HORIZON AEROSPACE

• 18333 EGRET BAY BOULEVARD, SUITE 300
• HOUSTON, TEXAS, USA 77058 • (713) 333-5944
• TELEFAX (713) 333-3743

SPACE BIOLOGY INITIATIVE PROGRAM DEFINITION REVIEW

TRADE STUDY 4

DESIGN MODULARITY AND COMMONALITY

FINAL REPORT

Prepared by:

HORIZON AEROSPACE

L. Neal Jackson, President
John Crenshaw, Sr. Engineer

and

EAGLE ENGINEERING, INC.

W.L. Davidson
F.J. Herbert
J.W. Bilodeau
J.M. Stoval

EAGLE TECHNICAL SERVICES

T. Sutton

Prepared for:

GE GOVERNMENT SERVICES
Houston, Texas
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Table of Contents

List of Figures

List of Tables

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)
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
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
FSU	Functional Support Unit
GGS	Gas Grain Simulator
HMF	Health Maintenance Facility
HPLC	High Performance Liquid Chromatograph
HQUL	Hardware Quantity and Usage List
HRF	Human Research Facility
JSC	Johnson 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
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

SLS	Space Laboratory Life Science
SSFP	Space Station Freedom Program
SSIS	Space Station Information Systems
STS	Space Transportation System
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. 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 modularizing 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 define the relative cost impacts (up or down) of developing Space Biology hardware using design modularity and commonality. Recommendations for how the hardware development should be accomplished to meet optimum design modularity requirements for Life Science investigation hardware will be provided. In addition, this study will define the relative cost impacts of implementing commonality of hardware for all Space Biology hardware. Cost analysis and supporting recommendations for levels of modularity and commonality will be presented. The study will provide a mathematical or statistical cost analysis method with the capability to support development of production design modularity and commonality impacts to parametric cost analysis.

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. The trade study results are planned to be produced in the form of factors, guidelines, rules of thumb, and technical discussions which provide insight on the effect of modularity/commonality 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 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 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 often elusive and change many times before final design. 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 Modularization/Commonality 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, including design modularity and commonality impacts to parametric cost analysis 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 modularization 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 modularization/commonality for space biology technology hardware.

1.5.4 Survey Data Integration

The Space Biology Hardware Baseline was reviewed and the facilities, assemblies, subassemblies, components, and functions of this hardware that have the potential for design modularity and commonality were identified as candidates for design modularity and commonality. The technical data collected from the survey were integrated with the Space

Biology Hardware Baseline database and a matrix of candidate functions, specifications, cost Analysis, design modularity and commonality applications will be developed.

The initial survey data analysis was performed to select a sample of the SBHB items which could be potential candidates for modularization. With limited study time and a SBHB of 93 referenced hardware items, Appendix A, a method was needed to separate the items which could have the most cost impact and were worthy of study resource application. The "initial few and trivial many" method (SBI #96) was used. This method applies the principal that in any population which contributes to a common effort (cost). A relative few of the contributors account for the bulk of the effort (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 5.3). Therefore, consideration was immediately limited to these 32 items. The modularization candidate sample set was chosen from Table 5.4-1 based on amenability to modularization and commonality. This list of 32 items does not mean the remaining 61 (93-32) items are of lesser importance in obtaining space biology information.

The sample set was then subjected to a more detailed analysis to determine important factors relative to commonality and to select the most representative functions/assemblies for final analysis. By this process, a reasonable effort could be devoted to analyze the impact more thoroughly.

1.5.5 Cost Analysis

Analyses were performed to demonstrate the relative cost impact for modularity and commonality within the candidate hardware items. Additional study was dedicated to the final selected item. Based on this cost assessment and historical data, the relative relationship of modularization/commonality to space biology hardware cost was assessed.

1.6 Definitions

1.6.1 Modularity

Modularization is the packaging of the instrument equipment in units which correspond to system functional elements in such a way that the units can be easily removed, replaced, and reconfigured.

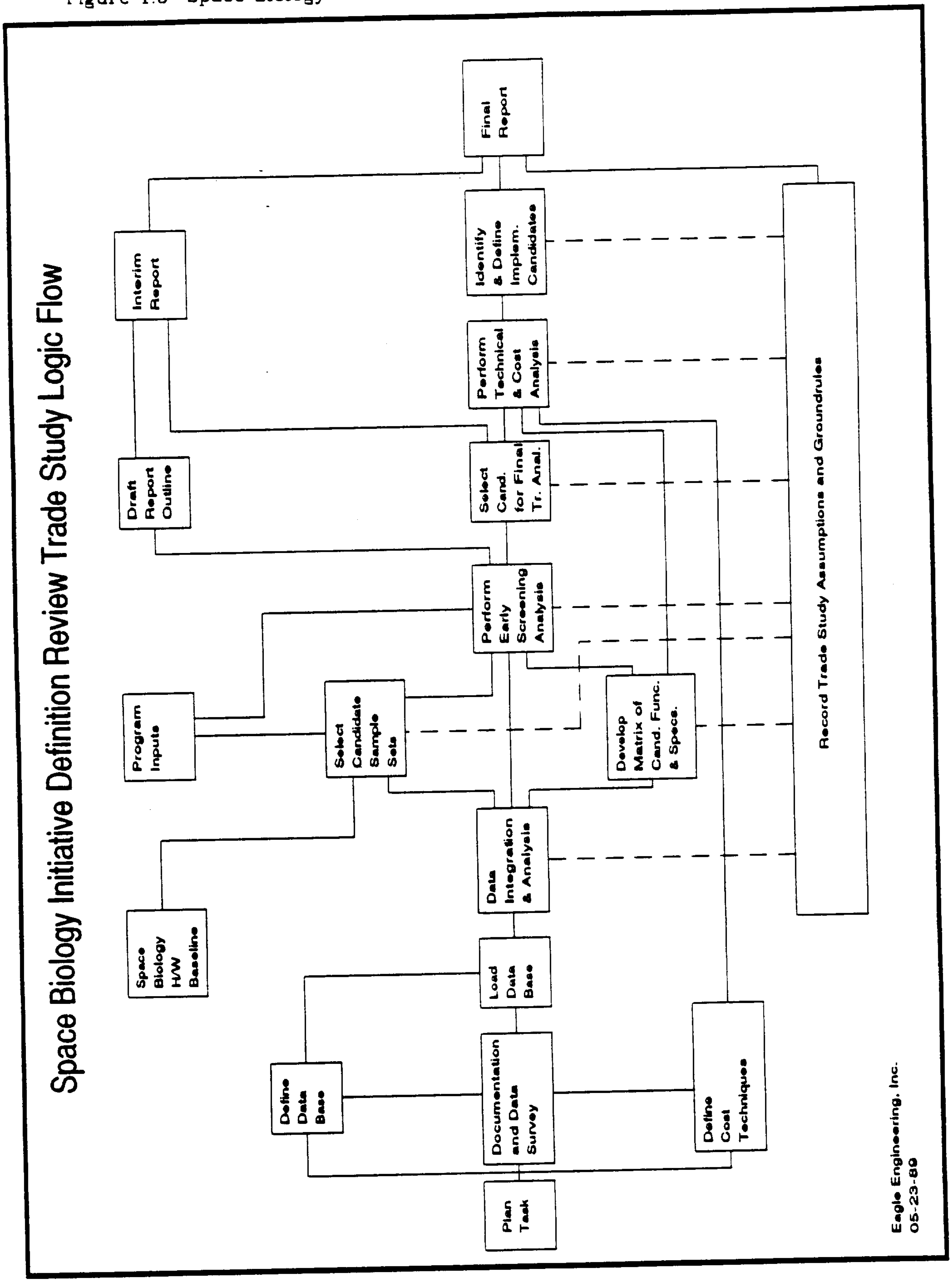
1.6.2 Commonality

Commonality refers to the commonness of an individual (item) "COMMON" from latin "communis" is defined as "belonging to or shared by two or more individuals or by all members of a group. It can broadly be defined as the use of identical, interchangeable, functionally compatible or similar items to satisfy different sets of functionally similar requirements.

Table 1.4 SBI Hardware Categories and Functions

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

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 a list common to all of the studies (Table 2.1-1). The assumptions which primarily affect the design modularity and commonality study are documented in a separate list (Table 2.1-2).

2.2 SBI Functional Element Candidates for Modularization/Commonality

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 mostly 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 87% by power (watts) of the total 93 items.

The 32 hardware items in Table 2.2-1 were reviewed and selective judgements were recorded on the potential for modularization (Table 2.2-2 repeated from Table 5.2-2). Each SBI hardware item was analyzed to determine if the entire item can be modularized or at least a portion of the components could be modularized. The confidence level is an indication of the knowledge and understanding of the individual items at the time of this study. There are five (5) items in this list where there was insufficient data to make an estimation for modularity/commonality (marked NO on Table 2.2-2). There are four (4) items on this list that are marked with a "P" for Pulmonary Group and four (4) marked "PL" for Plant Monitoring Group. The Pulmonary Group has a total of eleven (11) hardware items (#56 thru 66 listed in Appendix A) with interrelated use of hardware for the planned functions and experiments. The group will be treated as one item for this trade study. It is assumed that most of the Pulmonary Group can be packaged or modularized together. The heaviest items in the group is the mass spectrometer which can possibly be used for other SBI functions. The details and practicality of adapting the mass spectrometer to the different applications (Pulmonary functions, Plant Gas Chromatograph, etc.) is not known at this time. The CELSS hardware item is presently planned as a separate experiment, however the function of this hardware item is plant monitoring which is why it has been grouped into this category.

The modularity candidate sample set (Table 2.2-3 is a repeat of Table 5.2.1) was derived by removing those items that have insufficient data and little or no modularization potential. The item in the two groups Pulmonary (P) and Plant Monitoring (PL) were left in this sample set with a high confidence level that the group or a portion of the group could be packaged (modularized) together.

The candidate hardware items were analyzed for common functions/assemblies by sorting the vital database listing (Table 5.2-3 and summarized in Table 2.2-4). The level of commonality was the lowest level possible with the available information. The Pulmonary Function Equipment Storage Assembly hardware items show an amplifier as being common. This particular hardware item would not use an amplifier; however, the Pulmonary Group would more than likely use this function/assembly. This type of analysis was used throughout the study for commonality. The number of common functions/assemblies will be subjective; however, the methodology does show a large potential cost savings through commonality. The level of commonality (i.e. assembly, sub assembly, component) has a direct effect on the implementation of the common solution which in turn has a direct effect on the overall cost of the program (SBI #89).

2.3 Modularity/Commonality Cost Impacts

The 15 candidates for modularity of the SBI hardware items are shown in Table 2.2-3. The cost impact of modularizing these items would require a redesign for the existing hardware, (i.e., Pulmonary and Plant Monitoring Group) and a new design for other items. Redesign costs would be much higher than new design of hardware in the conception phase. No cost analysis data is presented in this trade study for modularity.

The commonality list of functions/assemblies is shown in Tables 2.2-4 and summarized in Table 2.3. Table 2.2-4 shows some of the functions/assemblies for the 32 SBI hardware items. The number of potential SBI hardware items using each function/assembly is shown in Table 2.3 with the possible cost reduction for each function. To estimate the potential cost reduction for each SBI hardware item will require additional, more detailed information on the individual functions, assemblies, subassemblies and components, (lowest level possible). As seen from Table 2.3 the potential cost reduction is quite large for the first few units. After 10 items, however, the cost reduction is essentially a flat curve. The details of developing the cost impact analysis is in section 5.3.2.1.

2.4 Future Work

Future studies should include more details on all of the functions/assemblies (lowest level possible) of the individual SBI hardware items. This information would then allow for a cost impact analysis of the individual SBI hardware items versus just the functions/assemblies. There is a high degree of confidence that with further, more detailed, trade studies there can be a large cost savings of modules/common items within the SBI group as well as with in other Space Station Freedom related activities. There may also be further cost savings with an analysis between the different trade studies. Other SSF activities (i.e. CHeC, EDCO, and HMF will have common hardware items and many of these will be flown on SLS-1 which could greatly reduce development cost.

2.5 Conclusion Summary

The analysis of this modularity/commonality trade study indicates that there can be considerable cost saving within these groups by modularizing the various assemblies and components for long duration missions. The analysis of the functions/assemblies for commonality, regardless of the factors that influence cost, shows that very large potential savings are available. Size (weight), complexity, development cost, fabrication cost and learning factors can vary over any foreseeable range of values, but common use of elements or assemblies will still produce large savings. The analysis in section 5.3.2.1, which relates development cost, first unit cost and learning factors, vividly demonstrates this important finding.

As can be seen from Table 7-1 in Appendix C, modularity has a favorable affect on life cycle costs in almost every step of a development, test, integration and operational life cycle. Therefore, a small cost in weight to make a design modular will yield large programmatic return over the whole Space Station life cycle. Modularity also can be implemented such that improved commonality results. Select the correct items for commonality development (Table 2.2-4) and major cost savings become achievable.

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 Modularity and Commonality Trade Study Assumptions and Groundrules

1) Many of the SBI hardware items are interrelated, i.e., pulmonary group, plant monitoring, etc., and were not treated as separate entities.

2) Any current SBI equipment hardware concept is subject to being redesigned to meet the benefits of design modularity and commonality.

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 Spectro-meter	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	Modularity Potential	Assessment Confidence Level	
					Low	High
1	168	CELSS		X-PL		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		NO	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		X	X	
14	61	Mass Spectrometer		X-P	X	
15	112	Plant HPLC Ion Chromatograph		X-PL		X
16	147	Head Torso Phantom		NO		X
17	63	Pulmonary Gas Cylinder Assem.		X-P	X	
18	110	Plant Gas Chromatograph/Mass Spec		X-PL	X	
19	115	Chemistry System		X	X	
20	138	Hematology		X	X	
21	34	Sample Preparation Device		X	X	
22	165	Experiment Control Computer System		X		X
23	62	Pulmonary Function Equip Stor. Assem.		X-P	X	
24	82	Motion Analysis System		NO		
25	99	Animal Biotelemetry System		NO		
26	100	Blood Pressure & Flow Instrumentation	NO			
27	109	Venous Pressure Transducer/Display	NO			
28	129	Cell Handling Accessories		X	X	
29	57	Bag-In-Box		X-P	X	
30	111	Plant Gas Cylinder Assem.		X-PL	X	
31	119	Gas Cylinder Assembly		X	X	
32	130	Cell Harvester		X	X	

P - Pulmonary Group
PL - Plant Monitoring Group

Table 2.2-2 Modularity Assessment Review for Sample Selection

Item # Prioritized by Mass	Hardware Item #	Hardware Item Name	Modularity Potential	Assessment Confidence Level	
				Low	High
1	168	CELSS	X-PL		X
2	169	Gas Grain Simulator Facility	X		X
5	126	Scintillation Counter	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-P	X	
15	112	Plant HPLC Ion Chromatograph	X-PL		X
17	63	Pulmonary Gas Cylinder Assem.	X-P	X	
18	110	Plant Gas Chromatograph/Mass Spec	X-PL	X	
22	165	Experiment Control Computer System	X		X
23	62	Pulmonary Function Equip Stor. Assem.	X-P	X	
29	57	Bag-In-Box	X-P	X	
30	111	Plant Gas Cylinder Assem.	X-PL	X	

P - Pulmonary Group
PL - Plant Monitoring Group

Table 2.2-3 Modularity Candidate Sample Set

Item # Prioritized by Mass	Hardware Item #	Hardware Item Name	Aerosol Generator	Amplifiers	Automation/Robotics	Cameras/Video	Centrifuge	Computers&Accessories	Converters	Detectors	Displays-Transducer	Environmental Control	Fluid Handling	Freezers	Gas Handling	Mass Spectrometer	Microbial Monitoring	Motors	Power Supply	Pumps	Radiation Handling	Recorders	Sample Prep Animal	Sample Prep Human	Sample Prep Plant	Scintillation Counter	Storage Locker	Temp.Press.Hum.Monitor	Thermal/Shock Isolation
1	168	CELSS			X	X		X	X			X		X	X		X	X	X	X	X	X			X			X	X
2	169	Gas Grain Simulator Facility	X			X		X	X			X			X	X		X	X	X	X	X			X		X	X	X
3	84	Soft Tissue Imaging System																											
4	77	Hard Tissue Imaging System																											
5	126	Scintillation Counter																								X			
6	74	Force Resistance System				X		X				X										X							
7	145	Automated Microbic System						X				X	X				X					X		X					
8	155	Total Hydrocarbon Analyzer																											
9	161	Inventory Control System						X		X													X		X	X		X	X
10	162	Lab Materials Pack & Hand. Equip.			X										X						X		X		X				
11	163	Test/Ckout/Calibration Instrumentation		X	X			X	X		X	X				X			X		X	X				X		X	X
12	106	Neck Baro-Cuff		X					X									X	X	X		X						X	
13	113	Blood Gas Analyzer					X		X	X		X			X				X									X	
14	61	Mass Spectrometer														X													
15	112	Plant HPLC Ion Chromatograph			X		X	X	X	X	X		X		X			X	X	X					X			X	X
16	147	Head Torso Phantom		X	X					X	X	X									X	X						X	
17	63	Pulmonary Gas Cylinder Assem.													X														
18	110	Plant Gas Chromatograph/Mass Spec														X									X				
19	115	Chemistry System					X						X	X															
20	138	Hematology					X						X	X										X					
21	34	Sample Preparation Device			X								X										X	X	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														X							
25	99	Animal Biotelemetry System		X		X		X	X	X	X	X							X			X	X					X	X
26	100	Blood Pressure & Flow Instrumentation																											
27	109	Venous Pressure Transducer/Display									X																		
28	129	Cell Handling Accessories											X											X					
29	57	Bag-In-Box													X							X						X	
30	111	Plant Gas Cylinder Assem.													X										X		X		
31	119	Gas Cylinder Assembly													X												X		
32	130	Cell Harvester																			X			X		X			
		Total Functions/Assemblies	1	6	6	5	4	10	7	5	5	8	6	3	9	4	2	4	7	4	6	10	4	5	8	4	4	10	6

Representive List of Functions/Assemblies

Table 2.2-4 SBI Hardware Items for Commonality

14

Table 2.3 Commonality List of Functions/Assemblies

Function/Assembly H/W List from Table 5.4.2		Possible Number of SBI H/W Items with Common Functions/Assemblies	Percent Cost Decrease
1	Aerosol Generator	1	0
2	Amplifiers	6	51-59
3	Automation/Robotics	6	51-59
4	Cameras/Video	5	47-55
5	Centrifuge	4	43-51
6	Computers & Accessories	10	59-66
7	Converters	7	54-61
8	Detectors	5	47-55
9	Displays-Transducer	5	47-55
10	Environmental Control	8	55-63
11	Fluid Handling	6	51-59
12	Freezers	3	37-43
13	Gas Handling	9	57-65
14	Mass Spectrometer	4	43-51
15	Microbial Monitoring	2	25-31
16	Motors	4	43-51
17	Power Supply	7	54-61
18	Pumps	4	43-51
19	Radiation Handling	6	51-59
20	Recorders	10	59-66
21	Sample Prep Animal	4	43-51
22	Sample Prep Human	5	47-55
23	Sample Prep Plant	8	55-63
24	Scintillation Counter	4	43-51
25	Storage Locker	4	43-51
26	Temp.Press.Hum. Monitor	10	59-66
27	Thermal/Shock Isolation	6	51-59

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 Modularity & Commonality and associated cost experience. Library searches were made using titles, authors, key words, acronyms, phrases, synonyms, time periods and any possible related activities to modularization and commonality. Interviews with personnel in the various scientific disciplines were made throughout the initial portion of the study.

4.1 Documentation Sources

There were many personal & telephone interviews with knowledgeable personnel in the various scientific fields. These interviews are summarized in Appendix B.

The following documentation sources were checked during the initial portion of the study.

4.1.1 Common 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.

4.1.2 Trade Study Bibliography for Modularity & Commonality

Particular reference information from Appendix B that is of special importance to modularity/commonality is repeated in Table 4.1.2.

4.2 Documentation Data

Cost effective reuse and checkout of hardware prior to launch will require an emphasis on standard tests, long design history of components, and modularity in components with a readily available set of spares. The program should emphasize maintainability, which must be made a priority at the beginning of the program during conceptual design. Although the belief is widespread that modularity and accessibility for maintenance and checkout will increase cost and weight, the experiences of Solar Max and the prelaunch history of the Hubble Space Telescope have refuted this thinking. The actual weight penalty for modularization of the Hubble was less than 400 lbs. on a 25,000 lb system. Had the modularization been initiated at conceptual design, Hubble Telescope engineers maintain there would not have been any weight penalty. Both Solar Max and Hubble system engineers have stated that modularity (ref the Space Assembly Maintenance and Servicing Study Report, USAF Space Division, 1988).

The Skylab program used a common amplifier for many of the Physiological Monitoring System (PMS) sensors. This amplifier was microminiaturized and became the standard amplifier throughout the program. The miniaturization was accomplished by reduction in size and weight of the electronic sensors which also reduced the cost of the various modules in the different hardware items. This same basic common microminiaturized amplifier is scheduled for use by the SBI Bioinstrumentation & Physiological Monitoring Group. (Appendix A lists this group 3)

Table 4.1-2 Bibliography for Modularity and Commonality

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 Modularity and Commonality

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 Implementation 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 Modularity and Commonality

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

Table 4.1-2 Bibliography for Modularity and Commonality

ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
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
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
SBI44	Huffstetler, W.	Skylab Biomedical Hardware Development		AIAA 20th Annual Meeting		Los Angeles, CA	08/22/74
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

Table 4.1-2 Bibliography for Modularity and Commonality

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 Modularity and Commonality

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
SBI89	Boeing	Space Station Program Commonality Plan Draft 3		Boeing	D683-10112-1		10/31/88

5.0 Modularity/Commonality Trade Study

5.1 Guidelines for Modularity/Commonality Functional Elements

Modular functional elements are readily replaceable Modules should be plug-in with blind-mating connectors, guides, and hold-down hardware that facilitates installation and removal.

Modular functional elements are readily maintainable Individual elements should have well-defined functional characteristics to facilitate trouble shooting and allow the use of automatic test sets - module design should enhance accessibility for servicing.

Modular functional elements facilitate system modification and expansion Individual elements should have well-defined interface characteristics of individual functions should be reasonably general to allow application flexibility.

Modular functional elements may not be adaptable to incorporation of technological advances. The chosen functional level might not readily accômmodate a new approach to component usage.

Common items should perform the same function as another item, which does not harm or degrate the system performance of that individual hardware item.

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 implementation of modularity and commonality. 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 method 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 (8.68 M^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 modularization and commonality. This list was further examined for those items that can be considered as a sample set of candidates for possible modularization (Table 5.2-2) and for commonality (Table 5.2-3). This list showing the possible level of modularity and commonality was developed using all available resources within the constraints of this trade study. This assessment of possible candidates 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.

5.2.1 Modularity Candidate Sample Set

All of the items in Table 5.2-2 were analyzed to determine if the entire item could be modularized or at least a portion of the components within the item could be modularized. The items that did not meet this category are marked with a No in the "Modularity Potential Column" on Table 5.2-2. The confidence level is an indication of the knowledge and understanding of the individual item at the time of this study. There are 5 items out of the 32 that had insufficient data due to the fact that they are new developments still under the conception phase. There were two areas where the items which have modularization potential were grouped together due to the interrelationship of the individual items (function checks and experiments requires more than one item to complete) These two groups are labeled (P) for Pulmonary and (PL) for Plant Monitoring. There are other areas which may be grouped together but were not considered in the study. The Pulmonary Group has a total of (11) eleven hardware items (#56 thru 66 Appendix A Group 3A) Most of these items are interrelated which is why these items should be packaged (modularized) together. A portion of this group is already packaged together and will be flown on SLS-1 as Astronaut Lung Function Equipment (ALFE). The mass spectrometer is the heaviest item in this group and special handling will be required when dealing with gas analysis (molecular fragments according to their atomic mass). There can be a tremendous cost and weight savings if the mass spectrometer can be used for other SBI functions (Plant Monitoring etc.). Some of the components in the mass spectrometer may be common; however, the details and practicality of adapting the unit to different applications is not known at this time. The CELSS hardware item is presently being planned as a separate experiment for plant monitoring ("crop growth research facility for seed-to-seed crop studies"). This appears to be the same function as the other items for plant monitoring and was therefore placed in this group.

The modularity candidate sample set was derived by filtering the "vital" list in Table 5.2-2 to remove SBI hardware items which did not appear to warrant analysis at this time. The sample set (Table 5.2.1) resulted from removing hardware items from the "vital" list that have:

A. Insufficient data to preform assessments.

B. No modularization potential and assessment confidence level is high.

C. Modularity potential, but the assessment level is low (unless part of a group).

5.2.2 Commonality Candidate Sample Set

The candidate hardware items were defined for commonality by sorting the modularity/commonality data base on the basis of having a common function/assemblies. The "vital" hardware items were evaluated for the potential of containing functions/assemblies in a representative list that was considered for this SBI trade study. A subjective analysis was performed as to which hardware items might use each given function/assembly. The amplifier has six areas where it might be used. The Pulmonary Function Equipment Storage Assembly hardware item would not use an amplifier; however, the Pulmonary Group will more than likely use this function. This type of analysis was used throughout the study for commonality. The numbers for common items will be subjective; however, this methodology was used to make a selection of those hardware items that may have possible potential cost savings through commonality. The level of commonality was analyzed to the lowest level possible with the available information. In most cases this was the assembly level or in a few cases subassembly. The level of commonality has a direct effect on the implementation of the common solution and the degree of commonality, which also has a direct affect on the overall cost of the program. (Ref. SBI #88)

All 28 (32-4 with insufficient data) of the vital hardware items had some areas of commonality (Table 5.2-3). The maximum number of common functions/assemblies shown on Table 5.2-3 is ten (10) and the smallest number is one (1).

5.3 Relative SBI Modularization and Commonality Cost Impact Analysis

Since modularity and commonality have multielements related design aspects (i.e. it is difficult to have successful modularity/commonality in a single equipment element), no example hardware item candidate was selected for individual cost analysis. The subjects were addressed in the multielement context or as related to the function that is modular or common.

5.3.1 Modularization Cost Impact Analysis

The redesign of the items listed for modularity will in most cases add additional cost. However, this redesign cost if incorporated into the initial conception phase may not add cost to the item. This initial increase in cost will in most cases be make up when life cycle analysis is incorporated into the overall cost. (Appendix C Table 7-1) The grouping of the hardware items may reduce an overlap in development cost if controlled by one organization.

5.3.2 Commonality Cost Impact Analysis

The candidate list of 32 hardware items was analyzed for commonality using the representative list of 27 functions/assemblies. The number of "Vital" SBI hardware items having potential application for each type of function/assembly has been compiled in Table 5.3.2. A lower level of commonality (i.e. subassembly/component) would increase the number of potential functions that would be common to the individual hardware items. This lower level of commonality may also allow for modularity of various subassemblies that would be common to more items. The number of common items would have a direct effect upon other areas such as the number of spares required, maintainability, transportation, packaging, storage, power requirements, crew training, crew time lines, and other potential cost drivers.

5.3.2.1 Empirical Cost Relationships

Analysis of the relative cost impact resulting the use of various numbers of common functions/assemblies in Table 5.3.2 must be based on empirical cost relationships since hardware definitions are not available. Appendix C contains a detailed definition of cost assessment techniques which can be applied to commonality. The techniques relate theoretical first unit

(TFU) cost to design and development (DD) cost and then applies learning factors to demonstrate the cost reduction potential for common application of hardware in SBI.

To further demonstrate how this assessment was applied to this trade study the formula used for calculations will be repeated from Appendix C Section 3.2.

CP_1 = D+Dcost (.35 or .15 D&D x L.F.) N

CP_1	= Cost of a single program or one (1) item
D&D	= Design and Development Cost
TFU	= Theoretical First Unit Cost
L.F.	= Learning Factor
N	= Number of Common Functions/Assemblies

For calculations used in this study

.15 and .35 D&D	= TFU
.80	= L.F.
Range of 0 to (10) Ten	= N

The Design and Development (D&D) cost factors of .15 and .35 were both used to give the range for the Theoretical First Unit (TFU) cost. The learning factor (L.F.) has a wide range based upon the type of hardware, type of fabrication, and type of manufacturing (automation). Table 3-5 in Appendix C displays the range of learning factors. This trade study used 80% (0.80) as an average learning factor (L.F.). The number (N) of common functions/assemblies for the SBI hardware items is from Table 5.2-3 (Data base print out). These numbers were generated from the information available at the time of this study. This same information on Table 5.2-3 is repeated in Table 2.2-3 Executive Summary.

The Figures 3-2 and 3-3 in appendix C were generated using (.35 D&D and .80 L.F. for Figure 3-2) and (.15 D&D and .80 L.F. for Figure 3-3) However, these figures only show (5) five items (N) and are shown primarily to dramatize the tremendous cost reduction for the first few units.

5.3.2.2 Lot Certification

The certification of various lots within the SBI Program is not feasible at this time.

5.3.2.3 Design Cost Reduction

The design cost reductions of the SBI items can be seen in Table 5.3.2-1 which shows the best possible candidates and the potential cost percentage reduction for these functions. This cost reduction is for applications within the SBI hardware list. There may be considerable more reduction if the trade study were to include other areas within Space Station Freedom. Many of the SBI commonality functions are common to the functions of Crew Health Care (CHeC) System, Extended Crew Operations (EDCO), and other Life Science activities. SBI #48 & 76.

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	38
3	84	Soft Tissue Imaging System	3	300.0	2100	59	35	48
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	81	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	22.0	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	52	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 Li. .ing for Modularity Sample Selection Assesment

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

Table 5.2-3 "Vital" Database Listing for Commonality Sample Selection Assesment

REPRESENTATIVE LIST OF FUNCTIONS AND ASSEMBLIES	PRIORITY # OF SBI HW. ITEM	HW ID #	SBI HARDWARE NAME	COUNT
** AERSOL GENERATOR				
AERSOL GENERATOR	2	169	Gas Grain Simulator	1
** Subtotal **				1
** AMPLIFIERS				
AMPLIFIERS	11	163	Test/Checkout/Calibration Instrumentation	1
AMPLIFIERS	12	106	Neck Baro-Cuff	1
AMPLIFIERS	16	147	Head/Torso Phantom	1
AMPLIFIERS	22	165	Experiment Control Computer System	1
AMPLIFIERS	23	62	Pulmonary Function Equipment Stowage Assembly	1
AMPLIFIERS	25	99	Animal Biotelemetry System	1
** Subtotal **				6
** AUTOMATION/ROBOTICS				
AUTOMATION/ROBOTICS	1	168	CELSS Test Facility	1
AUTOMATION/ROBOTICS	10	162	Lab Materials Packaging & Handling Equipment	1
AUTOMATION/ROBOTICS	11	163	Test/Checkout/Calibration Instrumentation	1
AUTOMATION/ROBOTICS	15	112	Plant HLPC Ion Chromatograph	1
AUTOMATION/ROBOTICS	16	147	Head/Torso Phantom	1
AUTOMATION/ROBOTICS	21	34	Sample Preparation Device	1
** Subtotal **				6
** CAMERAS/VIDEO				
CAMERAS/VIDEO	1	168	CELSS Test Facility	1
CAMERAS/VIDEO	2	169	Gas Grain Simulator	1
CAMERAS/VIDEO	6	74	Force Resistance System	1
CAMERAS/VIDEO	24	82	Motion Analysis System	1
CAMERAS/VIDEO	25	99	Animal Biotelemetry System	1
** Subtotal **				5

Table 5.2-3 "Vital" Database Listing for Commonality Sample Selection Assesment

REPRESENTATIVE LIST OF FUNCTIONS AND ASSEMBLIES	PRIORITY # OF SBI HW. ITEM	HW ID #	SBI HARDWARE NAME	COUNT
** CENTRIFUGE				
CENTRIFUGE	13	113	Blood Gas Analyzer	1
CENTRIFUGE	15	112	Plant HLPC Ion Chromatograph	1
CENTRIFUGE	19	115	Chemistry System	1
CENTRIFUGE	20	138	Hematology System	1
** Subtotal **				4
** COMPUTERS & ACCESSORIES				
COMPUTERS & ACCESSORIES	1	168	CELSS Test Facility	1
COMPUTERS & ACCESSORIES	2	169	Gas Grain Simulator	1
COMPUTERS & ACCESSORIES	6	74	Force Resistance System	1
COMPUTERS & ACCESSORIES	7	145	Automated Microbal System	1
COMPUTERS & ACCESSORIES	9	161	Inventory Control System	1
COMPUTERS & ACCESSORIES	11	163	Test/Checkout/Calibration Instrumentation	1
COMPUTERS & ACCESSORIES	15	112	Plant HLPC Ion Chromatograph	1
COMPUTERS & ACCESSORIES	22	165	Experiment Control Computer System	1
COMPUTERS & ACCESSORIES	24	82	Motion Analysis System	1
COMPUTERS & ACCESSORIES	25	99	Animal Biotelemetry System	1
** Subtotal **				10
** CONVERTERS				
CONVERTERS	1	168	CELSS Test Facility	1
CONVERTERS	2	169	Gas Grain Simulator	1
CONVERTERS	11	163	Test/Checkout/Calibration Instrumentation	1
CONVERTERS	12	106	Neck Baro-Cuff	1
CONVERTERS	13	113	Blood Gas Analyzer	1
CONVERTERS	15	112	Plant HLPC Ion Chromatograph	1
CONVERTERS	25	99	Animal Biotelemetry System	1
** Subtotal **				7
** DETECTORS				
DETECTORS	9	161	Inventory Control System	1
DETECTORS	13	113	Blood Gas Analyzer	1
DETECTORS	15	112	Plant HLPC Ion Chromatograph	1

Table 5.2-3 "Vital" Database Listing for Commonality Sample Selection Assesment

REPRESENTATIVE LIST OF FUNCTIONS AND ASSEMBLIES	PRIORITY # OF SBI HW. ITEM	HW ID #	SBI HARDWARE NAME	COUNT
DETECTORS	16	147	Head/Torso Phantom	1
DETECTORS	25	99	Animal Biotelemetry System	1
** Subtotal **				5
** DISPLAYS-TRANSDUCERS				
DISPLAYS-TRANSDUCERS	11	163	Test/Checkout/Calibration Instrumentation	1
DISPLAYS-TRANSDUCERS	15	112	Plant HLPC Ion Chromatograph	1
DISPLAYS-TRANSDUCERS	16	147	Head/Torso Phantom	1
DISPLAYS-TRANSDUCERS	25	99	Animal Biotelemetry System	1
DISPLAYS-TRANSDUCERS	27	109	Venous Pressure Transducer/Display	0
** Subtotal **				4
** ENVIRONMENTAL CONTROL				
ENVIRONMENTAL CONTROL	1	168	CELSS Test Facility	1
ENVIRONMENTAL CONTROL	2	169	Gas Grain Simulator	1
ENVIRONMENTAL CONTROL	6	74	Force Resistance System	1
ENVIRONMENTAL CONTROL	7	145	Automated Microbal System	1
ENVIRONMENTAL CONTROL	11	163	Test/Checkout/Calibration Instrumentation	1
ENVIRONMENTAL CONTROL	13	113	Blood Gas Analyzer	1
ENVIRONMENTAL CONTROL	16	147	Head/Torso Phantom	1
ENVIRONMENTAL CONTROL	25	99	Animal Biotelemetry System	1
** Subtotal **				8
** FLUID HANDLING				
FLUID HANDLING	7	145	Automated Microbal System	1
FLUID HANDLING	13	113	Blood Gas Analyzer	1
FLUID HANDLING	19	115	Chemistry System	1
FLUID HANDLING	20	138	Hematology System	1
FLUID HANDLING	21	34	Sample Preparation Device	1
FLUID HANDLING	28	129	Cell Handling Accessories	1
** Subtotal **				6

Table 5.2-3 "Vital" Database Listing for Commonality Sample Selection Assesment

REPRESENTATIVE LIST OF FUNCTIONS AND ASSEMBLIES	PRIORITY # OF SBI HW. ITEM	HW ID #	SBI HARDWARE NAME	COUNT
** FREEZERS				
FREEZERS	1	168	CELSS Test Facility	1
FREEZERS	19	115	Chemistry System	1
FREEZERS	20	138	Hematology System	1
** Subtotal **				3
** GAS HANDLING				
GAS HANDLING	1	168	CELSS Test Facility	1
GAS HANDLING	2	169	Gas Grain Simulator	1
GAS HANDLING	10	162	Lab Materials Packaging & Handling Equipment	1
GAS HANDLING	13	113	Blood Gas Analyzer	1
GAS HANDLING	15	112	Plant HLPC Ion Chromatograph	1
GAS HANDLING	17	63	Pulmonary Gas Cylinder Assembly	1
GAS HANDLING	29	57	Bag-in-Box	1
GAS HANDLING	30	111	Plant Gas Cylinder Assembly	1
GAS HANDLING	31	119	Gas Cylinder Assembly	1
** Subtotal **				9
** MASS SPECTROMETERS				
MASS SPECTROMETERS	2	169	Gas Grain Simulator	1
MASS SPECTROMETERS	11	163	Test/Checkout/Calibration Instrumentation	1
MASS SPECTROMETERS	14	61	Mass Spectrometer	1
MASS SPECTROMETERS	18	110	Plant Gas Chromatograph/Mass Spectrometer	1
** Subtotal **				4
** MICROBIAL MONITORING				
MICROBIAL MONITORING	1	168	CELSS Test Facility	1
MICROBIAL MONITORING	7	145	Automated Microbal System	1
** Subtotal **				2
** MOTORS				
MOTORS	1	168	CELSS Test Facility	1

Table 5.2-3 "Vital" Database Listing for Commonality Sample Selection Assesment

REPRESENTATIVE LIST OF FUNCTIONS AND ASSEMBLIES	PRIORITY # OF SBI HW. ITEM	HW ID #	SBI HARDWARE NAME	COUNT
MOTORS	2	169	Gas Grain Simulator	1
MOTORS	12	106	Neck Baro-Cuff	1
MOTORS	15	112	Plant HLPC Ion Chromatograph	1
** Subtotal **				4
** POWER SUPPLY				
POWER SUPPLY	1	168	CELSS Test Facility	1
POWER SUPPLY	2	169	Gas Grain Simulator	1
POWER SUPPLY	11	163	Test/Checkout/Calibration Instrumentation	1
POWER SUPPLY	12	106	Neck Baro-Cuff	1
POWER SUPPLY	13	113	Blood Gas Analyzer	1
POWER SUPPLY	15	112	Plant HLPC Ion Chromatograph	1
POWER SUPPLY	25	99	Animal Biotelemetry System	1
** Subtotal **				7
** PUMPS				
PUMPS	1	168	CELSS Test Facility	1
PUMPS	2	169	Gas Grain Simulator	1
PUMPS	12	106	Neck Baro-Cuff	1
PUMPS	15	112	Plant HLPC Ion Chromatograph	1
** Subtotal **				4
** RADIATION HANDLING				
RADIATION HANDLING	1	168	CELSS Test Facility	1
RADIATION HANDLING	2	169	Gas Grain Simulator	1
RADIATION HANDLING	10	162	Lab Materials Packaging & Handling Equipment	1
RADIATION HANDLING	11	163	Test/Checkout/Calibration Instrumentation	1
RADIATION HANDLING	16	147	Head/Torso Phantom	1
RADIATION HANDLING	32	130	Cell Harvestor	1
** Subtotal **				6
** RECORDERS				
RECORDERS	1	168	CELSS Test Facility	1

Table 5.2-3 "Vital" Database Listing for Commonality Sample Selection Assesment

REPRESENTATIVE LIST OF FUNCTIONS AND ASSEMBLIES	PRIORITY # OF SBI HW. ITEM	HW ID #	SBI HARDWARE NAME	COUNT
RECORDERS	2	169	Gas Grain Simulator	1
RECORDERS	6	74	Force Resistance System	1
RECORDERS	7	145	Automated Microbal System	1
RECORDERS	11	163	Test/Checkout/Calibration Instrumentation	1
RECORDERS	12	106	Neck Baro-Cuff	1
RECORDERS	16	147	Head/Torso Phantom	1
RECORDERS	24	82	Motion Analysis System	1
RECORDERS	25	99	Animal Biotelemetry System	1
RECORDERS	29	57	Bag-in-Box	1
** Subtotal **				10
** SAMPLE PREP. ANIMAL				
SAMPLE PREP. ANIMAL	9	161	Inventory Control System	1
SAMPLE PREP. ANIMAL	10	162	Lab Materials Packaging & Handling Equipment	1
SAMPLE PREP. ANIMAL	21	34	Sample Preparation Device	1
SAMPLE PREP. ANIMAL	25	99	Animal Biotelemetry System	1
** Subtotal **				4
** SAMPLE PREP. HUMAN				
SAMPLE PREP. HUMAN	7	145	Automated Microbal System	1
SAMPLE PREP. HUMAN	20	138	Hematology System	1
SAMPLE PREP. HUMAN	21	34	Sample Preparation Device	1
SAMPLE PREP. HUMAN	28	129	Cell Handling Accessories	1
SAMPLE PREP. HUMAN	32	130	Cell Harvestor	1
** Subtotal **				5
** SAMPLE PREP. PLANT				
SAMPLE PREP. PLANT	1	168	CELSS Test Facility	1
SAMPLE PREP. PLANT	2	169	Gas Grain Simulator	1
SAMPLE PREP. PLANT	9	161	Inventory Control System	1
SAMPLE PREP. PLANT	10	162	Lab Materials Packaging & Handling Equipment	1
SAMPLE PREP. PLANT	15	112	Plant HLPC Ion Chromatograph	1
SAMPLE PREP. PLANT	18	110	Plant Gas Chromatograph/Mass Spectrometer	1

Table 5.2-3 "Vital" Database Listing for Commonality Sample Selection Assesment

REPRESENTATIVE LIST OF FUNCTIONS AND ASSEMBLIES	PRIORITY # OF SBI HW. ITEM	HW ID #	SBI HARDWARE NAME	COUNT
RECORDERS	2	169	Gas Grain Simulator	1
RECORDERS	6	74	Force Resistance System	1
RECORDERS	7	145	Automated Microbal System	1
RECORDERS	11	163	Test/Checkout/Calibration Instrumentation	1
RECORDERS	12	106	Neck Baro-Cuff	1
RECORDERS	16	147	Head/Torso Phantom	1
RECORDERS	24	82	Motion Analysis System	1
RECORDERS	25	99	Animal Biotelemetry System	1
RECORDERS	29	57	Bag-in-Box	1
** Subtotal **				10
** SAMPLE PREP. ANIMAL				
SAMPLE PREP. ANIMAL	9	161	Inventory Control System	1
SAMPLE PREP. ANIMAL	10	162	Lab Materials Packaging & Handling Equipment	1
SAMPLE PREP. ANIMAL	21	34	Sample Preparation Device	1
SAMPLE PREP. ANIMAL	25	99	Animal Biotelemetry System	1
** Subtotal **				4
** SAMPLE PREP. HUMAN				
SAMPLE PREP. HUMAN	7	145	Automated Microbal System	1
SAMPLE PREP. HUMAN	20	138	Hematology System	1
SAMPLE PREP. HUMAN	21	34	Sample Preparation Device	1
SAMPLE PREP. HUMAN	28	129	Cell Handling Accessories	1
SAMPLE PREP. HUMAN	32	130	Cell Harvestor	1
** Subtotal **				5
** SAMPLE PREP. PLANT				
SAMPLE PREP. PLANT	1	168	CELSS Test Facility	1
SAMPLE PREP. PLANT	2	169	Gas Grain Simulator	1
SAMPLE PREP. PLANT	9	161	Inventory Control System	1
SAMPLE PREP. PLANT	10	162	Lab Materials Packaging & Handling Equipment	1
SAMPLE PREP. PLANT	15	112	Plant HLPC Ion Chromatograph	1
SAMPLE PREP. PLANT	18	110	Plant Gas Chromatograph/Mass Spectrometer	1

Table 5.2-3 "Vital" Database Listing for Commonality Sample Selection Assesment

REPRESENTATIVE LIST OF FUNCTIONS AND ASSEMBLIES	PRIORITY # OF SBI HW. ITEM	HW ID #	SBI HARDWARE NAME	COUNT
SAMPLE PREP. PLANT	21	34	Sample Preparation Device	1
SAMPLE PREP. PLANT	30	111	Plant Gas Cylinder Assembly	1
** Subtotal **				8
** SCINTILLATION COUNTER				
SCINTILLATION COUNTER	5	126	Scintillation Counter	1
SCINTILLATION COUNTER	9	161	Inventory Control System	1
SCINTILLATION COUNTER	11	163	Test/Checkout/Calibration Instrumentation	1
SCINTILLATION COUNTER	32	130	Cell Harvestor	1
** Subtotal **				4
** STORAGE LOCKER				
STORAGE LOCKER	2	169	Gas Grain Simulator	1
STORAGE LOCKER	23	62	Pulmonary Function Equipment Stowage Assembly	1
STORAGE LOCKER	30	111	Plant Gas Cylinder Assembly	1
STORAGE LOCKER	31	119	Gas Cylinder Assembly	1
** Subtotal **				4
** TEMP.PRESS.HUMIDITY MONITORING				
TEMP.PRESS.HUMIDITY MONITORING	1	168	CELSS Test Facility	1
TEMP.PRESS.HUMIDITY MONITORING	2	169	Gas Grain Simulator	1
TEMP.PRESS.HUMIDITY MONITORING	9	161	Inventory Control System	1
TEMP.PRESS.HUMIDITY MONITORING	11	163	Test/Checkout/Calibration Instrumentation	1
TEMP.PRESS.HUMIDITY MONITORING	12	106	Neck Baro-Cuff	1
TEMP.PRESS.HUMIDITY MONITORING	13	113	Blood Gas Analyzer	1
TEMP.PRESS.HUMIDITY MONITORING	15	112	Plant HLPC Ion Chromatograph	1
TEMP.PRESS.HUMIDITY MONITORING	16	147	Head/Torso Phantom	1
TEMP.PRESS.HUMIDITY MONITORING	25	99	Animal Biotelemetry System	1
TEMP.PRESS.HUMIDITY MONITORING	29	57	Bag-in-Box	1
** Subtotal **				10
** THERMAL/SHOCK ISOLATION				
THERMAL/SHOCK ISOLATION	9	161	Inventory Control System	1

Table 5.2-3 "Vital" Database Listing for Commonality Sample Selection Assesment

REPRESENTATIVE LIST OF FUNCTIONS AND ASSEMBLIES	PRIORITY # OF SBI HW. ITEM	HW ID #	SBI HARDWARE NAME	COUNT
THERMAL/SHOCK ISOLATION	15	112	Plant HLPC Ion Chromatograph	1
THERMAL/SHOCK ISOLATION	1	168	CELSS Test Facility	1
THERMAL/SHOCK ISOLATION	2	169	Gas Grain Simulator	1
THERMAL/SHOCK ISOLATION	11	163	Test/Checkout/Calibration Instrumentation	1
THERMAL/SHOCK ISOLATION	25	99	Animal Biotelemetry System	1
** Subtotal **				6
*** Total ***				151

Table 5.2.1 Database Listing of Modularity Candidate Sample Set

Item # Prioritized by Mass	HW Item #	Hardware Item Name	Sufficient Data Available	Modularity	Modularity Confidence Level
1	168	CELSS Test Facility	Yes	PL	High
2	169	Gas Grain Simulator	Yes	Item	High
5	126	Scintillation Counter	Yes	Item	High
7	145	Automated Microbal System	Yes	Item	High
9	161	Inventory Control System	Yes	Item	High
11	163	Test/Checkout/Calibration Instrumentation	Yes	Item	High
12	106	Neck Baro-Cuff	Yes	Item	High
14	61	Mass Spectrometer	Yes	P	Low
15	112	Plant HLPC Ion Chromatograph	Yes	PL	High
17	63	Pulmonary Gas Cylinder Assembly	Yes	P	Low
18	110	Plant Gas Chromatograph/Mass Spectrometer	Yes	PL	Low
22	165	Experiment Control Computer System	Yes	Item	High
23	62	Pulmonary Function Equipment Stowage Assembly	Yes	P	Low
29	57	Bag-in-Box	Yes	P	Low
30	111	Plant Gas Cylinder Assembly	Yes	PL	Low

Table 5.3.2 Commonality List of Functions/Assemblies

Function/Assembly H/W List from Table 5.4.2		Possible Number of SBI H/W Items with Common Functions/Assemblies	Percent Cost Decrease
1	Aerosol Generator	1	0
2	Amplifiers	6	51-59
3	Automation/Robotics	6	51-59
4	Cameras/Video	5	47-55
5	Centrifuge	4	43-51
6	Computers & Accessories	10	59-66
7	Converters	7	54-61
8	Detectors	5	47-55
9	Displays-Transducer	5	47-55
10	Environmental Control	8	55-63
11	Fluid Handling	6	51-59
12	Freezers	3	37-43
13	Gas Handling	9	57-65
14	Mass Spectrometer	4	43-51
15	Microbial Monitoring	2	25-31
16	Motors	4	43-51
17	Power Supply	7	54-61
18	Pumps	4	43-51
19	Radiation Handling	6	51-59
20	Recorders	10	59-66
21	Sample Prep Animal	4	43-51
22	Sample Prep Human	5	47-55
23	Sample Prep Plant	8	55-63
24	Scintillation Counter	4	43-51
25	Storage Locker	4	43-51
26	Temp.Press.Hum. Monitor	10	59-66
27	Thermal/Shock Isolation	6	51-59

6.0 Conclusions

6.1 Discussion

There appears to be a potential cost savings for packaging (modularity) the various hardware items into groups of related activities and then have these supervised by one organization. The optimum case is where identical items can serve multiple purposes and be controlled and standardized by a single specification. The utilization of common components will enhance modularity and standardization across all systems and result in design and operational cost savings. Modularization/commonality should only be considered after assurance that all candidate hardware items will provide the performance, reliability, safety, energy efficiency, and can be worked within the program milestones as if they were developed as unique.

During the early phase of a conceptual design there may be little cost savings (may even add cost) resulting from commonality. However, in the later phases these costs would more than balance out by the elimination of duplicate design activity. These cost saving from commonality could possibly be increased substantially when other programs (i.e. CHeC etc) are considered.

6.2 Implementation Guidelines

- Use commonality as extensively as possible, but use it on only two applications if only two are available. The savings is substantial.
- To assess savings, use realistic learning factors. All SBI elements will be subject to some degree of learning factor.
- Consider minor weight penalties as acceptable for purposes of implementing common modules in design.
- Look outside SBI at CHeCs, etc., to broaden the opportunity to save cost.

6.3 Other Considerations

This trade study was limited to only SBI hardware for modularity and commonality. Future studies should consider Crew Health Care System (CHeC), Extended Crew Operations (EDCO) and other Life Science activities. The potential cost savings from having common modules/components throughout all of these systems is substantial. The cost reduction for spares, maintainability, transportation, packaging, storage, power requirements, crew training, and other potential cost drivers should be considered in all future studies.

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~~ 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 CEP S=SBI F=FDCO 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 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)
	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

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

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 CEP, S=SRL, E=FDCO, W=WP-01

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)
	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	70 114	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. 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 Jackson 5-23

LIFE SCIENCES HARDWARE LIST FOR THE SPACE STATION FREEDOM ERA

Baselined: December 1988

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

A=ARC, J=JSC, '=Prime

Updated: 3/22/89

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
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				A
99	Animal Biotelemetry System	S	0.05	20	100				AJ'
100	Blood Pressure And Flow Instrumentation	S	0.06	20	200				J
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				A
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				J
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		AJ'
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				AJ'
162	Lab Materials Packaging & Handling Equipment	S	0.20	70	500				A'J
163	Test/Checkout/Calibration Instrumentation	S	0.20	70	200				AJ'
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

Appendix B - Complete SBI Trade Studies Bibliography

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

Appendix B - Complete SBI Trade Studies Bibliography

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

Appendix B - Complete SBI Trade Studies Bibliography

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 Fogress 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

Appendix B - Complete SBI Trade Studies Bibliography

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

Appendix B - Complete SBI Trade Studies Bibliography

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

Appendix B - Complete SBI Trade Studies Bibliography

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

Appendix B - Complete SBI Trade Studies Bibliography

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

Appendix B - Complete SBI Trade Studies Bibliography

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

Appendix C - Cost Assessment Techniques Summary

1.0 Introduction

1.1 Relative Cost Impact Analysis Task

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

1.2 Documentation Approach

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

1.3 Cost Method Overview

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2.0 General Development Cost Methods

2.1 Empirical Methods

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

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

Where

- $wt =$ weight of the system, module or assembly
- $n =$ an exponent selected on the basis of system complexity
- $df =$ a factor reflecting the amount of new design required (design factor)
- $C_1 =$ constant selected to establish the cost trend origin
- $C_2 =$ a constant to reflect special requirements such as tooling - can be zero

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

2.2 System Complexity Exponents (n)

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

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

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

2.3 Design Factors (df)

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

2.4 Method Summary

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

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

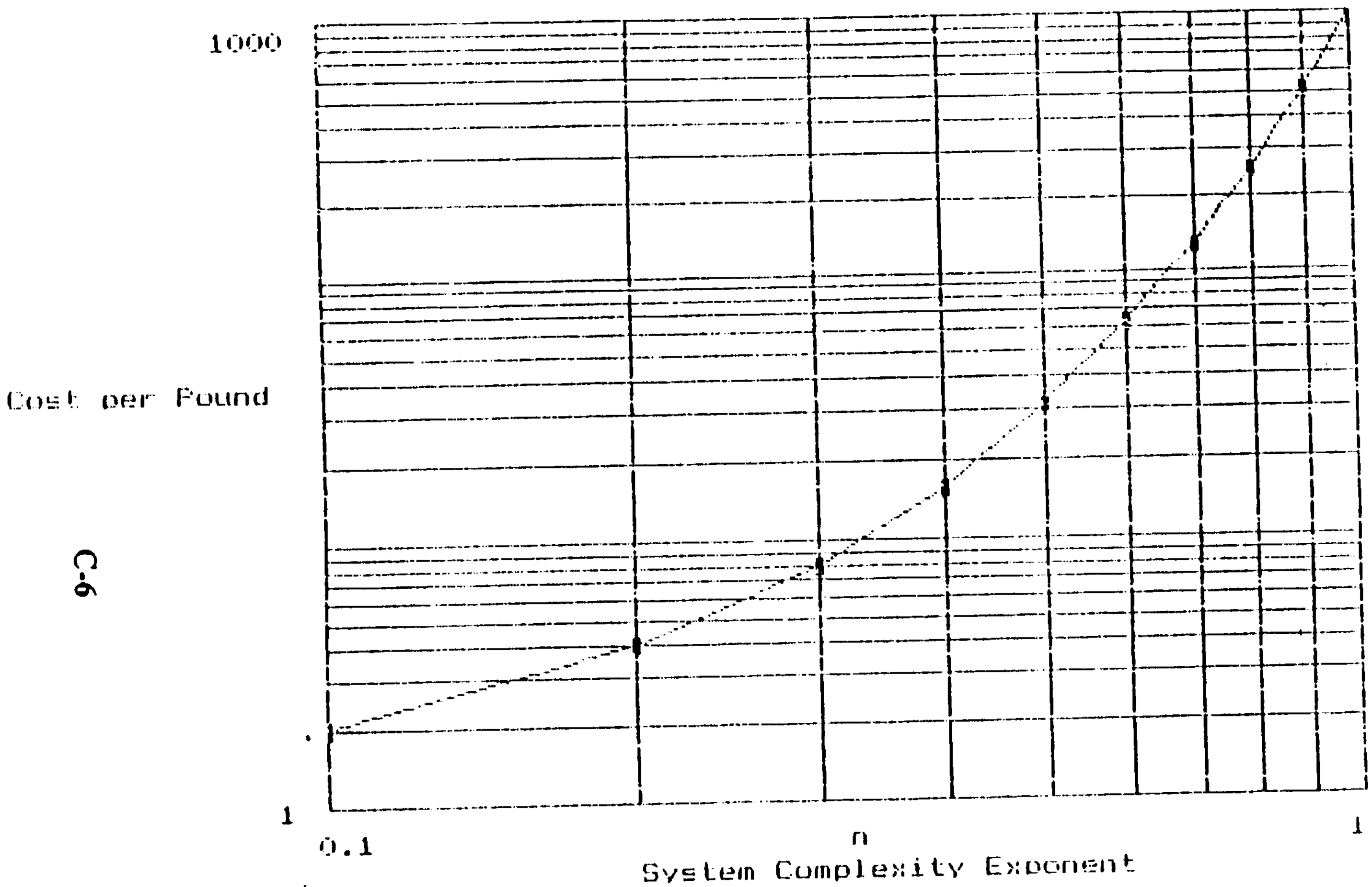


Figure 2-2 Design Factors

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

3.0 Cost Methods Applicable to Specific Trade Studies

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

3.1 Hardware Miniaturization Cost Drivers

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

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

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

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

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

Table 3-1
Miniaturization Guide Chart
n=.2

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

Table 3-2
Miniaturization Guide Chart
n=.4

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

Table 3-3
Miniaturization Guide Chart
n=.6

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

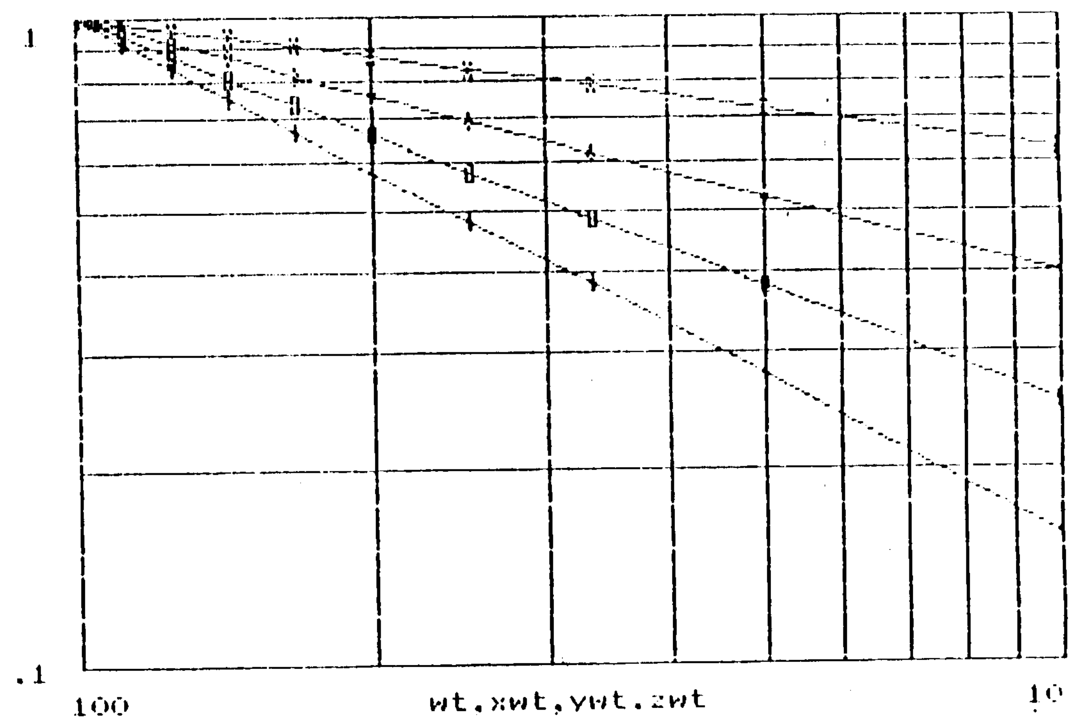
Table 3-4
Miniaturization Guide Chart
n=.8

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

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

Figure 3 -1

Variation of Cost as a Function of Weight



x = Normalized Cost for n =.2
y = Normalized Cost for n =.4
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).

<u>**Caution is advised!**</u> for several reasons:

1. Some items <u>cannot</u> be reduced in size.

2. Some items <u>should not</u> 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 <u>and</u> 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 tnan 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.

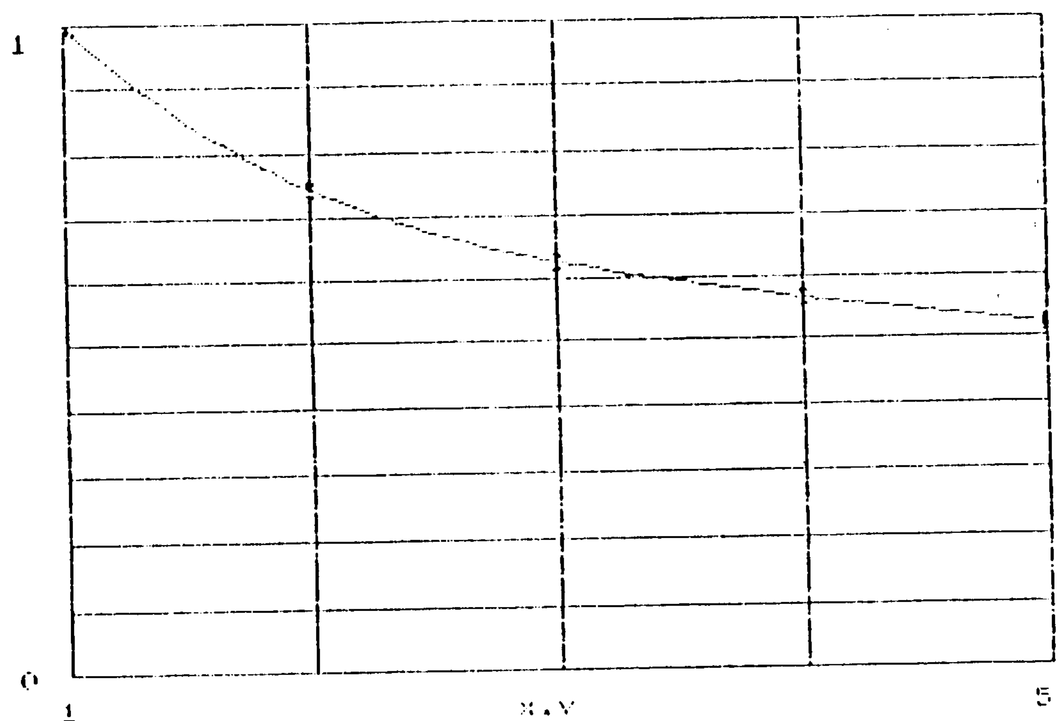
Specific modifications to COTS may be simple enough to invalidate the assumption that modifications and redesign costs are similar. If so, alternate COTS modification cost methods will be required and will reflect greater savings. Thus, the foregoing assumption degrades gracefully because it is conservative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

Relative Cost of
Hardware used in
Multiple Places

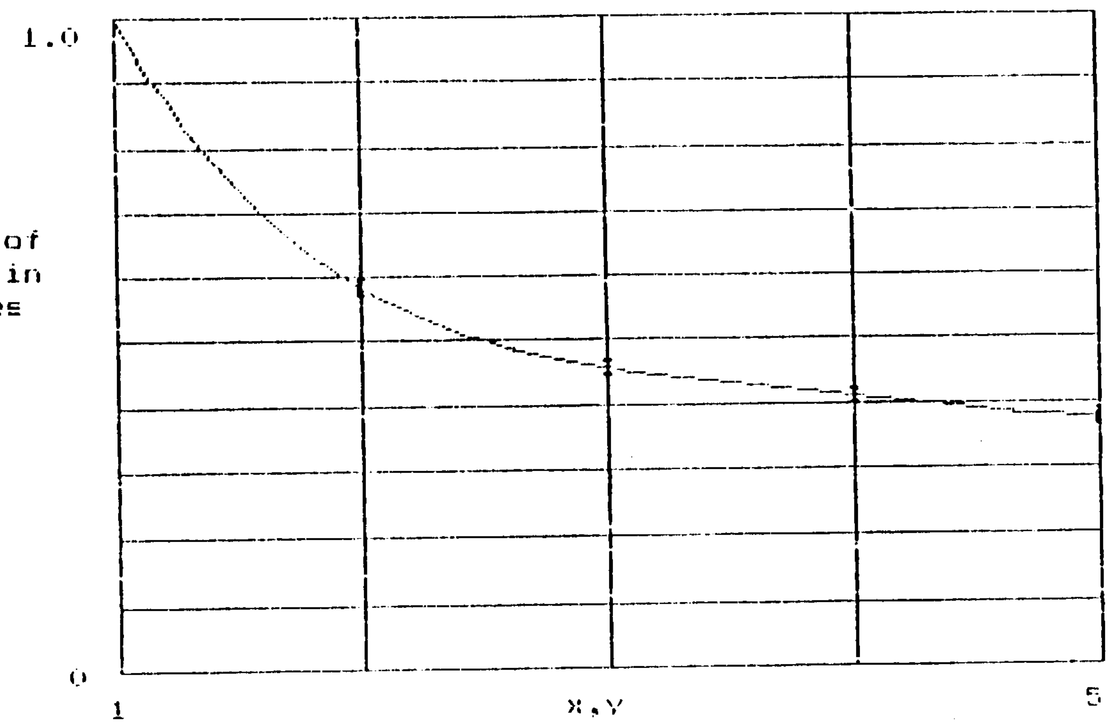


Number of Hardware Uses

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

Learning Factor = 80%

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



Relative Cost of
Hardware Used in
Multiple Places

Number of Hardware Uses

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

Learning Factor = 80%

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

System Complexity Factor (n) =.2

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

Notes: 1) All costs are in thousands of dollars

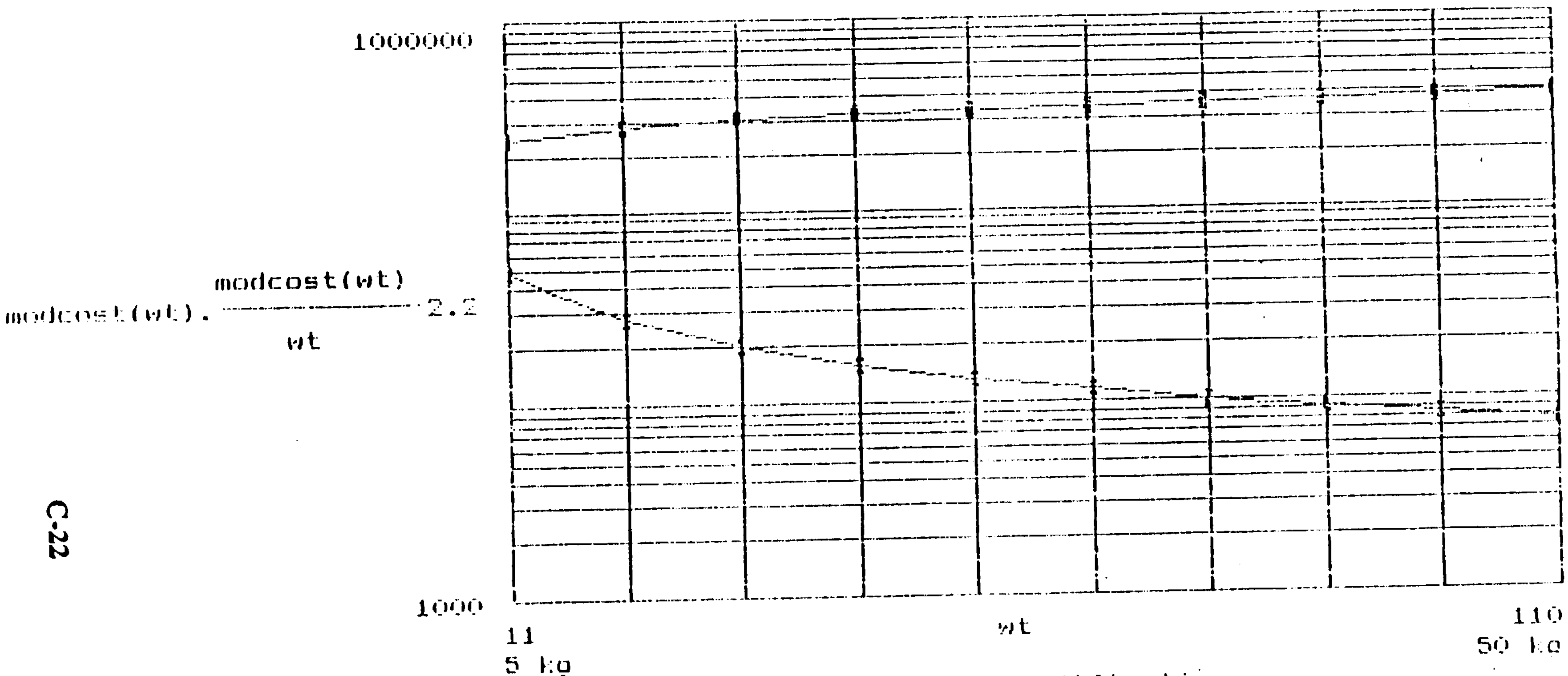
Table 3-8 Cost of Modifying Commercial Off-the Shelf Hardware

System Complexity Factor (n) =.4

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

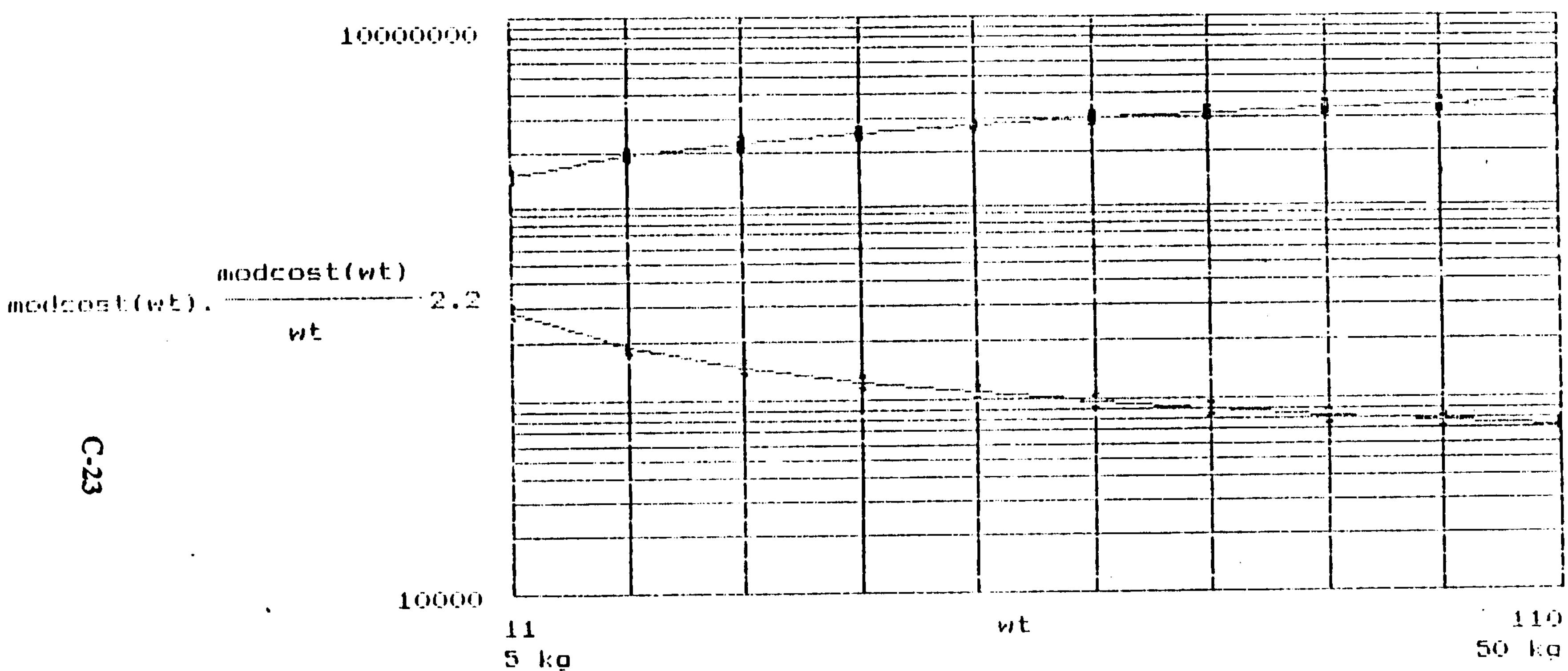
Notes: 1) All costs are in thousands of dollars

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



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

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



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

4.0 Testing Costs

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

4.1 Test Hardware

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

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

4.2 Integration Assembly and Checkout (IACO)

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

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

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

4.3 Test Operations

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

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

5.0 SE&I Costs

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

6.0 Program Management Costs

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

7.0 Life Cycle Costs

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

7.1 Study No. 3 - Miniaturization

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

7.2 Study No. 4 - Modularity and Commonality

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

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

7.3 Study No. 5 - COTS vs. New Hardware

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

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

7.4 Study No. 6 - Rack Compatibility

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

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

Table 7 -1 Life Cycle Cost

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

8.0 Recommendations

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

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

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

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

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Appendix D - Database Definition

Appendix D - Database Definition

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

Database Structure For SBI Trade Studies

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

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

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

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

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

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

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

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

Appendix D - Database Dictionary for Space Biology Initiative Trade Studies

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

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

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 Descriptions

Controlled Ecological Life Support System

CELSS

Title	Germination Experiment Kit
Element No	1
Revision	A
Project	FEAST

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.

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.

Data Downlink Reqs

1.5 MBPS Video; 1.6 KBPS Voice

Rack Mounted/Stowed STS Middeck

Hardware Specifications

Hardware Status Mod existing

Revision Date Apr 4, 1989

Hardware Description

Modified Plant Growth Unit.

Desired Features/Functions

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

Item Specific Support Equipt

Plant Growth Module

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

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 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.

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.

Hardware Status Planned

Revision Date Apr 4, 1989

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.

Item Specific Support Equipt

none

Design Status

New Design

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

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

Hardware Description

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

Objective

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

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

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.

Controlled Ecological Life Support System

Hardware Status Planned

Revision Date Apr 4, 1989

Title Nutrient Delivery Test H/W

Element No 4 **Revision** A

Project FEAST

Hardware Description

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

Objective

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

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

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

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 Stowed

Hardware Specifications

Design Status

New Design

Development Cost ($K) 3,475

Development Time (months) 24

Anticipated Launch Date 1992 & 1996

Risk Category 4

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

Title	CELSS Test Facility
Element No 5	**Revision** A
Project	FEAST

Hardware Status	Planned
Revision Date	Apr 4, 1989

Hardware Description

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

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.

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.

Controlled Ecological Life Support System

Hardware Status Planned

Revision Date

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 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

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

Item Specific Support Equipt

none

Data Downlink Reqs

none

Rack Mounted/Stowed Stowed

Hardware Specifications

Approximately the size of a NSTS Middeck Locker.

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

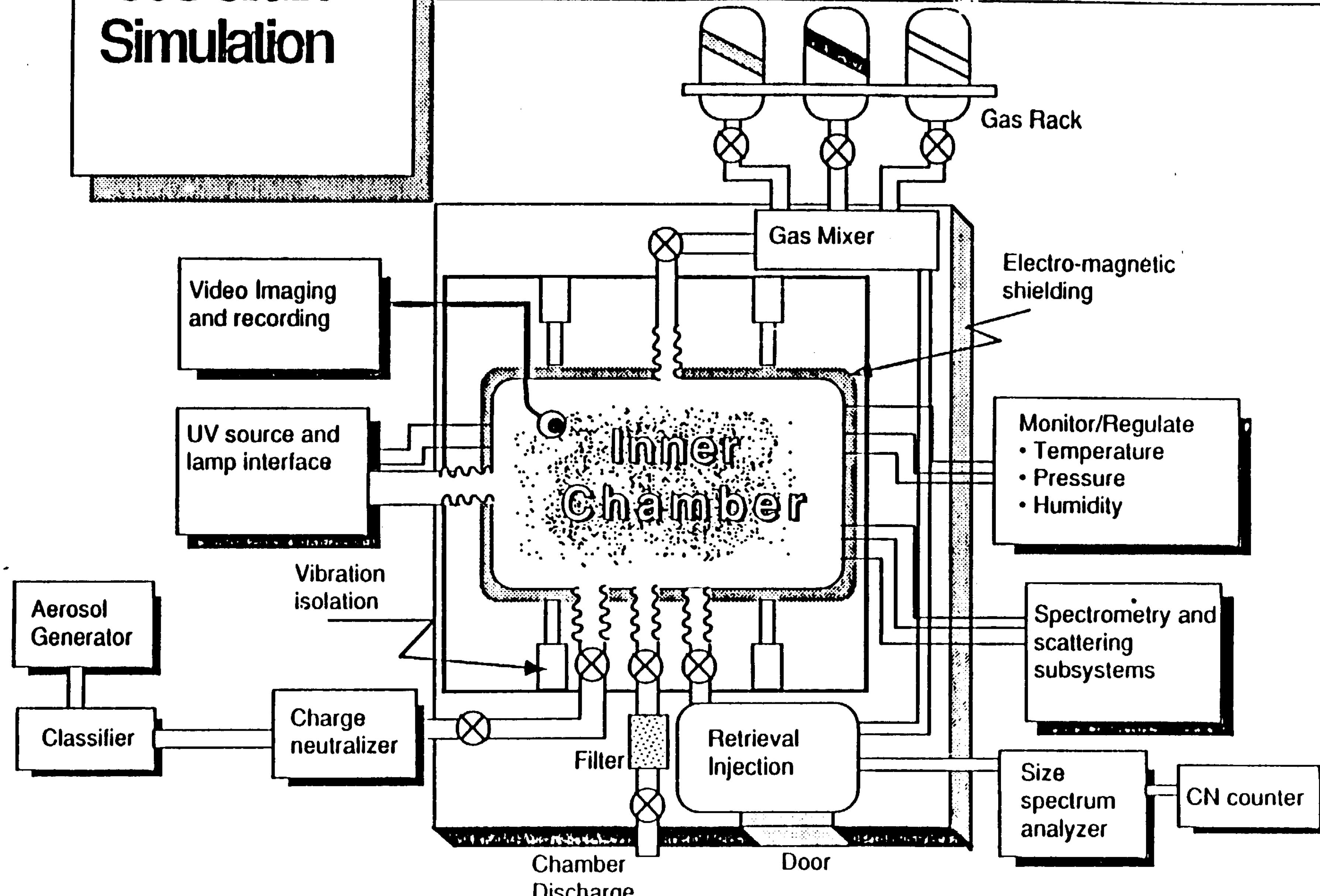
Safety Issues

Flight Opportunity PMC Space Station Freedom

Notes

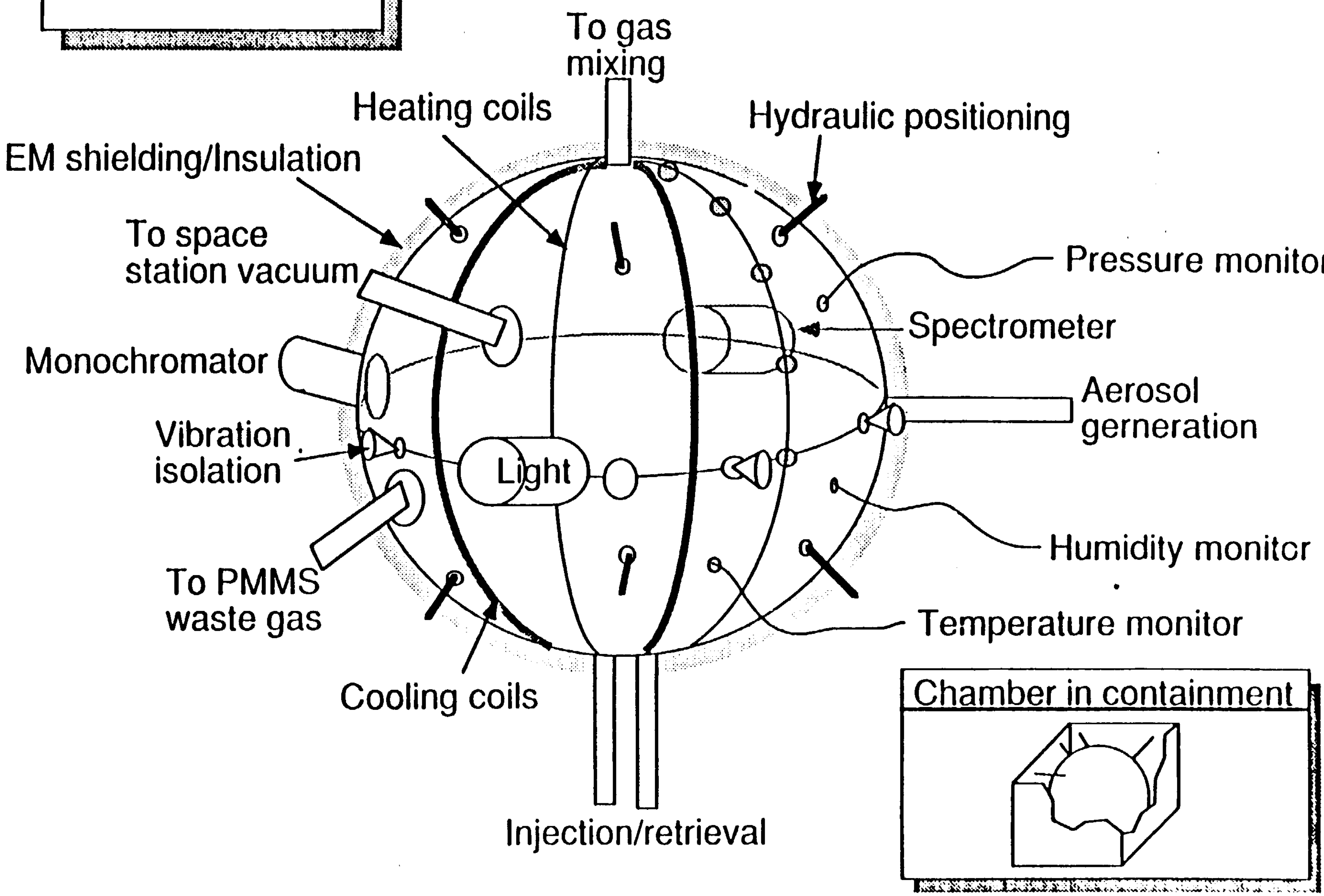
1. Provides for two separate and independent compartments: a.) Seed storage compartment and b.) Germination compartment.
2. Seed compartment could also be used for misc. equipment stowage

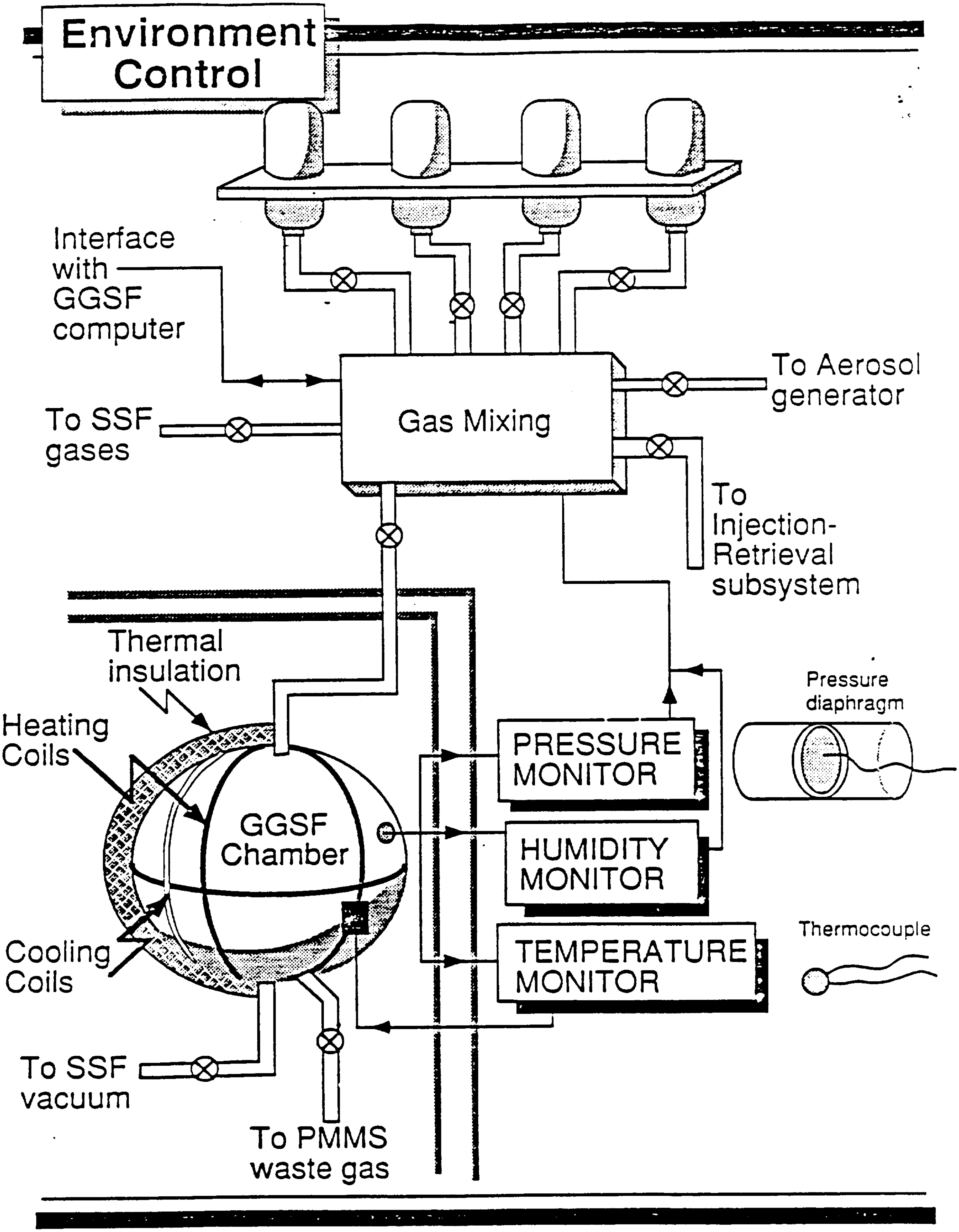
Gas Grain Simulation



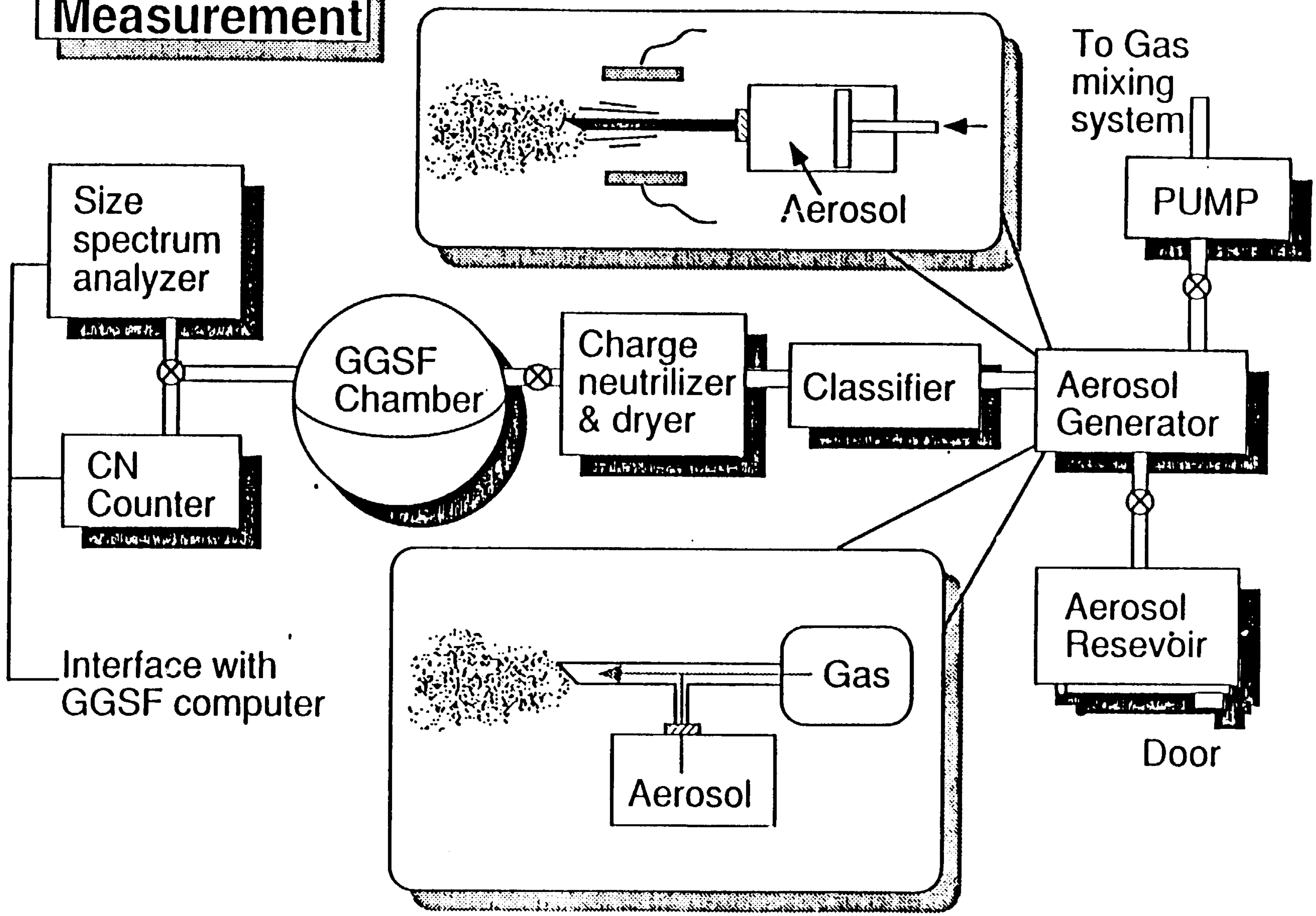
GGSF Chamber

Ports and component connections indicated

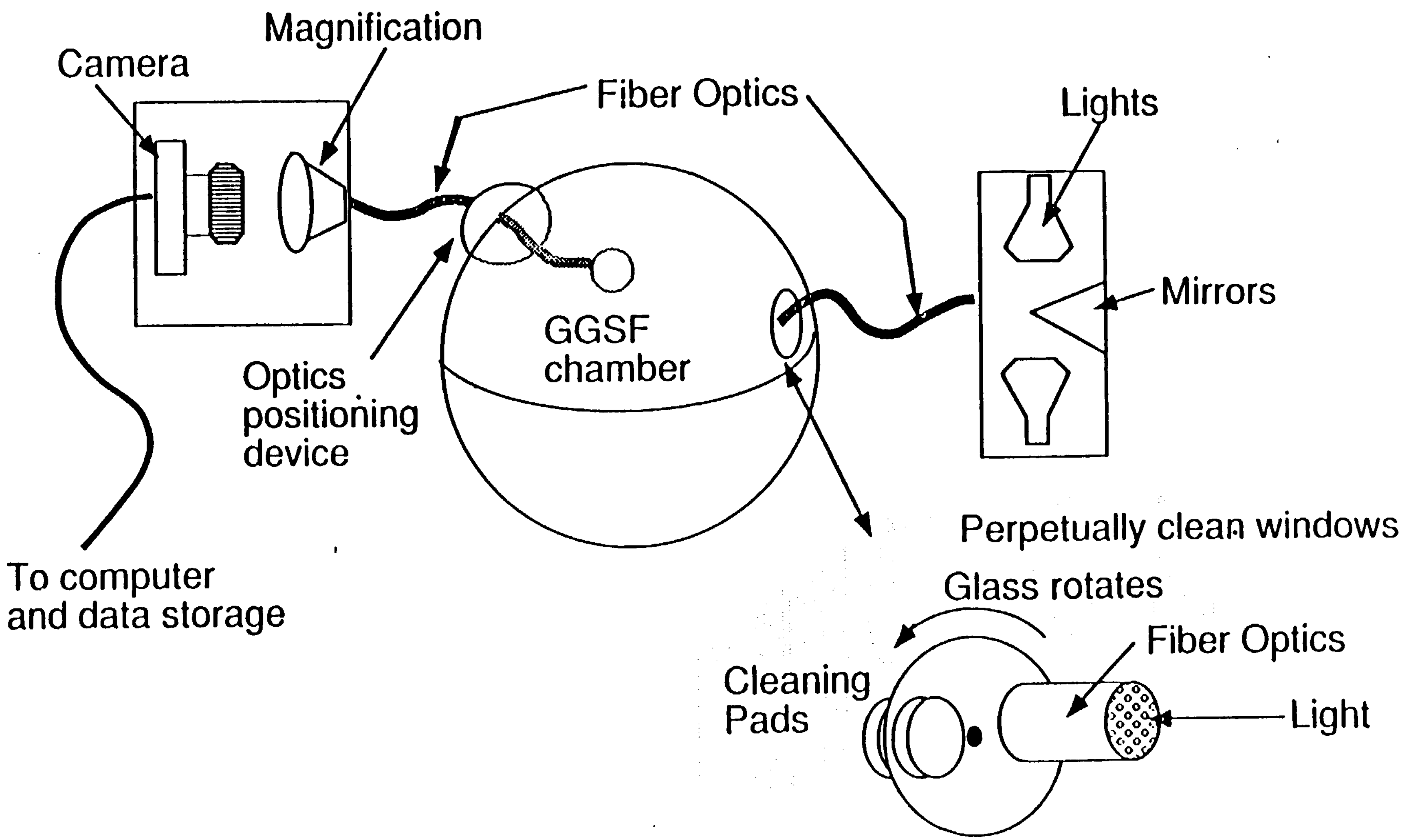



Environment Control
Interface with GGSF computer
To SSF gases
Gas Mixing
To Aerosol generator
To Injection-Retrieval subsystem
Thermal insulation
Heating Coils
GGSF Chamber
Cooling Coils
PRESSURE MONITOR
HUMIDITY MONITOR
TEMPERATURE MONITOR
Pressure diaphragm
Thermocouple
To SSF vacuum
To PMMS waste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

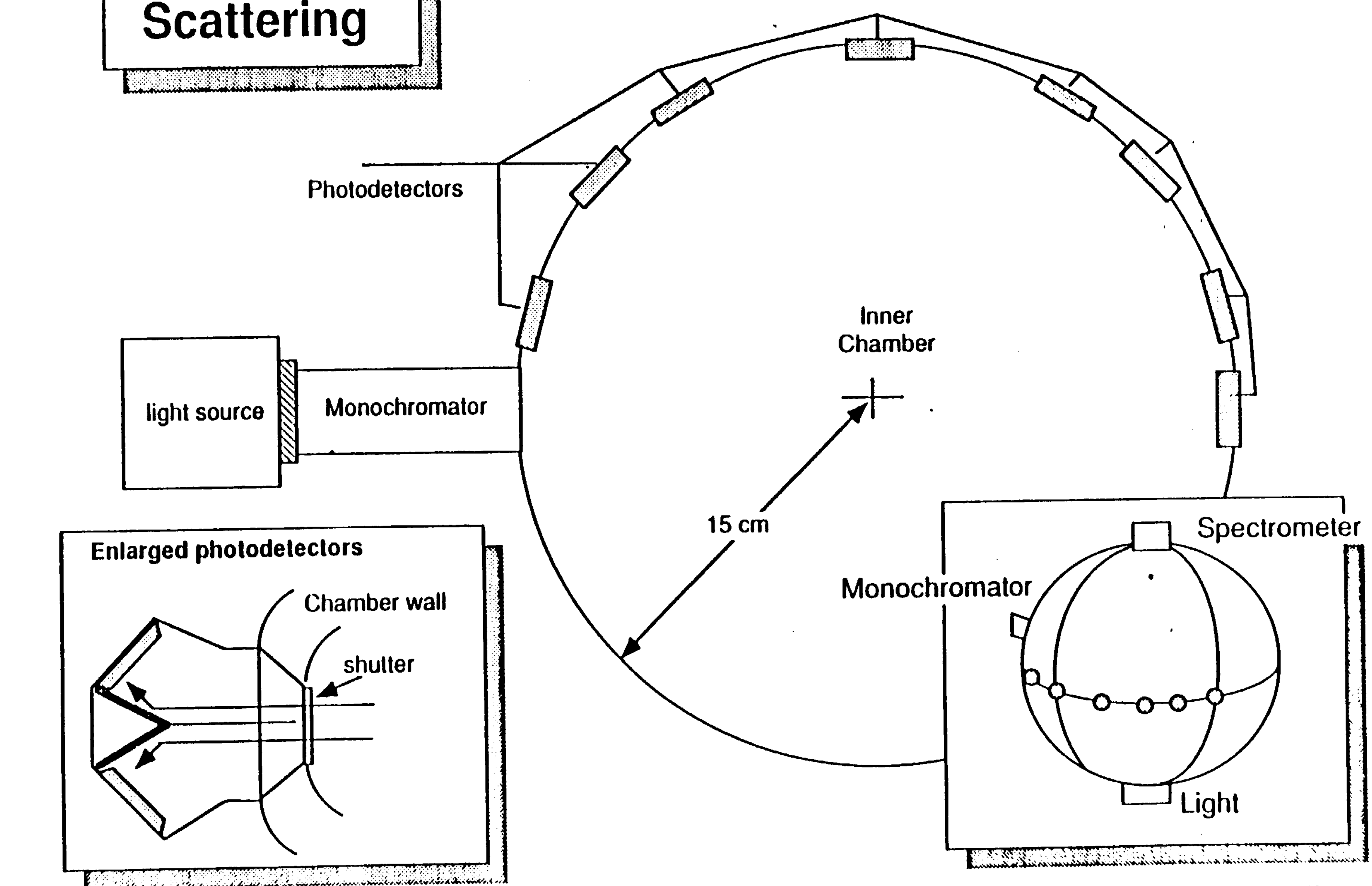
Aerosol Generation-Measurement



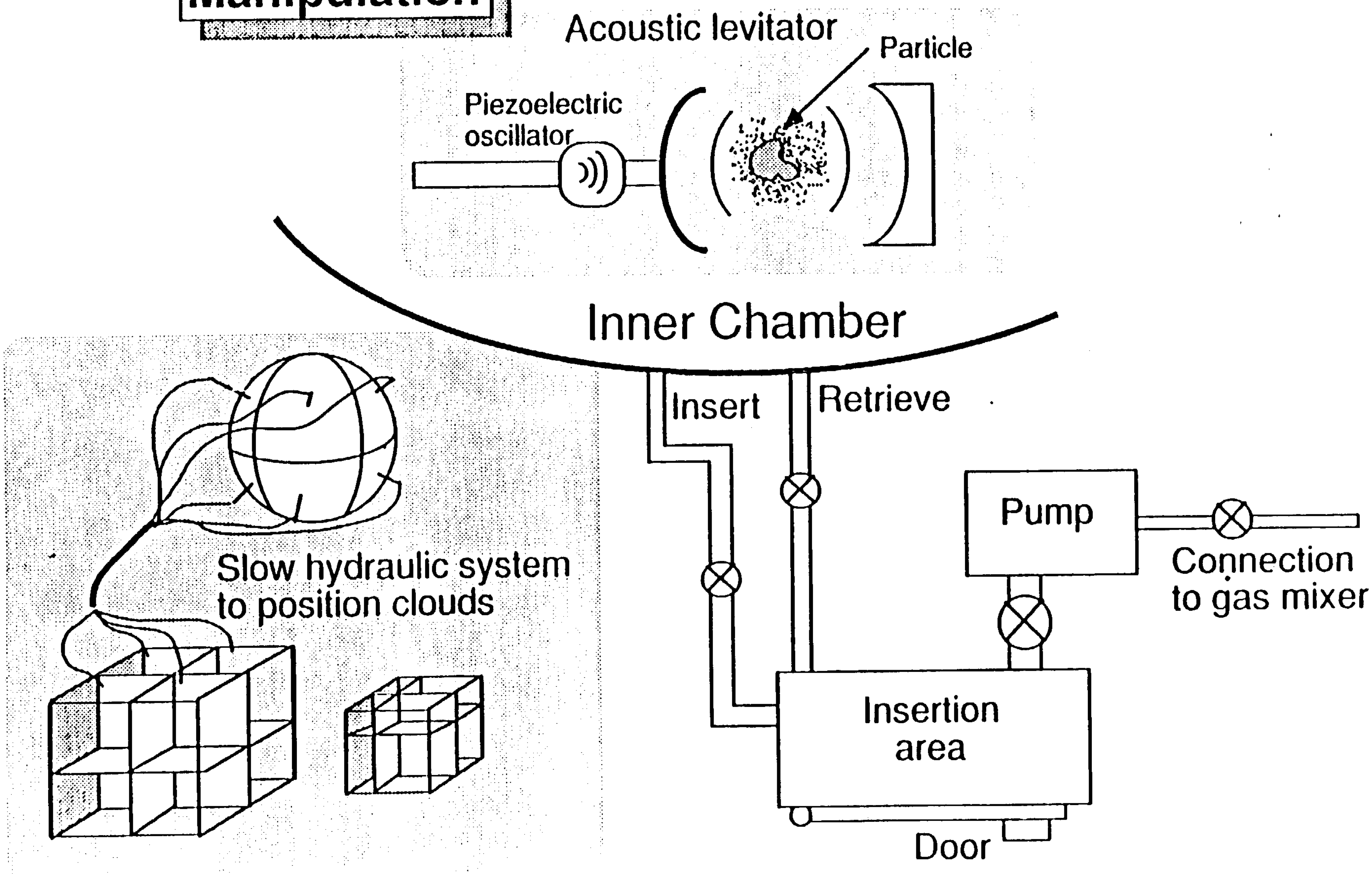
Imaging Systems



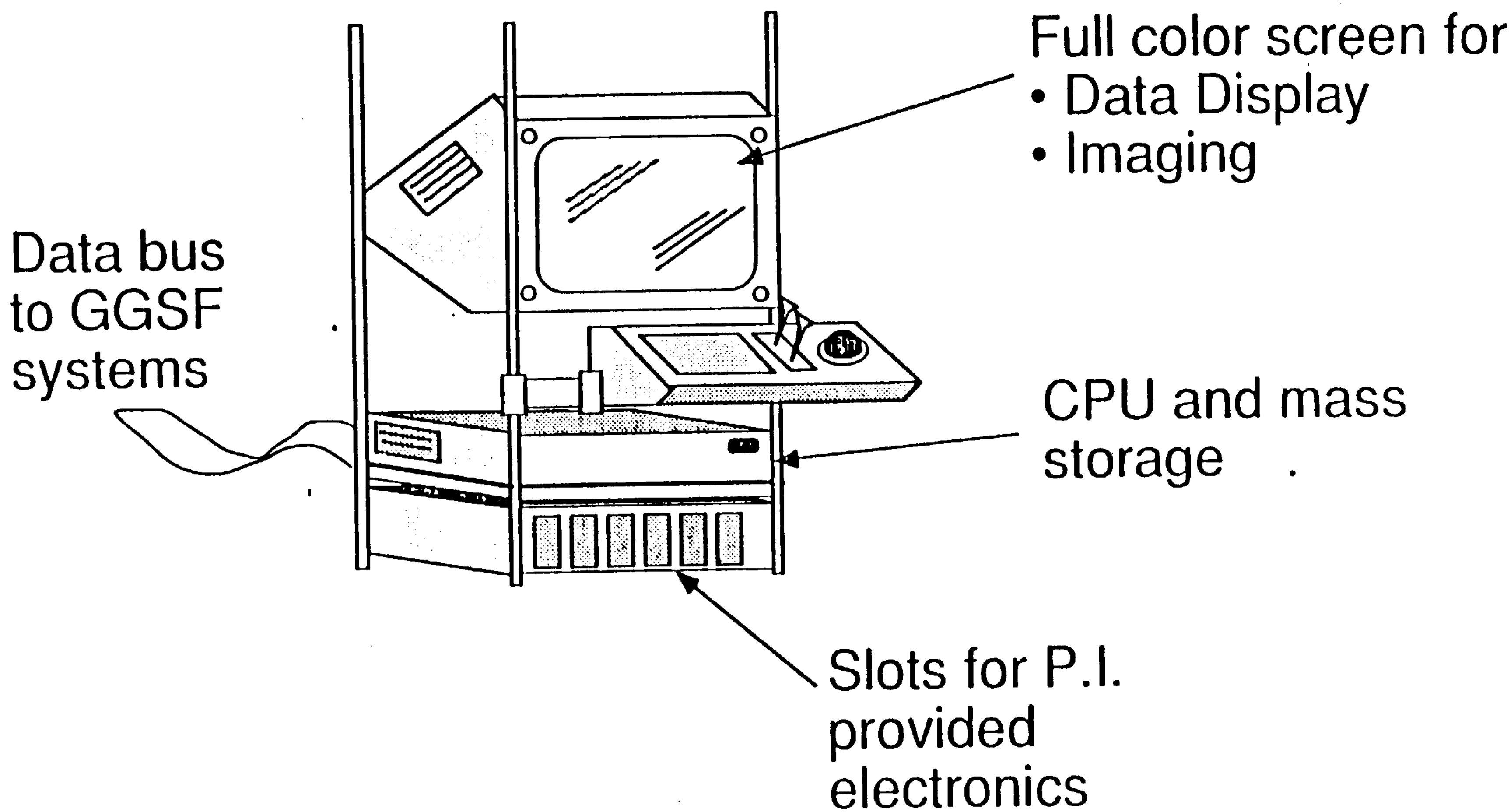
Spectrometry and Scattering



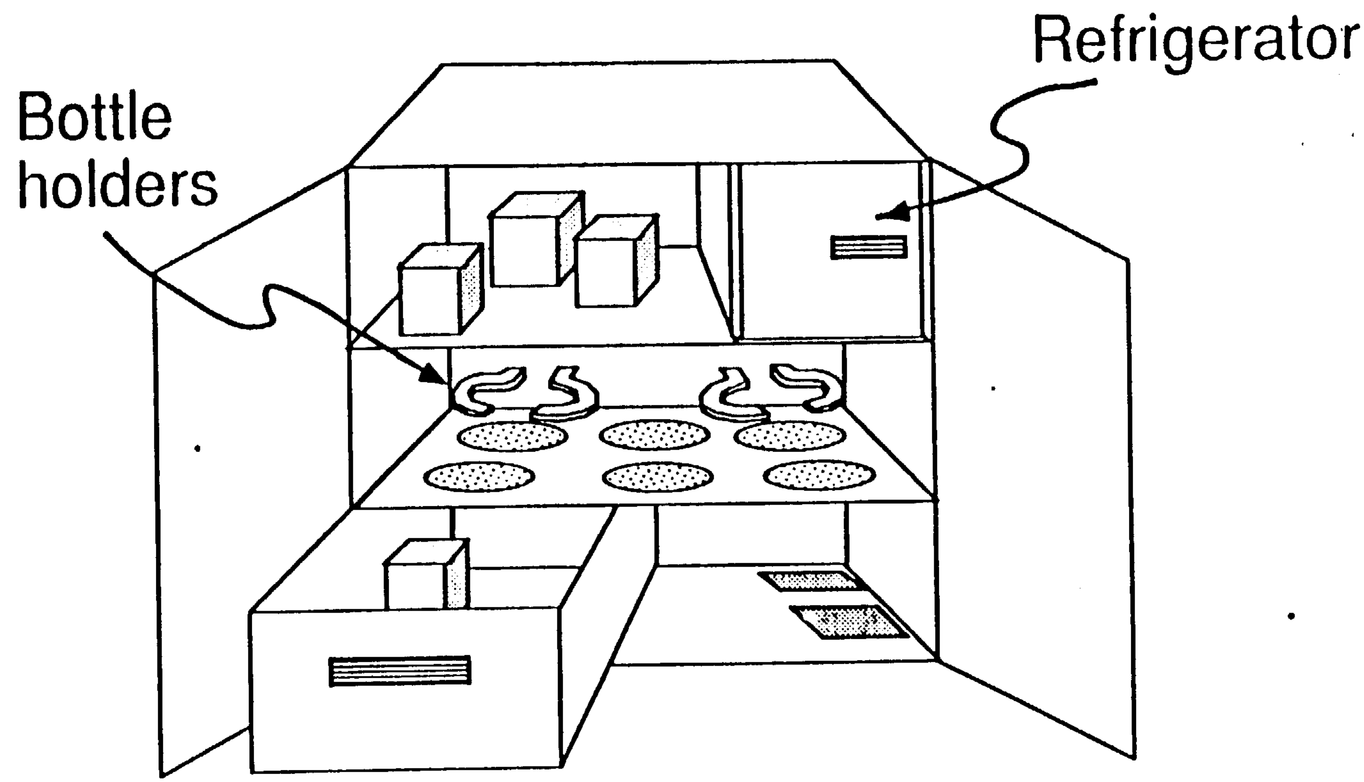
Retrieval Injection Manipulation



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.

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.