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LIFE SCIENCES PAYLOAD DEFINITION AND INTEGRATION STUDY

VOLUME I + MANAGEMENT SUMMARY

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Convair Aerospace Division

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VOLUME I + MANGEMENT SUMMARY

March 1972

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National Aeronautics and Space Administration
GEORGE C. MARSHALL SPACE FLIGHT CENTER
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SECTION 1

INTRODUCTION AND SUMMARY

1.1 OBJECTIVES

The current NASA space program is being guided by overall objectives which include (1) acheiving greater scientific knowledge, and (2) hastening and expanding the practical application of space technology. The Life Sciences Payload Definition and Integration Study is an integral part of this NASA program.

The primary objectives of the payload definition study were to:

a. Identify the research functions which must be performed aboard potential life sciences spacecraft laboratories and the equipment needed to support these functions (Task A, Fig. 1.1).

b. Develop layouts and preliminary conceptual designs of several potential baseline payloads for the accomplishment of life sciences research in space (Task B, Fig. 1.1).

1.2 BACKGROUND

The Life Sciences Payload Definition and Integration Study was originally funded as the Space Biology Payload Definition Study and was to cover all four tasks shown in Figure 1-1. After four and one-half months of activity (mid-point of Task B), the program scope was expanded to include all of life sciences. The added Functional Program Elements (FPEs) of biomedicine, life support protective systems, and man-system integration were then made a part of a redefined activity called the Life Sciences Payload Definition and Integration Study. This study was then structured to perform only Task A and Task B (Payload Definition Phase) with the limited funds that were originally provided to do the entire program for space biology.

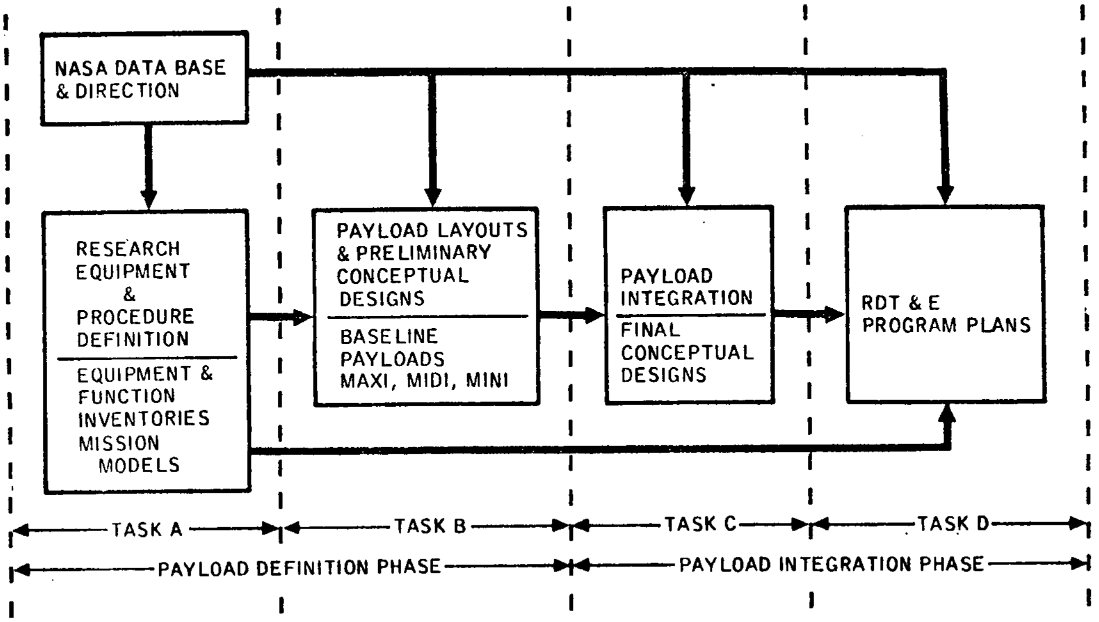


Figure 1.1 Program Overview.

1.3 CONDUCT OF THE STUDY

During Task A (Fig. 1.1), the basic research requirements were obtained from NASA Life Scientists and, under their guidance, from various sources of information. This included, (1) direct contact with pertinent life scientists including consulting biologists from the University of California at San Diego, (2) ad hoc NASA documents, (3) the NASA Blue Book, and (4) NASA/aerospace industry reports. From these data sources, inventories of functions (activities) and equipment necessary to conduct life sciences research in space were compiled. These inventories, containing pertinent information on the functions and equipment, were placed on computer cards in a format which permitted rapid print-out and updating, as well as computer processing. In compiling the master inventories of functions and equipment, mission parameters and other constraints were purposely not imposed in order to obtain comprehensive inventories. The master inventories thus provided a reference as to the maximum reasonable content and capability of an idealized orbital life sciences facility. Any reduction from this functional or equipment capability proposed for any reason could be monitored by the scientist/managers and approved or denied.

During Task B, preliminary conceptual designs were developed for several potential life sciences payloads. The functions and equipment inventories were screened for each potential payload according to a particular set of payload criteria. Thus, listings of appropriate functions and equipment for each payload were obtained and used as the basis for the Task B design studies. Work was performed on preliminary conceptual design layouts, research crew operations analysis, preliminary cost specifications, and supporting subsystem conceptual designs.

Throughout the study, the general philosophy of the laboratory "facility" approach was followed. This term refers to the fact, herein, that life sciences laboratory "facility" payloads capable of a wide variety of experimentation were developed rather than groupings of specific equipment designed to perform specific experiments. The experiments which might be accomplished in the time frame of the candidate payloads cannot be accurately defined at present, and will be dependent on the experimental results of earlier flights. Also, the long mission duration of the advanced research laboratories requires that they be capable of accommodating completely unknown experiments. Therefore, it was essential that a laboratory "facility" approach be used to (1) prevent initially locking-on to specific experiments which later may prove unrealistic, and (2) permit flexibility in program planning by NASA life sciences administrators.

Other general guidelines used during the study included (1) allowing the research requirements to dictate the payload characteristics with minimum constraints imposed by supporting mission and spacecraft, (2) use of evolutionary payload concepts to provide orderly growth from payloads with lesser capability to those with comprehensive capability, and (3) maintaining full responsiveness to the broad desires of the life scientists. The research requirements were emphasized, and engineering design concepts to meet these requirements were defined. This resulted in some payloads with broad capability that were completely responsive to all the scientists desires. These comprehensive laboratories were used as reference payloads, from which lesser capability payloads were defined with appropriate reduction in scientific responsiveness.

It is important to note that, having defined the maximum research capability requirement predictable from current knowledge, it is now possible to maintain accountability for all reductions in research capability due to any tradeoffs. This detailed accounting permitted the scientist/managers to confirm or refuse any specific capability reduction suggested by designers, since the scientist was kept fully aware of specific functions lost by modification or deletion of a given equipment item. Thus maximum responsiveness to scientists' needs was maintained, and the direction of integration planning impact is <u>from</u> science requirement <u>upon</u> design response.

The above comprehensive laboratories were referred to as maximum laboratories or payloads. They were to be supported by RAM payloads modules attached to a space station operating in a time period beyond 1980. The payloads with decreased capability were referred to as minimum laboratories or payloads. These were generally supported by a RAM payload module and a RAM support module operating in a shuttle sortie mode (1978 to 1980 time period). Support of the minimum payloads by Skylabs was also considered but this option was dropped early in the study.

1.4 SUMMARY OF BASELINE PAYLOADS

The final output of Task B was a set of four baseline preliminary conceptual design payloads. These are briefly described below.

a. The maximum laboratory (Maxi-Max) is the reference baseline payload providing full life sciences research capability. It can support research on large numbers of biological organisms to provide many simultaneous experiments yielding statistically valid results. Biomedical, Man-Systems Integration (MSI), and Life Support and Protective Systems (LSPS) research can also be fully supported. This laboratory was not constrained by practical considerations since it was intended only as reference payload, not to be flown. Most facilities which were suggested or desired by the research scientists were included. Broad capability scientific instruments rather than special purpose instruments were included to yield the maximum scientific return. A large dual purpose centrifuge was postulated as required to accommodate human, biological and technological research using 1g controls and various levels of g from 0-1g for test purposes.

b. The Maximum Nominal laboratory (Maxi-Nom) is foreseen as the most comprehensive laboratory which could actually be flown with the Space Station complex (Figure 1.2). Its Biomedical research capability is equivalent to the Maxi-Max, including all mandatory, highly desirable and desired research functions. Only the mandatory and highly desired functions are incorporated in the areas of Life Support and Protective Systems, Man-System Integration

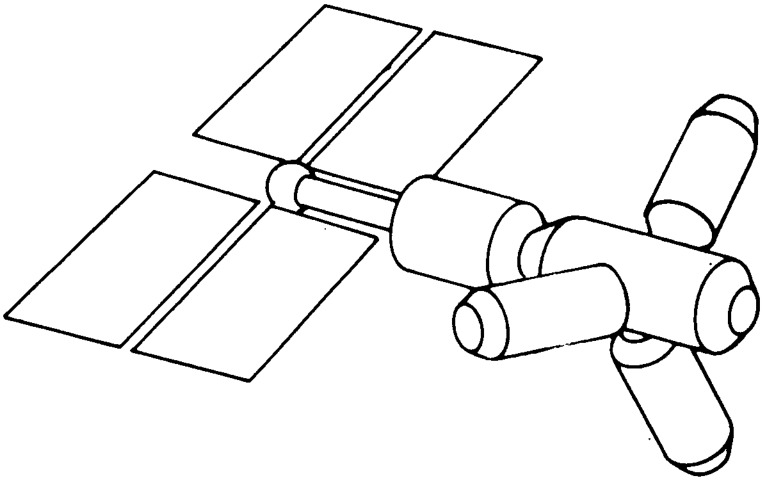


Figure 1.2. Space Station Configuration (for the Maxi-Nom and Growth Version Mini-30 Baseline Laboratories).

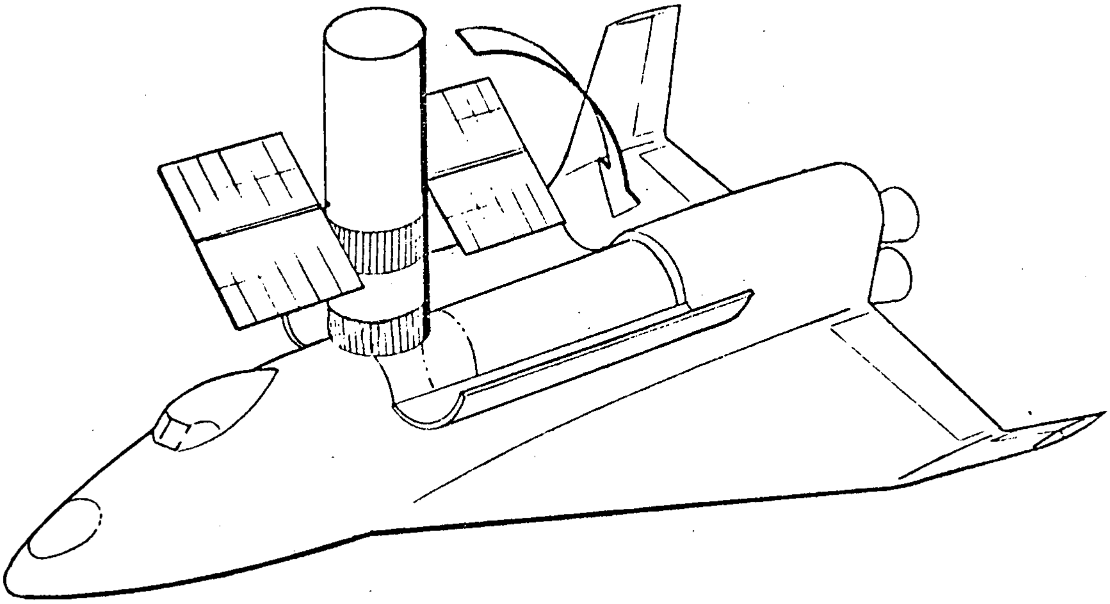


Figure 1.3. RAM/Shuttle Sortie Configuration (for Mini-30 and Mini-7 Baseline Payloads).

and Biology. However, the laboratory can support primates, small vertebrates, invertebrates, cells and tissues, and plants in sufficient quantities to provide statistically valid results on several simultaneous experiments. (Section 2.2.3 contains the complete tabulation on the number of organisms in each baseline payload.) The laboratory contains an internal centrifuge for biology studies. Research operations are semi-automatic, where possible, to reduce crew time requirements. On-board analysis is featured to minimize delay in obtaining near real time experiment results. The Maxi-Nom laboratory would fit into a RAM module 16.3M (53.3 ft) long and would weigh a total of 17,800 kg (39,200 lbs).

c. The Minimum-30 payload (Mini-30) is applicable to an initial Space Station mission as well as the 30-day RAM/Shuttle sortie flights (Figures 1.2 and 1.3). For a Space Station mission duration of one year, the Mini-30 laboratory could operate on a 30-day resupply basis. Operation with the RAM/Shuttle sortie would be for 30 days, but the laboratory could be used for multiple flights and experiments in series. Biomedical and Life Support and Protective Systems research capabilities accommodate both the mandatory and highly desirable functions. Man-system integration and Biology are supported only at the mandatory level of function. Ground analysis of specimens taken in space is used where possible to minimize equipment and the crew work load. No centrifuge is provided with this payload. The Mini-30 requires a RAM module 11 m (36.3 ft) long and it weighs 10,630 kg (23,390 lbs).

d. The Minimum-7 payload (Mini-7) is the smallest payload and would operate in a RAM/Shuttle sortie mode of 7 days total mission duration. The laboratory equipment would be reusable for multiple flights and experiments. For this round of payload definition the Biomedical research capability was omitted from this particular payload at the direction of the scientist/managers. However, Biomedical monitoring and flight support was assumed to be aboard as a distinctive operational feature and function of the sortie mission, but not included in nor assessed against the research payload. The remaining areas of Life Sciences research functions were included at the level, mandatory. Individual experiments in man-system integration and Life Support and Protective Systems can be accommodated by the Mini-7 laboratory for each sortie. The biology equipment will support research on cells and tissues, invertebrates and plants. No centrifuge is provided and samples taken in orbit will be returned to Earth for analysis. The Mini-7 requires a portion of a RAM module which is 6.7M (21.9 ft) long, and the total laboratory weighs 6.450 kg (14,190 lbs).

SECTION 2

LIFE SCIENCES RESEARCH FUNCTIONS, EQUIPMENT AND PAYLOAD DEFINITIONS

2.1 BACKGROUND

The functions and equipment required to support life sciences research in space were determined by a broad based study team containing members from various technical disciplines and working environments. The disciplines included biology, medicine, man-systems integration, life support/protective systems, systems engineering and design. The NASA team members represented NASA Headquarters, Ames Research Center (ARC), Langley Research Center (LRC), Manned Spacecraft Center (MSC), and Marshall Space Flight Center (MSFC). The academic team members were on the staff of the University of California San Diego. Convair Aerospace representing industry provided systems and design engineering as well as biological and medical capabilities.

This team used as a starting point, the reports and findings of the candidate experiment selection activities previously accomplished by the various Life Sciences elements of NASA. In this discussion the area of biology will be used as an example of how the study team worked with these data. However, it will be noted that the same approach was used to derive the functions and equipment requirements in the other Life Sciences disciplines from candidate flight experiment data.

The source material used to estimate the overall biology research capability requirements arises from the early 1960's and later when candidate experiment proposals (e.g., from Biosatellite, AAP, SR&T, and Experiment Survey Program, etc.) were initially evaluated. Scientific reviews of these proposals had been accomplished by various standing advisory and ad hoc panels operating for the NASA Office of Space Science and Applications (OSSA). The engineering feasibility and flight mission compatibility of the proposed experiments had been determined by NASA/ARC and MSC. After a final review, the Space Biology Subcommittee had recommended, over the years, a considerable number of experiments as candidates for flight. Some of these were chosen by OSSA for specific flights, but all of the candidate experiment outputs of this review and selection process served as the basic source material for this study. This base was supplemented by documentation from the Reference Earth Orbital Research and Applications Investigations Study, the Earth Orbital Experiments Program and Requirements Study and the Biotechnology Laboratory Study.

In addition to the above source material, specific direction and guidance was provided by the responsible NASA centers. In biology, for example, the study depended heavily upon the participation of ARC review and working groups. The initial selection of representative experiments and equipment was done by ARC. This selection defined in broad terms the biological research requirements and the common operational research equipment items (CORE) that were to be used during the payload study. NASA/ARC personnel also recommended that scientists from the University of California San Diego assist in development of the list of research functions and equipment.

A detailed study of the candidate biology experiments and other basic data discussed above, identified the individual activities, at the simplest feasible level, which, grouped in various combinations, constituted meaningful tasks. These were gathered into the biology functions inventory. Each individual function had one or more methods of accomplishment and associated with each method a complement of equipment items. By compiling the equipment items, and removing duplication, the biology equipment inventory was derived.

The fields of Biomedicine, Man-System Integration and Life Support and Protective Systems were treated in the same manner as Biology, after the expansion of the study to encompass all Life Sciences. Potential experiments and research requirements selected in these fields over the years were used to develop similar functions and equipment inventories for each respective field. Under the guidance of Scientist/Managers from each of the Life Sciences Centers, Convair Aerospace eliminated overall duplication and developed master Life Sciences functions and equipment inventories. The master inventories were finally reviewed for completeness and accuracy by the participating NASA Scientist/Managers and supporting representatives from their Centers.

From the master inventories, specific functions and related equipment were selected for each payload as a result of screening the inventories according to specific guidelines. In biology, for example, these guidelines were provided by the NASA/ARC review team and included: persisting research questions, the known experiment proposals, organism selection, numbers of organisms required for statistical validity, and preferred equipment and methods to perform the research. These or other guidelines were provided by the representatives of other disciplines. The selected payloads of functionally related equipment, provided the desired levels of research capability as determined by the NASA/Convair study team. This equipment was placed in common consoles and modules which were then used in the layout studies for the various life sciences laboratories. The layout studies included many variations of equipment location, orientation, and crew interface for the same payload research capability.

2.2 DEFINITION OF RESEARCH CAPABILITY

Fig. 2.1 shows an overview of the elements and the steps used in defining the payload research capabilities during the study. The data sources of exemplary experiments and reviews discussed in Section 2.1 formed the basis of NASA requirements input for this study. The second element involves the research functions. These are activities which must be performed in accomplishing the specific experiments. The third element is the method by which the function must be performed in accomplishing the specific experiments. This is a key element as it brings together the various desires and approaches of many scientists and, when applicable, results in a common approach using a minimum number of equipment items. The fourth element is the equipment required for the selected method. The last element is the process of selecting (sorting) and arranging the functions, methods, and equipment into logical functional research payloads.

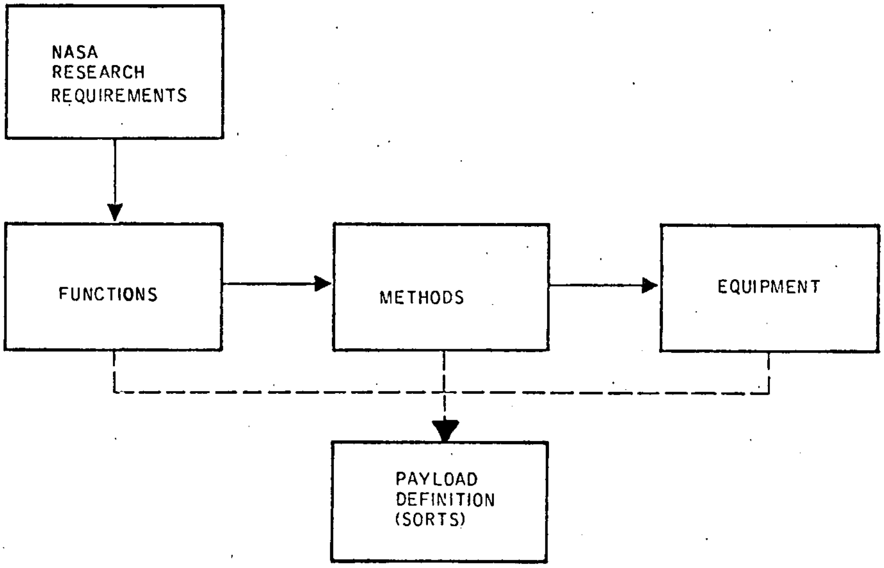


Figure 2.1. Steps in Development of a Research Capability

2.2.1. FUNCTIONS AND EQUIPMENT INVENTORIES. The functions inventory is a maximum reasonable list of possible research functions (activities) which might be required to be performed in Earth orbit. As shown in Fig. 2.2, the functions generally fall into four categories. Observations and measurements include all crew and camera observations and measurements made in space. Support operations are those functions required of the crew or equipment supporting observations and measurements. Organism holding functions are those required for organism housing, environmental support, and waste management of research organisms. Maintenance functions are those required for equipment maintenance, cleanup and instrument repair. The equipment inventory is a list of the possible equipment that might be needed to accomplish all functions in the inventory by any reasonable method. The functions inventory contains 455 activities required for space research, and the equipment inventory contains 382 items. Due to the size of these inventories, and the requirement to periodically accept new data, a computerized listing and processing program was developed. These listings can be updated as required to provide support for future life sciences payload studies.

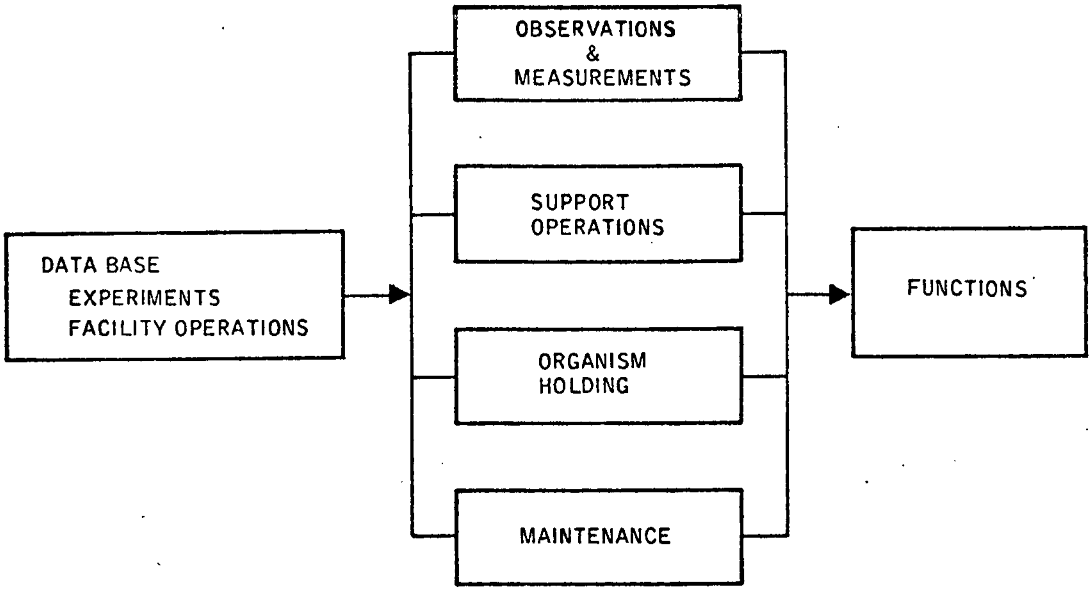


Figure 2.2. Function Categories

The functions inventory printout includes the following types of information.

a. Function Data - The title of the function and data which describes some of the characteristics of the function.

b. Methods Data - Information on one or more methods and associated procedures for performing the function.

c. Equipment Data - Preliminary information on the equipment required for each of the methods listed.

Examples of the functions are: vertebrate feeding; ECG monitoring; mass measurements; histological staining; plant lignin assay; and fungal culturing.

Some of the more pertinent information contained in the equipment inventory printout for each equipment item includes:

a. The data source.

b. The name of the item.

c. An equipment unit number which indicates a functional group of equipment into which the equipment item has been assigned.

d. Weight, power, and volume.

e. A code number indicating the degree of development required to obtain a flight qualified item.

f. A general classification which best describes the equipment item, such as electro-mechanical, electronic, optical, structural, and pneumatic.

g. Estimated development time in years.

h. A development risk rating (low, medium, high).

i. Estimated equipment item cost.

The numbers of functions and equipment contained in the inventories are summarized in Figure 2.3. The characteristic that is most apparent from the summary is the commonality of functions among FPE's, thus indicating the desireability of having a single laboratory to support all of life sciences research. As shown in the table, a total of 1055 functions would result in the functions required for individual FPE's were counted separately. However, because of commonality there are only 455 actual functions required to totally support the life sciences research capability. Similarly the equipment items have multiple use for the various FPE's within life sciences.

		BIOLOGY								
		VERTEBRATE	PLANT	INVERTEBRATE	CELLS & TISSUE	BIO-MED	LSPS	MAN SYSTEM INTEG. (MSI)	TOTAL	COMMON INVENTORY
FUNCTIONS		276	106	95	93	276	79	130	1,055	455
EQUIPMENT UNITS	CORE	7								
	FPE	6	5	5	5	8	2	6	37	20
EQUIPMENT ITEMS										382

Figure 2.3. Inventory Summary

2.2.2 PAYLOAD DEFINITION. The overall procedure for obtaining ordered payloads is diagrammed in Figure 2.4. This diagram illustrates the procedure used in screening the functions and equipment inventories to obtain a specific payload sort. The payload rationale and the available resource estimates are used by the NASA management team to determine such things as the basic content of the payload, the criticality of functions, and the level of automation or crew involvement. Such discrete payload requirements are used to select functions and optional methods for a specific payload.

The selection of specific methods by NASA Scientist/Managers for each function results in the requirements for specific equipment aboard the payload. This data is input to a computer program which interrogrates the equipment inventory for the required equipment items, arranges them in appropriate Equipment Units (EU) and sums up such characteristics as total weight, volume and power by Equipment Unit and for the whole payload.

The resulting set of functions, methods, and equipment make up a specific payload and are used as inputs to other analyses. The payload sorts provide the function and equipment data necessary for: scientists review, design and layout activity, commonality evaluation, cost evaluation, experiment time lining, hardware specifications development, SRT identification, and operations analysis.

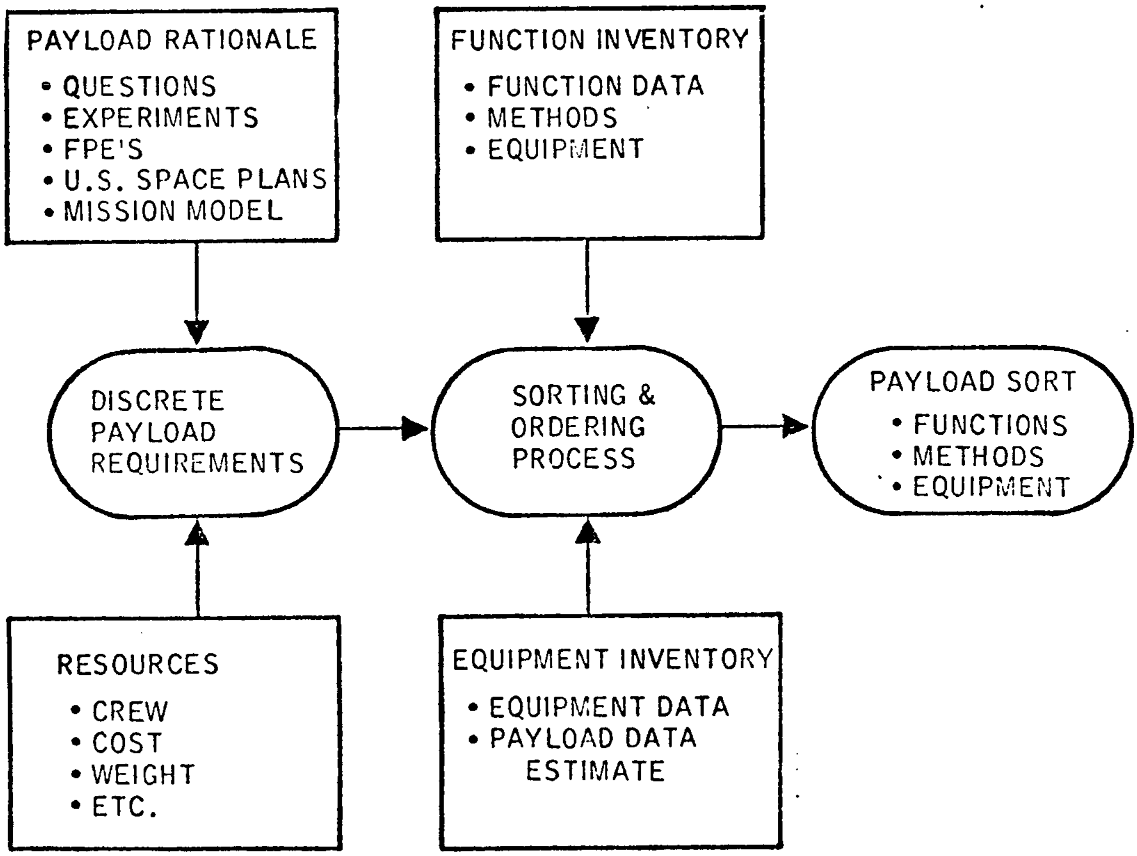


Figure 2.4. Ordered Payload Definition

2.2.3 BASELINE PAYLOADS

The capability of the baseline payloads is shown in Table 2-1 in terms of the number of test subjects which can be supported. Also indicated, where applicable, are the resulting number of cage modules required. A cage module is a basic holding unit used in all the payloads to house small vertebrates, plants, invertebrates, and cells and tissues. It is basically a sealed independent ventilated cabinet approximately 0.5 m x 0.5 m x 0.65 m.

TABLE 2-1

SUMMARY OF BASELINE PAYLOAD CAPABILITIES

	Number of Test Subjects Aboard Baseline Payloads			
Experiment Class & Test Subject	Mini-7	Mini-30	Maxi-Nom	(Maxi-Max, Reference)
Vertebrates: Chimpanzees	0	0	0	2
Macaques	0	2	2	4
Rats	0	16 (2 cm)	128 (16 cm)	512 (64 cm)
Plants: Marigolds	16 (1 cm)*	16 (1 cm)	128 (8 cm)	288 (18 cm)
Invertebrates	(1 cm)	(1 cm)	(2 cm)	(6 cm)
Cells & Tissues	(2 cm)	(2 cm)	(2 cm)	(8 cm)
Biomedicine: Human Test Subjects	0	4	12	12
Life Support & Protective Systems: Hardware Test Units	1	1	1	2
Manned System Integration: Human Test Subjects	4	4	12	12
Centrifuge	None	None	Internal	Separate Module

*Indicates the number of cage modules (cm) to support the organism.

The Maxi-Max reference payload is complete with respect to its capability to perform life sciences research. It is used as a point of comparison for the baseline payloads. It requires two zero-g modules for the containment of the entire laboratory in addition to the third common use research centrifuge module. Generally, one zero-g module is devoted to biology research, and the other is primarily devoted to biomedical, life support, and man-system integration research. The facility can support six primates in two 1.5 m (5 ft.) diameter primate spheres and four primate cylinders. It contains a total of 96 cage modules for the vertebrate, plant, invertebrate, and cells and tissues FPE's. The number of men assumed available as test subjects for the biomedicine and man-system integration FPE's is 12, and life support and protective systems capability (appropriate consoles and volumes for test articles) is based on the requirement to run two major experiments simultaneously in each discipline. A radiobiology room is included and is wedge-shaped with a maximum isotope exposure area of approximately 1.5 m by 1.5 m and a source-to-subject distance of 1 meter.

The Maxi-Nom baseline payload is contained in a single RAM module with two chambers. One is for biology and the other contains biomedicine, life support and protective systems, and man-systems integration. The manned research capability for Maxi-Nom is basically the same as that of Maxi-Max, where 12 men are assumed available as subjects. Manned System and Life Support and Protective Systems research consoles and test article volume are provided to run one major experiment in each discipline simultaneously. In the biology area, a small internal biology centrifuge is included. The centrifuge can accommodate eight cage modules which house vertebrates or any mixture of organisms that is required by the research experiments. The number of primates in the Maxi-Nom is 2 macaque type primates, and the number of vertebrates is 128 rats or their equivalent (more mice or fewer hamsters) divided equally between the zero-g lab and the centrifuge. The facility will accommodate the equivalent of 128 dwarf marigolds, and two cage modules each for invertebrates, and cells and tissues.

The Mini-30 payload can be integrated into a portion of a RAM module. The biomedical research capability is somewhat reduced from the Maxi-Nom, but can support a continuing major research program. Biology specimen holding facilities are provided for two small primates, 16 rats or an equivalent number of other small vertebrates, 16 dwarf marigolds, 2 cage modules for cells and tissues, and 1 cage module for invertebrates. Only 4 actual cage modules are integrated into the payload; internal fittings can be exchanged in different periods of a space station research program or between sortie flights. This permits the 4 cage modules to do the work of the 6 (Table 2-1) required to accomplish the long range Biology program. Cells and tissues research capability is emphasized in this payload due to limitations of payload volume and subsystem support. This area is also emphasized because of the high turnover rate of these specimens, permitting several generations of specimens to be reared during a short mission duration. The Man-System Integration and Life Support and Protective Systems console and test item volume capability are sufficient to accomplish one experiment in each discipline simultaneously. A series of test items may be evaluated in a single mission. The number of men available as test subjects for Biomedical and Man-Systems Integration research is four.

The Mini-7 payload will accommodate those organisms and experiments with a time course of interest that is compatible with the 7-day mission. As noted in a previous section, the Biomedical research capability was deleted purposefully in this payload. Man-Systems Integration and Life Support and Protective Systems are provided for the facilities to accomplish one major experiment in either one or the other of these two disciplines in a given flight. Alternation of discipline emphasis in successive sorties permits fulfillment of program goals. One cage module is allocated for plants, one cage module for invertebrates, and two cage modules for cells and tissues. The emphasis is on cells and tissues for the same reasons stated for the Mini-30 payload.

SECTION 3

PAYLOAD CONFIGURATIONS AND SUBSYSTEMS

3.1 CONFIGURATIONS DEVELOPMENT

The general approach to layout development for the payloads is illustrated in Figure 3.1. The first generation layouts were reviewed by NASA and Convair Aerospace with the results used as the basis for second generation layout development. Layout designs selected by NASA from second generation layouts were refined to become the baseline payload layouts.

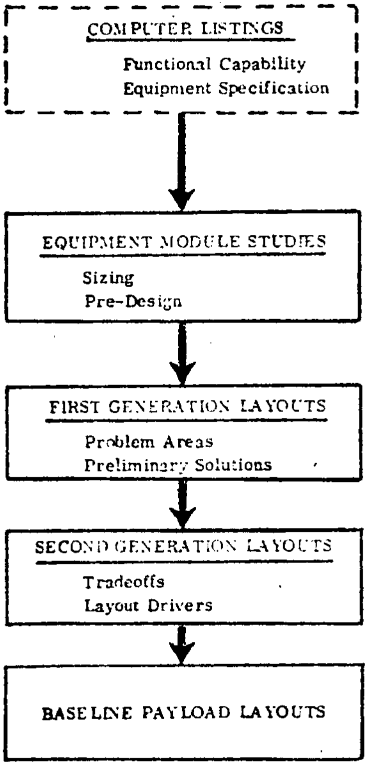


Figure 3.1. Layout Development.

3.2 EQUIPMENT MODULE DEVELOPMENT

This activity provided a set of Equipment Module configurations that represent the initial building blocks for layout designs. Each payload is made up of a number of Equipment Units (EU). An EU may be a part of the Common Operational Research Equipment (CORE) or a section of the FPE-peculiar equipment. An Equipment Unit is sized for a particular payload and is composed of one or more Equipment Modules (EM). The Equipment Modules, in turn, may take the form of equipment racks, consoles or combinations of both. The lowest level of Equipment Item integration is into these Equipment Modules. The initial task, therefore, was to obtain the required scientific Equipment Items from the function and equipment inventories for a given payload, in accord with appropriate guidelines; determine the approximate size and shape of each item; and arrange them in racks and consoles.

The equipment racks and consoles for the second generation layouts were designed using the modular approach. A two-meter (6.57 ft.) high standard equipment module, 0.61 x 0.61 meters (2 ft. by 2 ft.) in cross-section, was selected. This selection was based on the standard size of electronic modules in use today, as well as crew mobility requirements, and the planned maintainability concept. The two-meter height was chosen to be compatible with crew pressure walking mobility techniques. The cross-section is compatible with the planned maintainability concept. That is, equipment installed in the racks is accessible from front, side and back, and components are within man's reach without having to first remove one or more other components. These modules allow implementation of that concept by swinging or rolling the modules away from the wall.

Two configurations of this standard module were developed to provide bench and control-display features as required. In addition to the standard modules, special equipment modules were developed where necessary.

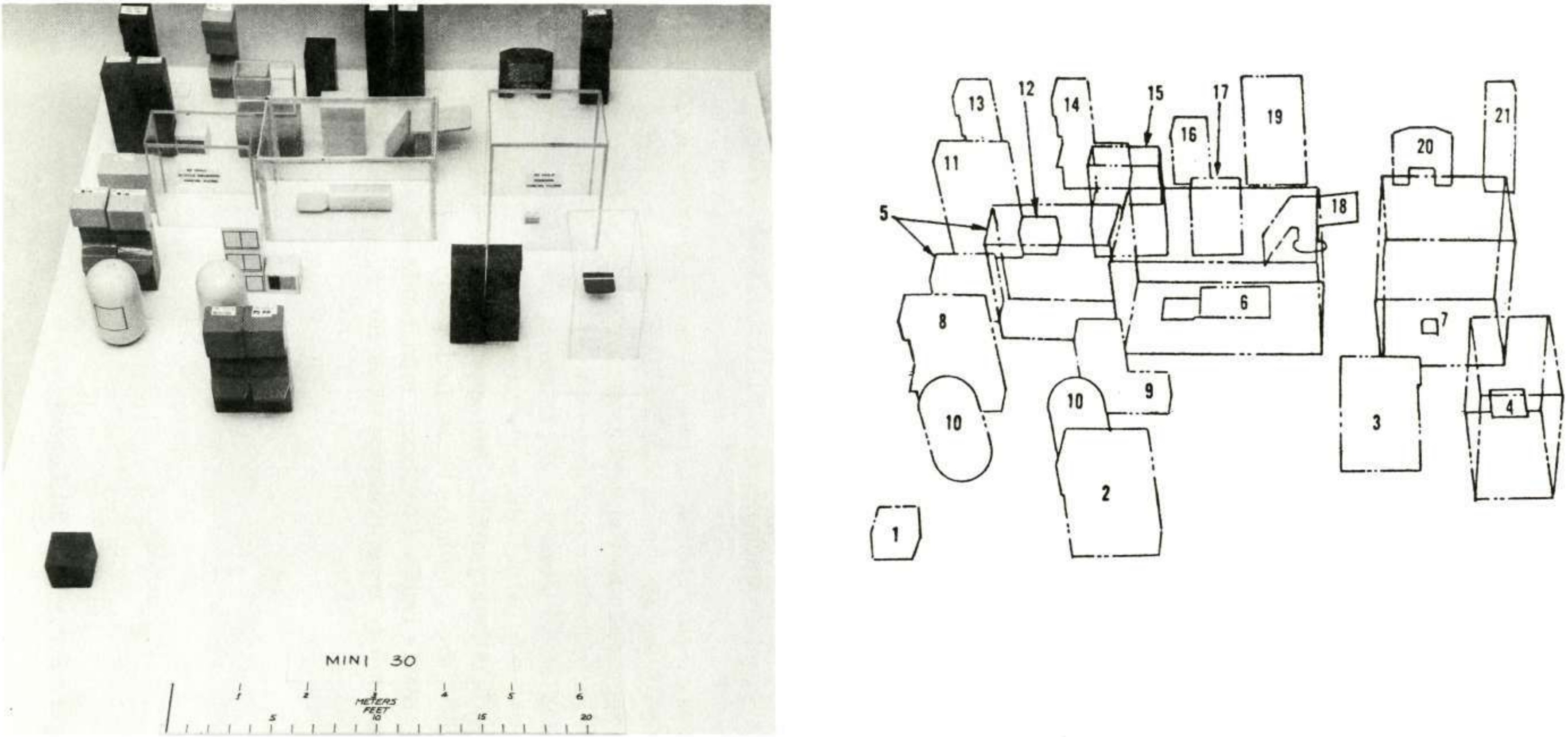
3.3 DEVELOPMENT OF BASELINE PAYLOAD LAYOUTS

The second generation layouts were developed in sufficient detail to: (1) demonstrate the feasibility of concept; (2) identify sensitivities, constraints, limitations, and design drivers; and (3) allow determination of detailed layout characteristics. A three-dimensional (3D) approach was used for the layouts to give increased visibility to the configurations. The layouts used 1/20th scale models of equipment modules (EMs), equipment racks (ERs), equipment consoles (ECs), and special equipment modules (SEMs). The models were color coded for rapid identification and photo documentation.

The 3D approach proved to have many advantages for the life sciences payload development. Its greatest advantage was the reduction in man-hours required to develop a new layout iteration. About one hour was required for each iteration. The models also provided considerable improvement in visibility of layouts which could not be obtained by conventional engineering drawings.

3.3.1 SELECTED BASELINES. A total of eighteen three-dimensional layout concepts were developed for the selected payloads. These were reviewed by NASA and Convair. The selected baseline payload layouts selected by NASA included the reference payload (Maxi-Max), the Maxi-Nom, Mini-30, and Mini-7. The layout configurations were selected based on: (1) mission responsiveness, (2) complexity of flight operations, and (3) ground checkout and real-time groundbased research "controls" requirements.

The photo documentation of the Mini-30 and Mini-7 payloads is presented as examples of the layout visibility obtained with the 3D model approach. These two payloads have been chosen because they are expected to be the first in the evolution of the payload series. Photo documentation of the more comprehensive Maxi-Max and Maxi-Nom are presented in Volume II of this report. Figure 3.2 shows the various equipment modules that make up the Mini-30 payload. Figure 3.3 presents these equipment modules placed within a model of a life sciences RAM. Figure 3.4 presents the equipment modules that make up the Mini-7 payload and Figure 3.5 shows these modules in the RAM shell. The Biology specimen holding capability is reduced to 3 cage modules in all Figures, illustrating alternate, minimum Biology research capacities for the Mini-30 and the Mini-7 payloads.



1. ANIMAL ENVIRONMENTAL CONTROL SYSTEM
2. BEHAVIORAL MEASUREMENTS UNIT
3 LIFE SUPPORT SUBSYSTEM TEST UNIT
4. LIFE SUPPORT SUBSYSTEM TEST UNIT
5. BICYCLE ERGOMETER & WORKING VOLUME
6. LOWER BODY NEGATIVE PRESSURE
7. EXERGENIE
8. BIO-MEDICAL MAN-SYSTEM INTEGRATION RESEARCH SUPPORT UNIT
9. CAGE MODULE & SUPPORT UNIT
10. PRIMATE HOLDING UNIT
11. MAINTENANCE REPAIR & FABRICATION UNIT
12. SUPPORT UNIT
13. VISUAL RECORDS & MICROSCOPY UNIT
14. DATA MANAGEMENT UNIT
15. REMOTE MANIPULATOR
16. LIFE SCIENCES EXPERIMENT SUPPORT LINK
17. BODY MASS MEASUREMENT
18. ROTATING LITTER CHAIR
19. PREPARATION & PRESERVATION UNIT
20. PREPARATION & PRESERVATION UNIT
21. BIOCHEMICAL & BIOPHYSICS ANALYSIS UNIT

Figure 3.2. Mini-30 Payload, 1/20 Scale Equipment Modules.

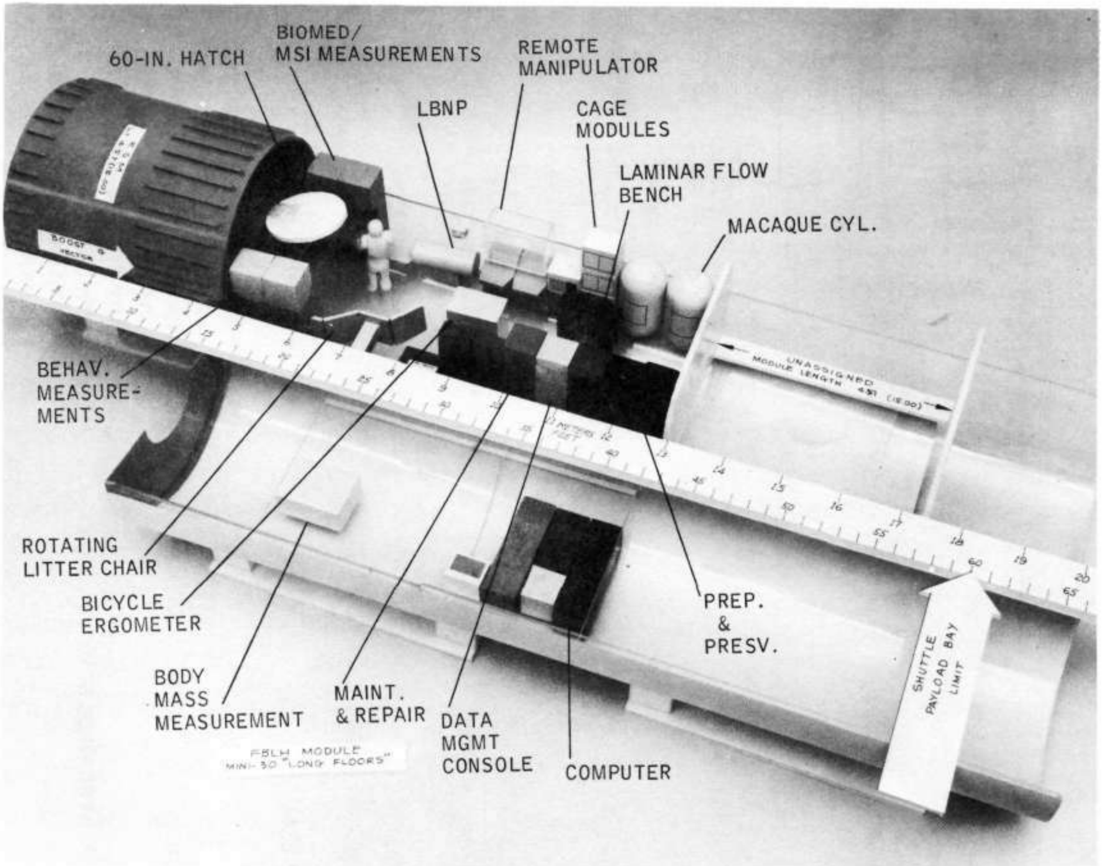
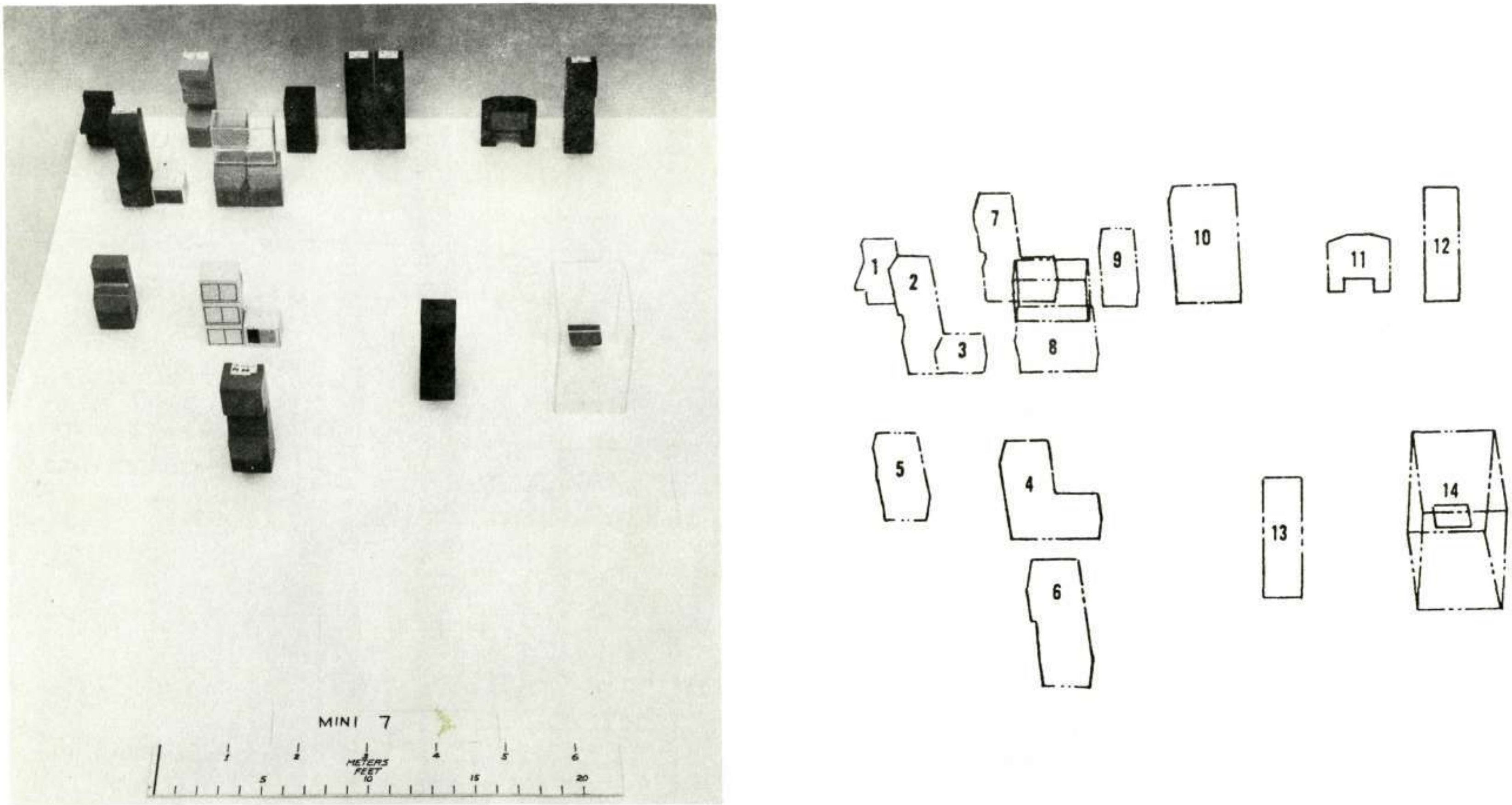


Figure 3.3. Mini-30 Layout.



1. VISUAL RECORDS & MICROSCOPY UNIT
2. MAINTENANCE REPAIR AND FABRICATION UNIT
3. SUPPORT UNIT
4. CAGE MODULE & SUPPORT UNIT
5. BIO-MEDICAL MAN-SYSTEM INTEGRATION RESEARCH SUPPORT UNIT
6. BEHAVIORAL MEASUREMENTS UNIT
7. DATA MANAGEMENT UNIT
8. REMOTE MANIPULATORS
9. LIFE SCIENCES EXPERIMENT SUPPORT UNIT
10. PREPARATION & PRESERVATION UNIT
11. PREPARATION & PRESERVATION UNIT
12. BIOCHEMICAL & BIOPHYSICS ANALYSIS UNIT
13. LIFE SUPPORT SUBSYSTEM TEST UNIT
14. LIFE SUPPORT SUBSYSTEM TEST UNIT

Figure 3.4. Mini-7 Payload, 1/20 Scale Equipment Modules.

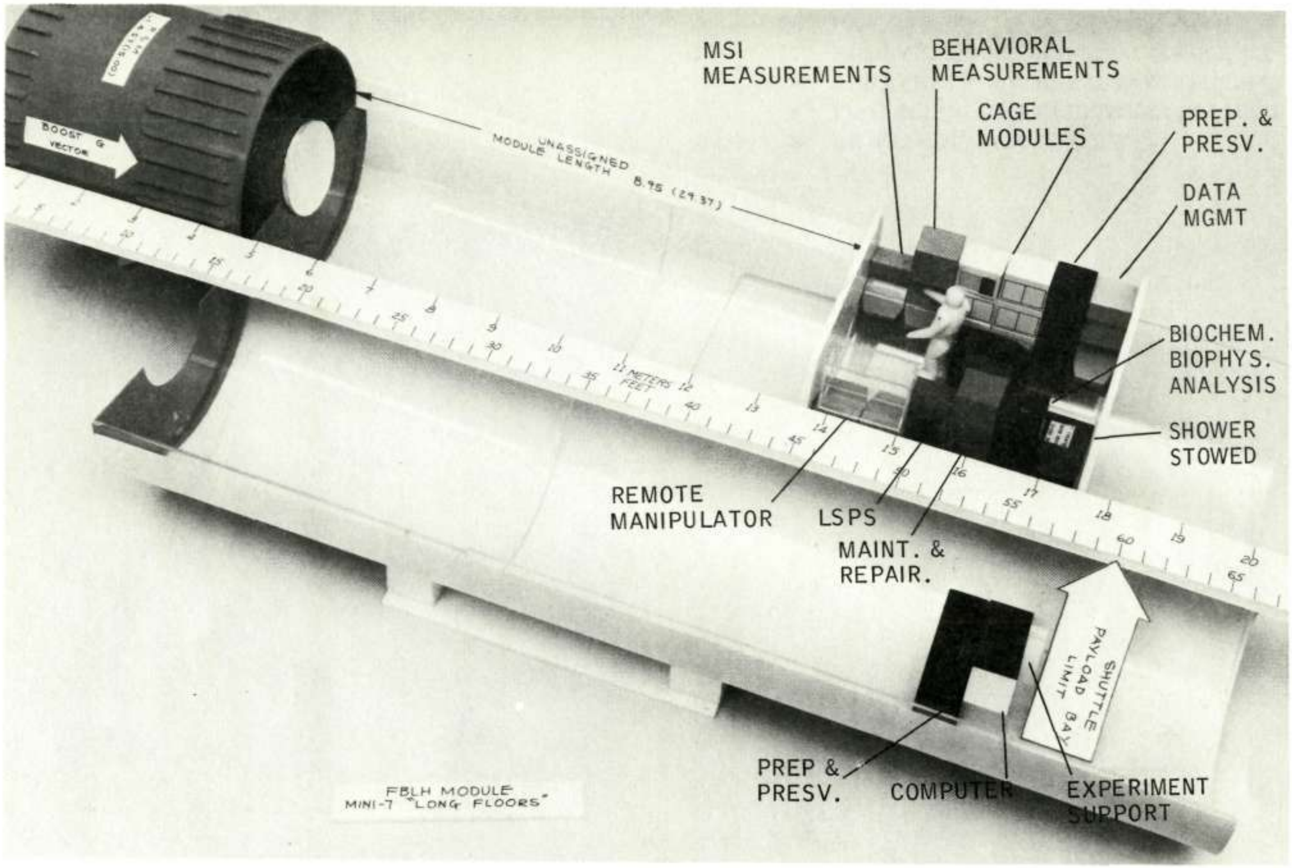


Figure 3.5. Mini-7 Layout.

3.4 SUBSYSTEMS

The subsystems required to support the life sciences payloads include the organism environmental control and life support subsystem (EC/LSS), crew EC/LSS, data management subsystem (DMS), electrical power subsystem, and thermal control subsystem. Subsystems for reaction control, propulsion, guidance and navigation, and stability and control were assumed to be provided by the support vehicle. A summary of the subsystem weight, volume, and power is given in Table 3-1.

TABLE 3-1. SUMMARY OF SUBSYSTEM WEIGHT, VOLUME, AND POWER*

Laboratories	Subsystem Organism EC/LSS	 Crew EC/LSS	 Data Management	 Electrical Power	 Thermal Control	 Totals
Mini-7						
Weight, KG (lbs)	1.7	70	151	79	274	591 (1300)
Volume, m^3 (ft^3)	0.03	0.41	0.33	0.009	1.05	1.91 (68)
Power, Kw	0.06	0.25	1.10	—	0.12	1.53
Mini-30						
Weight, KG (lbs)	176	70	306	123	356	1031 (2270)
Volume, m^3 (ft^3)	0.25	0.41	0.67	0.14	1.64	3.11 (11
Power, Kw	0.14	0.25	2.22	—	0.16	2.77
Maxi-Nom						
Weight, KG (lbs)	660	208	513	277	926	2584 (5460)
Volume, m^3 (ft^3)	1.89	0.65	1.08	0.32	3.82	7.76 (275
Power, Kw	1.83	0.72	3.52	—	0.43	6.50
Maxi-Max						
Weight, KG (lbs)	1950	511	739	549	1897	5646 (12,400)
Volume, m^3 (ft^3)	5.6	1.68	1.60	0.64	9.13	18.65 (658)
Power, Kw	6.34	1.72	5.01	—	0.89	13.96

*Excluding Consumables

3.4.1 ORGANISM ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEM.

The EC/LSS for the organisms was designed to be consistent with the philosophy of isolation from the crew compartments of the life sciences laboratories. Hence, separate isolated EC/LSSs for the organisms are provided.

The primary organism EC/LSS loads result from the vertebrates. A summary of vertebrate oxygen consumption and heat output is shown in Table 3-2 for a chimpanzee, monkey, and rat. These three organisms were used for calculating overall laboratory metabolic loads. Also given are the ratios of the animal oxygen consumption to that of man. These ratios were used to compare the size of the laboratory organism EC/LSS loads to those of manned systems.

TABLE 3-2. SUMMARY OF PRELIMINARY DESIGN METABOLIC DATA FOR VERTEBRATES

	BODY WEIGHT	O_2 CONSUMPTION		HEAT OUTPUT	
	KG (LB.)	KG/DAY (LB./DAY)	ANIMALS PER MAN	K JOULES/DAY KCAL/DAY	ANIMALS PER MAN
CREWMAN	72 (158)	0.84 (1.84)	1.0	11,900 (2,830)	1.0
CHIMPANZEE	18.2 (40)	0.38 (0.83)	2.2	4,340 (1,036)	2.7
MONKEY	9.1 (20)	0.20 (0.45)	4.1	2,560 (610)	4.6
RAT	0.35 (0.77)	0.018 (0.040)	46.3	230 (55)	51.8

The Mini-7 EC/LSS consists of a simple ventilation and dehumidification loop with LiOH for CO_2 removal, high pressure stored oxygen and stored water. The Mini-30 system is similar except that water is purified for reuse. For the short duration Mini flights, food supplies and wastes can be handled within the cage module and no external transport or storage equipment is required. Both Maxi laboratories have water purification and oxygen regeneration systems. External storage is provided for food and water.

3.4.2 CREW ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEM. In the interest of minimizing equipment, the life sciences laboratory crew EC/LSSs were designed to utilize the support vehicle's systems. In general, purified air is supplied by the supporting spacecraft environmental control system, but flow and temperature are controlled in the laboratory. Free air interchange in the Minis allows the use of the RAM support module equipment for dehumidification, and CO_2 and contaminant removal. For the Maxis, dehumidification is accomplished locally, and CO_2 concentration and contamination removal is accomplished by limited ducted air interchange with the Space Station ECS. Oxygen, nitrogen, water processing, fecal collection, waste management, nutrition, and hygiene are all provided by the supporting spacecraft.

3.4.3 DATA MANAGEMENT SUBSYSTEM. The data management subsystem (DMS) supports the life sciences research through control of equipment, data acquisition, data processing, and data disposition. Sampled data is common in the laboratories and is handled in a pulse code modulated (PCM) form. This data is introduced into a computer for processing, and is also stored on instrumentation tape for transmission to ground. PCM data acquisition is controlled by a data management computer through execution of a data acquisition program.

Continuous data signals originate in analog form from numerous sources including physiological signals such as ECGs, EEGs, and EMGs. The analog data handling system is a group of analog data acquisition, processing, signal conditioning, switching, and recording equipment interconnected by a network of wide-band data trunk lines. Analog-to-digital conversion and computer entry of data is provided for those signal sources and experiments which require computer support, such as waveform analysis of ECG signals.

3.4.4 ELECTRICAL POWER SUBSYSTEM. The life sciences laboratory modules always operate attached to a supporting spacecraft, even during rendezvous and docking to the Space Station by means of the Space Shuttle orbiter. Therefore, no operational power sources or their associated storage batteries are required aboard the laboratories. The main requirement is for power distribution equipment and some power conditioning equipment.

3.4.5 THERMAL CONTROL SUBSYSTEM. Preliminary thermal control subsystem properties were estimated by using the current concepts being developed at Convair Aerospace on the RAM study in conjunction with estimated life sciences laboratory heat loads. The major Thermal Control Subsystem equipment includes liquid loop components, cold plates, an integral heat rejection radiator, and integral wall insulation. The major thermal control liquid loop components include pumps, accumulators, heat exchangers, filters, lines, and valves. A dual loop system is used with water inside and Freon 21 outside the spacecraft.

3.5 SUMMARY OF DESIGN ANALYSES

Tables 3-3 and 3-4 summarize the design analyses made of the Mini-30 and Mini-7 baseline payload layouts. The characteristics of the baselines that can be of greatest value in future studies have been included. The more pertinent of these are: (1) size of the RAM, (2) scientific payload weight, (3) Shuttle launches required, and (4) gross cost estimates. R&D costs were estimated assuming that each payload was developed independently of all others. If an evolutionary approach to payload development is used, savings could be made in, at least, equipment costs.

Development schedules, manpower requirements, in-depth cost breakouts and other program planning data vital to advanced planning by the NASA Office of Space Life Sciences could not be developed within the limits of current study resources. These data must be developed under the integration phase of this study. (Tasks C and D, Payload Integration, see Section 1.0).

Table 3-3. Mini-30 Design Concept Analysis

DESIGN CONFIGURATION				Item No.	Longitudinal Floors
MODULE TYPE				1	FBLH
SIZE OF LIFE SCIENCE RAM REQUIRED	Number of Modules			2	1
	Total Length		M (ft)	3	11.07 (1) (36.30)
	Usable Volume		M^3 (ft^3)	4	92.3 (2) (3,260)
	WEIGHT	MODULE STRUCTURE	Kg (lb)	5	4,200 (3) (9,249)
		INTERFACE STRUCTURE	Kg (lb)	6	1,360 (2,998)
		COMMON SUBSYSTEMS	Kg (lb)	7	553 (4) (1,217)
		ORGANISM ENVIRONMENTAL CONTROL SYSTEM	Kg (lb)	8	177 (389)
		CONSUMABLES	Kg (lb)	9	In Cage Module
		TOTAL	Kg (lb)	10	6,297 (13,853)
SCIENTIFIC AND SUPPORT EQUIPMENT PAYLOAD	VOLUME - M^3 (ft^3)			11	24.8 (876)
	WEIGHT - Kg (lb)			12	4,336 (9,540)
SHUTTLE LAUNCHES REQUIRED	WEIGHT OF DEDICATED LAUNCHES		Kg (lb)	13	10.633 (6) (23,393)
	WEIGHT OF CARGO LAUNCHES		Kg (lb)	14	--
	TOTAL NUMBER OF LAUNCHES			15	1
COST ($ x 10^{-6})	MODULE & COMMON SUBSYSTEMS			16	8.29 (5)
	SCIENTIFIC AND SUPPORT EQUIPMENT PAYLOAD			17	98.01
	ORGANISM ECS				12.90
	LAUNCH	MODULE		18	3.40 (5)
		CARGO		19	--
	INTEGRATION/MAINTENANCE AND SPARES			20	125.11
	TOTAL			21	247.71
TOTAL FACILITY					
	WEIGHT (ITEM 10 + ITEM 12)		Kg (lb)	22	10,633 (23,393)
EFFICIENCY	PAYLOAD VOLUME / USABLE VOLUME (ITEM 11 ÷ ITEM 4)			23	0.268
	PAYLOAD WEIGHT / TOTAL WEIGHT (ITEM 12 ÷ ITEM 22)			24	0.408

1. Length of common subsystem and FBLH section only
2. Volume in FBLH section only
3. Includes 2,640 Kg (5,819 lb) which will be shared with other scientific disciplines
4. This weight will be shared with the other scientific disciplines
5. Pro-rated Cost
6. Sum of items 10 & 12

Table 3-4. Mini-7 Design Concept Analysis

DESIGN CONFIGURATION			Item No.	Longitudinal Floors
MODULE TYPE			1	FBLH
SIZE OF LIFE SCIENCE RAM REQUIRED	Number of Modules		2	1
	Total Length - M (ft)		3	6.67 (21.9) (1)
	Usable Volume - M^3 (ft^3)		4	43.7 (1,540) (2)
	WEIGHT	MODULE STRUCTURE Kg (lb)	5	3,380 (7,439) (3)
		INTERFACE STRUCTURE Kg (lb)	6	512 (1,126)
		COMMON SUBSYSTEMS Kg (lb)	7	428 (941) (4)
		ORGANISM ENVIRONMENTAL CONTROL SYSTEM Kg (lb)	8	17 (38)
		CONSUMABLES Kg (lb)	9	In Cage Module
		TOTAL Kg (lb)	10	4,338 (9,544)
SCIENTIFIC AND SUPPORT EQUIPMENT PAYLOAD	VOLUME - M^3 (ft^3)		11	11 (388)
	WEIGHT - Kg (lb)		12	2,111 (4,645)

SHUTTLE LAUNCHES REQUIRED	WEIGHT OF DEDICATED LAUNCHES Kg (lb)		13	6,450 (14,189) (6)
	WEIGHT OF CARGO LAUNCHES Kg (lb)		14	--
	TOTAL NUMBER OF LAUNCHES		15	1
COST ($\$ \times 10^{-6}$)	MODULE & COMMON SUBSYSTEMS		16	3.81 (5)
	SCIENTIFIC AND SUPPORT EQUIPMENT PAYLOAD		17	71.61
	ORGANISM ECS			4.28
	LAUNCH	MODULE	18	1.40 (5)
		CARGO	19	--
	INTEGRATION/MAINTENANCE AND SPARES		20	93.85
	TOTAL		21	174.95
TOTAL FACILITY				
	WEIGHT (ITEM 10 + ITEM 12) Kg (lb)		22	6,450 (14,189)
EFFICIENCY	PAYLOAD VOLUME / USABLE VOLUME (ITEM 11 ÷ ITEM 4)		23	0.252
	PAYLOAD WEIGHT / TOTAL WEIGHT (ITEM 12 ÷ ITEM 22)		24	0.327

1. Length of common subsystem and FBLH section only
2. Volume in FBLH section only
3. Includes 2,640 Kg (5,819 lb) which will be shared with other scientific disciplines.
4. This weight will be shared with the other scientific disciplines.
5. Pro-rated Cost
6. Sum of items 10 & 12

SECTION 4

CONCLUSIONS

The Task A and B activities have provided two significant outputs to assist in the continued development of a space life sciences research program. The first is the comprehensive functions and equipment inventories which provide improved visibility of the life sciences research, payload research hardware requirements. These inventories are in computer format which permits easy update of information and computer processing to aid in selection of various payload capabilities. The second output is the representative baseline payloads, including laboratory layout concepts, subsystem requirements, costs, and crew sizes and skills.

4.1 BASELINE PAYLOAD SUMMARY

The major characteristics which describe the conceptual baseline payloads are shown in Table 4-1. The total weight includes the scientific payload, the supporting subsystems, and the pro-rated portion of the RAM structure. The power requirements include all experiment and subsystem demands of the life sciences payloads. The equipment costs includes the R&D cost and the equipment unit cost. The R&D costs shown assume that each payload is developed independent of the other. Actually in an evolutionary program starting with a Mini-7, the R&D cost of one payload would support those of the growth versions. The indications are that once a Mini-7 payload was developed it could evolve to a Mini-30 for approximately 26 million dollars.

4.2 CONCLUSIONS AND RECOMMENDATIONS

The intent of the current study was to determine the life sciences laboratory research requirements, and to develop preliminary design concepts. The guideline used during the study was to minimize mission constraints and limitations, and determine the life sciences laboratory requirements without considering integration with the supporting spacecraft. Hence, no specific studies were made regarding potential problems in this area. However, some general conclusions in this area became evident as the study progressed. These are as follows:

a. Significant cost savings can be realized by adoption of a long range payload plan based on an evolutionary approach to payload equipment development. The simplest form of evolution consists of revising, or buying, add-on lower cost duplicates of hardware produced for earlier payloads, to build up the more complex payloads of the later time frame.

SCIENTIFIC PAYLOAD	TOTAL WEIGHT(KG)	AVERAGE POWER(KW)	EQUIPMENT COST ($ MILLIONS)			CREW SIZE
			R&D	UNIT	TOTAL	
MAXI-MAX	36,970 (81,400 LB.)	17.56	121	43	164 Δ51	8
MAXI-NOM	17,823 (39,210 LB.)	8.88	93	20	113 Δ15	3
MINI-30	10,633 (23,393 LB.)	3.92	85	13	98 Δ26	2
MINI-7	6,450 (14,189 LB.)	2.53	61	11	72	2

ΔCost is the amount over cost of next smaller payload

Table 4-1. Baseline Payload Characteristics.

b. The electrical power requirements of the payloads are very high and probably exceed the supporting vehicle's power availability. For example, the Maxi-Nom requires 8.9 kw (average) whereas the current RAM power available for life sciences from the Space Station is 4.3 kw.

c. The data management system design is independent of the supporting vehicle. The expected supporting vehicles' capability in data management could provide significant power and weight reductions, depending upon the degree of integration.

d. Manning levels are high and may be unrealistic with respect to the supporting vehicle's crew availability.

e. Payload weights for dedicated RAMs will exceed the launch capability and will impact logistics operations.

f. The preliminary costs of the various payloads were not significantly affected by the equipment placement/arrangement within the RAM modules. Only major changes in scientific capability caused any significant cost changes, i.e., Maxi-Nom to Min-7.

g. Overall mission characteristics play an important role in the determination of preliminary design layouts. Important characteristics include the launch schedule, gravity vector orientation, acceleration vector orientation, the launch sequence of various laboratory modules, and logistics operations.

h. The organism EC/LS system can be large and complex for a full fledged bioresearch program onboard the space station. Mini payloads require only minimal support consisting of one small module.

i. Ground support operations significantly influence the payload designs. Procedures and equipment for ground control experiments must be co-ordinated with the spacecraft designs.

The preceding list of preliminary conclusions strongly alludes to the fact that the payload integration phase of the life sciences payload definition activity may be particularly impacting. Even preliminary layouts and subsystem designs are heavily dependent upon overall mission, spacecraft operations, and design parameters. Thus, a major recommedation resulting from this study is that the originally planned payload integration phase be undertaken (see Figure 1.1). Based on integration tradeoff studies to be accomplished in Task C, the proposed Task D can assist NASA management in developing the high confidence program plans for payload development so necessary to assure Life Sciences participation in Earth orbital missions of the future.