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SPACE BIOLOGY INITIATIVE
PROGRAM DEFINITION REVIEW

TRADE STUDY 5

MODIFICATION OF EXISTING HARDWARE (COTS)
vs
NEW HARDWARE BUILD
COST ANALYSIS

FINAL REPORT

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Foreword

The "Modification of Existing Hardware Versus New Hardware Build" was performed as part of the Space Biology Initiative (SBI) Definition Trade Studies Contract which is a NASA activity intended to develop supporting data for JSC use in the Space Biology Initiative Definition (Non-Advocate) Review with NASA Headquarters, Code B, scheduled for the June-July 1989 time period. The task personnel researched, acquired, recorded, and analyzed information pertaining to a Make-or-Buy analysis of space biology equipment. The study data provides parametric information indicating the factors which influence the cost and design for categories and functions of SBI hardware.

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

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

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Trade Study Manager:	Ms. Carolyn Blacknall
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List of Abbreviations and Acronyms

AI	Artificial Intelligence
APM	Attached Pressurized Module
ARC	Ames Research Center
ASTP	Apollo - Soyuz Test Program
BmRP	Biomedical Research Project (Human/Crew Members)
BRP	Biological Research Project (Non-Human/Rodents, primates or plants)
BSHF	Biological Specimen Holding Facility
CELSS	Closed Ecological Life Support System
CER	Cost Estimating Relationship
CHeC	Crew Health Care
COTS	Commercial Off-The-Shelf
DDT&E	Design, Development, Test and Evaluation
DF	Design Factor
DFI	Development Flight Instrumentation
DMS	Data Management System
ECF	Exercise Countermeasure Facility
ECLSS	Environmental Control and Life Support System
EDCO	Extended Duration Crew Operations
EEI	Eagle Engineering, Inc.
EHS	Environmental Health System
EPDS	Electrical Power Distribution System
ESA	European Space Agency
FDA	Food and Drug Administration
FSU	Functional Support Unit
HMF	Health Maintenance Facility
HQUL	Hardware Quantity and Usage List
HRF	Human Research Facility
HW	Hardware
IOC	Initial Operating Capability
ISS	International Space Station
JEM	Japanese Experiment Module
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KG	Kilogram
LAN	Local Area Network
LSCO	Low Cost Systems Office
LSE	Laboratory Support Equipment
LSFEP	Life Sciences Flight Experiment Program
LSLE	Life Sciences Laboratory Equipment
LSRF	Life Science Research Facility
MATSCG	Management and Technical Service Company
MDE	Mission Dependent Equipment
MDU	Medical Development Unit
MLI	Multi-Layer Insulation
MOB	Make or Buy

MRDB	Mission Requirements Data Base
MTBF	Mean Time Between Failure
NASA	National Aeronautics and Space Administration
NIO	New Initiatives Office
NSTS	NASA Space Transportation System
OTS	Off-The-Shelf
PI	Principal Investigator
PMC	Permanent Manned Capability
POCC	Payload Operations Control Center
PSI	Pounds/Square Inch
QA	Quality Assurance
RMOAD	Reference Mission Operational Analysis Document
SAIS	Science & Applications Information System
SBHB	Space Biology Hardware Baseline
SBI	Space Biology Initiative
SLM	Science Laboratory Module
SSF	Space Station Freedom
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
US	United States
WAN	Wide Area Network
WG	Working Group

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.

Buy, or Purchase
: Equipment which will be purchased commercially and then modified, as necessary, for use in space.

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 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.

Commercial Off-The-Shelf (COTS), Off-The-Shelf (OTS)
: Equipment which is, or is expected to be, commercially available for purchase.

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.

Make, Made, Build, or New Build

Equipment which is designed and built "from scratch" specifically for use in the micro-gravity environment of space.

Modified Off-The-Shelf

Commercially available equipment which has been modified to adhere to NASA's standards for use in space. Most SBI hardware will require modifications if purchased commercially because of NASA's high standards for safety and reliability.

Orbital replaceable unit (ORU)

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

Payload integration activities

Space Station Freedom payload integration activities will include the following:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Verification

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

1.0 Introduction

1.1 Background

The JSC Life Sciences Project Division has been directly supporting NASA Headquarters, Life Sciences Division, in the preparation of data from JSC and ARC to assist in defining the Space Biology Initiative (SBI). GE Government Services and Horizon Aerospace have provided contract support for the development and integration of review data, reports, presentations, and detailed supporting data. An SBI Definition (Non-Advocate) Review at NASA Headquarters, Code B, has been scheduled for the June-July 1989 time period. In a previous NASA Headquarters review, NASA determined that additional supporting data would be beneficial to determine the potential advantages in modifying commercial off-the-shelf (COTS) hardware for some 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

This study compares the relative costs of modifying existing commercial off-the-shelf (COTS) hardware to fabricating new hardware. This study surveys and identifies a historical basis for new build versus modifying COTS to meet current NMI specifications for Manned Space Flight hardware. This study will also identify selected SBI hardware as potential candidates for off-the-shelf modification and provide statistical estimates on the relative cost of modifying COTS versus new build.

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 modifying commercial off-the-shelf equipment versus new build 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 make-or-OTS-buy cost effects by the SBI cost estimators in developing and defining the required PRICE input parameters.

This study examines the list of reference biology equipment in the Space Biology Hardware Baseline and lists the hardware which will have a significant cost savings if modified from commercial off-the-shelf equipment. In addition, this study identifies historical make-or-OTS-buy costs and develops statistical cost analysis methods based on this historical data. This information can then be used to assist in performing a make-or-OTS-buy analysis on other reference SBI hardware or actual equipment.

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 end item specifications are evolving and usually change many times during the design phase. For this reason, the trade study analyses have focused on the category and function of each hardware item (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 Make-or-OTS-Buy Trade Study is shown in Figure 1.5. It consists of the initial, important phase of search and acquisition of related data; followed by a period of data integration and analysis; and, finally, the payoff phase where candidate items and implementation factors are identified including relative cost reduction assessment for SBI hardware that can be implemented using existing OTS equipment.

1.5.1 Data And Documentation Survey

A literature review and database search were conducted immediately upon study initiation. In establishing criteria for make-or-OTS-buy decisions for SBI hardware, historical situations were reviewed. Decisions to modify off-the-shelf hardware or develop it from scratch have been made in Mercury, Gemini, Apollo, ASTP, medical, and in other scientific areas. These decisions are currently underway in several areas of the Space Station Freedom Program.

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 modifying commercial off-the-shelf hardware equipment.

1.5.4 Survey Data Integration

The reference Space Biology Hardware Baseline (SBHB) was reviewed for a make-or-OTS-buy assessment of potential candidate hardware. The technical data collected from the survey was integrated with the Space Biology Hardware Baseline and a list of considerations affecting a make-or-OTS-buy analysis was compiled. The initial survey data analysis was performed to select a sample of the SBHB items which could be potential candidates for implementation using modified COTS equipment. With limited study time and a SBHB of 93 items, a method was needed to separate the items which could have the most cost impact and were worthy of study resource application. The "vital few and trivial many" method (SBI #96) was used. This method applies the principle that in any population which contributes to a common effect (cost), a relative few of the contributors account for the bulk of the effect (cost). All SBHB items were listed in descending order of probable acquisition cost. Weight was used as an indication of probable acquisition cost based on historical experience in previous space programs. It was found that 34 percent of the items (32 items) accounted for 93 percent of the mass or probable cost (Table 5.7). Therefore, consideration was immediately limited to these 32 items. The make-or-OTS-buy candidate sample set was chosen from Table 5.7 based on amenability to use of modified COTS equipment.

The sample set was then subjected to a more detailed analysis to determine important factors relative to make-or-OTS-buy and to select the most representative candidate for final analysis. By this process, a reasonable effort could be devoted to the analysis of candidates for a possible make, OTS-buy, or for either a make or OTS buy decision.

1.5.5 Cost Analysis

Historical costs for both new build hardware and modified commercial off-the-shelf equipment were analyzed for several NASA programs. Design, development, test and evaluation (DDT&E) cost estimating relationships between new build and modified off-the-shelf were then established. The 32 most significant items of the Space Biology Hardware Baseline in terms of weight were then individually analyzed for make-or-OTS-buy potential. The method for this analysis is shown in Section 5.8, Make-or-OTS-Buy Cost Impact Analysis. The percentage of off-the-shelf hardware was estimated for each of the 32 SBHB items. Using the developed cost estimating relationships, the relative potential cost reduction for each item was estimated and entered in Table 5.7.2-1.

1.6 Definitions

The following definitions have been established for the purpose of this trade study:

Commercial Off-The-Shelf (COTS), Off-The-Shelf (OTS):
Equipment which is or is expected to be commercially available for purchase.

Modified Off-The-Shelf:

Commercially available equipment which has been modified to adhere to NASA's standards for use in space.

Make, Made, Build, or New Build:

Equipment which is designed and built "from scratch" specifically for use in the micro-gravity environment of space.

Buy, or OTS-Buy:

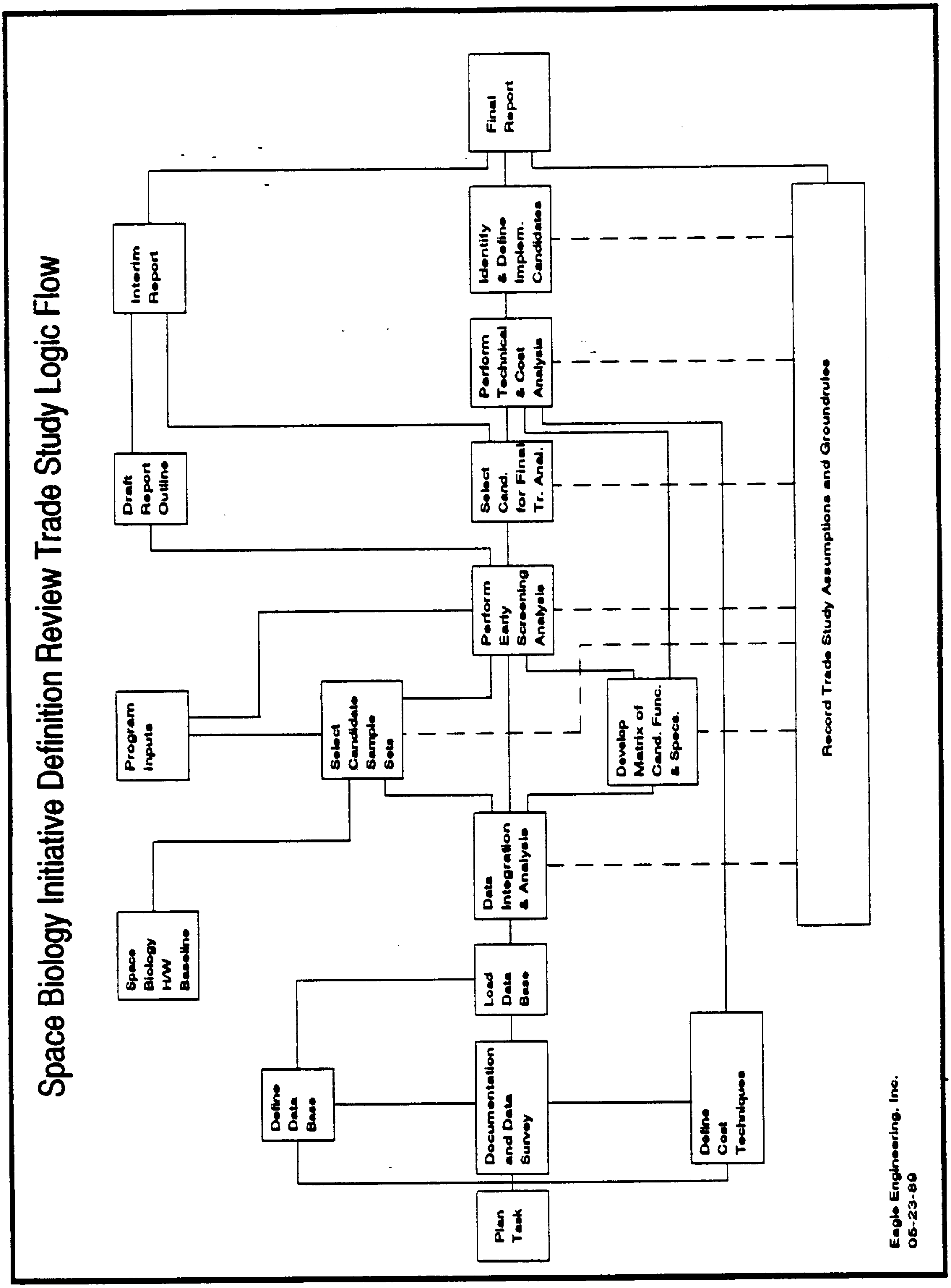
Off-the-shelf equipment which will be purchased commercially and then modified, as necessary, for use in space. Most SBI hardware will require modifications if purchased commercially because of NASA's high standards for safety and reliability.

CAUTION: In many industry make-or-buy plans, "make" refers to an in-house new build and "buy" refers to subcontracted new build. These definitions must be taken into consideration when comparing plans. In this trade study, only the stated definitions have been used.

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 COTS modification study are documented in a separate list (Table 2.1-2).

2.2 Make-or-OTS-Buy Analysis Summary

2.2.1 SBI Hardware Vital to Program Cost Impact Analysis

The baseline candidate list of 93 SBI hardware items is shown in Appendix A with an "S" by each item. Space flight history has established that project costs are most significantly affected by space equipment weight. To determine which SBI hardware warranted the most study resources, the SBI hardware list was prioritized by mass (Table 2.2-1 from data base printout on Table 5.7) this table shows the top 32 items which represent 93% of the mass, 87% of the volume, and 82% by power (watts) of the total 93 SBI items.

2.2.2 Make-or-OTS-Buy Assessment Review for Sample Selection

The 32 hardware items in Table 2.2-1 were broken down by assembly and analyzed for the potential of substituting with off-the-shelf equipment. According to the guidelines determined in this study, only off-the-shelf equipment which required modifications less than or equal to 40 percent of the item (by weight) were considered as potential OTS candidates. Hardware assemblies which would greater than a 40 percent modification if purchased OTS were calculated as new build, since these assemblies have little, if any, potential as an OTS purchase. (see Table 2.2-2 Make-or-OTS-Buy Assessment Review for Sample Selection). The following are definitions of the columns of Table 2.2-2:

Item Number Prioritized by Mass:

This column lists the hardware cost impact order to the total SBI program in terms of the hardware's weight. Since weight has been found to be the major indicator of cost based on historical experience in previous space programs, this factor was used to establish priority.

Hardware Item Number:

This column gives the hardware identification number from the Space Biology Hardware Baseline (SBHB) listed in Appendix A.

Hardware Item Name:

This column gives the hardware Item name from the Space Biology Hardware Baseline (SBHB) listed in Appendix A.

% Buy:

The percentage of each piece of hardware which could be commercially obtained was estimated by assembly. The total percentage of this hardware which could be used from OTS equipment was placed in the "% Buy" column.

Sufficient Data Available:

This column marks with a "no" the hardware items for which sufficient data was not available for a make-or-OTS-buy analysis.

% Mod to Buy:

The modifications which would be required to the new commercial hardware chosen in the % Buy column for space applications were then calculated. The percent of modifications to the new hardware were placed in the "% Mod to Buy" column. NOTE: The numbers in the "% Mod to Buy" column represent the amount of modification needed by the commercial hardware, located in the "% Buy" column. These numbers do not represent the percentage of modifications to the entire piece of equipment.

Confidence Level:

This column indicates the confidence of the evaluators in the buy and modification estimates based on the depth and detail of hardware and historical information.

2.2.3 SBI Hardware OTS-Buy Candidates Selection

Table 2.2.2 was examined for potential candidates for modified OTS-buy. Those items marked with a "no" under the column Sufficient Data Available were eliminated from consideration. Those candidates which were estimated to have no potential for OTS buy were also eliminated. The remaining SBI hardware items which are potential OTS-buy candidates are listed in Table 2.2.3 SBI Hardware OTS-Buy Candidates.

2.3 Relative Cost Impacts

This trade study examines and compares the development cost of new build versus modified off-the-shelf hardware. Of the 32 items from the vital list of space biology hardware, 23 were found to have a potential to be acquired as modified off-the-shelf hardware. Total costing considerations should also consider operational and life cycle costs.

Table 2.2.3, SBI Hardware Potential Cost Savings for Modified OTS Buy, examines the SBI hardware items in Table 2.2.2 and determines the % OTS and Potential % Cost Savings. The following are columns of Table 2.2.3:

% OTS:

This column shows the percentage of COTS hardware that does not require modification for each item of SBI hardware. The formula for this column is:
% OTS = % Buy - (% Mod to Buy * % Buy)/100.

This figure gives the total percentage OTS for costing purposes. For example, if 100% of an item is purchased OTS, but 30% is modified, then only 70% is considered OTS for costing.

% Cost Savings:

The percentage cost savings for each piece of SBI hardware is given in this column. OTS costs are taken as 15% of the cost of new build hardware, based on historical cost data information. The discussion of this estimate is developed in Section 5.2.

2.3.1 Potential Percentage Cost Savings Derivation

The potential percentage cost savings was derived as follows:

a. The percentage of hardware to be flown without modification is costed at 15% of new design.

b. The portion of OTS to be modified is estimated to cost 50% as much as a new design.

The cost of the modified OTS is then calculated as:

Modified Item Cost = (% unmodified) * .15 + (% modified) * .50

Potential Cost Savings = 100% - Modified Item Cost

An example may serve to illustrate. Assume that a given item is 60% modified and 40% unmodified. Then the cost is given at:

Cost Modified Item = .40 * .15 + .60 * .50
= .06 + .30 = .36

Savings = 1.00 - .36 = .64 or 64%

If one varies the numbers and assumes 60% is modified and the modification cost is equal to the new design cost then:

Cost of modified item = .60 * 100% + .40 * .15
= .60 + .06 = 66%

Potential Cost Savings = 100 - 66 = 34%

2.3.2 Potential Cost Savings Summary

Based upon the assumptions that OTS costs 15% as much as new hardware and that modification costs are 50% as much as all new design, the figures in the Potential % Cost Savings column of Table 2.3 were compiled. As the table illustrates, the potential savings in using modified off-the-shelf hardware items are very substantial.

2.4 Future Work

2.4.1 Make-or-OTS-Buy Analysis of All SBI Hardware

This trade study analyzed only the 32 SBI hardware items which have the greatest cost impact in terms of weight induced cost. Of these items, 23 were found to have a potential to be acquired as off-the-shelf hardware and modified to satisfy the SBI hardware definitions. Based on this early analysis, purchasing these items off-the-shelf would result in significant savings to the program. However, all items of SBI hardware would benefit from a make-or-OTS-buy analysis.

2.4.2 Make-or-OTS-Buy Comparisons for Other Life Sciences Hardware

In the course of research for this study, it was noticed that some similarity exists between SBI medical equipment and medical equipment used for Crew Health Care (CHeC) in Space Station Freedom and Extended Duration Crew Operations (EDCO). A future study might compare make-or-OTS-buy plans for SBI equipment with those of CHeC and other Life Sciences equipment. Additionally, this study could see if any similar equipment is being considered by the Space Station international partners.

2.4.3 Trade-Off Between Reliability and Cost

The trade-off between reliability and cost may be a significant factor in hardware design. For instance, light weight low-cost commercial quality equipment could be placed into orbit and should a failure occur, it could be returned for repair. In-flight maintenance is possible and a trade-off can be established between crew time and hardware cost. Mean-time-between-failure (MTBF) could be used to select hardware items for flight use. Modular instruments such as those with card-cage mounted PC boards could be easily repaired on-orbit if spare parts kits are included. For general purpose laboratory equipment which is to remain on-orbit for extended periods of time, trade-offs must be established between initial hardware cost and reliability, balanced with the use of in-flight maintenance and change-out schedules for calibration or refurbishment.

2.4.4 Other Cost Analysis Techniques

Additional cost analysis techniques were developed in Section 3.3 of Appendix C. Comparisons of the costs of modifying commercial off-the-shelf hardware are calculated in Table 3-7 for a system complexity factor of 2, and in Table 3-8 for a system complexity factor of 4. A future task might use this cost analysis method for OTS-buy costs.

2.5 Conclusion Summary

This study encountered examples of make-or-OTS-buy decisions from past NASA programs. It would be an oversimplification to group hardware items by classification or function and use this information to make a make-or-buy decision on other hardware. This study concluded that all pieces of SBI hardware should be individually analyzed for make-or-OTS-buy potential. However, the indications from this study all point to the fact that SBI can be developed using a significant percentage of modified COTS or OTS and save substantial amounts of money in the process.

Based upon the assumption that modification design costs are 50% as much as an all new design and that purchase costs are 15% of a new design, the potential cost savings for each SBHB make-or-buy candidate were calculated and presented in Table 2.3.

Two definite conclusions can be drawn from this trade study.

a. Each actual SBI hardware item must be analyzed by assembly for potential as a modified OTS purchase, once the actual hardware has been baselined and chosen. Then each item must be costed separately based upon a careful evaluation of the modification cost required and the cost of the basic unit compared to a new design.

b. The potential for cost savings by purchasing and modifying OTS hardware wherever possible is substantial even where the modification costs are high.

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 COTS Modification Trade Study Assumptions and Groundrules

1) COTS modification costs are 50% less than new build costs.

2) Commercial off-the-shelf hardware costs 15% as much as new build hardware.

3) Due to the high level of cost required to modify and certify hardware for spaceflight use, the original cost of COTS equipment is assumed to be relatively low and not significant in cost impact analysis.

4) Some off-the-shelf hardware may require such substantial modifications that changes will not be cost effective. A goal of this study will be to determine the maximum amount of recommended COTS hardware modifications.

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

93 SBI H/W Items 89 Items have 3535 kg mass 10.0M^3 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	% Buy	% Mod to Buy	Assessment Confidence Level	
						Low	High
1	168	CELSS		20	30		X
2	169	Gas Grain Simulator Facility		33	30		X
3	84	Soft Tissue Imaging System	no				
4	77	Hard Tissue Imaging System	no				
5	126	Scintillation Counter		95	30		
6	74	Force Resistance System		95	25		X
7	145	Automated Microbic System		95	40	X	
8	155	Total Hydrocarbon Analyzer		100	30	X	
9	161	Inventory Control System		95	15		X
10	162	Lab Materials Pack & Hand. Equip.		0	0		X
11	163	Test/Ckout/Calibration Instrumentation		50	20		X
12	106	Neck Baro-Cuff		95	30		X
13	113	Blood Gas Analyzer	no				
14	61	Mass Spectrometer		95	35		
15	112	Plant HPLC Ion Chromatograph	no				
16	147	Head Torso Phantom		3	35		X
17	63	Pulmonary Gas Cylinder Assem.		95	10		X
18	110	Plant Gas Chromatograph/Mass Spec.		95	35	X	
19	115	Chemistry System		95	30		X
20	138	Hematology		95	40	X	
21	34	Sample Preparation Device		0	0		X
22	165	Experiment Control Computer System		80	30		X
23	62	Pulmonary Function Equip Stor. Assem.		0	0		X
24	82	Motion Analysis System		90	20		X
25	99	Animal Biotelemetry System		95	20		X
26	100	Blood Pressure & Flow Instrumentation		85	250		X
27	109	Venous Pressure Transducer/Display		85	20		X
28	129	Cell Handling Accessories		0	0		X
29	57	Bag-in-Box		80	20	X	
30	111	Plant Gas Cylinder Assem.		95	10		X
31	119	Gas Cylinder Assembly		95	10		X
32	130	Cell Harvester		0	0	X	

Table 2.2-2 Make-or-OTS Buy Assessment Review for Sample Selection

Hardware Item #	Hardware Item Name
168	CELSS
169	Gas Grain Simulator Facility
126	Scintillation Counter
74	Force Resistance System
145	Automated Microbic System
155	Total Hydrocarbon Analyzer
161	Inventory Control System
163	Test/Ckout/Calibration Instrumentation
106	Neck Baro-Cuff
61	Mass Spectrometer
147	Head Torso Phantom
63	Pulmonary Gas Cylinder Assem.
110	Plant Gas Chromatograph/Mass Spec
115	Chemistry System
138	Hematology
165	Experiment Control Computer System
82	Motion Analysis System
99	Animal Biotelemetry System
100	Blood Pressure & Flow Instrumentation
109	Venous Pressure Transducer/Display
57	Bag-in-Box
111	Plant Gas Cylinder Assem.
119	Gas Cylinder Assembly

Table 2.2-3 SBI Hardware OTS Buy Candidates

Hardware Item #	Hardware Item Name	Mass (kg)	% Buy	% Mod to Buy	% OTS	Potential % Cost Savings
168	CELSS	1000	20	20	14	15
169	Gas Grain Simulator Facility	800	33	30	23	25
126	Scintillation Counter	90	95	30	67	71
74	Force Resistance System	70	95	25	71	72
145	Automated Microbic System	70	95	40	57	67
155	Total Hydrocarbon Analyzer	70	100	30	70	74
161	Inventory Control System	70	95	15	81	76
163	Test/Ckout/Calibration Instrumentation	70	50	20	40	39
106	Neck Baro-Cuff	45	95	30	66	71
61	Mass Spectrometer	41	70	35	45	51
147	Head Torso Phantom	32	3	35	2	2
63	Pulmonary Gas Cylinder Assem.	30	95	10	85	77
110	Plant Gas Chromatograph/Mass Spec	25	70	35	46	53
115	Chemistry System	23	50	30	35	38
138	Hematology	23	50	30	35	38
165	Experiment Control Computer System	20	80	30	56	60
82	Motion Analysis System	20	90	20	72	70
99	Animal Biotelemetry System	20	95	20	76	74
100	Blood Pressure & Flow Instrumentation	20	85	20	68	67
109	Venous Pressure Transducer/Display	20	85	20	68	67
57	Bag-in-Box	19	80	20	64	62
111	Plant Gas Cylinder Assem	19	95	10	86	77
119	Gas Cylinder Assembly	19	95	10	86	77

Table 2.3 SBI Hardware Potential Cost Savings for Modified OTS Buy

3.0 Trade Study Database

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

3.1 Database Files

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

3.2 Database Management

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

3.3 Database Use

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

4.0 Documentation Survey

A literature review and database search were conducted immediately upon study initiation. In establishing criteria for make-or-OTS-buy decisions for SBI hardware, historical situations were reviewed. Decisions to modify off-the-shelf hardware or develop it from scratch have been made in Mercury, Gemini, Apollo, ASTP, medical, and in other scientific areas. These decisions are also currently underway in several areas of the Space Station Freedom Program. Library searches were make using titles, authors, key words, acronyms, phrases, synonyms, time periods and any possible (both in-person and by telephone) having knowledge of the study subject activities. Interviews with personnel were made throughout the initial portion of the study.

4.1 Documentation Sources

4.1.1 Complete SBI Trade Study Bibliography

The complete list of all references used in the four Eagle Engineering, Inc. trade studies is provided in Appendix B. A unique EEI SBI reference index number has been assigned to each information source.

4.1.2 Make-Or-Buy Trade Study Bibliography

Particular reference information from Appendix B that is of special importance to modification of COTS hardware is repeated in Table 4.1.2. The literature was searched for reference to make-or-OTS-buy analysis and historical comparison costs.

4.2 Historical Make-Or-OTS-Buy Cases

4.2.1 Life Sciences Laboratory Equipment (LSLE) Experiences

In the Spacelab 4 mission, the decision was made to fly a commercial echocardiograph. NASA life sciences managers decided that it is impractical for complex instruments such as the LSLE echocardiograph to be fully developed by NASA when commercial technology is readily available. The Life Sciences Study for the Space Station, SBI #94, suggested that many items identified for use in the Health Maintenance Facility (HMF) will lend themselves to the modified commercial hardware approach.

NASA life sciences managers decided that candidate equipment which could be developed by modification of commercial hardware would include general purpose laboratory equipment such as computers, TV/video systems, oscilloscopes, chromatography systems, and certain specialized medical equipment such as a defibrillator, anesthesia apparatus and a blood analyzer.

Lessons learned from the design and development of LSLE are directly applicable to the SBI program. Jim Evans, of JSC, in interview SBI #70, had several comments on LSLE hardware development which are applicable to SBI equipment in the life sciences discipline.

In modifying commercial off-the-shelf equipment, sometimes unexpected problems arise which add greatly to the complexity of the modifications. However, where the decision has already been made to "OTS-buy", modification continues even though it would be reasonable to stop and redesign the hardware as a new build. No one wants to admit a mistake in judgement. Mr. Evans suggests having a modification policy which states that, every time a major modification requirement is encountered, the advantages and disadvantages of modifying be again compared against new build. This policy would encourage the examination of both "make" and "OTS-buy" options even though some cost was already spent examining modifications.

Mr. Evans stated that there can be no absolute make-or-OTS-buy policy for all hardware; i.e., some hardware is best as new build and some is best as modified COTS. Each hardware item must be examined individually in a make-or-OTS-buy analysis and items with very similar functions could result in different approaches. Mr. Evans comments were included in the Make-or-OTS-Buy criteria in Section 5.3.

4.2.2 Apollo Soyuz Test Program Experience

The Apollo Soyuz Test Program (ASTP) used the cost saving techniques of modularity, commonality, modifying commercial OTS equipment, and reducing paperwork suggested by the Low Cost Systems Office. Figure 4.2.2 shows the results of cost saving methods on this program (SBI #22, SBI #24).

4.2.3 Skylab: Beware of Off-The-Shelf Hardware

In the Skylab program, the $6 million S071/72 experiment had to do with mice and gnats living in an environmental package. All test animals died due to a failure caused by poor packaging of a commercial off-the-shelf invertor (SBI #97. Three off-the-shelf invertors were bought for the Skylab program at a cost of about $300 each. These invertors had the company inspector's stamp on them and were acceptance tested to reasonable requirements.

In NASA tests, one invertor was subjected to several thermal vacuum mission profiles and was judged ready to fly. Subsequent to failure test and analysis, which pointed to the invertor, the two remaining invertors were opened up for inspection. Conductors in several places were very close to being exposed and, in those places where wires were exposed (i.e. insulation missing), a piece of tape was used to provide insulation from the metal case. In several areas, there were signs of charring caused by arcing from the conductors to the case even though the invertors had passed all tests.

In a memo entitled "Beware of Off-the-Shelf Hardware" written in October 1973 (SBI #97), Donald Arabian states:

> "There is a lesson to be learned; off-the-shelf items should be taken apart and visually inspected with the "eyeball" as part of the evaluation. Know what you are buying. Reliance on the inspector stamp and reliance on acceptance tests are not sufficient. I have seen off-the-shelf items that have very good design, superb packaging, choice inspection, and which I would stage against the elegance in quantity and inspection of space hardware. On the other hand, I have seen the opposite to be true, as in this case. We should make darn sure that we look into the guts of off-the-shelf items and not solely depend on credentials of the component. The cost of doing this is peanuts. In this case,

the mice would have been put to good use and the $6 M would have produced some scientific data."

4.2.4 Make-or-OTS-Buy Examples From Other NASA Programs

This study encountered examples of make-or-OTS-buy decisions from past NASA programs. It would be an oversimplification to group hardware items by some classification or function and use this information to make a make-or-OTS-buy decision on other hardware. However, information and "lessons learned" from past programs can be extremely useful for those responsible for the decision to make or buy hardware. The following list provides known items of NASA equipment previously considered for make-or-OTS-buy implementation and identifies the resulting decision:

Hardware	Program	Make-or-Buy
DFI Telemetry	Apollo	Mod OTS
Lunar Comm RY	Apollo	New Build
AF Tape Player	Apollo	Mod OTS
TV Systems	Apollo, STS	New Build
Signal Process	STS	New Build
Teleprinter	STS	Mod OTS
Cabin Leak Detector	STS	Mod OTS
Sir-C Payload	STS	International Dev

Richard Whitlock of the JSC Cost Analysis Office was also interviewed (SBI #64). He also advised caution and reconsideration of a "buy" choice if the amount of modification could be greater than 30 to 40 percent. Mr. Whitlock's suggestions were included in the make-or-OTS-Buy Criteria in Section 5.2.

4.2.5 Crew Health Care

An in-house make versus subcontractor make analysis was performed for each element of the CHeC program by McDonnell Douglas Astronautics Company (SBI #38). This study was made in accordance with their Make-or-Buy plan (DR MR-08, Report No. MDC H4013) dated February 1988. The process used is shown in Figure 4.2.5. The decision was made to buy almost all CHeC items from subcontractors because of the high dollar value, technical risk, degree of subcontract interface, contractual complexity, or schedule criticality required or the application of specific techniques in the preparation, consummation, and administration of the contractual arrangements. Table 4.2.5 lists these subcontract items. The items were given to subcontractors making similar equipment; however, the actual amount which can be considered off-the-shelf is not known.

Even though the "make-or-buy" terms used in CHeC vary from the "make-or-OTS-buy" idea of this report, an investigation of MDAC's CHeC make-or-buy analysis is beneficial to the understanding of the SBI make-or-OTS-buy decision.The analysis of the CHeC hardware divided the items into the following categories: 1) must make, 2) can make or buy, 3) must buy, or 4) must buy from a major subcontractor (in this case, either IBM or Honeywell). An examination of the make-or-OTS-buy philosophy for CHeC items may be useful in considering alternatives for SBI hardware. Appendix E contains the Make-or-Buy Analysis for CHeC.

4.2.6 Low Cost Systems Office

The Low Cost Systems Office was established at NASA Headquarters in 1973. Its broad mandate was to facilitate significant reductions in the costs of developing, producing, launching, and acquiring spacecraft systems and subsystems. In its four years of existence, this office examined cost saving methods such as modularity and commonality, modifying commercial off-the-shelf equipment, reducing paperwork, and listing standardized components, such as batteries, for use in several space hardware items (SBI #22, SBI #24). Figure 4.2.2 shows the cost savings benefits of the Low Cost Systems Office approach on the Apollo Soyuz Test Program.

4.2.7 Industry Make-or-OTS-Buy Plans

Major commercial industries have investigated the relative merits of new build hardware versus modifying existing equipment. Many of these companies have documented a Make-or-OTS-Buy plan. However, the information in these documents is considered proprietary and access to the documents is often restricted. These documents may contain historical cost relation information which could benefit further make-or-buy studies of SBI hardware. However, care must be taken with industry definitions of make-or-buy since "make" often refers to an in house build and "buy" often refers to a new build by a subcontractor.

Table 4.1-2 Bibliography for COTS vs New Hardware

ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SB104	Shannon, J.	Business Practice Low Cost System Activity		NASA JSC		Houston, TX.	11/12/75
SB122	LMSC	Low-Cost Program Practices For Future NASA Space Programs		LMSC	LMSC-D387518	Sunnyvale, CA.	05/30/74
SB123	Steward, GMiller, L	Biomedical Equipment Technology Assesment For The Science Laboratory Module		Management and Technical Services Company		Houston, TX.	08/01/86
SB150	MDAC	Crew Health Care	1	MDAC	MDC H3924	Houston, Texas	11/01/88
SB157	Rockwell Intl.	Space Shuttle Management Proposal	II	Rockwell Intl.	SD 72-SH-50-2		05/12/72
SB158	LMSC	Space Shuttle Management Proposal	II	LMSC	LMSC-D157364		05/12/72
SB159	MDAC	Space Shuttle Program Management Proposal		MDAC	E0600		05/12/72
SB168	Hamaker, Joe	Telephone interview relating to MSFC history and techniques for cost estimating.		Cost Analysis Branch Chief MSFC		Huntsville, Al.	04/27/89
SB170	Evans, Jim	Personal Interview		Life Science Project Division JSC		Houston, TX.	04/19/89
SB171	Heberlig,Jack	Telephone interview relating to make-or-buy lessons learned from Apollo		International Business Machines (IBM)		Houston, TX.	03/10/89
SB172	Loftus, Joe	Telephone interview relating to make-or-buy history		Assistant Director (Plans) JSC		Houston,TX.	03/14/89
SB173	Christy, Neil	Telephone interview relating to hardware development student experiments, and make-or-buy				Houston, TX.	03/15/89

Table 4.1-2 Bibliography for COTS vs New Hardware

ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SB174	McAllister, Fred	Telephone Interview		Man-System Division, JSC		Houston, TX	03/14/89
SB175	Trowbridge, John	Interview relating to CHeC make-or-buy		McDonnell Douglas		Houston, TX.	03/17/89
SB176	Trowbridge, John	Personal interview relating CHeC experience to miniaturization, modularity and make-or-buy		McDonnell Douglas		Houston, TX.	03/29/89
SB177	Nagel, John	Personal Interview relating to LSLE make-or-buy experience		Eagle Technical Services		Houston, TX	03/27/89
SB178	McFadyen, Gary	Personal Interview relating to life science hardware background at JSC		Southwest Research Institute		Houston, TX.	04/10/89
SB192		Spacelab Payloads Accomodations Handbook		NASA MSFC	SLP/2104	Huntsvillle, Al.	08/16/85
SB194		Life Sciences Study for the Space Station		Management and Technical Services Co.		Houston, TX.	08/01/84
SB197	Arabian, D.	Beware Off-the-Shelf Hardware		NASA JSC		Houston, TX.	10/17/73
SB198	SB198NASA JSC	Experimenting with Baroceptor Reflexes	12	NASA Tech Briefs	No. 11	New York, NY	12/01/88

NASA-S-75-1029C

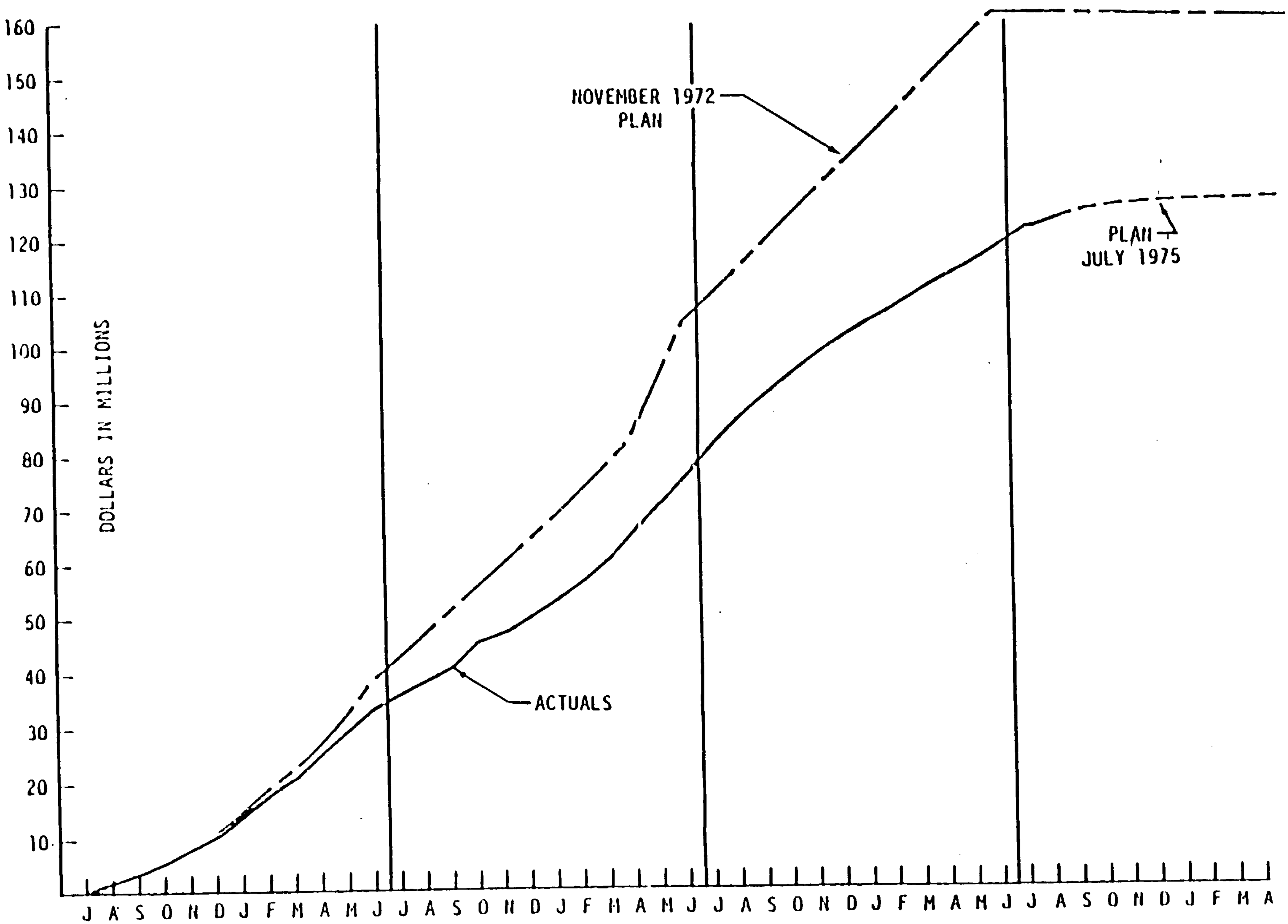


Figure 4.2.2 JSC - ASTP COST PLAN VS ACTUAL COST

Figure 4.2.5 Make-or-Buy (MOB) Plan for CHeC

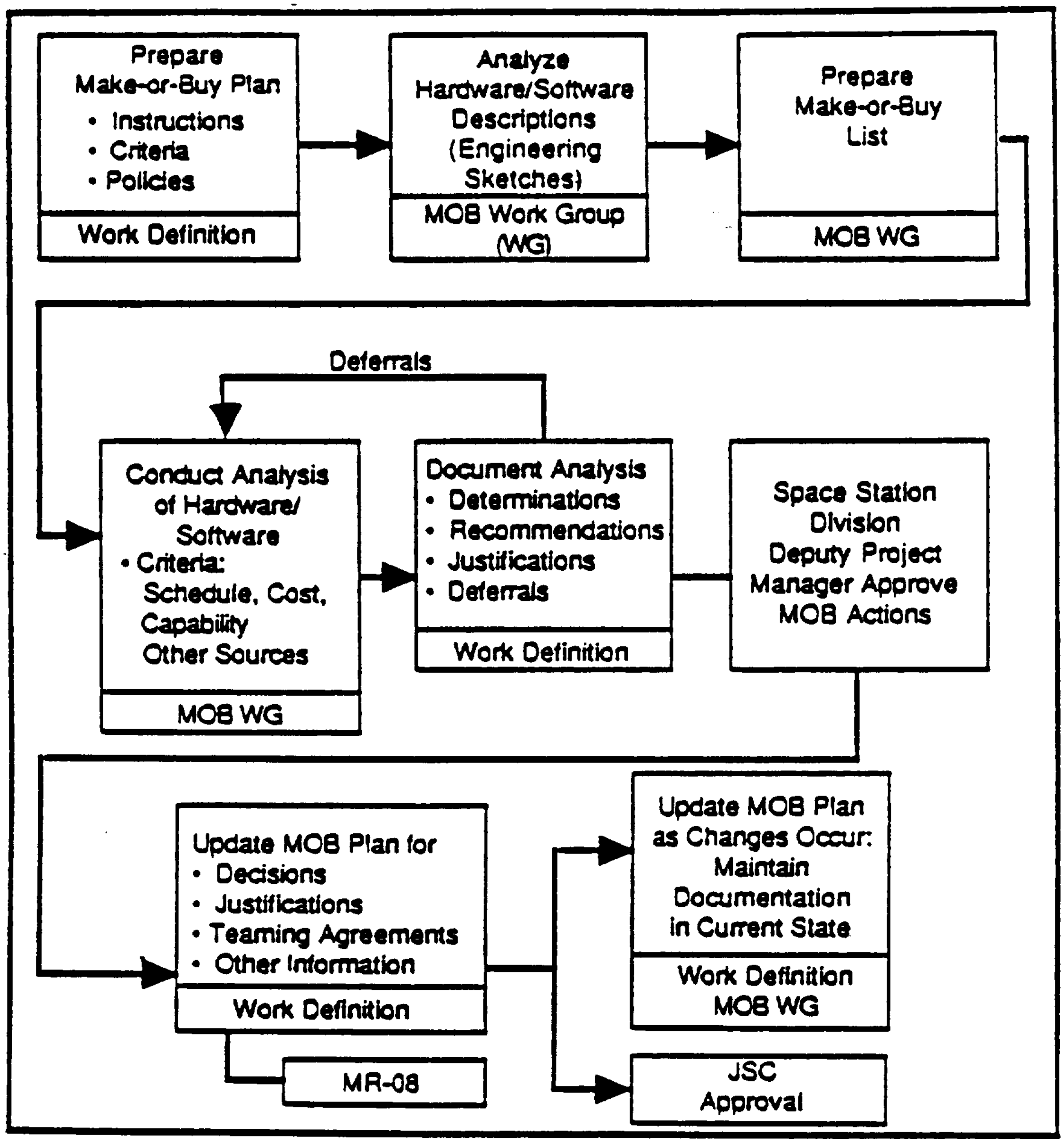


Table 4.2.5 Buy Items To Be Subcontracted For CHeC

Aerometer
Archival Particulate Sampler
Auto Microbial Identification Sys.
BCC
Bike/Rowe
Bioimpedance Analyzer
Blood Gas Analyzer
Blood Pressure Monitor
Body Mass Measuring Device
Cassette Processor/Tape Backup
Cautery Device
Centrifuge
Charged Particle Telescope Sensor & Electronics (EV)
Clinical Chemistry Analyzer
Compound Specific Analyzers
DCC
Defibrillator
Dental Camera
Dental Power Hand Tool
Dental X-Ray Collimator
Display Monitor
Dynamic Environment Mea. Sys.
ECG Monitor
EDP-1
Fluid Bags
Gas Chromotograph/Mass Spectrometer
Graphics
Heat and Moisture Exchanger
Hematology Analyzer
Incubator
Infusion Pumps
Interface Hardware Kit
Ion Chromotograph
Ion Specific Electrodes
Line Vacuum Air/Fluid Separator
Mass Storage Unit (MSU)
MDAC I/O
Medical Local Bus Controller
Metabolic Gas Monitor
Metal Aerosol Analyzer

Microbial Air Sampler System
Microbial Detoxification/Disposal System
Monochrome Raster Display Monitor
MPAC Processor (Modified)
Multiplexer/Demultiplexer
Multivariable Monitor Graphics
NIU (Special for X-ray)
Osmometer
Passive Thermoluminescent Detectors (TLD)
Portable Air Compressor
Portable Air/Fluid Separator
Portable Compressed Gas Tracks
Portable MPAC
Portable Total Hydrocarbon Analyzer
Pressure Regulator
Pulse Oximeter
Real Time Particulate Counter & Data Logger
Remote Network Interface Unit (RNIU)
Resistive Exercise Device
SDP-4B
SDP-X
Secondary Power Unit
Slide Staining System
Sound Level Monitor and Recorder
Spectrophotometer (UV-VIS)
Sterile Water for Injection System
Task Lighting
Tissue Equivalent Proportional Counter
Anneal and Storage
Total Organic Carbon Analyzer
Transport Monitor
Treadmill
Turbidity Meter
Utility Interface Panel
Ventilator
Vibration Isolation Device
Volatile Organics Analyzer (GC/MS)
Volatile Organics Sampler
Warm Blood Collection System
X-Ray Source/HV Generator

5.0 Trade Study

5.1 Considerations For Make-Or-OTS-Buy Analysis

There are many issues which must be considered in determining a make-or-OTS-buy decision. These factors must be considered in the design and development of equipment or in the analysis of commercially available hardware for modification.

5.1.1 Gravity Dependence

The impacts of a micro-gravity environment on commercial medical equipment must be considered. Plans and schematics must be reviewed to eliminate gravity dependance.

Devices which rely on gravity for their operation on Earth may have to be completely redesigned for operation in space. Fluid handling will be one of the problems encountered when performing life science research in a micro-gravity environment. Because a great majority of analytical biomedical equipment requires some degree of fluid handling during sample preparation, sample analysis and clean up procedures, this problem must be addressed.

5.1.2 Electromagnetic Interference

There is a significant risk of Electromagnetic Interference (EMI) among the various pieces of biomedical hardware. This could lead to erroneous results that could be difficult to detect. Major SBI equipment must also be checked for possible EMI with the NSTS and Space Station Freedom.

5.1.3 Toxicology

Modifications to commercial biomedical equipment may be required due to environmental toxicology constraints. Many of the plastics found in current biomedical hardware, along with many common disinfectants and reagents, will not be allowed aboard Space Station Freedom since they have potential toxic effects at certain atmospheric concentrations. Many compounds will not be allowed in the closed environment of the Space Station even at a sea level pressure of 14.7 PSI. A study to assess the impact of toxicology regulations on candidate biomedical equipment should, therefore, be done for all make-or-OTS-buy candidate equipment. Toxicology considerations include contamination from outgassing and the restrictions of dangerous materials such as mercury. Materials such as glass must also be avoided because of crew safety.

5.1.4 Crew Interfaces

Safety requirements include review of vehicle and crew interfaces to eliminate hazards to the crew and hazards which might damage the vehicle. This includes elimination of sharp edges and corners, stress analysis of mounting points, and proper fusing and grounding. Latches, levers, cranks, hooks and controls that can catch/retain equipment should be designed and located to prevent gaps, overhangs, and/or snags. In addition, latches should be designed to prevent inadvertent actuation. All dials, controls, and gauges must be easy for the crew to read and operate.

5.1.5 Weight And Fit

Commercial equipment must be examined for excessive weight or size. If either of these are high, then a study should be made to investigate miniaturization and weight reduction capabilities if designed from scratch.

5.1.6 Servicing

Another issue is the frequency with which commercially available biomedical equipment needs to be serviced. Both routine calibrations and preventive maintenance, as well as unexpected breakdowns, are common occurrences in commercial labs. Without modifications, this servicing frequency can only be expected to increase in a micro-gravity environment. Modifications enhancing reliability are essential both to the collection of the science data and the reduction of crew time for maintenance and service. Designs which allow for modular replacement parts should be considered in reducing SBI equipment servicing. The added initial cost for increasing reliability will be compensated for by the reduced long-term costs for replacement storage and on-board crew time.

5.1.7 Medical Certification

One issue that needs to be addressed in any make-or-OTS-buy decision is medical certification. Any commercial medical equipment which can be potentially dangerous to humans must undergo severe testing by the Food and Drug Administration (FDA). However, modifications to this equipment, even to the housing or structure, could potentially nullify any FDA certification. In a make-or-OTS-buy analysis of complex medical equipment such as a tissue imaging system, the amount of time for medical approval and certification on made or modified equipment must be considered.

5.1.8 Flammability

Off-the-shelf products must be evaluated for flammability and the possible catalytic combination of materials. Some pieces of commercial medical equipment already meets requirements for safety in oxygen-rich environments such as operating rooms.

5.1.9 Standardization

Commercial medical equipment may contain non-standard parts without quality checks or traceability. Commercial units are not necessarily identical with each other. Documentation of commercial equipment may be poor.

5.1.10 Power Requirements

The power requirements of commercial off-the-shelf equipment must meet those of the NASA supplier. Cables and connectors must interface with NASA spacecraft.

5.1.11 Extra Features

Commercial off-the-shelf hardware may provide extra features and functions which may, on inspection, prove to be unnecessary to SBI equipment users. Taking out these extra features may reduce weight or volume and may be advisable except in cases where the total system is so complex that these changes require extra certification and inspection.

5.1.12 Batch Procurement

After make-or-OTS-buy decisions have been completed, a listing can be made of SBI hardware to be purchased. Examination of this list will determine the efficiency of grouping some hardware under a single subcontract. Batch procurement can lower contract management manpower and costs.

5.1.13 License Agreements

Some hardware requires license agreements to ensure that sufficient rights are available to allow the production of modified equipment meeting program requirements. During the evaluation phase, contract managers initiate extensive industry surveys to establish appropriate licenses with potential suppliers. NASA must be able to obtain access to any information, such as source codes and wiring diagrams, needed for equipment performance and testing. Equipment with information limited as "proprietary" may not be acceptable.

5.1.14 Increased Status Reviews and Reports

Periodic status reviews are necessary to monitor and assess the progress of SBI hardware development. Reviews may be accomplished at the subcontractor's facility when necessary to ensure open and effective communication. Subcontractors developing complex equipment items are reviewed often while routine items are reviewed as necessary based on progress. For example, an image digitizing system represents advanced technology and high risk; this system would undergo several formal reviews. During critical stages of development, on-site technical representation ensures that all system requirements have been addressed. Detailed reporting of cost, schedule, and technical milestones enhances monitoring of SBI hardware development.

5.2 Make-or-Buy Criteria

A more in-depth make-or-OTS-buy analysis would group SBI equipment hardware into one of these categories: 1) Must OTS-buy, 2) Must make, 3) Can make or OTS-buy. The requirements for these categories were developed from the McDonnell Douglas Astronautics Company (MDAC) make-or-buy decisions for Crew Health Care SBI #48). Examination of these guidelines would be useful in a detailed make-or-OTS-buy analysis of SBI hardware.

5.2.1 Must-OTS-Buy Considerations

The following must-OTS-buy considerations were developed from the MDAC make-or-OTS-buy analysis for CHeC. However, these considerations are of value in determining factors necessary to consider in an SBI make-or-OTS buy analysis. Must-OTS-buy decisions can be based on the following criteria:

A. The item involves development that has been already completed by an outside source on prior similar programs and it is not cost or schedule effective to duplicate such development effort on the new program.

B. An outside source possessed unique processes, tooling, facility, relative technical superiority, or exclusive franchises for a given item or task.

C. When the financial or technical risks are not involved, a buy decision can be made if comparative capabilities, schedules, and costs favor a buy recommendation. In evaluating suppliers, the relative competence, ability, experience, size, and location (small business, small disadvantage business, or labor surplus areas) of suppliers must be considered. Supplier proximity (or the logistics involved in coordination, delivery or assembly of supplier parts), supplier accessibility, prior performance, parts replacement, and warranties are also evaluation factors.

5.2.2 Must-Make Considerations

Based on the information of the MDAC make-or-buy analysis for CHeC, must-make decisions should take the following criteria into consideration:

A. An item could be developed and produced without requiring additional facilities at equal or lower cost than if purchased.

B. An item was, or is being made cost-effectively by NASA on other similar space biology programs.

C. Certain complex items or those with critical interfaces, determined to involve quality, cost, schedule, or technical risks, warranted "must make" recommendation to ensure maximum management attention to and control of these items to minimize such risks.

D. In a make-or-buy situation, where the successful development of a complex item depends in large measure on close interface control and rapid adaptation to changing in-house design conditions or interface requirements, a make decision was warranted even though the item or task could be competitively purchased in terms of comparable costs and performance.

E. When certain new assemblies or schedule-critical components required close management or engineering surveillance during the development process in order to ensure meeting program need dates, a make decision was made.

5.2.3 Make-or-OTS-Buy Considerations

Either make-or-buy conditions occurred in the CHeC analysis where neither a strong make-or-buy recommendation existed. Other factors considered by MDAC in the make-or-buy analysis for CHeC, include:

A. Make-or-OTS-buy tradeoff factors which include the relative availability of specialized personnel, material, or processes for a given program; capacity considerations, such as the impact on plant workloads; facility changes and costs; laboratory, manufacturing, or manpower resources; new business and future production requirements; and market conditions.

B. New technology or product lines and future technological innovations must be assessed to determine whether to embark on the new product line in-house or to solicit and support outside development of the item.

5.3 Benefits of Make

The following are advantages of new build hardware:

New build may be the only way to construct unique hardware.

Can specify extremes of reliability and safety if needed.

Ability to incorporate miniaturization, commonality, modularity, or other special features.

Possibility of reduced operational maintenance cost due to modularity.

5.4 Benefits of Buy

The following are advantages of modified OTS hardware:

Possibility of significantly less DDT&E and production cost.

Possibility of significantly less DDT&E time.

Vendor's design and production expertise utilized.

Spare parts usually available in future.

Technology updates available in future.

Significant cost reduction.

5.5 Knowledge of Commercial Technologies

It is imperative that a thorough search of existing and planned commercial technologies be performed before any decision is made to design a product from scratch. For example, fluid handling will be one of the problems encountered when performing life science research in a micro-gravity environment. Because a great majority of analytical biomedical equipment requires some degree of fluid handling during sample preparation, sample analysis and clean up procedures, this problem must be addressed. A capability for fluid transfer in a microgravity environment might be considered non-existent in the commercial market; however, an in-depth survey could reveal that equipment to perform these tasks exists commercially.

For example, current laboratory techniques for diluting, dispensing, pipeting and titration of fluids usually rely on gravity-dependent processes. However, a survey of commercial capabilities done by Management and Technical Services Company (MATSCO) and published in "Biomedical Equipment Technology Assessment for the Science Laboratory Module" (SBI #23) found that some sample preparation devices are currently being manufactured which could work in micro-gravity. These systems can provide for fluid handling, reduce crewtime requirements, and reduce the volume of reagents and samples necessary because of eliminated waste and higher accuracy. One such system is the Beckman Accu-Prep. It uses positive displacement rather than peristaltic pumps to transfer fluid and should, therefore, work fine in micro-gravity regardless of cabin pressure. An additional advantage of the Accu Prep is its built-in microcomputer which is able to store up to 50 separate sample preparation protocols, thereby eliminating the need for hardcopy or uplinked Payload Crew Activity Plans. Further studies could then be done to investigate the feasibility of modifying this equipment for use in space.

5.6 Uniformity of Design Requirements

Uniformity of design requirements needs to be established between the design organization and the flight agency (NASA) certifying quality assurance. Uniform criteria for application of reliability standards, materials requirements and requirements, to the many classes of hardware to be developed must be established. The Management and Technical Services Company (MATSCO) in preparing the Life Sciences Study for the Space Station, SBI #94, learned that testing done by the manufacturer of commercial equipment may exceed spacecraft requirements, see Table 5.6. Information on the Spacelab requirements was obtained from the Spacelab Payload Accommodation Handbook, SBI #92.

5.7 Hardware Make-or-OTS-Buy Analysis

5.7.1 SBI Hardware Vital to Program Costs

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.

This list is a reference list only. 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 make-or-OTS-buy. 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 (see Table 5.7, Database Listing for SBI Hardware Vital to Program Cost Impact Analysis). 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. Thus these 32 items account for the majority of the cost of SBI hardware.

5.7.2 SBI Hardware Sample Selection

The prioritized list of "vital" hardware items was considered for as a sample set of candidates for buy. This list was further examined for those items which could be obtained from modified COTS hardware. The 32 hardware items in Table 5.7 were broken down by assembly and analyzed for the potential of substituting with off-the-shelf equipment. According to the guidelines determined in this study, only off-the-shelf equipment which required modifications less than or equal to 40 percent of the item (by weight) were considered as potential OTS candidates. Hardware assemblies which would require greater than a 40 percent modification if purchased OTS were calculated as new build, since these assemblies have little, if any, potential as an OTS purchase. This list was developed using all available resources within the constraints of this study. This assessment of possible candidates is based upon the best knowledge of the SBI hardware items at the time of this study. The items for which estimates were left blank in this table ("No" under Sufficient Data) indicates that these items are still in a conceptual phase and sufficient data was not available for assessment. (See Table 5.7-1, Database Listing for Make-or-OTS-Buy Sample Selection Assessment.)

5.7.3 SBI OTS-Buy Candidates Selection

The hardware items in Table 5.7-1 were examined for potential off-the-shelf buy candidates. Items of SBI hardware for which sufficient data was unavailable for breakdown and analysis be assembly were eliminated for consideration. Those hardware items judged to have no potential for OTS-buy were also eliminated. The remaining SBI hardware items were judged to have a potential for use as modified commercial off-the-shelf equipment items. These OTS-buy candidates are listed in Table 5.7-2, Database Listing for Make-or-Buy Candidate Sample Set and summarized in Table 2.2.3.

5.8 Make-or-OTS-Buy Cost Impact Analysis

Table 5.7-2 lists the % Buy, % Mod to Buy, and % OTS of the most important pieces of SBI hardware. The potential percentage cost savings were then calculated for each item, using the following method:

The potential percentage cost savings was derived as follows:

a. The percentage of hardware to be flown without modification is costed at 15% of new design.

b. The portion of OTS to be modified is estimated to cost 50% as much as a new design.

The cost of the modified OTS is then calculated as:

Modified Item Cost = (% unmodified) * .15 + (% modified) * .50

Potential Cost Savings = 100% - Modified Item Cost

An example may serve to illustrate. Assume that a given item is 60% modified and 40% unmodified. Then the cost is given at:

Cost Modified Item = .40 * .15 + .60 * .50
= .06 + .30 = .36

Savings = 1.00 - .36 = .64 or 64%

If one varies the number and assumes 60% is modified and the modification cost is equal to the new design cost then:

Cost of modified item = .60 * 100% + .40 * .15
= .60 + .06 = 66%

Potential Cost Savings = 100 - 66 = 34%

5.8.1 Neck Baro-Cuff Make-or-OTS-Buy Example

The 32 items accounting for 94 percent of the mass of SBI hardware were examined for the possibility of purchase as commercial off-the-shelf equipment, with modifications for use in the micro-gravity environment of space. Each of these 32 pieces of SBI hardware was broken down into major components and the components analyzed for make-or-buy recommendations. The Neck Baro-Cuff, SBHB item #106, is shown as an example of this process.

The Neck Baro-Cuff, also known as the Carotid Sinus Baroreceptor Stimulator, is a chamber strapped to the neck of a human subject which applies pressure or suction of controlled magnitude and duration to the carotid arteries. The Baro-Cuff was designed to study the blood pressure reflex responses of astronauts in space. A Neck Baro-Cuff drawing, which appeared in NASA Tech Briefs, Dec. 1988 (SBI #98), is shown in Figure 5.2.

The Neck Baro-Cuff was broken down into the following components:

Neck chamber and umbilical tube

Pressure sensor
Bellows
Stepping motor
Electronic system

The Baro-Cuff Neck Chamber is modified uniquely to fit the front of the subject's neck so that it provides a seal for both positive and negative pressures. The seal leaks so little that a bellows can be used instead of a pump to change the pressure in the chamber. The bellows, driven by a stepping motor, is smaller and quieter than a pump and uses less power. The electronic system contains a microprocessor chip which controls the stepping motor and collect the data. Erasable, programmable, read-only memory chips store custom software for the microprocessor. Instruments measure and display the pressure in the chamber and the subject's electrocardiogram and respiration.

5.8.2 Neck Baro-Cuff Make-or-OTS-Buy Analysis

Each of the Baro-Cuff components were analyzed for possible off-the-shelf purchase. The neck chamber was immediately eliminated since it must be designed and fitted to conform to the test subject. However, the pressure sensor, bellows, stepping motor, and electronic system were found to all have the potential for off-the-shelf purchase followed by modifications for use in space. These items were judged to account for 95 percent of the weight of the Baro-Cuff system. Each of these items was then analyzed for the amount of modifications which would be required. The percentage of OTS that must be modified was estimated to be 30%. This means 66% is OTS with no modification required and 29% is OTS which must be modified. Modification costs are then estimated to be 50% as much as a new design and OTS cost taken as 15% the cost of new design. The result is a net savings on the baro-cuff of 70% compared to all new design. Had the modification cost been taken as equal to the cost of new design, and the OTS cost taken as 25% of a new design, the net savings would be reduced to 49%.

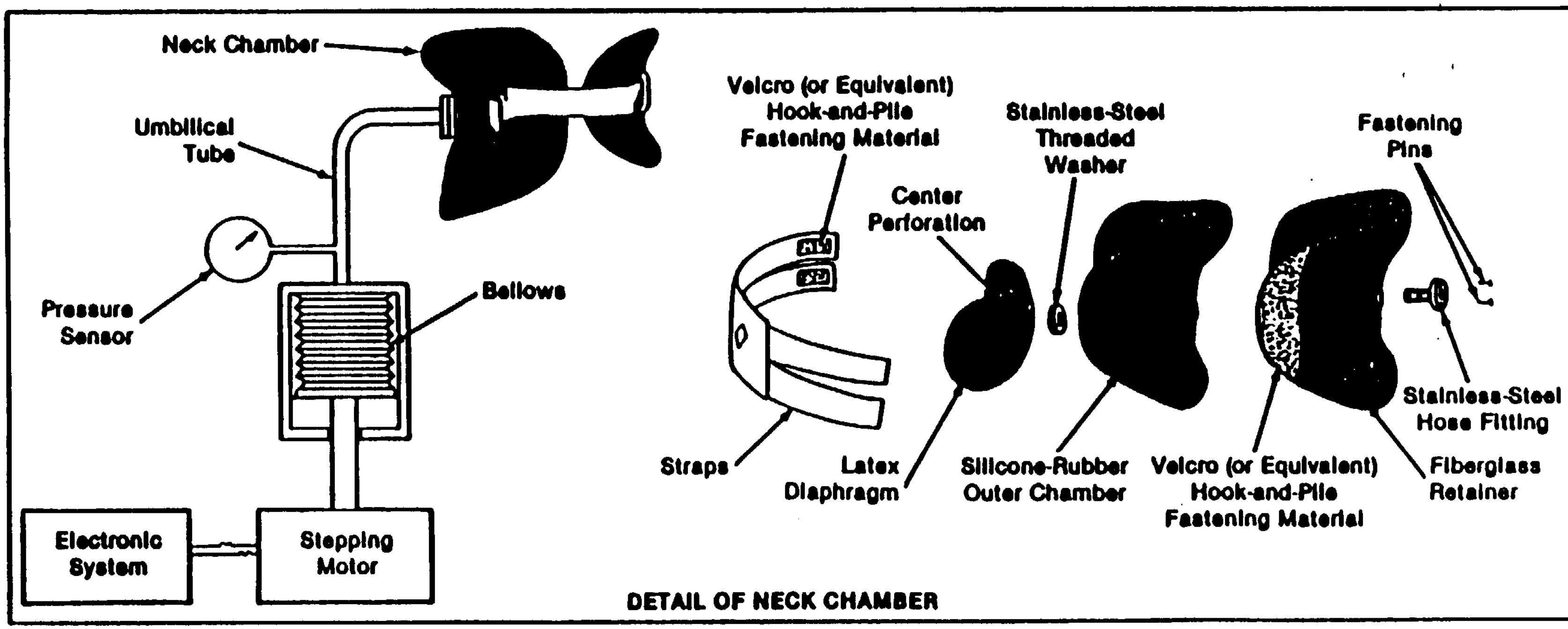


Figure 5.2-1 Make-or-Buy Cost Impact Analysis Example

Table 5.6 Comparison of Environmental Standards Between a Commercial Company and Spacelab

	HEWLETT-PACKARD	SPACELAB REQUIREMENT
TEMPERATURE:	-40°C to 75°C (Non Operating) -20°C to 65°C (Operating)	-10°C to +55°C
HUMIDITY:	40°C 5-95% RH 65°C 90% RH (Non Operating)	Test Not Required
VIBRATION:	5 - 55 - 5 Hz .015 IN 1 Min/Octave	Vibration Spectrum Defined in SPAH*
SHOCK:	30g 11MS 18 Shocks	20g 11MSs 18 Shocks
BENCH HANDLING:	Per MIL-T-28800A Paragraph 4.5.5.4.4 (4" Drop Test)	Test Not Required
EMI:	Radiated-Conducted- Electrostatic Discharge Power Line Transients Susceptibility Magnetic Fields	Radiated Only Per MSFC Spec 521
STRIFE:	Temperature Cycling for 1 Month	168 HR 55°C Burn-In
PRESSURE:	Low Pressure Test to Qualify for Air Transport Shipment	Not required

Table 5.7 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	26	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	23.0	3050	86	71	78
21	34	Sample Preparation Device	23	22.0	3072	87	73	79
22	165	Experiment Control Computer System	24	20.1	3092	87	77	80
23	62	Pulmonary Function Equipment Stowage Assembly	25	20.0	3112	88	77	80
24	82	Motion Analysis System	26	20.0	3132	89	77	81
25	99	Animal Biotelemetry System	27	20.0	3152	99	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 5.7-1 Database Listing for Make-or-Buy Sample Selection Assessment

Item # Prioritized by Mass	HW Item #	Hardware Item Name	Sufficient Data Available	% Buy	% Mod to Buy	Assessment Confidence Level
1	168	CELSS Test Facility	YES	20	30	HIGH
2	169	Gas Grain Simulator	YES	33	30	HIGH
3	84	Soft Tissue Imaging System	NO	0	0	
4	77	Hard Tissue Imaging System	NO	0	0	
5	126	Scintillation Counter	YES	95	30	HIGH
6	74	Force Resistance System	YES	95	25	HIGH
7	145	Automated Microbal System	YES	95	40	LOW
8	155	Total Hyrdocarbon Analyzer	YES	100	30	LOW
9	161	Inventory Control System	YES	95	15	HIGH
10	162	Lab Materials Packaging & Handling Equipment	YES	0	0	HIGH
11	163	Test/Checkout/Calibration Instrumentation	YES	50	20	HIGH
12	106	Neck Baro-Cuff	YES	95	30	HIGH
13	113	Blood Gas Analyzer	NO	0	0	
14	61	Mass Spectrometer	YES	70	35	LOW
15	112	Plant HLPC Ion Chromatograph	NO	0	0	
16	147	Head/Torso Phantom	YES	3	35	HIGH
17	63	Pulmonary Gas Cylinder Assembly	YES	95	10	HIGH
18	110	Plant Gas Chromatograph/Mass Spectrometer	YES	70	35	LOW
19	115	Chemistry System	YES	50	30	LOW
20	138	Hematology System	YES	50	30	LOW
21	34	Sample Preparation Device	YES	0	0	HIGH
22	165	Experiment Control Computer System	YES	80	30	HIGH
23	62	Pulmonary Function Equipment Stowage Assembly	YES	0	0	HIGH
24	82	Motion Analysis System	YES	90	20	HIGH
25	99	Animal Biotelemetry System	YES	95	20	HIGH
26	100	Blood Pressure and Flow Instrumentation	YES	85	20	HIGH
27	109	Venous Pressure Transducer/Display	YES	85	20	HIGH
28	129	Cell Handling Accessories	YES	0	0	HIGH
29	57	Bag-in-Box	YES	80	20	LOW
30	111	Plant Gas Cylinder Assembly	YES	95	10	HIGH
31	119	Gas Cylinder Assembly	YES	95	10	HIGH
32	130	Cell Harvestor	YES	0	0	LOW

Table 5.7-2 Database Listing for Make-or-Buy Candidate Sample Set

HW Item #	Hardware Item Name	Mass (kg)	% Buy	% Mod to Buy	% OTS	Assessment Confidence Level
168	CELSS Test Facility	1000.0	20	30	14	HIGH
169	Gas Grain Simulator	800.00	33	30	23	HIGH
126	Scintillation Counter	90.000	95	30	67	HIGH
74	Force Resistance System	70.000	95	25	71	HIGH
145	Automated Microbal System	70.000	95	40	57	LOW
155	Total Hyrdocarbon Analyzer	70.000	100	30	70	LOW
161	Inventory Control System	70.000	95	15	81	HIGH
163	Test/Checkout/Calibration Instrumentation	70.000	50	20	40	HIGH
106	Neck Baro-Cuff	45.200	95	30	66	HIGH
61	Mass Spectrometer	40.700	70	35	45	LOW
147	Head/Torso Phantom	32.000	3	35	2	HIGH
63	Pulmonary Gas Cylinder Assembly	30.000	95	10	85	HIGH
110	Plant Gas Chromatograph/Mass Spectrometer	25.000	70	35	46	LOW
115	Chemistry System	23.000	50	30	35	LOW
138	Hematology System	23.000	50	30	35	LOW
165	Experiment Control Computer System	20.100	80	30	56	HIGH
82	Motion Analysis System	20.000	90	20	72	HIGH
99	Animal Biotelemetry System	20.000	95	20	76	HIGH
100	Blood Pressure and Flow Instrumentation	20.000	85	20	68	HIGH
109	Venous Pressure Transducer/Display	20.000	85	20	68	HIGH
57	Bag-in-Box	19.000	80	20	64	LOW
111	Plant Gas Cylinder Assembly	19.000	95	10	86	HIGH
119	Gas Cylinder Assembly	19.000	95	10	86	HIGH

6.0 Conclusion

In this study, a make-or-OTS-buy analysis was made from the Space Biology Hardware Baseline (SBHB). Of the 32 SBHB items accounting for 93 percent of the mass, 23 were found to have a potential to be acquired as modified off-the-shelf. The percentages (by weight) of these 32 SBHB items which could be acquired as modified off-the-shelf were then found and listed in Table 5.7.-1.

This study encountered many examples of make-or-OTS-buy decisions from past NASA programs. It would be an oversimplification to group hardware items by some classification or function and use this information to make a make-or-OTS-buy decision on other hardware. This study concluded that all pieces of SBI hardware should be individually analyzed for make-or-OTS-buy potential. However, the indications from this study all point to the fact that SBI can be developed using a significant percentage of modified COTS or OTS and save substantial amount of money in the process.

There are two conclusions which can be drawn from this relative cost evaluation.

a. After the final selection of SBI hardware items, each individual item must be costed separately based upon a careful evaluation of the modification cost required and the cost of the basic unit compared to a new design.

b. The potential for cost savings or cost avoidance is very substantial even where the modification costs are high. Appendix C, Table 3-7 and Table 3.8 contain estimated dollar cost per kilogram for modification cost over a range of design factors, df.

Based upon the assumption that modification design costs are 50% as much as an all new design and that purchase costs are 15% of a new design, the potential cost savings for each SBHB make-or-OTS-buy candidate were calculated and presented in Table 5.7-2 and 2.2.3.

As space operations and research becomes more accessible, the need become more pronounced for using equipment routinely found in medical facilities/research labs on the ground. Decisions on whether to develop hardware or modify commercial hardware will become extremely significant in terms development times and costs.

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	CO_2 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

C-2

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

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

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

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

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

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

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

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

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

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

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

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

source codes: C=1.8 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 CP
	CLOSED ECOLOGICAL LIFE SUPPORT FACILITY (7)				
	FEAST GROUP (7A)				
168	CELSS Test Facility	S	1.92	1000	1300
	EXOBIOLOGY FACILITY (8)				
	GAS/GRAIN GROUP (8A)				
169	Gas Grain Simulator	S	1.92	800	1500

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

LIFE SCIENCES HARDWARE LIST FOR THE SPACE STATION FREEDOM Eh^

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

A=ARC, J=JSC, '=Prime

Updated: 3/22/89

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

A-ARC, J-JSC, '-Prime

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

Appendix B - Complete SBI Trade Studies Bibliography

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

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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SBI14	JPL	Flight Projects Office Payload Classification Product Assurance Provisions		JPL	JPL D-1489 Rev. A	Pasadena, CA.	04/30/87
SBI15	PRC Systems	Cost Estimate For The Search for Extraterrestrial Intelligence (SETI) Revised		PRC Systems Services		Huntsville, AL.	06/15/87
SBI16	NASA SSPO	Space Station Commonality Process Requirements Rev.B		NASA SSPO	SSP 30285 Rev. B	Reston, Virgina	09/15/88
SBI17	Webb, D.	Technology Forecasting Using Price - H		Rockwell International		Anaheim, CA.	04/17/86
SBI18	NASA	Classification Of NASA Office Of Space Science And Applications (OSSA) Space Station Payloads		NASA JSC		Houston, TX.	/ /
SBI19	NASA	Life Science Research Objectives And Representative Experiments For The Space Station (Green Book)		NASA Ames Life Science Division		Moffet Field, CA.	01/01/86
SBI20	NASA	Medical Requirements Of An In-Flight Medical System For Space Station		NASA JSC	JSC 31013	Houston, TX.	11/30/87
SBI21	TRW	A Study Of Low Cost Approaches To Scientific Experiment Implementa-tion For Shuttle Launched And Serviced Automated Spacecraft		TRW Systems Group	Contract NASW - 2717	Redondo Beach, CA.	03/19/89

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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SBI22	LMSC	Low-Cost Program Practices For Future NASA Space Programs		LMSC	LMSC-D387518	Sunnyvale, CA.	05/30/74
SBI23	Steward, GMiller, L	Biomedical Equipment Technology Assesment For The Science Laboratory Module		Management and Technical Services Company		Houston, TX.	08/01/86
SBI24	General Electric	WP-3 Commonality Plan		General Electric	NAS5-32000	Philadelphia , PA	04/22/88
SBI25	NASA	Microbiology Support Plan For Space Station		NASA JSC	JSC-32015	Houston, TX.	09/01/86
SBI26	NASA	Concepts And Requirements For Space Station Life Sciences Ground Support And Operations		NASA JSC	LS-70034	Houston, TX.	04/11/88
SBI27	NASA	Spacelab Mission 4 Integrated Payload Requirements Document		NASA JSC	SM-SE-03	Houston, TX.	06/01/83
SBI28	General Dynamics	Life Sciences Payload Definition And Integration Study	IV	General Dynamics	CASD-NAS-74-046	San Diego, CA.	08/01/74
SBI29	General Dynamics	Life Sciences Payload Definition and Integration Study - Executive Summary	1	General Dynamics	CASD-NAS-74-046	San Diego, CA.	08/01/74
SBI30	NASA	SL-3 Ames Research Center Life Sciences Payload Familiarization Manual		Ames Research Center	ADP-81-50-001	Moffet Field, CA.	02/01/81
SBI31	Rockwell Intl.	EMS Data Data Package 2.3A S4200.2 Methodology Definition - Commonality Analysis Trade Study		Rockwell Internation	SSS 85-0168	Downey, Ca.	10/04/85

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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SBI32	Rockwell Intl.	EMS Data Data Package 2.2B S4201.2, Module Commonality Analysis		Rockwell International	SSS 85-0137	Downey, CA	09/06/85
SBI33	General Electric	Space Station Work Package 3 Definition And Preliminary Design Commonality Candidates		General Electric Space Systems Division	DRD - 19	Philadelphia , PA	05/10/85
SBI34	Rockwell Intl.	EMS Data Data Package 2.3A S4203.2, Module Outfitting/System Commonality Analysis		Rockwell International	SSS 85-0158	Downey, CA	10/28/85
SBI35	NASA JSC	Space Station Freedom Human-Oriented Life Sciences Research Baseline Reference Experiment Scenario		JSC- Medical Sciences Space Station Office	Blue Book	Houston, TX.	10/01/88
SBI36	NASA SSPO	Space Station Approved Electrical Electronic, And Electromechanical Parts List		Space Station Program Office	SSP 30423 Rev. A	Reston, Virgina	11/15/88
SBI37	NASA SSPO	Space Station Program Design Criteria and Practices		Space Station Program Office	SSP 30213 Rev. B	Reston, Virgina	07/30/88
SBI38	MDAC	Manufacturing Management Plan		McDonnel Douglas	DR MU-01	Houston, TX	/ /
SBI39	NASA JSC	July 1988 Pogress Report On Experiment Standard User Interfaces Study		JSC - Life Sciences Project Division		Houston, TX.	07/01/88
SBI40	Rockwell Intl.	EMS Data Data Package 2.3A S4207.2, GSE Commonality Analysis		Rockwell International	SSS 85-0099	Downey, CA	10/04/85
SBI41	NASA OSSA	Life Sciences Space Station Planning Document: A Reference Payload For The Life Sciences Research Facility		Office of Space Science and Applications	NASA TM 89188	Washington, D.C.	01/01/86

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

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

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SBI68	Hamaker, Joe	Telephone interview relating to MSFC history and techniques for cost estimating.		Cost Analysis Branch Chief MSFC		Huntsville, Al.	04/27/89
SBI69	Booker, Clef	Personal Interview		Man-Systems Division JSC		Houston, TX.	04/04/89
SBI70	Evans, Jim	Personal Interview		Life Science Project Division JSC		Houston, TX.	04/19/89
SBI71	Heberlig,Jack	Telephone interview relating to make-or-buy lessons learned from Apollo		International Business Machines (IBM)		Houston, TX.	03/10/89
SBI72	Loftus, Joe	Telephone interview relating to make-or-buy history		Assistant Director (Plans) JSC		Houston,TX.	03/14/89
SBI73	Christy, Neil	Telephone interview relating to hardware development student experiments, and make-or-buy				Houston, TX.	03/15/89
SBI74	McAllister,Fred	Telephone Interview		Man-System Division, JSC		Houston,TX	03/14/89
SBI75	Trowbridge, John	Interview relating to CHeC make-or-buy		McDonnell Douglas		Houston,TX.	03/17/89
SBI76	Trowbridge, John	Personal interview relating CHeC experience to miniaturization, modularity and make-or-buy		McDonnell Douglas		Houston, TX.	03/29/89
SBI77	Nagel, John	Personal Interview relating to LSLE make-or-buy experience		Eagle Technical Services		Houston, TX	03/27/89
SBI78	McFadyen, Gary	Personal Interview relating to life science hardware background at JSC		Southwest Research Institute		Houston, TX.	04/10/89

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ID #	AUTHOR	TITLE	VOL. NO.	PUBLISHER	REPORT/DOCUMENT NUMBER	PUBLISHER LOCATION	DATE
SBI79	Booker, Clef	Personal Interview - Minaturization on amplifiers, computers and modularity		NASA JSC/SP 341 Man-System Division		Houston, TX.	04/04/89
SBI80	McFadyen	Bioengineering on SBI hardware		Southwest Research Institute		San Antonio, TX.	04/06/89
SBI81	Allen, Joe	Personal interview - S.S. Life Science AIAA Meeting		Space Industries		Houston, TX.	04/07/89
SBI82	Averner, Maurice	Personal interview on CELSS		NASA HQ. CELSS Coordinator		Washington, DC.	04/07/89
SBI83	Fogleman, G. PhD	Personal interview relating to Gas Grain Simulation Facility		NASA AMES		Moffet Field, CA.	04/06/89
SBI84	White. Bob	Personal Interview relating to modularity and commonality		NASA JPL		Pasadena, CA.	04/10/89
SBI85	Grumm, Richard	Personal interview relating to SBI hardware		NASA JPL		Pasadena, CA.	04/11/89
SBI86	Boeing	U.S. Lab Review Workshop					/ /
SBI87	McGillroy,B.	Personal Interview on CELSS		NASA AMES		Moffet Field, CA	05/05/89
SBI88	NASA JSC	Life Science Flight Experiments Program Life Sciences Laboratory Equipment (LSLE) Descriptions		NASA JSC	JSC-16254-I	Houston, TX.	09/01/86
SBI89	Boeing	Space Station Program Commonality Plan Draft 3		Boeing	D683-10112-1		10/31/88
SBI90	GE Govt.Services	Life Sciences Hardware List for the Space Station Freedom Era - Baselined December 1988 Updated 3/22/89		GE Government Services		Houston, TX.	03/22/89

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

Appendix C - Cost Assessment Techniques Summary

1.0 Introduction

1.1 Relative Cost Impact Analysis Task

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

1.2 Documentation Approach

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

1.3 Cost Method Overview

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2.0 General Development Cost Methods

2.1 Empirical Methods

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

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

Where

wt = weight of the system, module or assembly

n = an exponent selected on the basis of system complexity

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

C_1 = constant selected to establish the cost trend origin

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

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

2.2 System Complexity Exponents (n)

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

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

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

2.3 Design Factors (df)

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

2.4 Method Summary

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

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

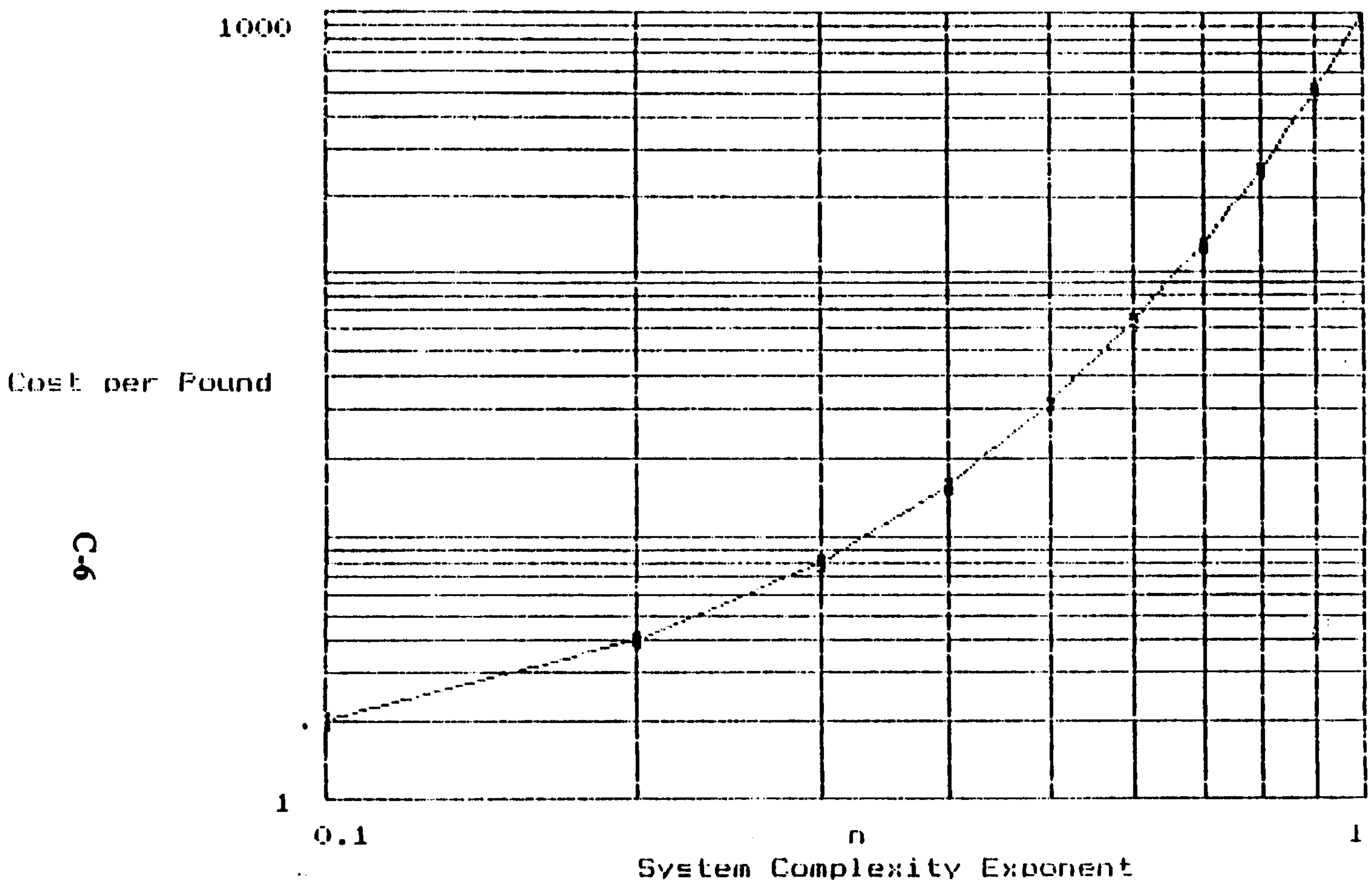


Figure 2-2 Design Factors

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

3.0 Cost Methods Applicable to Specific Trade Studies

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

3.1 Hardware Miniaturization Cost Drivers

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

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

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

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

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

Table 3-1
Miniaturization Guide Chart
n=.2

di \ % 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

di \ % 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

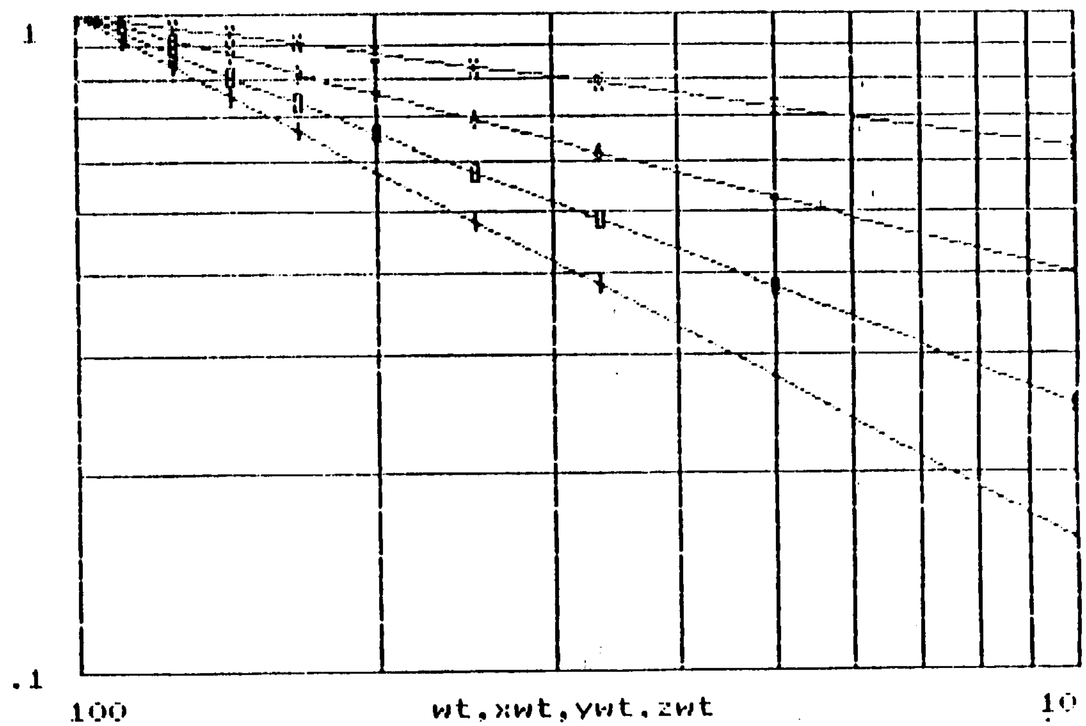
df / % Miniat.	0	10	20	30	40	50	60	70	80	90
Design Integration Only	1.00	.94	.86	.81	.74	.66	.58	.49	.38	.25
Significant Modification Req'd (30%)	2.00	1.88	1.72	1.62	1.48	1.32	1.16	.98	.76	.50
Major Modification Req'd (50%)	3.00	2.82	2.58	2.43	2.22	1.98	1.74	1.47	1.14	.75
All New Design	6.00	5.64	5.16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

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

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

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

Caution is advised! for several reasons:

1. Some items cannot be reduced in size.

2. Some items should not be reduced in size.

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

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

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

3.2 Modularity and Commonality

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

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

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

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

Then:

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

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

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

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

Normalized cost = C.P./4.1248 D&D

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

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

Quantity		2	4	8	16	24	32	64
Learning Factor								
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%

otes:

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

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

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

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

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

Table 3-6
Cost of Multiple Applications

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

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

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

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

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

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

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

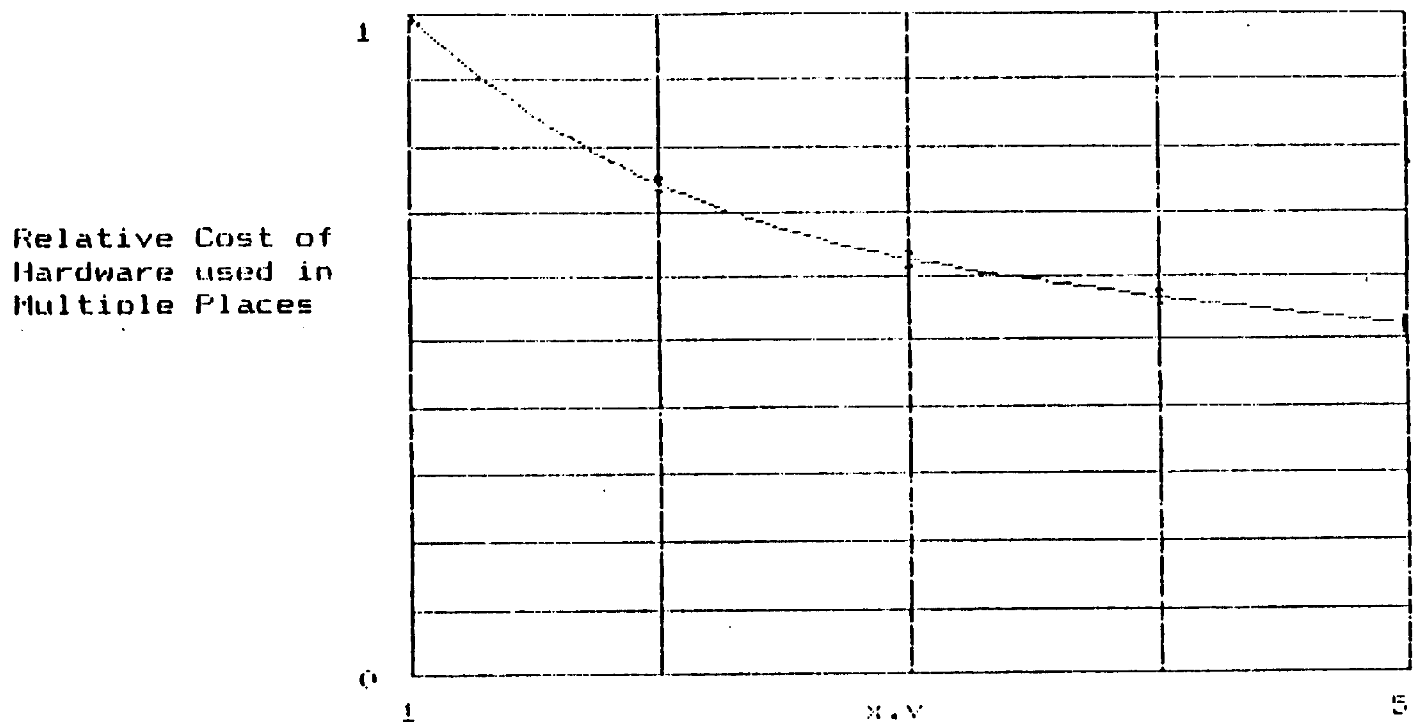
The costs shown in Tables 3-7 and 3-8 are based upon the assumption that COTS modifications are approximately the same cost as are redesigns to existing systems. The degree of modification (or redesign) is reflected in the design factor, df. The degree of system complexity is reflected by the system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

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

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

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

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

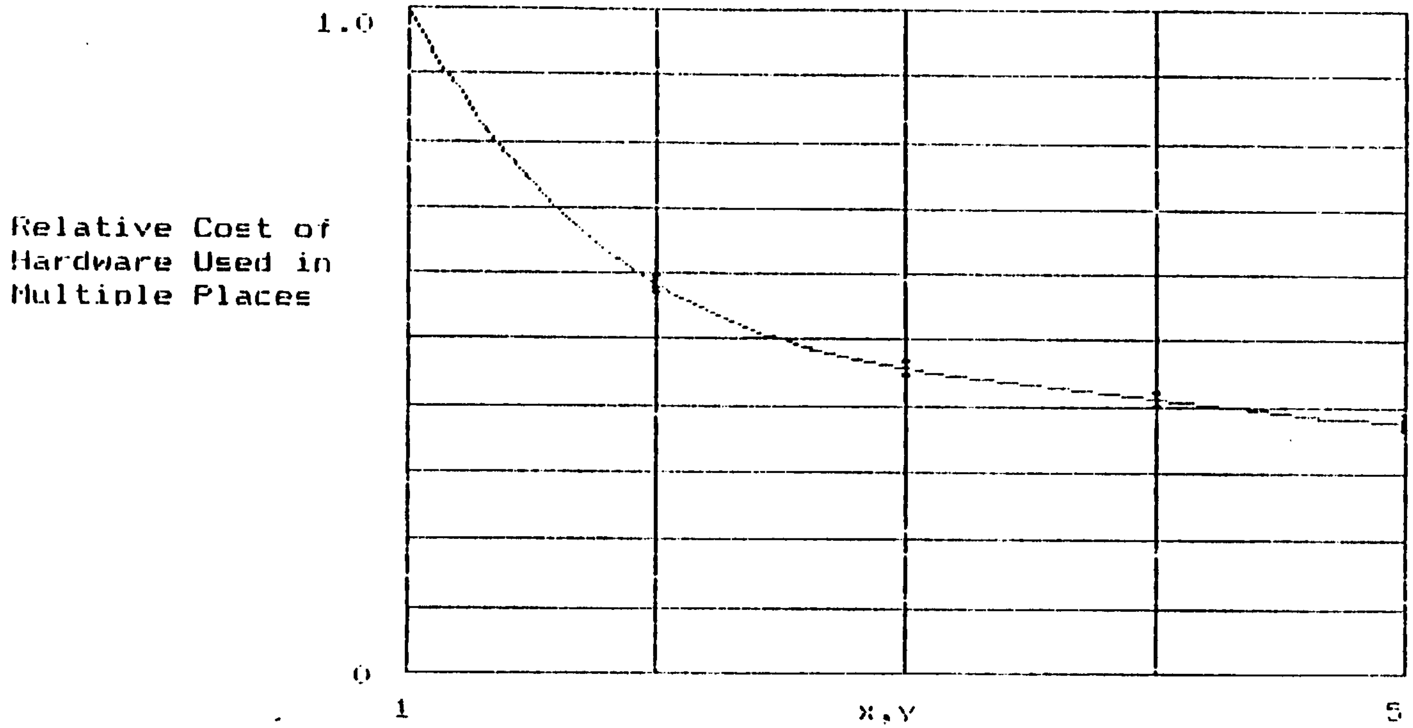


Number of Hardware Uses

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

Learning Factor = 80%

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



Number of Hardware Uses

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

Learning Factor = 80%

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

System Complexity Factor (n) =.2

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

Notes: 1) All costs are in thousands of dollars

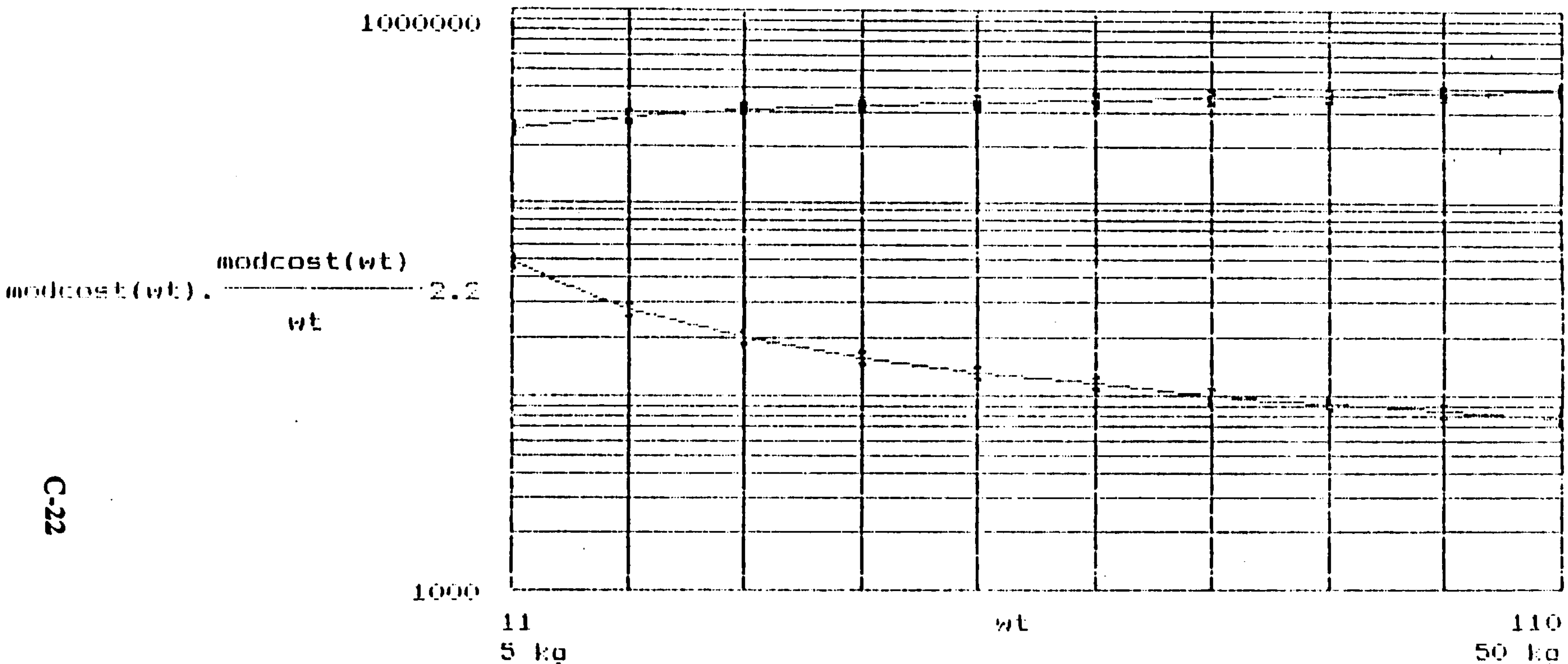
Table 3-8 Cost of Modifying Commercial Off-the Shelf Hardware

System Complexity Factor (n) =.4

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

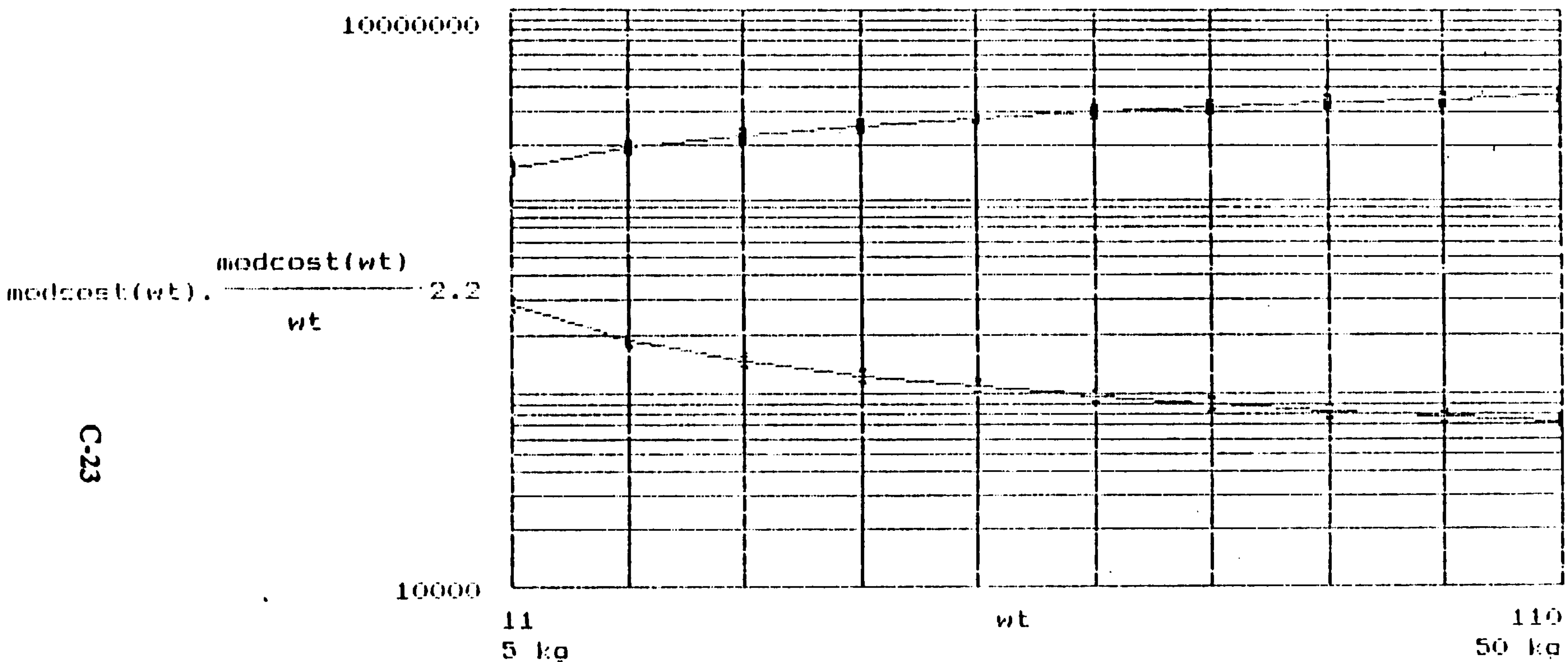
Notes: 1) All costs are in thousands of dollars

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



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

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



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

4.0 Testing Costs

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

4.1 Test Hardware

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

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

4.2 Integration Assembly and Checkout (IACO)

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

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

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

4.3 Test Operations

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

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

5.0 SE&I Costs

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

6.0 Program Management Costs

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

7.0 Life Cycle Costs

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

7.1 Study No. 3 - Miniaturization

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

7.2 Study No. 4 - Modularity and Commonality

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

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

7.3 Study No. 5 - COTS vs. New Hardware

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

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

7.4 Study No. 6 - Rack Compatibility

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

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

Table 7 -1 Life Cycle Cost

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

8.0 Recommendations

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

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

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

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

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Appendix D - Database Definition

Appendix D - Database Definition

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

Database Structure For SBI Trade Studies

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

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

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

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

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

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

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

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

Appendix D - Database Dictionary for Space Biology Initiative Trade Studies

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

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

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 - Make-or-Buy Analysis for CHeC

Appendix E - MAKE-OR-BUY ANALYSIS FOR CHeC

This appendix contains brief descriptions of the Make-or-Buy categories developed by McDonnell Douglas Astronautics Company (MDAC) for Crew Health Care (CHeC). This information was obtained from MDC H3924, CHeC Volume 1, Narrative, November 1988.

The items in Category 1 (must make) are of two types. The first type consists of items that are either identical to or similar to Space Station items that are being designed for reasons other than CHeC. Examples are compartment assemblies. The second type of Category 1 item is software. We believe that we must design the software associated with Data Management System (DMs) in order to ensure compatibility with the rest of the DMS.

Items that are considered to be in Category 2 (can make or buy) are of seven types: First, there are instruments that are primarily electronic in nature. We chose to buy these in most cases because many companies are available that can develop and produce such instruments at competitive prices. The second Category 2 type consists of containers, such as those used for kits. We have chosen to design these in Houston, and have them fabricated by small businesses in the Houston area. The third type consists of simple fabricated items as a specialized nature, and the fourth consists of complex fabricated items of a specialized nature. We plan to design both of these types in Houston; the simple ones will be fabricated locally by small businesses; the complex ones will be fabricated in-house in Huntington Beach. The fifth Category 2 type consists of wire harnesses; the sixth of plumbing. We plan to design both harness and plumbing in Houston. Both will be fabricated in Huntington Beach to take advantage of the availability of specialized equipment and experienced personnel. The seventh Category 2 type consists of low fidelity mockups. We plan to design and fabricate these in Houston. Fabrication of these noncritical items can safely be accomplished there, since specialized equipment and specially trained personnel are not required.

Category 3 (must buy) items are of four types. The first consists of instruments that involve more than just electronics, and other specialized flight equipment. We normally buy these items because certain companies have experienced and specialized equipment that makes them better qualified sources than our own company. There are two exceptions, where we decided that specialized flight equipment falls in Category 2 (can make or buy). These are the incubator and the glove box, where our company has directly applicable specialized experience. We plan to design the glove box in Houston, and fabricate it in Huntington Beach. The incubator is planned to be bought, but could be designed and built by a St. Louis division of our company. The second Category 3 type is the contents of kits. The third Category 3 is supplies. For both of these types of items, we expect that existing off-the-shelf items will be suitable for the CHeC requirements. The fourth category 3 type consists of items requiring specialized technology that is available only in certain companies. Examples are surgery drapes and task lighting.

Category 4 (must buy from major subcontractor) consists of those items that are identical to or similar to items normally supplied by our major subcontractors for Space Station. Examples are a Multipurpose Application Console (MPAC) processor and a modified Network Interface Unit (NIU) (less the bedside communications controller), both of which will be supplied by IBM.

In addition to the four categories discussed above, there is a GSE category. This has been used for items normally provided to us by the government because they are produced as part of another work package contract.

AUTOMATION COST VS CREW UTILIZATION

TRADE STUDIES

JOHNSON SPACE CENTER
HOUSTON, TEXAS
77058

SPACE BIOLOGY

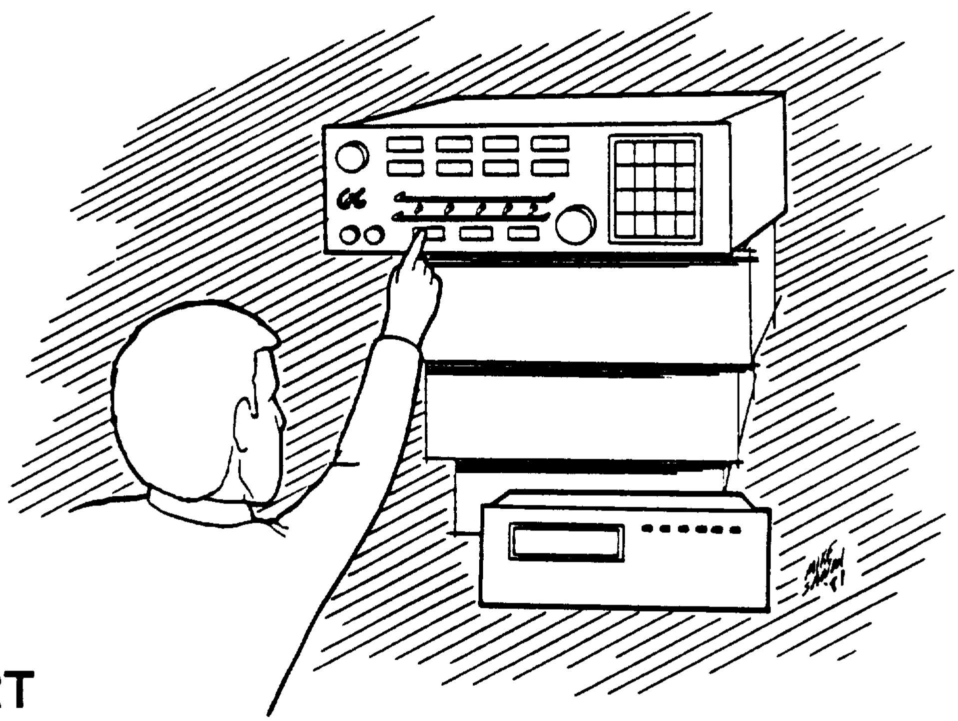
INITIATIVE

Space Biology Initiative
Program Definition Review

Lyndon B. Johnson Space Center
Houston, Texas 77058

*HORIZON
AEROSPACE*

Automation Costs
vs.
Crew Utilization



FINAL REPORT

June 1, 1989