Contamination
NSTS 07700	Space Shuttle Systems Payload Accommodations, Vol. 14, Revision J, 21 Oct. '86
KMI 1710.1	Safety, Reliability and Quality Assurance Program, Vol. 4, 2.1.6 and 4.1.3
MIL-HDBK-217	Reliability Prediction of Electronic Equipment, Vol. 4, 3.2.5.2
MIL-STD-105D	Sampling Procedures and Tables for Inspection by Attributes, Vol. 4, 4.11.1
MIL-STD-414	Sampling Procedures by Variables for Percent Defect, Vol 4, 4.11.1
MIL-STD-756	Reliability Modeling and Prediction, Vol. 4, 3.2.5.3
MIL-STD-970	Order of Precedence for the Selection of Standards and Specifications, Vol. 4, 3.3.2
MIL-STD-975	NASA Standard Electrical, Electronic and Electro-mechanical Parts List, Vol. 4, 3.3.1.2 and 3.3.1.4 and 3.3.1.6
NASA RP 1024	Anthropometric Source Book, Vol. 1 11 Nov., '86
NASA STD 3000	Man Systems Integration Standard Vol. 4, 21 Nov. '86

NHB 1700.1	Basic Safety Manual, Vol. 1A, 2.1.5 and 2.3 and 4.2.3
NHB 1700.1	System Safety, Vol. 3, 2.2.1
NSTS 07700	Space Shuttle Systems Payload Accommodations, Vol. 14, Revision J, 21 Oct. '86
SSP 30240	Space Station Grounding Standard Vol. 3
SSP 30257	Architectural Control Document Man-Systems: Revision B 15 June '88
NHB 1700.7A	Safety Policy and Requirements for Payloads Using the STS Vol. 4 2.2.2
SSP 30000	Product Assurance Requirements Section 9, Revision A 18 Mar '88
SSP 30309	Instructions for the Preparation of Hazard Analysis for the SSP Revision A, 15 Aug '88
SSP 30312	Electrical, Electronic and Electro-mechanical Parts Management and Implementation Plan for Space Station Jan '87
SSP 30233	Space Station Requirements for Materials Processing Vol. 4, 3.2.11
SSP 30234	Instructions for Preparation of FMEA/CIL For Space Station Vol. 4, 3.2.3
SSP 30309	Instructions for the Preparation of Hazard Analysis, Vol. 4, 2.2.3

SSP 30312	EEE Parts Management for Implementation Plan Vol. 4, 3.3.1.1 and 3.3.1.7 and 3.3.1.8
SSP 30313	Space Station Reliability/Maintainability Analysis, Vol. 4, 3.2.5
SSP 30423	Space Station Approved EEE Parts List (SSAEPL) Vol. 4, 3.3.1.2
SSP 30260	Architectural Control Document Communications and Tracking System Revision A,. Change 1, 5 Feb '88
SSP 30261	Architectural Control Document Data Management System, Revision B, Change 1, 19 Feb '88
SSP 30262	Architectural Control Document Environmental Control Life Support System, Revision B, 30 July '88
SSP 30263	Architectural Control Document Electrical Power System Revision B, Change 1, 19 Feb '88
SSP 30264	Architectural Control Document Fluid Management Systems Revision B, 15 Jan '87
SSP 30420	Space Station Electromagnetic, Ionizing Radiation and Plasma Environment Definition and Design Requirements, 15 Jan '87
SSP 30482	Space Station Electrical Power Characteristics, 5 May '87

APPENDIX B

PERSONAL INTERVIEWS AND OPINIONS

1. Aeivoli, Domonic; Program Manager for Commonality; General Electric Co., Philadelphia, PA. Telephone conversation covered wide range of flight hardware related subjects including: commercial communication satellites, earth resources (Landsat), and military satellites. Discussion included Protoflight type articles. He stressed that under all circumstances use of an engineering model prototype is essential.

2. Barnes, William J.; Design Engineering Manger, AT&T Technologies Systems: Burlington, NC. Mr. Barnes discussed use of prototypes in AT&T laboratory (was Bell Telephone Laboratory) development of guided missiles and commercial telephone equipment. He was unable to discuss exact details of under sea telephone signal repeater amplifiers for proprietary reasons. The laboratories utilize a large number of prototypes and extensive testing before building flight or commercial operational equipment.

3. Buckley, J.; Program General Manager, Science and Applications Programs, General Electric, Cherry Hills, NJ. Mr. Buckley discussed electronic parts problems and protoflight hardware programs. He described how program costs and schedules had been unfavorably impacted by lack of an engineering protoytpe model. His experience strongly demonstrates that it is essential to perform engineering development and thorough testing on prototype equipment prior to application of full R&QA formal documentation.

4. Burns, Frederick T., Jr.; Assistant Manager, Flight Support Equipment Office; Orbiter and GFE Projects Office Johnson Space Center. Mr. Burns provided extensive information on the rules, regulations, and procedures which must be complied with in order to fly equipment on the STS. He identified documents which greatly simplify and facilitate the process for hardware of certain types such as DTO and DSO programs.

5. Cubley, Dean, Ph.D.; Director of Engineering, Communications and Data Systems Associates, Webster, Texas. Dr. Cubley described how their company has been able to use computer

simulation in place of breadboard and brassboard prototypes in a protoflight development program. The single flight article will be used to conduct superconductivity experiments in space.

6. Evans, James S.; Technical Assistant, Life Sciences Project Division, Space and Life Sciences Office, Johnson Space Center. In two long and wide ranging meetings, Mr. Evans discussed many aspects of development programs for science and medical prototype equipment. He discussed both the good and bad experiences using the various techniques described in this study. He shared findings of a number of investigations he has conducted involving medical and science hardware used throughout all of NASA's manned space flight programs.

7. Fielder, George H.; Manager for Orbiter and GFE Projects; Safety, Reliability and Quality Assurance Office, Johnson Space Center. Mr. Fielder provided information related to the programmatic requirements imposed on flight hardware to be used on the Shuttle spacecraft. He also suggested individual persons to be contacted for specialized details and experiences.

8. Frey, Michael; Director, Mechanical Engineering; Intermedics Inc., Freeport, Tx. Mr. Frey's company is a world leader in the design and manufacture of implantable medical devices such as pacemakers and drug dispensers. Their products require the highest reliability attainable. He described their extensive and essential use of prototype development and test hardware. He described the effect of the parts availablilty problems on their company. It is now necessary for them to manufacture most of their components. With the exception of a few items such as batteries, they build all of their components including custom microcircuits and semiconductors.

9. Glanville, Roy W.; SSF Regulation Specialist; Reliability and Maintainability Division; Safety, Reliabililty and Quality Assurance Office, Johnson Space Center. Mr. Glanville provided an excellent insight into the documentation which will control every aspect of the design and application of flight hardware for the Space Station Freedom. He provided an understanding which allowed this study to identify the magnitude and complexity of the regulatory problem confronting any manufacturer wishing to design and build prototype and flight hardware for the SSF.

10. Goeke, Robert, Ph. D.; Center for Space Research, MIT, Cambridge MA. Dr. Geoke has had extensive experience in the design and fabrication of flight hardware for scientific investigations in space. Included are several pieces of LSLE equipment and astro physics payloads. He provided this study with much additional insight into the parts problems, the essential need for in-house design and hands-on hardware expertise, cost effective use of FMEAs, and many details which can boost reliability and flight article quantities while keeping costs at a minimum.

11. Graham, Olin L.; Section Head, Television Systems Section, Tracking and Communications Division, Engineering Directorate, Johnson Space Center. Mr. Graham provided details on prototype development programs, part problems, requirement documentation, and adaptation of commercial off-the-shelf hardware. Based on his extensive experience with flight hardware, he strongly recommended incorporation of numerous prototypes to achieve the greatest technical maturity possible.

12. Harlan, Charles S.; Director, Safety, Reliability & Quality Assurance Directorate, Johnson Space Center. The meeting with Mr. Harlan assisted in determining good contacts from which to obtain historical information. Part problems were discussed and he and his staff are interested in examining the potential benefits of Destructive Physical Analysis of semiconductor products.

13. Harris, Jackson D.; Technical Manager, Man-Systems Support, Lockheed Engineering. Mr. Harris assisted in understanding details of the Space Station Freedom programmatic technical requirements. Various subjects were discussed including which organizations and individuals could provide needed information on scientific instruments and their integration into SSF.

14. Holt, Aubry; Manager, Oil Equipment Systems Design; Smith International, Houston, Tx. Mr. Holt's company specializes in development and use of oil field instruments which operate under extremely adverse conditions of temperature, vibration, and pressure at the bottom of an oil well hole. Reliability is essential in their hardware. His insight into the parts problem, the use of development prototypes, and quality control testing contributed much pertinent new information.

15. Hymer, Robert L.; Manager, Nuclear Weapons Manufacturing Office, US Department of Energy, Albuquerque Operations Office, Albuquerque, NM. Mr. Hymer is responsible for nuclear weapons manufacturing in the United States and has an extreme interest in and understanding of reliable hardware development. He is an advocate of the use of numerous prototypes to develop device maturity before production. His insight into the parts problem led this study to the technique of Destructive Physical Analysis and the experts at Allied and Crane who perform it.

16. Kujawski, Peter; Chief, Re-Entry Systems, General Electric Company, Philadelphia, PA. Mr. Kujawski, who previously headed the GE Science and Applications Programs, is highly experienced in the development of reliable space flight hardware. He managed a massive protoflight program which produced the UARS (Upper Atmospher Research Satellite). His experience proves that it is extremely false economy to use too few prototype articles in a development program. He provided insight into the techniques of protoflight development.

17. Land, D. Kenneth; Chief, Tracking and Techniques Branch, Tracking and Communications Division, Engineering Directorate, Johnson Space Center, Houston, Tx. Mr. Land has extensive experience in all aspects of design and development of flight hardware. He has had notable success with modification of off-the shelf hardware. His identification of important details has contributed to the study.

18. Ramsey, Jim; Manager, Physical Analysis Laboratories, Naval Weapons Support Center, Crane, Indiana. Mr. Ramsey has a very great insight into all aspects of flight hardware reliability and production control. He contributed many details to this study. He and his personnel perform the Destructive Physical Analysis for DOD, DOE, and numerous private companies. They provided an understanding of the process and ways in which it may contribute to the SBI program.

19. Richards, Randall W.; Section Head, Command and Modulation Section, Tracking and Communications Division, Engineering Directorate, JSC. Mr. Richards has extensive experience in the development of GFE flight hardware. He is a strong advocate of ample prototype hardware. He assisted in understanding the

requirements placed on GFE flight hardware by the Shuttle program and clarified many points about the STS documentation tree. He provided very useful history of prototype development programs of all types.

20. Schulze, Arthur E.; Director, Biomedical Technologies Division; Lovelace Scientific Resources. Mr. Schulze provided some opinions on various aspects of designing and manufacturing medical and scientific equipment. During his career in the biomedical device industry, he has had the opportunity to optimize techniques for providing mature, reliable, hospital and space flight hardware. He has provided an historical perspective from the vendor's side of NASA's hardware programs which date back to the Skylab era.

21. Sinderson, Richard, Jr.; Section Head, Telemetry and Audio Section, Tracking and Communications Division Engineering Directorate, Johnson Space Center. Mr. Sinderson provided a myriad of facts describing the various methods by which NASA, JSC, has obtained much of its manned flight hardware from the time of Apollo on. His detailed procedures preserve much of the development technique for future developers to adapt for their needs.

22. Wilson, Burris G.; Engineering Manager, Kansas City Division Allied Signal Aerospace Company, Kansas City, Kansas. Mr. Wilson's organization performs many of the hardware development and manufacturing activities involved in equipping the nations weapons arsenals. He has provided information and contacts which have assisted this study in scoping the parts reliability problems. The Destructive Physical Analysis technique which he described is of interest to NASA's SR&QA personnel and will be explored by them for possible use by JSC.

APPENDIX C

BIBLIOGRAPHY

1. Arno, Roger (ed): Life Science Research Objectives and Representative Experiments for the Space Station, Biological Research Project, NASA Ames Research Center, Life Science Division, Advanced Program Office January, 1986

2. Evans, James S.: Memorandum SE3-1/88-011 to Chief, Life Sciences Project Division, NASA, JSC, 1988

3. Hopcroft, John : "Electronic Prototyping", IEEE Transactions on Aerospace and Electronic Systems, Vol. 24, No. 2, March, 1988, pp. 663-667

4. Juran, J. M. ; Gryna, Jr., Frank M.; Bingham, Jr., R.S.: Quality Control Handbook, McGraw-Hill Book Company, New York, NY, 1951

5. Lerner, Eric J,: "Finding Weak Electronics Links," Aerospace America, Washington, DC, April, 1989 pg. 50

6. Lion, Kurt S. : Instrumentation in Scientific Research, McGraw-Hill Book Company, New York, NY, 1959

7. Lowery, A. ; Rivera, R. J. : Device Good Manufacturing Practices Manual, Third Edition, Publication HHS (FDA) 85-4179, Washington, DC, 1984

8. Machol, Robert E. (ed.) : System Engineering Handbook, McGraw-Hill Book Company, New York, NY, 1965

9. NASA Technical Memorandum 89188: Life Sciences Space Station Planning Document: A Reference Payload for the Life Sciences Research Facility, August, 1986

10. Taylor, Gerald R., Ph.D. (ed): Space Station Freedom, Human-Oriented Life Sciences Research Baseline Reference Experiment Scenario, NASA Johnson Space Center, October, 1988

11. Tillman, George: "Prototyping for the Right Results," Technology Forum, DATAMATION, April, 1989, pg. 42-45

12. Vaghi, S. : "Hipparcos-Ready for Launch," ESA Bulletin 57, ESTEC, Noordwijk, The Netherlands, Feb., 1989

APPENDIX D

LIFE SCIENCES HARDWARE LIST

FOR THE

SPACE STATION FREEDOM ERA

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

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)				
	SAMPLE COLLECTION AND PROCESSING GROUP (2C)				
16	Animal Tissue Biopsy Equipment	S	0.03	8	0
17	Blood Collection System	S	0.02	1	0
18	Centrifuge Refrigerated	W	0.15	40	450
19	Centrifuge Standard Lab	E	0.09	26	200
20	Digital Thermometer	W	0.01	2	.34
21	Drug Administration Equipment	E	0.01	1	0
22	Electrofusion Device	S	0.06	TBD	TBD
23	Fixation Unit	S	0.02	4	0
24	Fluid Handling Tools/System	W	0.48	80	100
25	Laboratory Sciences Workbench	W	0.96	300	700
26	Life Sciences Glove Box (Copy 2 of 2)	W	0.96	350	800
27	Microscope System (Stereo Macroscope Subset, Copy 2	W	0.25	80	200
28	Muscle Biopsy Equipment	S	0.01	1	0
29	Perfusion & Fixation Unit	S	0.01	2	0
30	Plant Care Unit	S	0.05	10	50
31	Plant Harvest/Dissection Unit	S	0.01	4	20
32	Radioimmunoassay Prep Device	E	0.01	2	0
33	Saliva Collection Unit	S	0.01	1	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	TBD	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)
	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	10	100
62	Pulmonary Function Equipment Stowage Assembly	S	0.39	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	0
69	Cameras	W	0.15	50	150
70	Compliance Volumometer	S	0.06	TBD	TBD
71	Electroencephalomagnetogram (EEMG)	S	0.06	TBD	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
75	Fundus Camera	S	0.03	TBD	TBD
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	TBD	0
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	S	0.10	TBD	TBD
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	70	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
146	Dosimeter, Passive	W	0.09	35	0
147	Head/Torso Phantom	S	0.12	TBD	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
150	Radiation Shielded Locker (Copy 2 of 2)	W	0.20	80	0
151	Reuter Microbiology Air Sampler	S	0.01	1	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	TBD	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	1	0
	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

LIFE SCIENCES HARDWARE BA_ _LINE, REV 1, DEFINITIONS

1.8 M Centrifuge	A device designed to produce a gravity gradient on plants, rodents and small primates, providing a 1g control for microgravity experiments.
Accelerometer Subsystem	A system of vectored accelerometers with interfaces to data recording and data processing, monitoring three-axis microgravity levels in the range of 1 E-7g to 1g within the U. S. Laboratory Module. Source: SS-SPEC-0002.
Accelerometer and Recorder	Measures and records the rate of change of velocity of an object, i.e., forward linear motion or vibration detection.
Animal Biotelemetry System	A set of sensors and transducers to monitor various physiological parameters of animal specimens.
Animal Tissue Biopsy Equipment	Set of specialized instruments to perform tissue studies on animal specimens.
Automated Microbic System	An instrument capable of identifying microbes based upon the automated analysis of changes in color or turbidity within incubated reaction chambers.
Bag Assembly	Re-breathing bag; part of the Pulmonary Function hardware set, used to measure lung function and capacity in microgravity.
Bag-in-Box	Part of the Pulmonary Function hardware set, used to measure lung function and capacity in microgravity.
Battery Charger	A compact device for recharging nickel cadmium batteries that are used in a number of small instruments (e.g. digital thermometers, digital multimeters) or payloads.
Blood Collection System	Blood collection items that can be used more than once. Includes vacutainer holders and tourniquets.
Blood Gas Analyzer	Instrument for detecting and measuring the amount of dissolved gases in blood, usually carbon dioxide.and oxygen.
Blood Pressure And Flow Instrumentation	Instrumentation for measuring arterial blood pressure and flow.

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Camera Locker	Provides equipment storage space for cameras, accessories and associated components, to include lights, mountings, hardware, etc.
Cameras	Still and video cameras for general laboratory photography.
Cardiodynamic Monitor	Determines cardiac output by measuring changes in regional (thoracic) impedance.
Cardiopulmonary Analyzer Flowmeter	Measures oxygen uptake, carbon.dioxide production and heart rate as it relates to total pulmonary ventilation.
Cell Handling Accessories	Tools used to transfer cells from specimens to microscope slides in a microgravity environment.
Cell Harvester	Used to isolate cells from a large sample and deposit isolated cells into a chamber for further analysis.
CELSS Test Facility	A testbed experiment for the Controlled Ecological Life Support System, intended to test the feasibility of a self-sustaining life support system in microgravity.
Centrifugal Incubator (5% CO2 @37 deg. C Copy 1 of 2)	A centrifuge, producing a 1g radial acceleration, with a set temperature of 37 degrees C and a carbon dioxide-rich atmosphere. This centrifuge will provide 1g control for tissue culture studies.
Centrifugal Incubator (5% CO2 @37 deg. C Copy 2 of 2)	Identical to above centrifuge (copy 1) except that the spinning function is disabled, for use in tissue culture studies.
Centrifuge Hematocrit	A specialized centrifuge for separating plasma from formed elements in blood samples.to determine hematocrit
Centrifuge Refrigerated	Uses centrifugal acceleration to separate materials by density in a temperature controlled environment.
Centrifuge Standard Lab	An instrument which provides centrifugal acceleration for separation or processing of liquid samples in hematology,microbiology and immunology.

Chemistry Analysis System	An instrument which employs liquid reagents to measure various components of serum, plasma, and urine. The system includes provisions for sample pick-up, sample delivery, protein separation, reagent addition, mixing, incubation, reaction detection and data presentation.
Chemistry System	An instrument primarily used to determine the levels of compounds in blood and urine (e.g. urea, glucose, calcium, etc).
Chromosomal Slide Preparation Device	A device used to prepare microscope slides in a manner such that the chromosomes can be properly observed.
Cleaning Equipment	Tools and supplies necessary to perform housekeeping and cleanup of laboratory equipment, to include interior surfaces of gloveboxes.
CO2 Administration Device	A device used to quantitatively increase the amount of CO2 inspired by either rodents or primates.
Digital Multimeter	General purpose hand-held voltage, current and resistance meter for use in maintenance and adjustment of electric/electronic equipment, and for temporary service in ad hoc experiments.
Digital Recording Oscilloscope	Instrument for detecting, digitizing, recording and displaying periodic and transient electrical waveforms for use in electronic maintenance and experiment calibration.
Digital Thermometer	Portable, hand-held temperature measurement system for spot checking and fault diagnosis in experiment systems, as well as for temporary service in ad-hoc experiments.
Doppler Recorder	Portable data recorder to record blood flow as monitored from doppler blood flow instrumentation.
Dosimeter Passive	A small badge (Thermoluminescent Dosimeter or TLD) used to monitor various forms of radiation. The TLD badge is read by placing it in a reader/annealer, specifically designed for this purpose. The badge emits light upon heating in proportion to radiation exposure; this release of energy in the form of light returns the badge to a ready-to-use condition.

Drug Administration Equipment	Equipment for the administration of various drugs to include oral, IV and rectal administration.
EEG Cap	A cap fitted with appropriate electrodes for the measurement and recording of brain electrical activity.
EEG Signal Conditioner	Instrumentation to provide biopotential signal amplification and conditioning.
Electro-Magnetic Tendon Striker	A device used to stimulate the contraction of voluntary muscle groups.
Electro-oculograph (EOG)	A device used to monitor the electrical activity of the muscles controlling eye movement.
Electrocardiograph (ECG)	Measures, records and displays the electrical activity of the heart.
Electrode Impedance Meter	An instrument used to measure impedance between electrodes (particularly EOG) to ensure signal quality.
Electromyograph (EMG)	A device used to monitor the electrical activity of skeletal muscles during contraction.
Electronics Control Assembly	Part of the Pulmonary Function hardware, which controls the mixture of gases introduced to the subject through the Bag Assembly.
ELISA Reader	Enzyme Linked Immuno-Sorbent Assay spectrophotometer. A device to record the change in spectral absorbance within the wells of an ELISA microtiter plate, with time, either single event, continuously or at frequent intervals, thus allowing kinetic measurements to be made.
Equipment Washer/Sanitizer	Device to clean and sanitize laboratory equipment, to include tools, animal cages, plant cuvettes, etc.
Experiment Control Computer System	Basic Life Sciences computer system to provide buffer memory and mass storage capability and interface between experiment hardware and the data management system.
Fecal Monitoring System (24 Hr)	Provides for fecal collection and measurement and allows for sample extraction.

Fixation Unit	A selection of biological dyes, fixatives and ancillary hardware necessary for sample preparation and preservation in a microgravity environment.
Flow Cytometer	An instrument which uses optical methods to count, measure and analyze individual cell characteristics.
Fluid Handling Tools/System	A system capable of handling bodily fluids and chemicals/reagents and be capable of measuring, separating, mixing, transferring, distributing and disposing of these liquids.
Force Measurement Device	A series of sensors capable of measuring force to be attached to various places on the body or to be used to monitor muscle force production.
Force Resistance System	A device to provide either positive or negative forces to counter muscle activity (either isometrically, isotonically or isokinetically) and measure force production during each case.
Freeze Dryer	Device which dehydrates samples by freezing them in a high vacuum.
Freezer (-20 deg. C)	Freezer which maintains -20 deg C.
Freezer (-70 deg. C)	Freezer which maintains -70 deg.C.
Freezer Cryogenic (-196 deg. C) w/ Snap Freezer	Freezer which incorporates a preliminary freezer to quick-freeze a specimen before storage to allow the main freezer to maintain a very low temperature.
Gas Chromatograph/Mass Spectrometer	(GC/MS) Identifies a substance by sorting a stream of electrified particles (ions) according to their volatility and/or mass. Monitors inspired and expired gases, and oxygen uptake to determine metabolic rate, etc.
Gas Cylinder Assembly	Several cylinders containing gases required for the operation of GC/MS, as well as Pulmonary Function Hardware (The gases required for each are different gases).
Gas Grain Simulator	Hardware used to analyze the interactions between gases and very fine particles in a microgravity environment.

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General Purpose Hand Tools	Tools required for general and/or minor maintenance of laboratory hardware.
Goniometer And Recorder	An instrument used to measure the range of motion of joints (angles) of crew members in microgravity.
Hard Tissue Imaging System	An instrument which produces two-dimensional images of dense tissues.
Hematology System	A device which performs red, white, and platelet cell counts, hemoglobin concentrations and other hematological measurements.
High Performance Liquid Chromatograph	Separates and identifies components of a solution by virtue of their differences in sign and magnitude of charge. It is capable of such functions as: high pressure liquid, gel permeation, reverse phase, and size exclusion chromatography.
Holter Recorder	Recorder used to monitor cardiac function by recording the analog signals produced by a continuous ECG.
Human Biotelemetry System	A set of sensors and transducers to monitor various physiological parameters of human subjects.
Image Digitizing System	Converts images from any source into digital form, performs limited pattern recognition, and transfers digital data from Space Station to ground communications.
Incubator (35-65 deg C Copy 1 of 2)	An enclosure used to provide proper atmospheric conditions required to grow biological specimens and microorganisms.
Incubator (35-65 deg C Copy 2 of 2)	Same as above.
Inventory Control System	Device to enter, monitor and control items in the current inventory, including biological specimens.
Isokinetic Measurement Device	Measures the resistive force of muscle at various points of motion with controlled force and compression determinations.

LIFE SCIENCES HARDWARE B/ :LINE, REV 1, DEFINITIONS

Lab Materials Packaging & Handling Equipment	System that provides for the transfer of biological materials (e.g. tissue samples, biological reagents), while maintaining bio-isolation from the crew.
Laboratory Sciences Workbench	A bench (or table top) where samples not requiring biolsolation can be prepared for storage or analysis.
LBNP Device	A Lower Body Negative Pressure device used to direct blood from the upper extremities to the lower extremities in a controlled manner.
Life Sciences Glove Box (Copy 1 of 2)	A bio-isolated compartment used for the manipulation of biological specimens and samples, specifically those associated with plant and animal studies.
Life Sciences Glove Box (Copy 2 of 2)	A bio-isolated compartment used for the manipulation of biological specimens and samples, specifically those associated human-oriented studies.
Mask/Regulator System	Part of the Pulmonary Function hardware complement which provides the crew interface.
Mass Calibration Unit	Set of known masses to calibrate onboard mass measuring devices.
Mass Measurement Device-Body	A device used to determine the mass of human subjects in microgravity.
Mass Measurement Device-Micro	A device used to determine the mass of specimens having a mass less than 1 mg in microgravity.
Mass Measurement Device-Small	A device used to determine the mass of specimens in the range of 1 mg to 10,000 gm in microgravity.
Mass Spectrometer	An instrument used to determine components of a solution or gas by analyzing the molecular fragments according to their atomic mass.
Microbial Preparation System	A system which automatically prepares microbial samples for analysis in the Automated Microbic System.
Microscope System (Optical & Stereo Macroscope Subsets)	LSE hardware which provides the functions of an optical microscope and stereo macroscope.

Microscope System (Stereo Macroscope Subset, Copy 2 of 2)	Stereo macroscope to be used for dissection of various biological specimens.
Mitogen Culture Device	A device which bathes incubated cells in a mitogen-rich environment to stimulate mitosis.
Modular Habitat Holding System	A system which accommodates the modular habitats used to house live animal subjects.
Motion Analysis System	Video system used to monitor, record and analyze the motion of crew members during weightlessness.
Multichannel Data Recorder	A recorder which can accept and condition signals from various physical parameters, simultaneously.
Muscle Biopsy Equipment	Tools and instruments required to harvest tissue specimens from rodents and primates.
Neurovestibular ECDI	Experiment Control and Data Interface, a computer-based system that controls and collects data from hardware used in neurovestibular investigations.
Neurovestibular Helmet Interface Box	Contains EOG signal conditioner that transmits analog signals to the ECDI.
Neurovestibular Helmet Assembly	Highly-modified "motorcycle helmet", instrumented and equipped for neurovestibular studies.
Neurovestibular Helmet Restraint	Attaches Helmet to the rotating chair.
Neurovestibular Optokinetic Stimulus	Part of the NV helmet assembly which provides the stimulus.
Neurovestibular Rotating Chair	Chair which revolves at different frequencies in two directions.
Osmometer	Measures the concentration of dissolved particles in a solution.
Perfusion & Fixation Unit	A set of chemicals and ancillary hardware required to treat and preserve tissue samples for later examination and study.

ph Meter/Ion Specific Analyzer	An instrument used to measure the acid-base status of various sample types, and with ion-specific electrodes, can measure the ionic concentration of the sample.
Physiological Hemodynamic Assess Device	Device used to measure Central Venous Pressure non-invasively. It utilizes a respiratory flow and pressure meter, in conjunction with doppler, ultrasound.
Physiological Monitoring System	An instrument, similar to a patient monitor, which monitors the cardiovascular system (heart rate, blood pressure, electrocardiograph, body temperature, etc.)
Plant Care Unit	Hardware required for the daily care and maintenance of plant in a microgravity environment.
Plant Gas Chromatograph/Mass Spectrometer	Identifies a substance by sorting a stream of electrified particles (ions) according to their volatility and/or mass, specifically designed for use in plant studies.
Plant Gas Cylinder Assembly	Gases used to support the Plant Gas Chromatograph/Mass Spectrometer.
Plant Growth Module	Container wherein plants will be grown in microgravity.
Plant Harvest/Dissection Unit	A set of specialized instruments to gather and dissect plant specimens.
Plant HPLC Ion Chromatograph	Separates and identifies components of a solution by virtue of their differences in sign and magnitude of charge, specifically designed for monitoring plant specimens.
Plethysmograph Measurement System	A system for measuring and recording the changes in volume of an organ, part or limb and the amount of blood present or passing through it.
Primate Blood Collection System	A system to safely collect sterile blood samples from primate subjects.
Primate Handling Equipment	A set of specialized equipment to be used to safely handle primate specimens in a microgravity environment.
Primate LBNP Device	A device for applying a negative atmospheric pressure to the lower extremities of a primate subject.

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Primate Module	Container wherein primates will be housed in microgravity.
Primate Surgery Platform	A device used to restrain a primate in positions suitable for surgery.
Primate Surgery/Dissection Unit	Tools required (e. g. scalpels, sutures, etc.) for the surgery and dissection of primates.
Primate Urine Collection System	A system to safely collect sterile urine samples from primate subjects.
Primate Veterinary Unit	A set of instruments and other required materials to ensure the health and safety of primate subjects.
Pulmonary Function Equipment Stowage Assembly	A unit which safely stows the portion of the Pulmonary Function Equipment which is not rack mounted.
Pulmonary Gas Cylinder Assembly	A set of compressed gas cylinders containing gases of known composition, used in support of the Pulmonary Function hardware.
Pulmonary Monitoring System	A instrument capable of monitoring human pulmonary function, such has total lung volume, reserve, tidal volume, maximum O_2 cosumption, etc.
Qualitative Reagent Strip And Reader	A device that will qualitatively assess levels of compounds or ions (e.g. hydrogen ions, glucose, urea, calcium) present in animal blood or urine.
Radiation Shielded Locker (Copy 1 of 2)	A locker for the storage of items which will be degraded if exposed to ionizing radiation.
Radiation Shielded Locker (Copy 2 of 2)	A locker which will accommodate radioactive items which require isolation.
Radioimmunoassay Prep Device	A device which would prepare blood or urine samples,for an immunological procedure in which hormones, antigens, antibodies, drugs and other substances occurring in minute quantities are measured using radioisotopes.
Radioimmunoassay	A device in which hormones, antigens, antibodies, drugs and other substances occurring in minute quantities are measured using radioisotopes.

LIFE SCIENCES HARDWARE BASELINE, REV 1, DEFINITIONS

Rebreathing Assembly	Pulmonary Function support equipment. Collects and measures exhaled air for rebreathing by subject.
Refrigerator (4 deg. C)	An insulated unit capable of storing various materials at 4 deg. C
Reuter Microbiology Air Sampler	A hand held centrifugal air sampler which collects microorganisms upon specific growth media.
Rodent Blood Collection System	A system to safely collect sterile blood samples from rodent subjects.
Rodent Caudal Vertebrae Thermal Device (CVTD)	A device used to warm the tails of rodents in a microgravity environment.
Rodent Guillotine	Device for the humane decapitation of rodent specimens.
Rodent Module	Container wherein rodents will be housed in microgravity.
Rodent Restraint	A device to safely hold a rat subject during handling.
Rodent Surgery Platform	A device used to restrain a rodent in positions suitable for surgery.
Rodent Surgery/Dissection Unit	Tools required (e. g. scalpels, sutures) for the surgery and dissection of rodents.
Rodent Urine Collection System	A system to safely collect sterile urine samples from rodent subjects.
Rodent Veterinary Unit	A set of instruments and other required materials to ensure the health and safety of rodent subjects.
Saliva Collection Unit	A device to safely collect saliva specimens from human subjects.
Sample Preparation Device	A device which will prepare various biological samples for subsequent analysis, which includes the addition of required reagents.
Scintillation Counter	Measures the light emitted when an x-ray or gamma ray is absorbed by a crystal or liquid radiation detector. It is based on the principal that exposure of certain materials to ionizing radiation results in the conversion of the kinetic energy of the particles or photons into the flashes of light or scintillations.

Shielded Isotope Container	A container for storing isotopes which inhibits the transmission of ionizing radiation.
Skin Window Device	A device which is applied to the surface of the skin to facilitate the collection and analysis of skin cells.
Slide Preparation Device	An automated device to fix and stain micro-organisms and blood
Small Primate Restraint	A device to safely hold a small primate subject during handling.
Soft Tissue Imaging System	A system which provide a two dimensional image of organs and other soft tissues.
Solid Sorbent Air Sampler	An air sampler that continuously deposits trace level air contaminants for lab analysis.
Specimen Labeling Tools/Device	A device capable of automatically labeling containers and specimens, which can be automatically read and entered into a database which contains all the information pertaining to that particular sample or specimen.
Spectrometer (Proton/Heavy Ion)	A device which measures protons from the trapped belts, heavy ions, and fragmented particles of heavy ions.
Spectrophotometer (UV/VIS/NIR)	An instrument capable of quantitatively measuring light-absorbing components in a solution.
Spirometry Assembly	Part of the Pulmonary Function support hardware which measures air inhaled and exhaled from the lungs.
Subject Restraint System	A system which immobilizes part or all of a human subject.
Surgery/Dissection Tools	Tools and instruments necessary for surgery or dissection of either rodents or primates.
Syringe (3 Liter Calibration)	Pulmonary Function support equipment which is used to calibrate the Bag-in-Box.
Test/Checkout/Calibration Instrumentation	Self explanatory.

Total Hydrocarbon Analyzer	An instrument used to measure the total hydrocarbon content in biological samples.
Turbidity Meter	A device which measures the degree of cell growth by measuring the turbidity of the cell media.
Ultrasonic Imaging System	Provides images for the visualization of deep structures of the body by recording the reflections of pulses of ultrasonic waves directed into the tissues.
Urine Analysis System	A system which provides for the analysis of urine samples in the microgravity environment.
Urine Monitoring System (24 Hr)	A system for the collection, storage, preservation and measurement of human urine samples in a microgravity environment.
Venous Pressure Transducer/Display	Transducers and displays used to measure central venous pressure, via the insertion of a catheter into either the right atrium or the vena cava.
Video System	System used to record the video images received from video cameras.
Visual Tracking System	Monitors and record eye movements during neurovestibular studies.
Voice Recorder	A hand-held device used to record crew voices during experiment procedures.