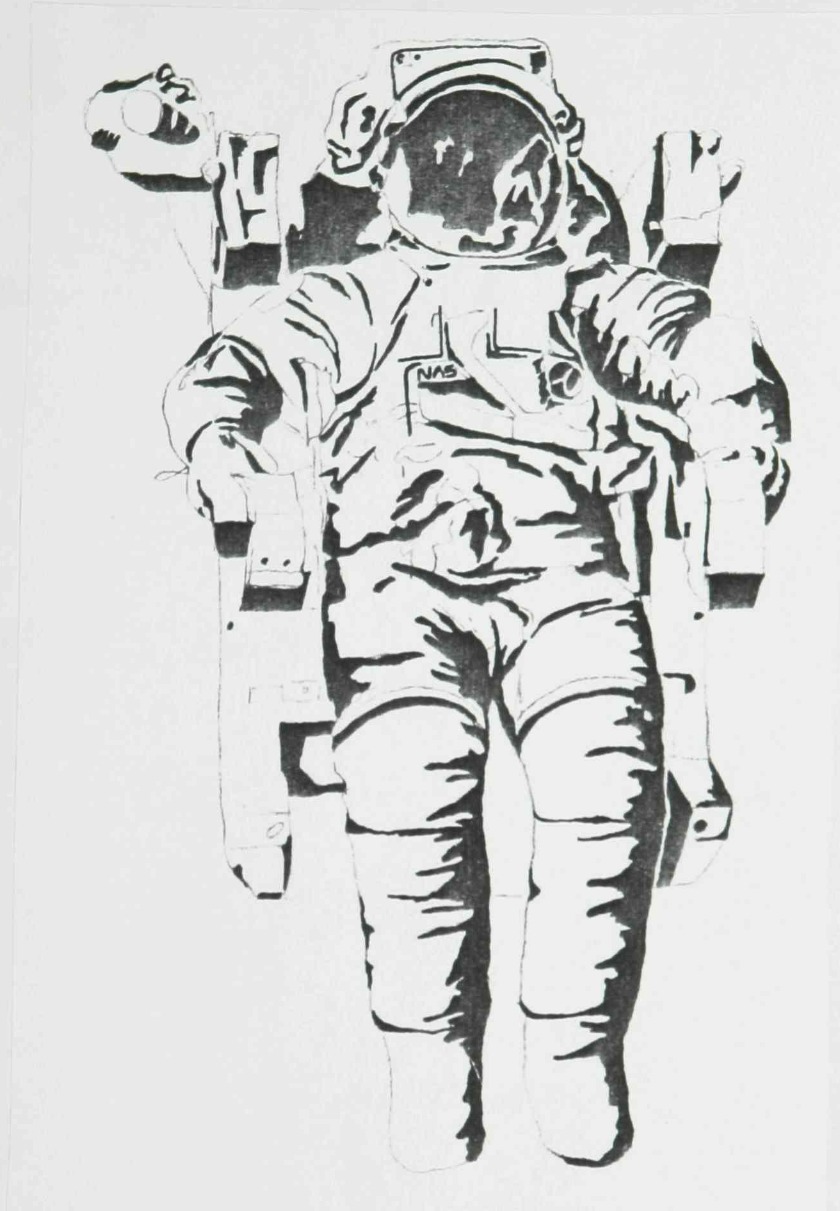

A • PROGRAM • FOR • SPACE

MATERIALS PROCESSING
A PLATFORM IN SPACE

by

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A THESIS

IN

ARCHITECTURE

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"For millinean earth inhabitants have lifted their eyes and their minds skyward or spaceward to seek benefits in the form of divine intervention and guidance whether to augment their Earthen life or alleviate their Earthen problems. Until recently for the enlightened, and until now for many others in the present world, the skies beyond the clouds still represent a realm of deep mystery where super human exploits are not impossible. It would not be an overstatement to say that man now has more reasons to look upward to space for enhancement of his terrestrial existence.

Space being over us all, no matter our creed, color or stage of development, no matter where we live - be it on the highest mountain or in the remotest valley, be it in a landlocked country or on an island - space is always there above us, in equal proximity to any inhabitant on this planet. The sun, the moon, the stars, and the entire space inventory, have been a part of man's life since his creation. Unlike the oceans, space affects all people with equal intensity, and is a conditio sine qua non for his livelihood."

from: International Developments in Space Stations and Space Technologies.
American Institute of Aeronautics and Astronautics

Before dealing with the implicit variations in the difference between architectural space and the physicality of astronautical space one must look at the inherent similiarities.

The excerpt above taken from R. Sunaryo, space is described as being there above us all, in equal proximity to any inhabitant of this planet. According to this observation one can look at architectural space being there amid us all. Ready to be used, modified, exploited or enhanced, architectural space is just as tangible, it is just generally not thought of in the esoteric terms one usually applies to aeronautical space. Architectural space, as an isolated entity, without the inputs donated by man, is hardly void. This is also true of aeronautical space, the only difference being the vast disparity between the scales. Untouched architectural space is never empty. The soil found below or the space above is teaming with possibility. The natural landforms or vegetation make up the framework for exploring architectural strategies. In outer space, the same framework or guidelines are set up, but one must look greater distances to view them. Asteriods, stars, suns and moons must frame or enhance the strategies pursued.

Perhaps the greatest concern for the aeronautical space designer is the absolute and unforgiving hostility of the environment. It is in this arena where architectural and aeronautical spaces truly diverge. In some instances architectural spaces are hostile, but compared to the alien frigidity of outer space these areas become merely a walk in the woods.

Another very important issue in the design of a space station is the present denial and insignificance of architectural imaging. The aesthetics of space dictate a sterile approach to the relationships between form and function. Larry Bell, when asked the question on image in in designing for space, stated, "You can't be concerned with image making." My goal and ultimately my thesis is to overcome this denial of image in an orbiting space station. Architecture is an art to evoke the senses in a feast of images and possibilities. The architect has the tools and the background to use the images that surround him and create an environment which is a footprint of his life, his culture, and his aspirations.

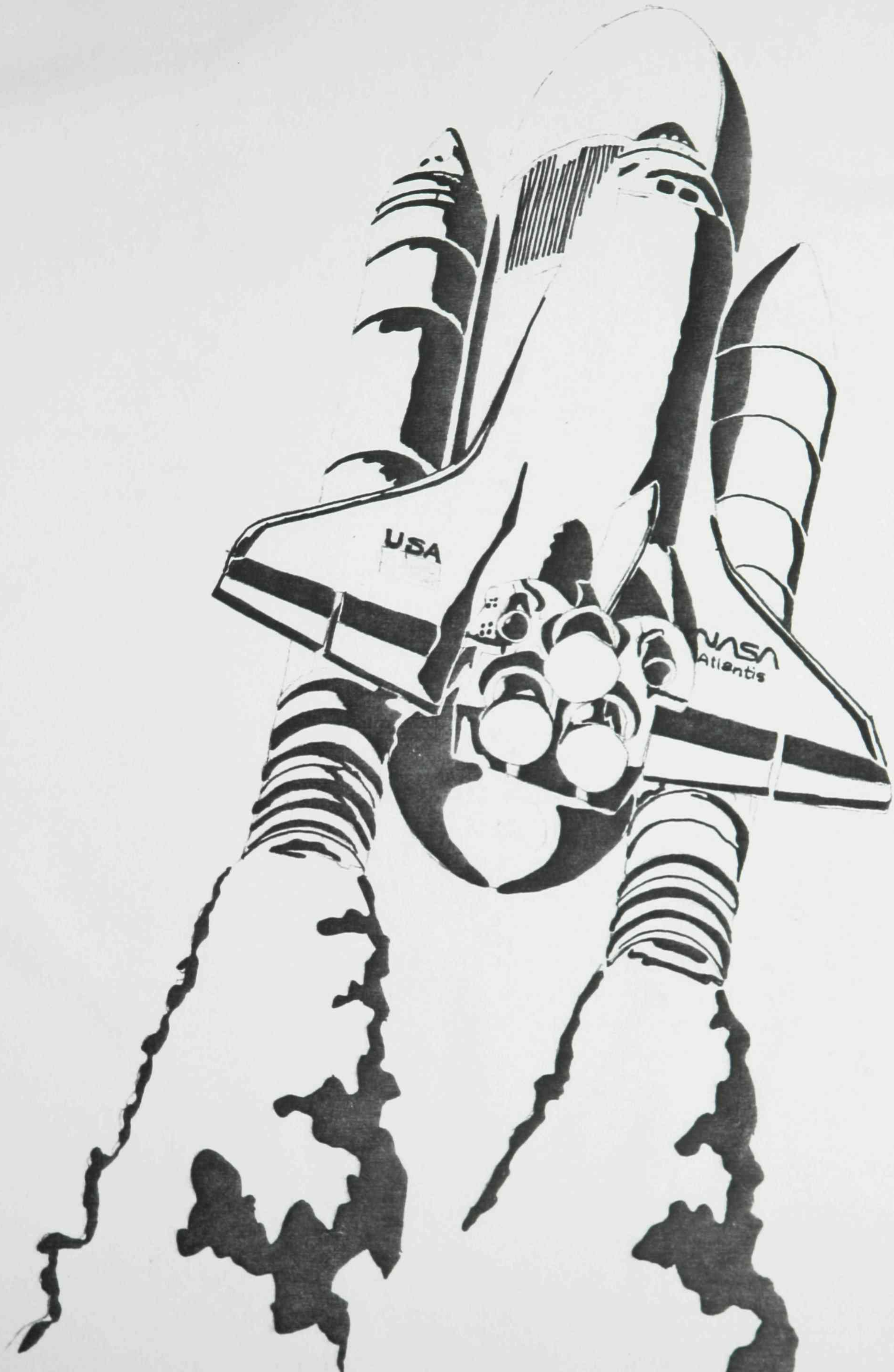
President Reagan has recently announced a national goal of building a permanent manned space station in Earth orbit. This is not a new idea, with Skylab before it, along with the dreams of many space enthusiasts. The idea of space manufacture has also been with us for a few years, with early material processing experiments carried on by the Apollo astronauts.

Many people see a space station only in terms of its military potential. There are also many potential peaceful uses, in fact some like G. Harry Stine see space based manufacture as a third industrial revolution; mechanization and automation being the first two revolutions. Among the peaceful uses of a space station are the monitoring of Earth resources, especially crops, and as a base for astronomers. A third, and perhaps most important, is space based manufacture. This is very important for a variety of reasons, the most obvious being pollution. Taking the long view, a permanent space station is viewed by space enthusiasts as a mere stepping stone, as the gate to the rest of the solar system and beyond. With materials hauled into earth orbit from the moon or asteriod belt, much of the material needed to build ships to explore the solar system will not have to be hauled up out of the Earth's gravity as well.

Closer to the real world, there are four sound reasons for locating manufacturing facilities in space. Free power is the first, with unlimited solar energy, virtually unlimited power is available at what it costs to build the facility. Control of temperature in the manufacturing process is another. Free vacuum is the third, with control of gravity being the fourth. Together they will present a totally different climate for industrial development. They will permit the manufacture of alloys that are not possible in a gravity field, the growth of ultra-pure crystals for the electronic industry, and the production of materials that need not touch the sides of containers they are processed in. The possibilities seem endless. We know that we can alloy aluminum and zinc in orbit and that ultra-pure crystals can be grown.

This thesis deals with a fantasy which is blooming into reality on a daily basis. It is architecture addressing technology and high-tech revolutions, it is possibility and it is reality, it is fantasy - but a fantasy which is manifesting itself in reality.

We do not know what constitutes reality and what is only fantasy in space. We have not been in space long enough to discover what the real advantages are to being there are......***yet***.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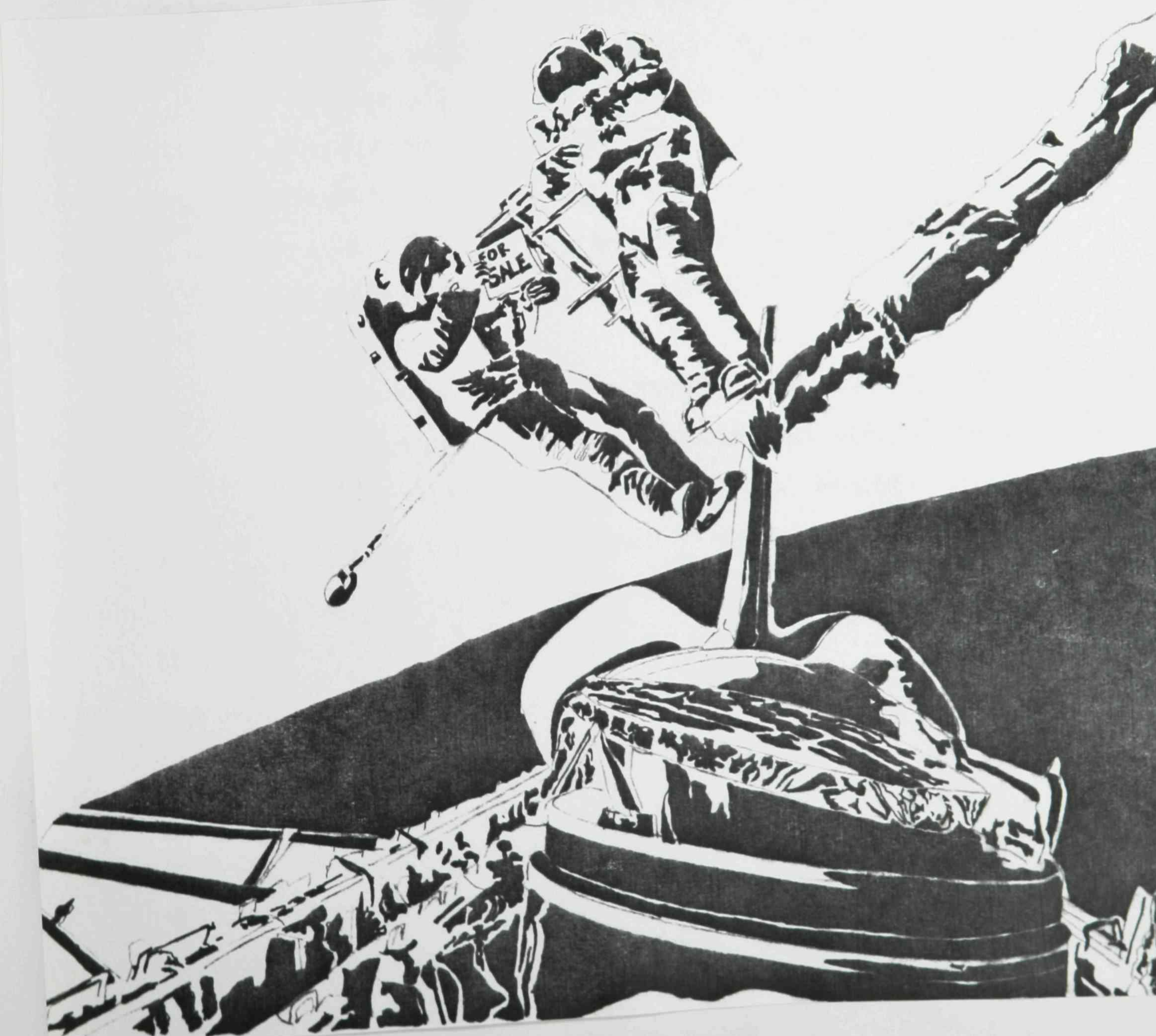

FOR SALE

The *initial* space station will consist of the following capabilities: laboratories, habitat, resources, multiple berthing, services, platforms, and support services. These capabilities will be transported to space by the space shuttle. The Shuttle will also be used to assemble these capabilities in space. Technologies for the space station deal with all of the housekeeping functions necessary to perform the above capabilities. The functions have been divided into ten disciplines: control and life support, data management, power, thermal, attitude control and stabilization, onboard propulsion, structures and mechanisms, human capabilities, and communications. This program will discuss the space station from a systems perspective. It will discuss: the application of automation to improve the space station's routine housekeeping and operations efficiency, the technologies to improve the effectiveness of man's participation in space operations, the priority of application of estimated technology effort required in each discipline, and in some cases, the application of technology to specific components and subsystems.

The space station user communities have also defined advanced technology needs. The users have been grouped into four areas: science and applications, commercial, national defense, and technology development missions. As the user communities mature, the technology needed to enable man to optimize uses of the space station will become more clearly defined. As the space station becomes operational, it will provide the equivalent of a new research facility specializing in developing advanced technologies that relate to space vacuum and micro-gravity.

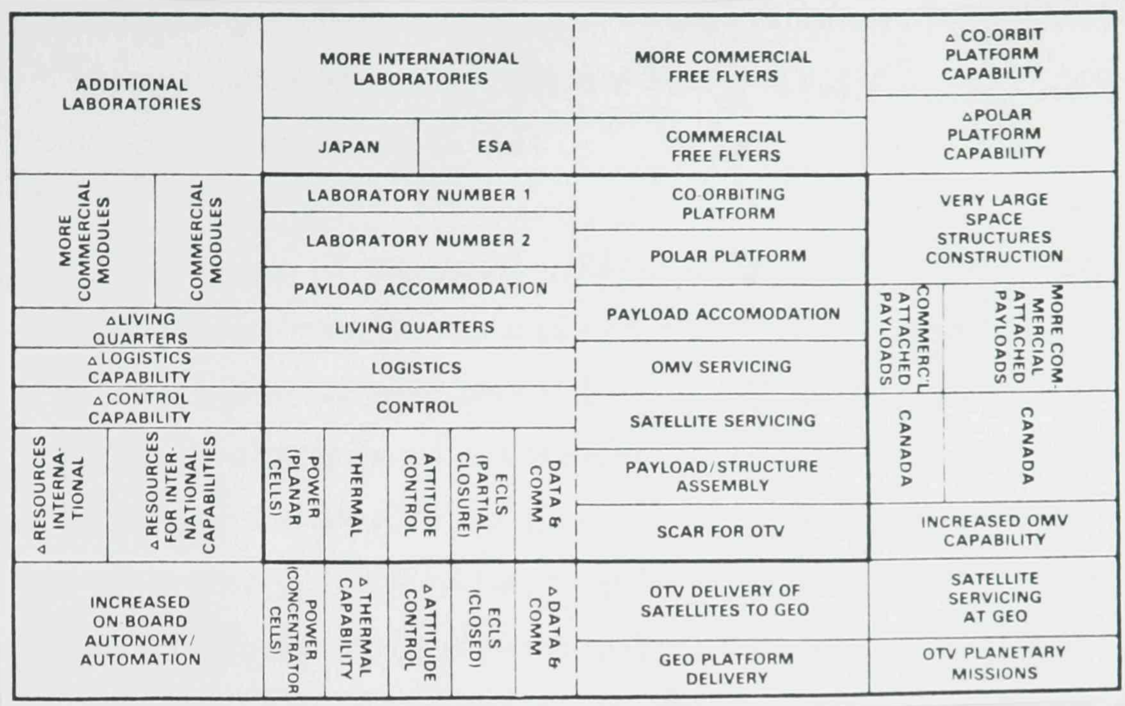
Investigation of technology missions on an operational space station have established over 150 potential experiments. These experiments deal with such things as: characteristics of fluids in micro-g, characterization of the combined radiation effects of space, evaluation of the characteristics of space plasma, etc. This program discusses the technology developments required for the operational space station to enable future technology experiments.

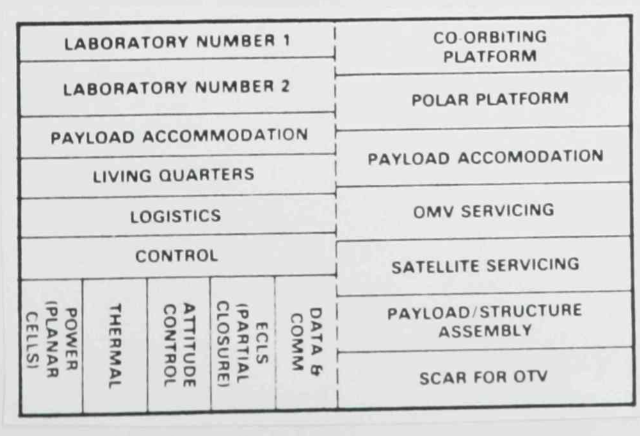
The program concludes with an overview of NASA technology planning to support the initial space station and to support the evolutionary growth of the space station.

In the future of an operational manned space station and an operational Shuttle, the technologist is challenged to provide new innovative techniques to enable new functions such as on-orbit servicing of space assets, on-board maintenance and repair of space station functions, on-board command and control, space resupply of space-based orbital transfer vehicles, performance of long duration space experiments, development of space manufacturing techniques, etc. These functions are to be accomplished on-board a manned space station that is maintained in orbit by on-board maintenance and supported by logistics from the Shuttle. The space station will be designed to include features to enable economical evolutionary growth and technological upgrade by space manufacture of required materials. This space station will consist of many of the activities one might find in any small township or community, the major difference being of course the scale and cost of construction.

The design approach for the evolutionary space station is to first envision the function and configuration of the growth station, and then to configure the initial space station to include the early functions and the necessary "scar" to enable an economic evolutionary growth space station by block changes (Figures 1 and 2). After the placement of the core block assembly, an extensive program for the development of a mega structure to house the factory for the production of semiconductors and structural steel will be discuused.

This factory is initially conceived to be a facility for the production of super-pure semiconductors and electronic crystals. These materials will be transported back to Earth and sold to commercial interests. The revenue for



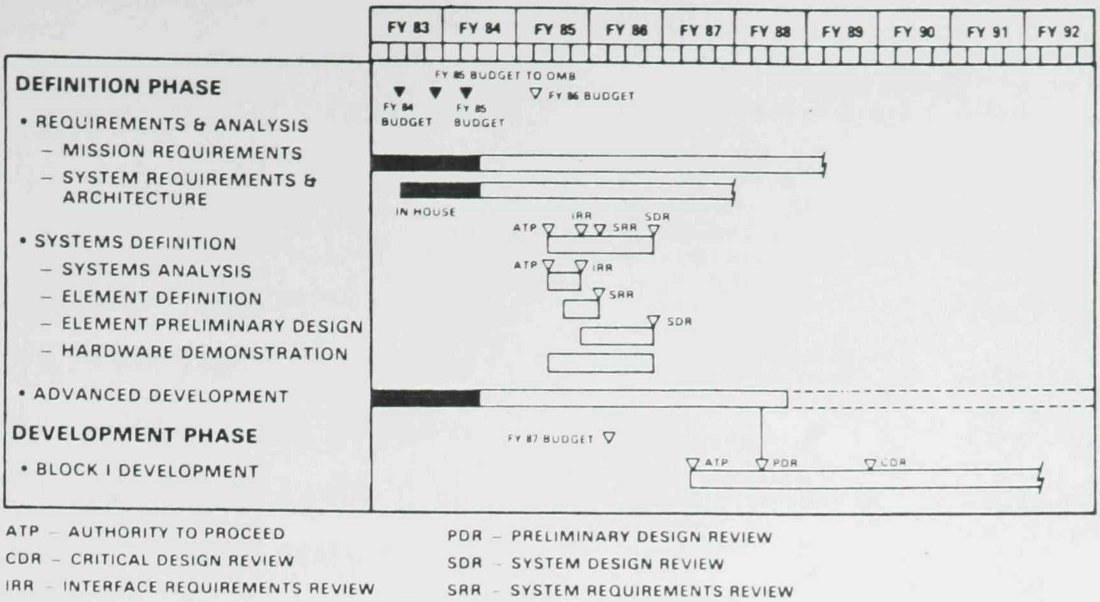


these materials will be used to finance the building of the space factory. The space factory will be built and operated under the existing conditions of microgravity. This factory will employ the latest advances in containerless processing and directional solidification and mixing of materials.

The power for this facility is to be supplied by large solar arrays and isothermal generators (Power options are discussed in greater detail under the technology discipline entitled Power). NASA's plans to build a huge electronic mail facility can and should be incorporated into the solar array. This will save money on the base structure requirements and also benefit from the necessary orientations to the sun and Earth, being that the requirements necessitate an 160° out-of-phase shift.

The definition phase of the space station includes extensive requirements analysis and system definition and a parallel technology/advanced development program. The technology/advanced development program objective is to mature pending technologies to a state-of-maturity so that new techniques can be substituted into the baseline design to improve performance or reduce cost. A "technology option" is defined as a "technological innovation that has been matured to a sufficient level-of-development to be considered as acceptable flight hardware". The technologies applicable for IOC must be judged promising by the beginning of the Phase C authority to proceed (ATP) and must reach the status of a "technology option" shortly after the preliminary design review (PDR) of Phase C (Figure 3).[1] If a technology development is promising but does not achieve the status of a "technology option" in time for IOC, it can continue in development and be incorporated in the space station growth mission by a block change.

The technologist's view of a space station is the integrated functional performance of ten major subsystems. Figure 4 lists the space station



subsystems and identifies a list of high-leverage "technology option" targets for the space station IOC.[2] These options are driven by the desire to minimize operational cost and to maximize the opportunity for future expansion of space station performance by evolutionary growth and technological improvements.

TECHNOLOGY OPTIONS BY DISCIPLINE

DISCIPLINE	TECHNOLOGY OPTION
SYSTEMS/OPERATIONS	DESIGN TOOLS
DATA MANAGEMENT	DISTRIBUTED ARCHITECTURE
STABILIZATION & CONTROL	DISTRIBUTED CONTROL
POWER	HIGH CAPACITY POWER SYSTEM
THERMAL	TWO-PHASE THERMAL BUS
EC/LSS	WATER AND AIR LOOP CLOSURE
HUMAN FACTORS	HABITABILITY; CREW AIDS
STRUCTURES	SYSTEM ANALYSIS TECHNIQUES
AUXILIARY PROPULSION	H_2O_2 ENGINES
COMMUNICATION	MULTIFUNCTION ANTENNA

Space Station Technology by Discipline

This program touches only a few of the technology challenges. No attempt is made to summarize all of the important ongoing technology tasks that will impact the program.

Systems/Operations

Figures 5 and 6 summarize the major technologies performed in Systems/Operations. A major challenge in systems technology is to develop systems design tools to be used in systems analysis and subsystem modules for system simulation.[3] An example of design tools is the integrated design engineering analysis system (IDEAS) developed at the Langley Research Center illustrated in Figure 7.[4] This system can configure a spacecraft based on simple input parameters and provide configuration, mass properties, rigid body control analysis, structural analysis, thermal analysis, etc.

SYSTEMS/OPERATIONS TECHNOLOGY FOR SPACE STATION

SYSTEM STUDIES
- EVOLUTIONARY DESIGN
- INTERACTIVE ANALYSIS
- USER REQUIREMENTS
- MANUFACTURING
- TECHNOLOGY MISSIONS
- SCIENCE AND APPLICATION
- SPACE STATION REQUIREMENTS
- DESIGN TOOL DEVELOPMENT

PRODUCTIVITY
- DESIGN GUIDELINES
- TOOLS, AIDS, WORK STATIONS
- MOTIVATION
- HUMAN FACTORS

CONTAMINATION/ENVIRONMENT
- MAN MADE DEBRIS
- PLASMA
- RADIATION
- OUTGASSING
- PLASMA IMPINGEMENT

MAINTAINABILITY
- DESIGN GUIDELINES
- PRELAUNCH/ON-ORBIT TEXT
- LOGISTICS
- DOCUMENTATION
- CONFIGURATION MANAGEMENT
- GROUND/ON-ORBIT REPAIR

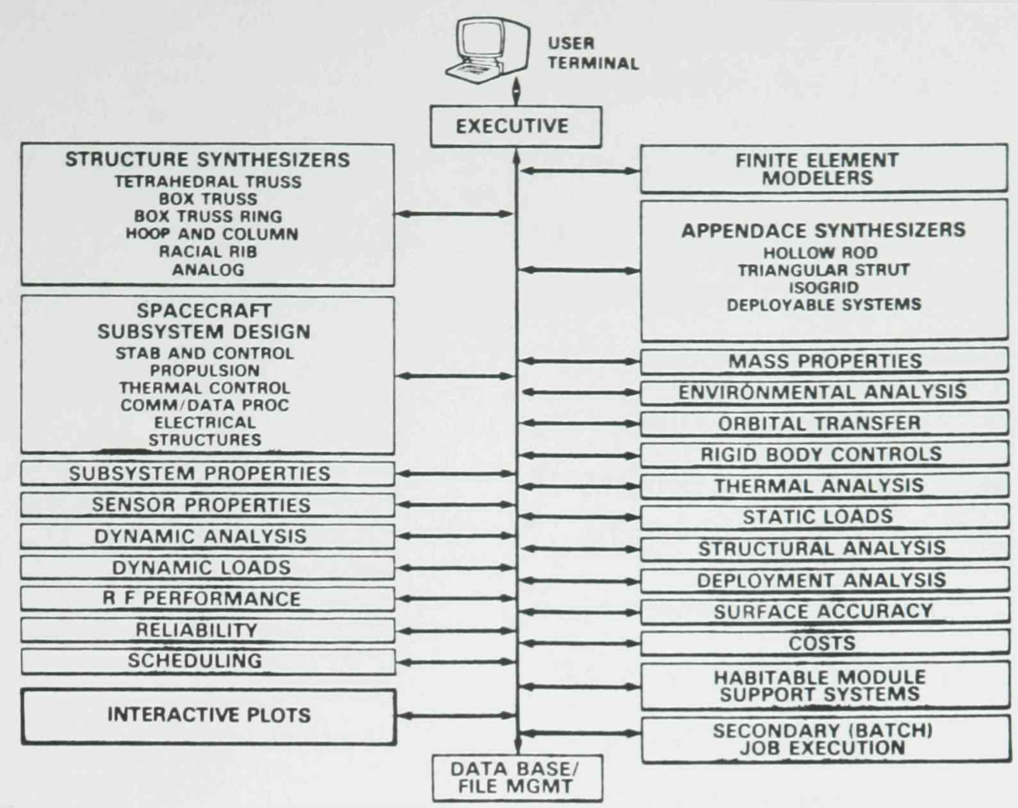
SYSTEMS/OPERATIONS TECHNOLOGY FOR SPACE STATION

AUTOMATION
- DESIGN GUIDELINES
- MAN INTERACTION
- FUNCTIONS
  - SYSTEM MONITORING
  - FAULT DETECTION & ISOLATION
  - REDUNDANCY MANAGEMENT
  - REVERIFICATION AFTER SERVICE
  - OPERATIONAL ANALYSIS & PLANNING
- HIGHER ORDER LANGUAGE
- ARTIFICIAL INTELLIGENCE
- AUTONOMY

MODELING AND SIMULATION
- PERFORMANCE/FUNCTIONAL SIMULATION
- OPERATIONS SIMULATION
- DESIGN/OPERATION DATA BASE

SATELLITE SERVICING
- IVA
- EVA
- TELEPRESENCE
- OTV'S
- LARGE SPACE STRUCTURES

Subsystem models will be used to simulate subsystem performance. The simulation will be improved by the use of flight hardware in conjunction with the simulation when the hardware becomes available.



As the subsystem simulation is validated with flight hardware, it will be combined into a total space station simulation that will represent the total space assembled space station system performance. The flight space station hardware will be instrumented (as defined by the system simulation) and the system simulation will be calibrated with flight data. This calibrated system simulation will become the ground representation of the on-orbit measured performance.

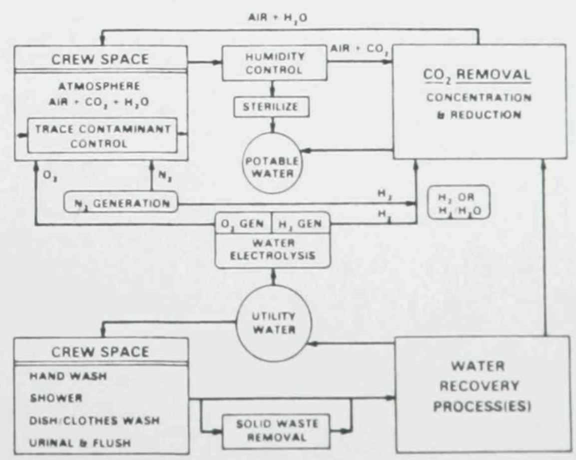
Operations technology includes operational analysis that defines high-leverage technology options that should be matured specifically to reduce operations cost. For example, on-board maintenance requires an extensive amount of on-board data and documentation. The architecture and packaging of the on-board data base, that permits easy access to the proper data to support on-orbit repair of random failures, is part of the operations technology task.

LIFE SUPPORT TECHNOLOGY FOR SPACE STATION

- ELECTROCHEMICAL CO_2 CONCENTRATION
- SOLID AMINE CO_2 CONCENTRATION
- HYPERFILTRATION WASH WATER RECOVERY
- VAPOR COMPRESSION URINE RECLAMATION
- THERMOLECTRICAL WATER RECOVERY
- STATIC FEED WATER ELECTROLYSIS
- SOLID POLYMER WATER ELECTROLYSIS
- PRE/POST WATER PROCESSING TREATMENT
- WATER QUALITY MONITOR
- AIR QUALITY MONITOR
- CONTROL MONITOR INSTRUMENTATION
- HYGIENE & WASH EQUIPMENT
- GALLEY EQUIPMENT
- TRACE CONTAMINANT CONTROL

Figure 8 depicts two techniques for removing CO_2 from the cabin atmosphere, seven techniques for reprocessing the water, three control monitors, equipment to reprocess wash water, and galley equipment. The technology status of all of these parallel techniques is reasonably mature. Hardware is moving into advanced development. The technology challenge is to configure a system design that permits phasing in the progressive closure of the reprocess/revitalization loops to provide a low-risk, cost-effective evolutionary design. An optimum evolutionary application of technology will enable the closure of the interactive loops illustrated in Figure 9 in an orderly and systematic way.

The waste management system for the IOC space station will be a derivative of the Shuttle system. An advanced waste management system called "supercritical water oxidation" is in early development as a block improvement change. This system operates on the



principle that water elevated above a critical point in pressure and temperature provides a highly oxidizing environment which will effectively "burn" all hydrocarbon waste products and reduce them to basic elements, water and a small residue of salts. This equipment will occupy approximately one cubic foot per crew man and could substantially eliminate the return of waste to Earth.

Data Management[6] The NASA data managment program (Figure 10) has been structured in an environment of exploding computer science technological development that is being accomplished outside NASA to meet commercial markets. The challenge to NASA is to supplement the commercial crew innovations with tasks that will let NASA exploit the exploding market by using the latest techniques in configuring a space station data system architecture that will meet the space station system performance requirements. One major difficulty in such a rapidly changing technological environment is in designing a data system that is the beginning of an evolving system to be in operation in excess of 20 years. With the rapid obsolescence of parts (approximately every 2 years), the data system architecture must be sufficiently modularized to accept technological upgrade transparent to the user.

SYSTEMS
- DATA SYSTEM ANALYSIS/ARCHITECTURE STUDY (SPACE STATION)
- STANDARD INTERFACES & PROTOCOLS
- NETWORK CONCEPTS

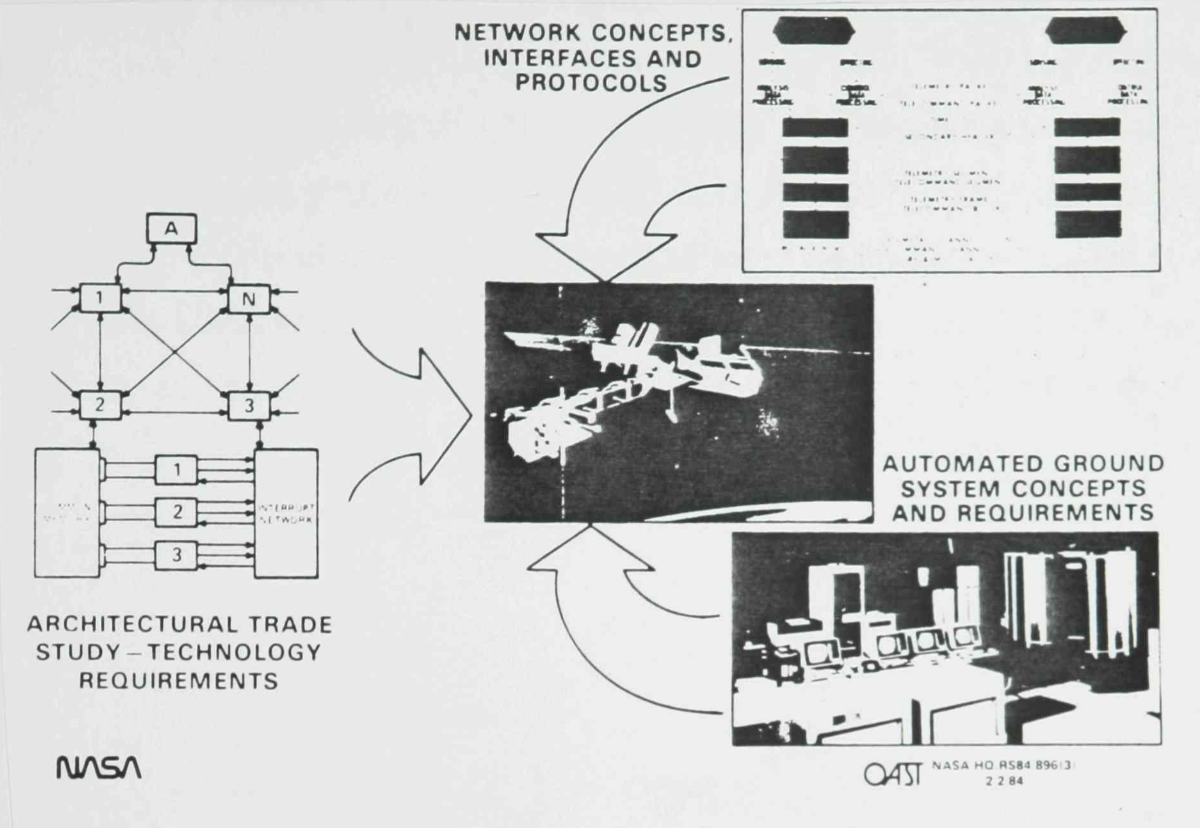
NETWORKS
- HIGH SPEED FAULT TOLERANT ADAPTIVE NODE NETWORKS
- OPTICAL DATA BUS/COMPONENTS
- NETWORK SIMULATION & ANALYSIS TECHNIQUES

SOFTWARE
- SOFTWARE ENGINEERING
- NETWORK OPERATING SYSTEM BREADBOARD

PROCESSORS
- FAULT-TOLERANT COMPUTER VALIDATION
- FAULT-TOLERANT CONCURRENT PROCESSING WITH ADA
- SPACE HARDENED MICROCIRCUITS

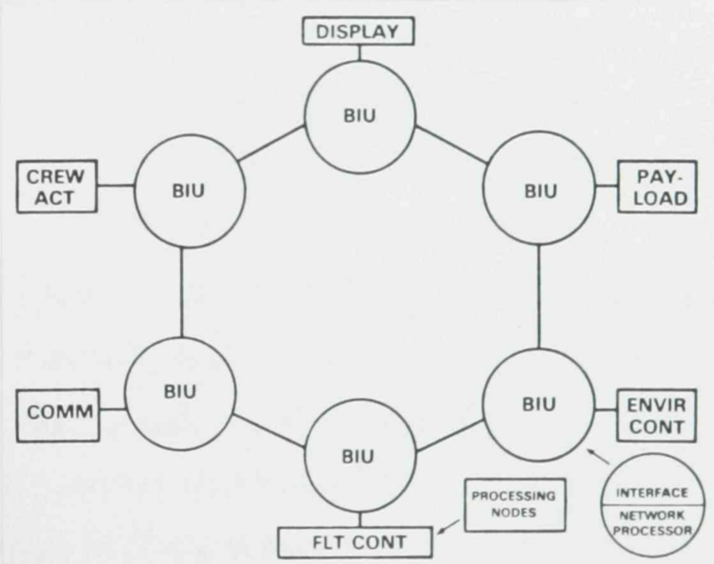
MASS STORAGE
- BUBBLE MEMORY SYSTEMS
- BUBBLE MEMORY DEVICES/MODULES
- OPTICAL DISK RECORDER

The major NASA technology tasks are concentrated on network concepts, interface and protocols, fault tolerant and redundancy management techniques, architecture trade studies, and the definition of data architecture specification requirements (Figure 11).



The data system will define a standard operating system and a standard hardware interface (bus interface unit, BIU) to each of the space station subsystems and users. The BIU will contain a common processor which will be a member of a technologically advancing family of processors each with increasing computational capability and expanding memory. One such processor is the 16 bit mil-spec 1750a and 32 bit 1862. The core DMS consists of a distributed network of BIU's where each BIU has one or more processors. The number of processors in a BIU is a function of the degree of fault tolerance required and the total computational capability necessary to support the core DMS at that node. NASA is currently developing a very high speed integrated circuit (VHSIC) 1750A processor with 5 million operations per second capability and a pipeline coprocessor with 10 million floating point operations per second.

The core DMS (Figure 12) is viewed as being incorporated in a network of BIU's using a distributed network operating system. The BIU functions as a standard interface for all subsystems and users. Each subsystem will contain one or more common processors to provide all functions that are unique to that specific



application. The subsystem contractor, therefore, will be able to develop his own unique hardware/software to run on the DMS foundation. The use of a common language such as ADA will provide a cost-effective efficient process for integration of all subsystems into the total on-board capabilities. In addition, the BIU's provide the linkage to a higher order language (ADA and interpreters) and standard software tools. By the use of common high-level user control/test/validation language and standard user gateways to the core DMS and to the user subsystem, the user space station system can look identical to the user ground system.

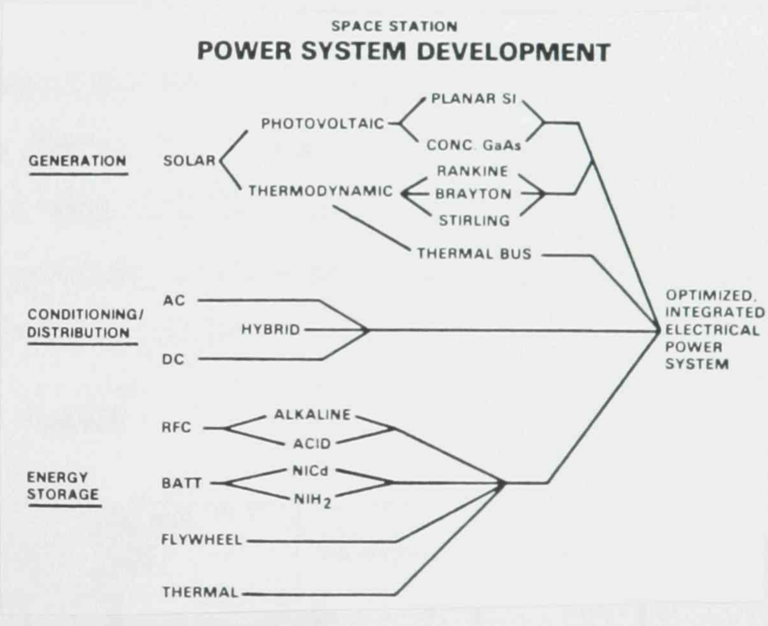
ELECTRIC POWER TECHNOLOGY FOR SPACE STATION

POWER GENERATION	PROCESSING AND CONDITIONING
• LARGE AREA PLANAR SOLAR ARRAYS • CONCENTRATOR SOLAR ARRAYS • PRIMARY LITHIUM BATTERIES	• HIGH VOLTAGE COMPONENTS • SOLAR ARRAY SWITCHING UNIT • INVERTERS
ENERGY STORAGE	**DISTRIBUTION AND CONTROL**
• NICKEL-HYDROGEN BATTERIES • HYDROGEN/OXYGEN REGENERATIVE FUEL CELLS (WATER ELECTROLYSIS) • INERTIAL SYSTEMS	• AUTOMATED POWER SYSTEM CONTROL • HIGH POWER SWITCH GEAR • BULK POWER TRANSFER • CABLES & CONNECTORS • ENVIRONMENTAL INTERACTIONS

Power[7] NASA has had a well organized electrical power system technology program for higher power requirements (Figure 13) and has several maturing techniques to offer as "technology options" for the IOC space station. The program can choose between advanced photovoltaic power generation techniques such as gallium arsenide (GaAs) cells with concentrators or an improved planar silicon cell with a back grid on a flexible superstrate blanket that offers approximately 20 percent improvement in efficiency and 40 percent reduction in alkaline fuel cells (water electrolysis) or advanced nickel hydrogen batteries for power storage. Regenerative fuel cells show an improvement over conventional nickel cadmium batteries by approximately 300 percent. Nickel hydrogen batteries show an improvement over nickel cadmium batteries by approximately 350 percent.

The large area of solar arrays required to meet the forecasted large power requirements (200-300 kw) for the growth station, has caused considerable interest in a solar thermal dynamic power conversion system. In this case, energy would be received and stored as heat. The heat energy will be converted to electricity by dynamic machinery such as the Brayton Cycle turbocompressor engine, the organic rankine or the free piston Stirling engine. The solar collector for a thermal dynamic system is considerably smaller than an equivalent photovoltaic solar array and, therefore, desirable because of the reduction in aerodynamic drag on the space station. Before the solar dynamic power system can be specified for space station application, there are several technological issues that must be resolved including life of the surface of the energy collector, engine reliability and life, and the performance of heat storage.

The major power system technological challenge for the IOC and growth space station is to find the optimum path (Figure 14) through the power system technology options for the IOC space stations and the first block of an evolutionary path to the desired growth station.



Thermal[8] Figure 15. The IOC space station is envisioned to have a utility type two-phase thermal system that will provide heat rejection to a thermal bus at a constant temperature throughout the space station. This isothermal two-phase system is connected together mechanically. This permits a distributed system that provides isolation so that a leak will not compromise the total system, and allows on-orbit changes in the system without breaking any fluid connections.

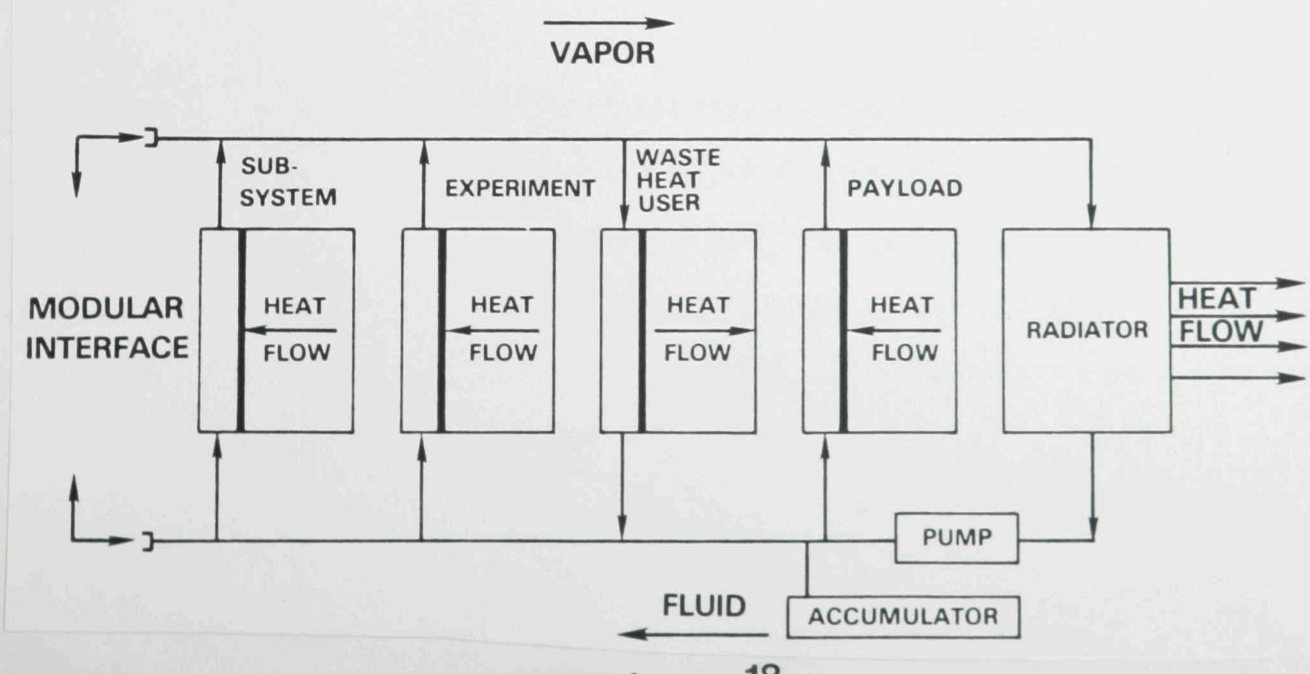
THERMAL MANAGEMENT TECHNOLOGY FOR SPACE STATION

LONG LIFE HEAT REJECTION
- HIGH CAPACITY HEAT PIPE RADIATOR
- DEPLOYABLE/CONSTRUCTIBLE RADIATOR MECHANISMS
- ENVIRONMENT SENSING RADIATOR MECHANISMS
- BODY MOUNTED RADIATORS
- THERMAL COATING MAINTENANCE/REFURBISHMENT

VERSATILE THERMAL ACUQISITION AND TRANSPORT
- CENTRALIZED THERMAL BUS TRANSPORT (TWO-PHASE)
- HIGH DENSITY HEAT ACQUISITION
- HEAT TRANSFER ACROSS STRUCTURAL BOUNDARIES

INTEGRATED THERMAL UTILITY
- THERMAL STORAGE/LOAD LEVELING/REFRIGERATION
- UTILITY SYSTEM INTEGRATION TEST BED
- AUTOMATIC SYSTEM CONTROL/MONITORING/FAULT DETECTION

There are several cold plate designs that have been built and evaluated in the laboratory. A typical cold plate design is a sandwich type construction with heat pipes welded internal to the sandwich. A typical mechanical connection uses a high pressure (100-150 pounds) contact that has demonstrated heat transfer coefficient as high as 500 BTU/HR/FT.



Prototypes of this design have been built and successfully tested in the laboratory. Long-length heat transport can be accomplished by heat pipes (demonstrated over 50 ft.) and a pumped two phase thermal loop (Figure 16). Heat rejected is accomplished by a heat pipe radiator. The radiator sections are similar to the two phase cold plate described earlier.

A major thermal technology challenge is in the constructable radiator. It is planned to demonstrate this technology in a Shuttle flight experiment in the 1988 - 1999 time frame.

ATTITUDE CONTROL AND STABILIZATION TECHNOLOGY FOR SPACE STATION

ANALYSIS CONCEPTS & METHODOLOGIES
- SYSTEM IDENTIFICATION
  - AUTOMATIC MASS PROPERTY TRACKING
  - SELF-CONTAINED STATION DYNAMICS IDENTIFICATION
  - DISTURBANCE IDENTIFICATION/ESTIMATION (FORCES/TORQUES)
- ADAPTIVE; DECENTRALIZED: AND MODULAR CONTROL
- AUTONOMOUS MOMENTUM MANAGEMENT

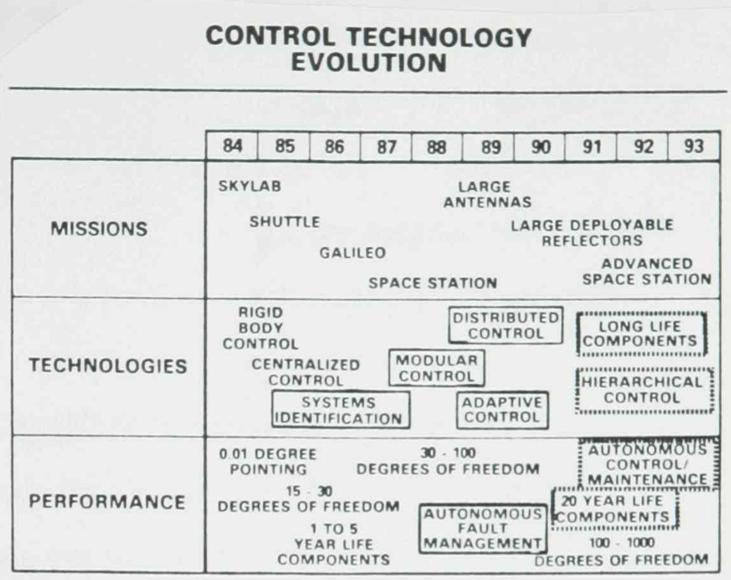
OPERATIONS/SERVICE METHODOLOGIES
- MULTIPLE PAYLOAD CONTROL SYSTEM
- ADAPTIVE CONTROL FOR DEVELOPMENT, DOCKING, BERTHING

GUIDANCE, NAVIGATION & CONTROL COMPONENTS/SENSORS
- ATTITUDE CONTROL
- SYSTEM IDENTIFICATION
- RENDEZVOUS AND DOCKING
- MOMENTUM EXCHANGE

Attitude Control and Stabilization[9] The content of the control system technology program is shown in Figure 17. A significant challenge to the control system's engineer is to provide a control system for the first element of the IOC space station that can provide attitude stability of that element and also provide stability for several major changes in plant during the assembly and build up of four to six elements to complete the space station IOC assembly on orbit. This same control system must also accept additional changes to enable specification control of the IOC space station through all of the interim configuration changes to the growth configuration.

Techniques such as system identification, distributed control, and adaptive control are being developed to provide a control system to adjust to meet such a broad range of performance (Figure 18).

These techniques can be analyzed, simulated, and synthesized. Hardware dynamics can be integrated into the laboratory simulation tests. Scale models can be tested. But it is unlikely that a full scale space station control system will be available for ground test.



A major technology challenge to the control systems designer is to establish the technique to validate a control system design that will provide an adequate level of confidence that the control system will operate satisfactorily in space. Several techniques will be traded from ground tests to a Shuttle flight test to instrumentation and evaluation of each element of the space station as it is launched.

Auxilliary Propulsion[10] It is envisioned that the on-board propulsion system used for orbit maintenance and momentum management will consist of two levels of thrusters. A H_20_2 chemical engine in the 25-100 pound class and a resistojet in the 1 pound class. The major technology task for each class of thruster is shown in Figure 19. The gaseous hydrogen-oxygen system consists of a propellant conditioning system, vaporizer, and a storage system.

AUXILIARY PROPULSION TECHNOLOGY FOR SPACE STATION

GASEOUS HYDROGEN/OXYGEN SUBSYSTEMS
- SYSTEM ANALYSIS & PRELIMINARY DESIGN
- THRUST CHAMBER/IGNITER
- PROPELLANT CONDITIONER
- PROPELLANT PUMP/COMPRESSOR & DRIVE

GASEOUS HYDROGEN & HYDRAZINE RESISTOJET SUBSYSTEMS
- SYSTEM ANALYSIS & PRELIMINARY DESIGN
- THRUSTERS
- HEAT EXCHANGERS
- POWER PROCESSORS
- PROPELLANT/MATERIAL/TEMPERATURE INTERACTIONS

Technology development tasks also include a health monitoring system that continuously monitors critical parameters such as component performance, fluid leaks, and temperatures and pressures throughout the system.

A resistojet is a low thrust monopropellant thruster that gains specific impulse by adding heat energy to the fuel. Various fuels may be used. It is most advantageous if waste products can be used as fuel. The low thrust is designed to operate nearly continuously for acceleration control.

STRUCTURES, MATERIALS, AND MECHANISMS TECHNOLOGY FOR SPACE STATION

SPACE DURABLE MATERIALS
- SPACE DEBRIS CHARACTERIZATION AND EFFECTS
- LONG-LIFE THERMAL COATINGS & RESISTANT POLYMER FILMS

SPACE STRUCTURAL CONCEPTS
- DEPLOYABLE TETRAHEDRAL TRUSS
- DEPLOYABLE TRUSS BEAM
- ASSEMBLY TECHNIQUES FOR ERECTABLE TRUSSES AND BEAMS

ANALYSIS AND SYNTHESIS TECHNIQUES
- STRUCTURAL DYNAMICS
- THERMAL-STRUCTURAL ANALYSIS
- INTEGRATED ANALYSIS/OPTIMIZATION

MECHANISMS
- LATCHES, HINGES, JOINTS
- ACTUATORS, SENSORS
- CONNECTORS, UMBILICALS, SEALS
- TOOLS, MANIPULATORS

Structures, Materials, and Mechanisms[11] The key features of this technology program are shown on Figure 20. A major technology task in materials is the development of new composite materials that are designed to resist penetration from high velocity particles (man made debris or meteoroids) traveling at velocities of

10-20 km/sec. Analysis and simulation will be validated by high velocity tests to be run in existing NASA facilities. Material thickness will be evaluated from 1mm to 10mm thick. Various designs and bumper configurations will be evaluated to determine a family of designs to minimize particle penetration. The results of composite high-speed particle tests will be compared with an existing data base for aluminum. Space debris testing is planned to be conducted in 1985-1986 which will provide additional data to the existing space debris data base and wil provide valuable realistic space penetration characteristics to compare with ground test and simulation.

Deployable and erectable structure techniques are a major building block for space station construction in orbit and represent a significant part of the structures technology program. Work is continuing on both techniques. It is assumed that EVA will be available for routine operations in space. Timeline for space operations is an evaluation criteria in the comparative tradeoff studies between these two techniques; but no penalty is assigned to the amount of EVA time required. The major technology challenge for erectable structure configurations is the design of structural joints asembled in space. They must be free enough to enhance the assembly process and rigid enough to provide the structural ridgidity specifications. A major disadvantage and, therefore, a technology challenge to improve, is the difficulty of integrating space station resources into the structure (such as copper and/or optic harnesses and structural hard points). Erectable structures have an advantage of their high density packaging for launch. The deployable design does permit some integration of space station services into the structure, but at the expense of the launch packaging density. Deployables tend to require less on-orbit assembly time compared to erectables. Both techniques are being developed. It is envisioned that both techniques will be used on this space station.

A third area in this technology is mechanisms. The technology in mechanism design is to acheive reliabilty over long life (approaching twenty years) operating in the environment of space. Much of this program deals with basic research in bearing seals and lubricants. The unique applications technology challenge is to develop mechanism configuration alternatives to meet classes of requirements such as gimbal drivers for solar arrays and thermal radiators, umbilicals and signal and power transfer across active joints, etc. Development of mechanical systems kinematic analysis capability including elastic effects and accumulation of tolerances across the environmental range will provide valuable improved design tools. A major space station focus for the mechanism technology program is the Shuttle/space station berthing mechanism.

HUMAN FACTORS TECHNOLOGY FOR SPACE STATION

- EVA WORKLOAD/SIMULATION/CAPABILITY ASSESSMENT
- EVA WORKSYSTEMS (RESTRAINTS, ATTACHMENT, TOOLS, END-EFFECTORS)
- GROUND CONTROL HUMAN FACTORS
- HABITABILITY DESIGN REQUIREMENTS
- HUMAN PERFORMANCE CAPABILITIES/LIMITATIONS
- MAN/MACHINE INTERFACE DESIGN OPTIMIZATION
- MEDICAL CARE/EQUIPMENT
- ORBITAL MAINTENANCE METHODOLOGY
- TELEOPERATOR OPERATION/CONTROL

Human Capabilities[12]

See Figure 21. The major technology challenge of this program is to partition the human function between the man and the machine, between the man's role to be accomplished internal to the vehicle, and to develop aids (tools, fixtures, crew stations) for man's activities. This task also deals with the habitability guidelines to improve man's state-of-health, attitude, and motivation; and the development of basic design data such as space anthropometry, methods for formating support documentation, and methods for allocating tasks between man and machine.

Crew station design focuses on the application of advanced display and control technology, (flat panel displays, touch sensitive panels, voice recognition/synthesis, etc.), and basic ingredients for comfort. The ideas of comfort in space are not too different from the ideas of comfort on Earth.

Temperature. When there is not too much physical activity, 72° F is considered ideal. Variations should not exceed 5° waarmer or cooler. Environmental-control systems of the spacecraft can easily maintain the temperature within this range, however long the stay in space.

Atmosphere. Present-day U.S. spacecraft provide a pure-oxygen atmosphere to breath at the low pressure of less than 5 pounds per square inch (absolute). This is about one third of the normal atmospheric pressure (14.9 pounds per square inch), and is like that located atop Mount Everest. But a breath of pure oxygen at 5 pound pressure gives the lungs enough - more oxygen, in fact, than is in a breath of three-times-denser normal air (21 percent oxygen, 79 percent nitrogen). The low pressure, besides saving spacecraft weight, gives space suits maximum flexibility to make wearers' movements easy. Using the same pressure in spaceccraft cabins and space suits avoids complications in changing from one to the other - for a spacewalk or in case a sudden failure of the cabin's pressure system forces the astronauts to close their helmets' faceplates or don their helmets and depend on the life giving atmosphere in their suits.

As to how long astronauts can breath pure oxygen without harm, however, there is considerable argument. The Gemini 7 flight proved that two weeks is acceptable and several Apollo flights lasting ten days confirmed that finding. But how about three months or even three years? No one really knows. Therefore, for a lack of experience the space station will be designed to incorporate a closed loop system of pressurization and environmental control. This means the system will use the 40 percent oxygen and 60 percent nitrogen mixture, close to that found in the Earth environment. Pressure will be strictly maintained at 13.5 pounds per square inch. This pressure is roughly equivalent to the pressure found in Mile High Stadium in Denver, Colorado.

Privacy. Individuals value the right to be left alone. After a year in space in crowded quarters even the simplest nuance of behaviour can be irritating.

The Space Station will be comprised of two main divisions. One will be the microgravity area for the factory, (the workplace), and the other will be the artificial gravity area for living, sleeping, socializing, and eating. The sleeping quarters will be built to insure each occupant the privacy one might find in a college dormitory. Separate areas will be provided to allow the workers, scientists and astronauts to interact socially. The central navigational and command center will also be located within the artificial gravity sector.

Food. Dehydrated and powdered food - reconstituted by moistening, kneading, and squeezing - may be fine for heroic explorers. But a man expected to perform at top efficiency in space for a year or more should get the same filet-mignon treatment as the business traveler on a flight from New York to Los Angeles.

Entertainment. We all need diversion. A man in a space station, will want something to listen to, or look at - whether it is the Beetles or Beethoven, Playboy or Plutarch. Advanced techniques offer ways to keep our space workers happy and balanced: taped music, microfilm libraries, laser for interplanetary color television.

Medical care. For a two week trip to the moon and back an astronaut need only to check in with his flight surgeon for a prompt okay. But that will not suffice for a one year stay in orbit. Anyone can have a toothache or catch a serious disease a few months after his doctor found him in perfect health. So it stands to reason that long stays in outer space will require a physician at hand. And astronaut-doctors will become a part of the space faring community, just as astronaut astronomers, astronaut meteorologists, and astronaut clergymen will. All of these specialist will require their own work areas just as the research personnel will.

Gravity. Astronauts Borman and Lovell were perfectly happy after two weeks of microgravity. Their comments sounded almost as if their major concern was whether or not they would ever get used to the nuisance of Earth gravity again. Medical experts still do not know what three months or a year of microgravity will do to a man. It is for this reason that artificial gravity will be employed into the living quarters of the space station. This will necessitate a major architectural design focus on the transition between the two areas.

Outputs of this technology are design guidelines to be used in the design of all equipment that interfaces with the crew. An example of a design guideline is the requirement of the helmet mounted data display used to provide instructions to astronauts on EVA. This guideline must address such things as: the configuration of the display (direct vision, fringe vision, static or dynamic, etc.), the format of the data, the technique, the details of the data, rate of change of the data, multi-channel use, etc. These guidelines would be used in the design of helmet/display system, the software pocketization, communication interface, data management interface, space operational procedures, etc.

COMMUNICATIONS TECHNOLOGY FOR SPACE STATION

INFRA-RED INTRAVEHICULAR COMMUNICATIONS

- ELIMINATES INTERFERENCE WITH OTHER SYSTEMS
- ENHANCES MOBILITY OF ASTRONAUTS
- ELIMINATES UNWELCOME RECEPTION

MULTIPLE FREQUENCY, MULTIPLE ACCESS ANTENNAS

- REDUCES PROLIFERATION OF ANTENNAS
- PROVIDES GREATER SYSTEM FLEXIBILITY

SOFT DOCKING, LASER RANGING

- PROVIDES ACCURATE MEASUREMENTS OF RANGE AND RELATIVE VELOCITY
- DETERMINES ORIENTATION OF APPROACHING VEHICLE

ANTENNA FIELDS OF VIEW

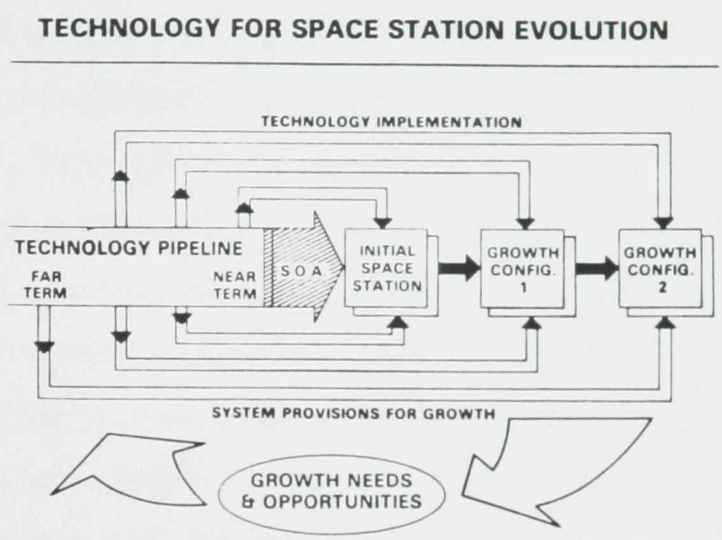
- SIMULATION OF SPACE STATION GEOMETRIES
- COMPUTATION OF SPHERICAL ANTENNA PATTERNS
- ENABLES SYSTEM DESIGN OF COMMUNICATION SYSTEM

Communications[13] See Figure 22. Major technology tasks include: reduction in operational constraints by use of multi-access systems and phased array body, mounted antenna, improvement in performance by the optical space-to-space links, use of 20/30 GHz and 60 GHz for tracking and rendevous to avoid the spectrum crowding/radio interference in the S- and Ku- band frequencies.

Technology development in antenna systems is concentrated on spherical coverage for proximity operations, optical links to near and far targets, multi-use antenna covering S-, X-, and Ku- band. Technology options include beam switching, multibeam, and phased arrays. Potential multi access approaches include: packet-oriented time domain multiple access (TDMA), frequency division multiple access (FDMA), frequency hop multiple access (FHMA), code division multiple access (CDMA), and space division multiple access (SDMA). These will be traded regarding cost and efficiency. Advanced laser ranging/tracking technology will be used for traffic control and proximity operations. Microwave radars envisioned for multi-target acquisition and tracking will use distributed phase array antenna and high speed signal processing technologies for the IOC space station. Internal and module to module communication infrared system can provide broadwidth needed for on-board wireless communication. This technology is reasonable, mature, and will be developed for the IOC space station.

Summary of Space Station Technology by Disciplines[14]

The technology desired to suopport the IOC space station has come into focus and been discussed above. The technology to support the evolutionary space station is not as well defined and focused. Several of the technologies discussed above for the IOC space station are back-options to be considered as the hardware phase approaches. Figure 23 illustrates the flexibility of the application of technologies to the space station program. If an innovative new approach is desirable for IOC, but at the time the IOC configuration is selected the new technology is considered too high a risk, the technology development can continue for later incorporation by block change.



Technology Themes

The technology discussion by disciplines does not provide the complete perspective of the space station technology development program. A sample cross-cut theme is presented here to illustrate the depth and breadth of the NASA space station technology program.

Automation is a technology category but it is not a discipline. It is a function that cross-cuts all of the space station disciplines. Hence, all of the discipline technologies will deal with the application of automation. Automation technology is being approached in three parallel ways: (1) Discipline technology deals with automation techniques such as the development of new appraoches to automation, new algorithms, new languages, new techniques such as expert systems, and planners. It deals with technique rather than application; (2) Systematic top-down definition of automation ground rules deals with partitioning of functions between the space station and the ground. It includes the definition of mission rules, that is, the orderly decision of priority when the system faces a conflict or a contradiction; and (3) Bottoms-up automation analysis for specific subsystems. The power subsystem and the environmental control and life support subsystems are presently being studied. At the conslusion of these two studies, common or generic trends for the automated control of subsystems will be identified. This analysis of subsystem automation approaches will be combined with the top-down space station automation study to establish an automation requirement document of the entire space station.

User Needs

The technology program includes technologies to assist in making the space station user friendly. NASA has a user group that is divided into three classes: (1) technology driver missions, (2) science and applications, and (3) commercial users. Each group is evaluating future space station uses and defining an envelope of user requirements. Technology planning has used the definition of user requirements to size the capacity of the space station resources. A good example of a technology development program to meet a user need is the technology to evaluate techniques to handle the transfer of cryofluids in zero-g. The technology has adddresed: (a) zero gravity fluid gaging, (b) reusable insulation for fluid transport, (c) leak-proof fluid coupling, (d) long term cryo storage on orbit, etc. The program has developed cryo-management, fluid-management, Shuttle flight test program that consists of several flight experiments.[15]

This Space Station program is derived from the NASA plan FY1985. The NASA plan is the culmination of two years of planning that has grown from the OAST generic base technology program (see Figure 24).

STEPS IN NASA TECHNOLOGY PLANNING

(1) REVIEW GENERIC BASE

(2) MODIFY GENERIC BASE TO BE MORE USEFUL

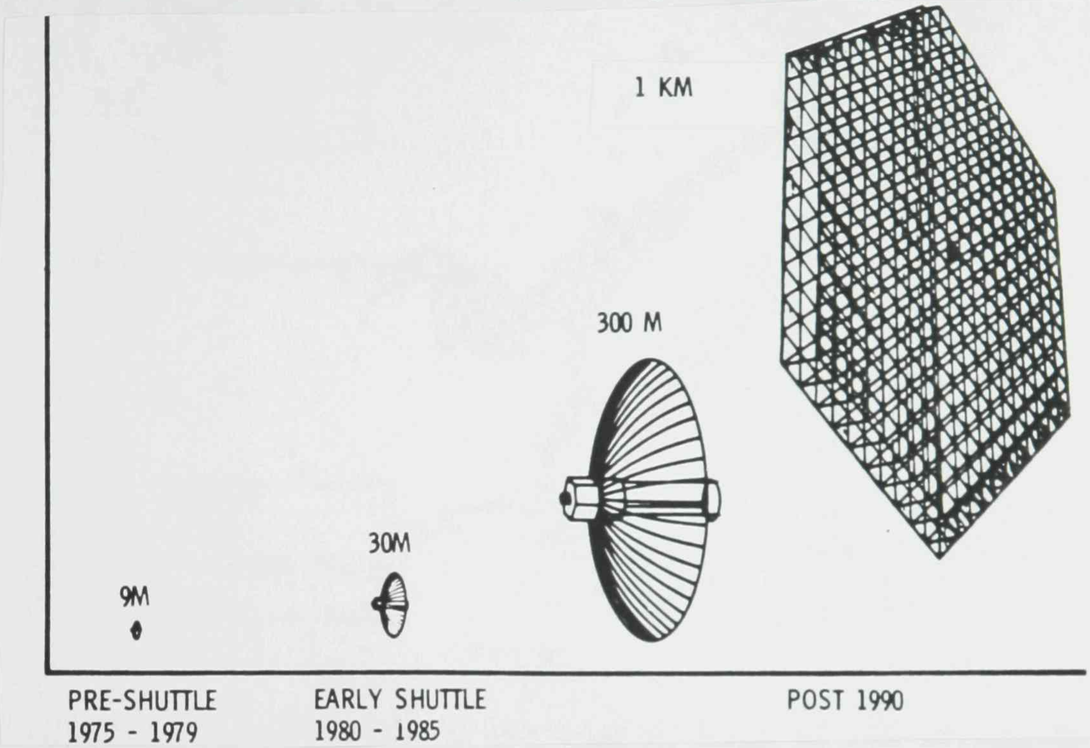
(3) ADD FOCUSED TECHNOLOGY

(4) BUILD ADVANCED DEVELOPMENT HARDWARE

(5) ESTABLISH TESTBEDS

(6) ENABLE A STS FLIGHT EXPERIMENT PROGRAM

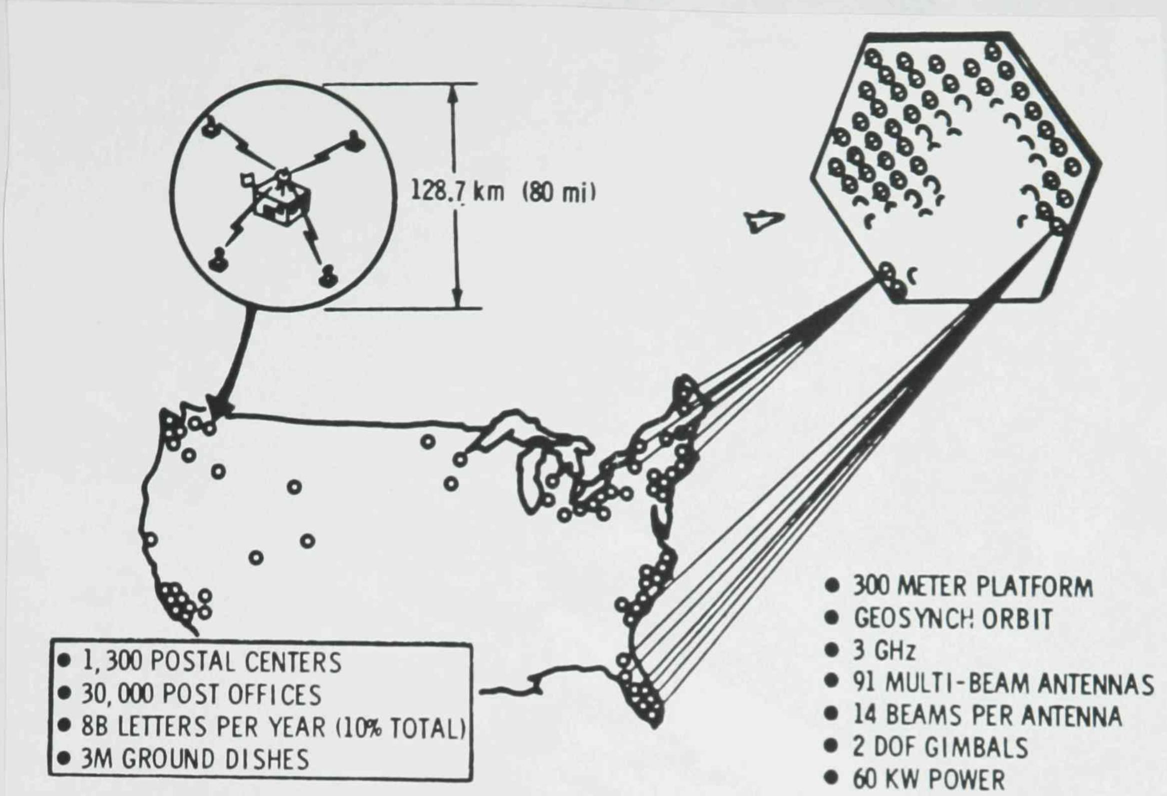
The first step of this program was to review the progress of the ongoing generic base technology program to determine what tasks where applicable to a space station. This assessment has been referred to as the space station "verticle cut" of the generic base. The second step was to modify those tasks that would be more applicable to a space station anticipated need but still preserve the generic application of those tasks to other platforms and large space structures. The third step was to augment the generic base and focus the output to a specific space station need and schedule. The fourth step was to seek space station technologies emerging from the generic and focused technology program to conduct advanced development evaluation of these technologies to determine the applicability to the space station design. The fifth step was to establish discipline test beds to evaluate the advanced development hardware before a technology option decision was required. The sixth step was investigate STS flight tests for mature and/or demonstrated advanced technology performance. These results will be incorporated into the program and will be correlated in accordance with my anthropometric program.



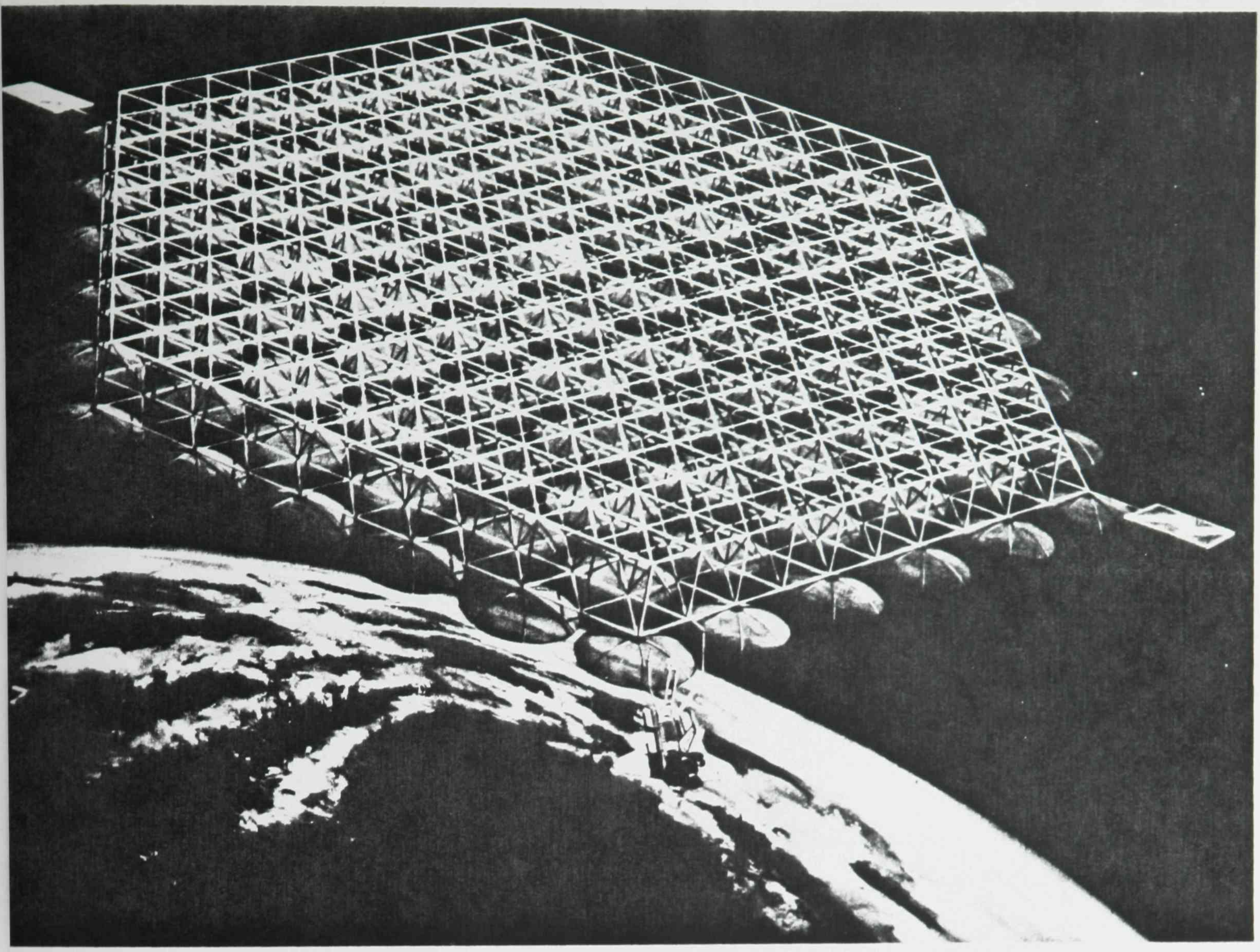
Planning for large construction projects in space

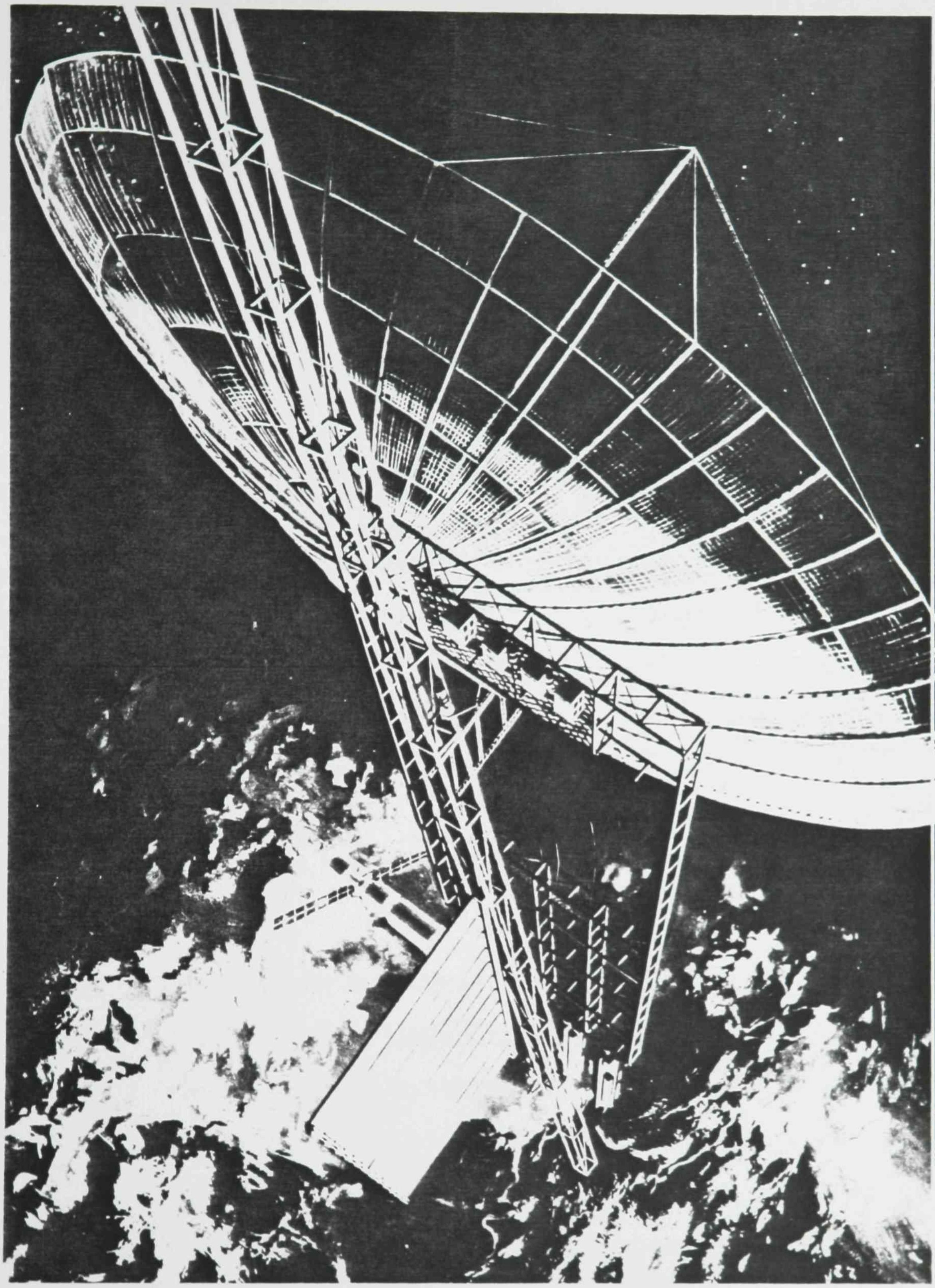
There is widespread agreement that our future in space will include operation of a variety of large complex systems which to one degree or another will require "construction in space." These systems cover a wide range of complexity aand timing. At the far end of the spectrum are multi-gigawatt satellite solar power stations which could supply a substantial fraction of our power needs on Earth by the end of the 21st century. At the near end of the spectrum are large deployable antennas and sizable in-orbit power supplies which will be needed to supply power in low Earth orbit in the early 1990's.

These trends and possible timing as now foreseen are summarized graphically in Figure 25.



We anticipate the need for dish shaped antennas as large as 300 meters in diameter for advanced communication purposes during the next decade or so. For that same period, scientists are considering dish shaped listening posts in space as large as 3000 meters in diameter to search for extraterrestial intelligence (SETI) or to detect faint RF sources of unknown origins. Similiarly, booms and planar surfaces hundreds of thousands of meters in extent are under consideration. Examples of these prospective systems are illustrated in Figures 26, 27, and 28. In particular, typical large structures for advanced communication and Earth sensing are shown.



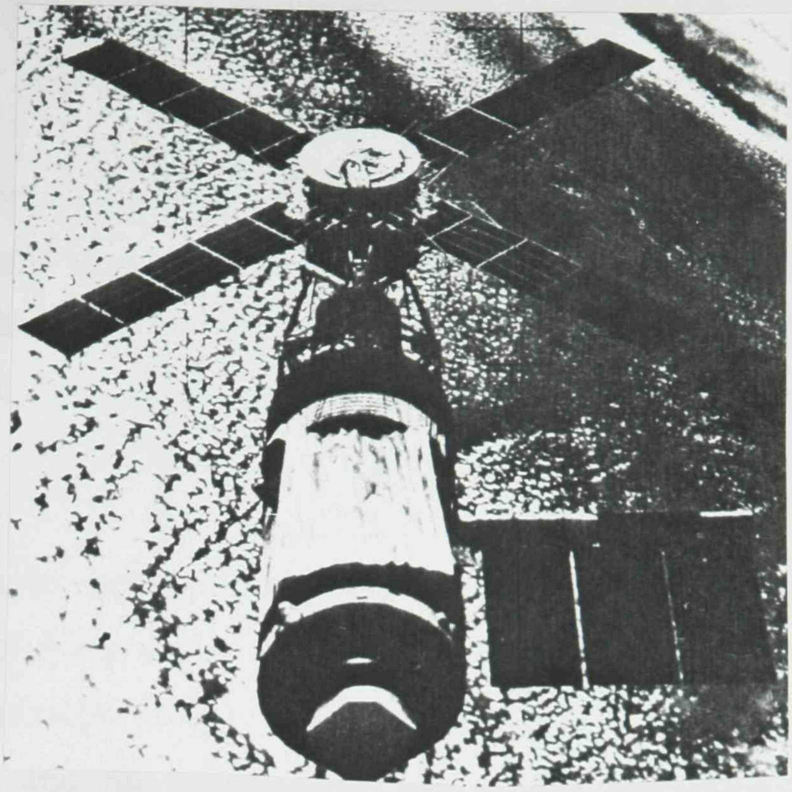


Related areas of technology are listed in Figure 29. It is apparent that the building of such large structures in space will entail advances on a number of technological fronts -- such as, analysis of the behavior of large flexible structures in near zero gravity, control laws and control mechanisms for such structures, signal sensing and processing, and long life dimensionally stable composite materials.

ASSOCIATED TECHNOLOGY AREAS CLOSELY COUPLED TO STRUCTURAL CONCEPTS

ANALYSES	CONTROLS
• PREDICTION OF STRUCTURAL BEHAVIOR (LOADS, DISTORTIONS, STRESS) • STRUCTURAL/CONTROL INTERACTION • ELECTROMAGNETIC AND CONTROL PERFORMANCE • INTEGRATED DESIGN DEVELOPMENT	DEVELOPMENT OF CONCEPTS FOR • SHAPE CONTROL • ATTITUDE/POINTING CONTROL • ORBITAL TRANSFER AND STATION KEEPING
ELECTRONICS	**ADVANCED MATERIALS AND JOINING**
DEVELOPMENT OF ELECTRONICS NEEDED FOR OPERATION AND CONTROL • SIGNAL CONDITIONING AND DATA ACQUISITIONS • POWER DISTRIBUTION • SIGNAL CHANNEL INTERFERENCE AND MULTIPACTION	• 30 YEAR DIMENSIONALLY STABLE COMPOSITES • TECHNIQUES FOR THERMAL CONTROL • THIN-LIGHTWEIGHT STRUCTURAL ALLOYS • MATERIAL JOINING TECHNIQUES FOR SPACE

Generally speaking, our large systems in space to date have used deployment principles to acheive their large size, although Gemini, Apollo, ASTP, and Skylab all used modular construction assembly to obtain their basic configuration. It is interesting to consider that in Skylab even the large sunshades used to effect in-orbit repair were deployed. In the case of the parasol-type sunshade first used, a combination of manual and automated deployment was employed. In the subsequent blanket sunshade, the entire deployment of the shade was done manually on to a manually assembled (tinker-toy style) framework (Figure 30).



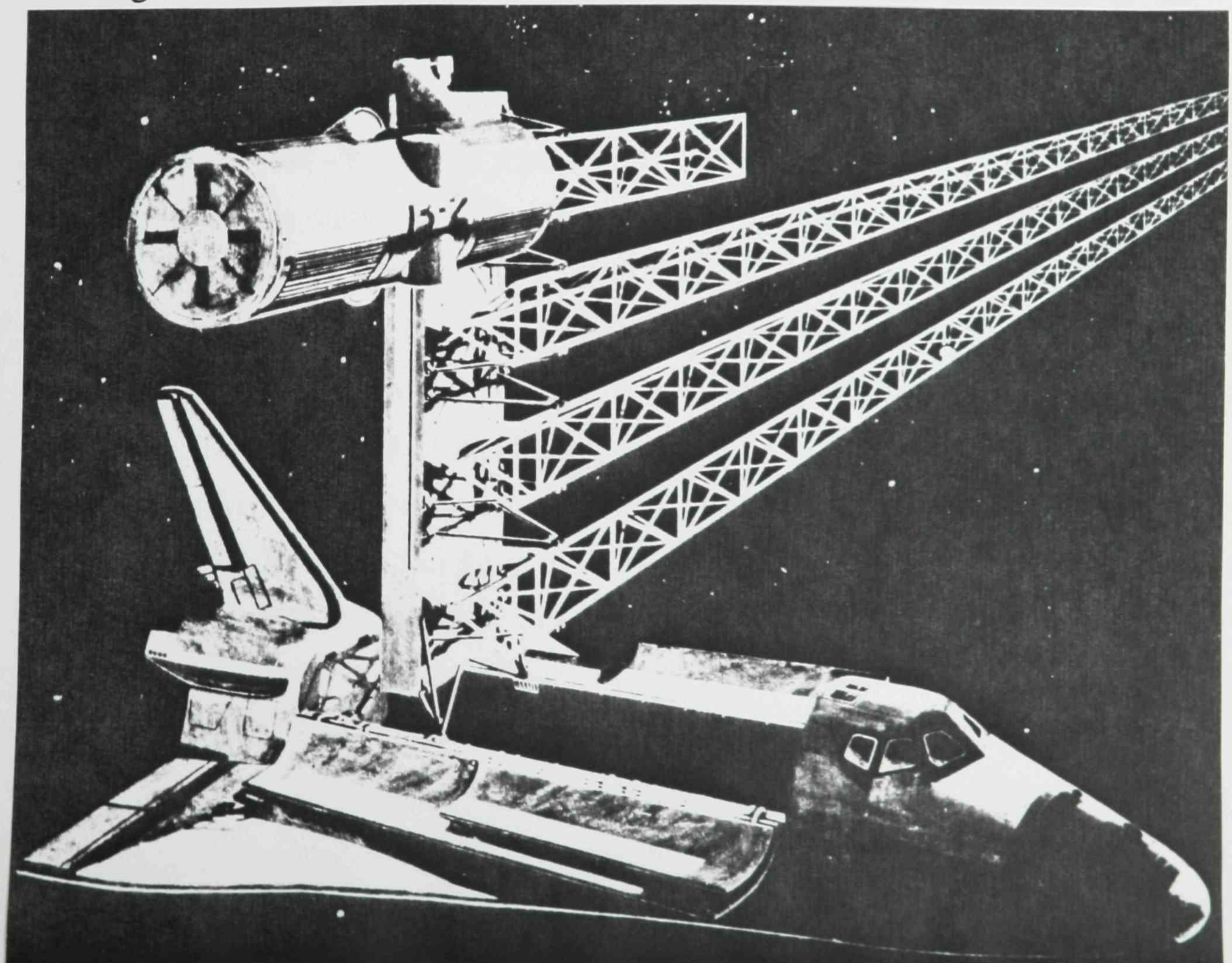
The basic capability needed to construct things in spacer an addition to transportation is a work site or "construction camp." The Space Shuttle orbiter provides such an initial capability, as well as providing the basic transportation.

Construction will be first carried out by assembly of earth built modules carried up in the Shuttle unassembled so as to fit within the cargo bay during launch or carried up by seperate shuttle flights and docked or joined in orbit much as was done on the Gemini, Apollo, Skylab and Apollo-Soyuz Programs. In these past programs, the seperate modules had the capability to maneuver and dock with each other by means of their own propulsion and stabilizing systems. For routine assembly operations in the near future, many of the elements or modules to be assembled will be passive and have to be externally manipulated or handled. To this end, the Shuttle has a remotely controlled manipulator system (RMS). The RMS is a manually controlled (servo-computer aided) from within the Shuttle by a human operator with direct visual or remote TV aided sensing and has the capability to reach 15 meters from the orbiter-mounted base. An extensive program of learning to use this versatile tool in space is required - first on the ground with zero gravity simulation through under-water or lighter-than-air buoyancy and later in test flights with the actual system. An initial flight evaluation is planned on a Shuttle mission in the 1990's.

In addition to remotely controlled assembly, it will be necessary also to have on-site human support for some operations - either as a part of the planned assembly process or in a trouble-shooting or repair mode. The Shuttle orbiter provides "EVA" support for two crewman up to 6 hours at a time in such a mode.

In contrast with our lack of experience with remote manipulators in space, we have a comparative wealth of EVA experience, going back to Ed White's "spacewalk" in 1965 and culminating in the magnificent in-flight repair work carried out by Pete Conrad and his fellow crewmen during the Skylab program. From these experiences, we have a good understanding of basic EVA capabilities and effectiveness and primary future needs will be specific task training for new crewmen. Neutral buoyancy (underwater) and zero-g aircraft training will be used extensively in these areas as in the past. The next basic tool needed will be a free-flying teleoperator system which will provide manipulative support at distances not reachable by the attached shuttle RMS or in circumstances not conducive to EVA. Such a system is currently under development and will be useful for payload placement and planned or contingency payload retrieval, as well as construction support. Development and training in the use of such devices is aided greatly by the use of air-bearing three-degree-of-freedom flight simulators and neutral buoyancy simulators.

In-space fabrication, as opposed to in-space assembly or deployment, means forming structural members in orbit from coils of sheet or other stock carried to orbit in bulk form. A simple analogy is the on-site fabrication of aluminum rain gutters for residential housing. Space fabrication has several advantages - primarily increased volumetric efficiency in carrying structural metal into orbit and the fact that in zero-g, structural elements of practically unlimited length can be extruded. Very large space structures may require this technique. However, the practical or desirable limits or size of deployed or assembled structures are by no means known at this time. The tradeoffs among the several techniques must be carried out on a case-by-case basis. In any event, it is felt that in-space fabrication is an important option for future large space construction as well as developmental in-space evaluation of such devices, as illustrated in Figure 31. In this illustration, a large planar assembly is being formed of on-orbit extruded beams.



At this point, it becomes apparent that for extended assembly/construction operations, more electric power and duration will be needed than are available from the basic Shuttle. The electric power supply for the Shuttle is furnished by hydrogen/oxygen fuel cells and enough reactants can normally be carried to support mission durations on orbit of 7 to 12 days without intruding into the payload bay with cryogenic tank storage. For longer missions, added cryogenic storage can be provided in the payload bay -- however, at the cost of payload bay weight and volume. An alternative solution, currently under study, is a space-stored electric power module which would be carried into orbit by the Shuttle where it would remain as a constant source of power and stabilization to orbiters docked with it. Such a power module uses a large deployed solar array. This array with a total area of 600 square meters and a span of 70 meters - substantially larger than the previous largest system flown (the Skylab array) would provide an average power of 25 KW (59 KW full sun) to the orbiter - essentially providing unlimited duration in orbit as far as electric power is concerned. In addition, the module would provide attitude stabilization and control to the orbiter through control moment gyroscopes mounted in the module. The solar array application of large deployble structures presents no particular problem of precision of Figure control or in pointing - the tolerances in both these areas being substantial. In this instance, the dominant requirements are low unit weight, and adequate strength to withstand maneuvering, docking and deployment loads. The basic orbiter with its hydrogen/oxygen fuel cells can provide about 7 KW of power for 30 days to the payload for this configuration. However, the cryo tanks take up substantial orbiter payload volume and substract about 16,000# from the available orbiter payload for this mode of operation. With the power module connected and the fuel cells shut down or "idling," about 11 KW of power can be supplied for 60 or more days--limiting factor now being food, water and other crew habitability requirements for the longer duration. In addition, the cryo tanks for this approach do not intrude into payload volume or substract from basic payload capability. This 25 KW power module is now under detailed definition and is being planned for 1984 availability. The 25 KW power module has several other attractive features. One is the potential it offers for support of high power free-flying payloads in a detached mode from the orbiter. The system will be configured with dual docking ports so that free-flying payloads can remain attached while the module is attached to the shuttle.

In addition to the role of the power module in supporting construction and operation of larger and more complex systems in orbit, it offers the potential for substantially enhanced Spacelab missions starting in the third and fourth year of Spacelab operations. Typical baseline orbiter-Spacelab misions operate 12 days, with about 35 KW of power available to the Spacelab payload, after orbiter-Spacelab housekeeping needs are taken care of and with the payload weight and volume penalties discussed earlier. On the other hand, with the 25 KW power module in use, a power of 7 KW can be provided for duration of 60 days or longer with essentially full payload volume and weight. NASA and ESA have agreed to pursue coordinated studies of the 25 KW power module use with Spacelab for these longer duration-higher power missions.

A longer term possibility for cooperative effort, offered by the 25 KW module is the concept of a spacelab modified to have free-flying capability, with attitude control and power capabilities provided by the 25 KW power module. Such a facility could provide long duration on-orbit capability with periodic resupply of food, water and other expendables by the shuttle. NASA and ESA have recognized this potential and further agreed to keep each other informed about related studies of user needs and system configurations.

The benefits to the user of the longer duration-higher power spacelab missions are many. Not the least of these will be economy - greatly reduced cost per day of experiment operations. In fact, for representative projected experiment requirements, our calculations indicate that in the 1988-90 period the power module can repay its total cost of development during its first year of operation through more effective utilization of the Shuttle-Spacelab system. In addition, there are many experiments that require longer than 7 to 30 day continuous on-orbit operations to meet mission objectives. Typical of these are experiments involving solar cycle related phenomena, where uninterrupted observationover two or more solar cycles (28 days each) are required; and life science experiments where uninterrupted zero-g is required over successive generations of animal or plant specimens.

With the augmented Shuttle-Spacelab combination, a very substantial orbital capability will exist in 1984. However, the power level of 25 KW falls well short of expected needs for a number of applications in the mid to late 1990's. As now perceived, these higher powers will be required in areas such as:

- Advanced communications
- Experimental Evaluation of Solar Power Satellite Parameters
- Materials Processing
- Advanced Space Propulsion

In the field of communications, of the order of a 100 KW may be required to power advanced systems such as the electronic mail concept or high power radars described in figure 26; several hundred KW will be required for proof of concept and evaluation of Extremely Low Frequency (ELF) space to under wter communication systems. For an operational ELF system, powers of the order of several tens of megawatts could be required .

With regard to the solar power satellite (SPS), it has been estimated that several hundred KW will be required for evaluating factors such as power transmission efficiency, ionospheric heating effects of high power density on space structure. All of these data will be necessary as a part of evaluating the SPS system before any decision to proceed into the development of a large scale model or a full scale system.

In the area of materials processing, if we assume that early Spacelab experiments will lead to a prototype processing facility, a need for the powers of the order of 50 KW are needed. Such a prototype facility could evolve from Spacelab or be a completely new facility designed for free-flight and intermittant Shuttle attendance.

Finally in the area of advanced propulsion, electric powers in the 100's of kilowatts will be required ultimately for operational systems. The likely first high power propulsion system will be an ion-drive for those missions requiring very high energy, such as rendezvous with the Encke comet. Subsequent uses for "ion drive" may include propelling large payloads from low to high orbit

Several space systems which are too large to be transported into orbit fully assembled have been proposed in recent years. Such a system is the Space Station which is now an ongoing project. Many unprecedented challenges arise in the design and certification of such systems. Several of these challenges in the interdisciplinary area of structural dynamics and control were articulated in connection with requirements for three large systems, the Land Mobile Satellite System, the Large Deployable Reflector, and the Space Station. These represent the three classes of large space structures, all with different requirements, but all sharing similiar challenges in design and certification.

In antennas, needs for higher gains and higher operating frequencies combine to produce demands on ground testing which are increasingly difficult due to gravity. In the case of the space station, gravitational considerations may prevent a fully assembled ground vibration test. These situations force much greater reliance on analysis than in past programs. As a consequence of this broadly based requirement on analysis, much ongoing research is oriented to obtaining increased confidence in the ability to analyze the structures accurately. On realistic structures, verification of this ability is significantly inhibited due to prominent gravitational effects. Scale models are less subject to gravitational effects but their applicability suffers. Inabilities to scale joints properly and to scale members with dimensions already close to minimum gage. Because of these and other difficulties associated with ground testing in the orbital environment becomes necessary. The expense of such tests requires the careful selection of test structures and a well planned test program.

Eigensystem Realization Algorithm. The new in the Eigensystem Realization Algorithm (ERA) is an application of system realization theory to structural dynamics analysis. A matrix called the generalized Hankel matriz, which represents the data structure in ERA, consists of Markoff parameters generated by free-decay responses. Using the singular value decomposition technique a linear model is then transformed into model space for model parameter identification.

The Galileo spacecraft is an interplanetary vehicle launched in 1986 for investigation of the chemical and physical composition of the planet Jupiter and its moons. It consists of a planetary orbiter and an atmospheric probe that will be deployed toward the planet. The ERA method has been applied to the Galileo spacecraft as part of a program conducted by the Jet Propulsion Laboratory to compare results of different dynamic data reduction methods. About 30 modes were identified in a frequency range of 10 to 50 Hz.

The solar array flight experiment was flown on the space shuttle. Objectives of the solar array flight experiment were to obtain space performance data on various types of solar cells along with a comparison of that data with ground test, to verify the method of 0-g deployment of the array and to verify two methods for obtaining dynamic data. One experiment methhod, not discussed here, involving reflectors and a charge-coupled device was conducted by the NASA Marshall Space Flight Center. The other method involving the use of the on-board shuttle video cameras and photogrammetic analysis of the motion of the white circular targets shown in the figure was performed by the Langley Research Center. In this data analysis procedure synchronized video tapes are stored frame-by-frame and subsequently each frame is analyzed to determine a location of the set of targets on the array. Then a photogrammetric analysis is performed to locate in space and as a result a time history is generated. This time history can be analyzed by any of several data analysis methods. The one which will be used at Langley will be the ERA.

Hoop-Column Antenna Concept. A significant challenge to both ground test and analysis is presented by the Hoop Column Antenna. This structure, known as the Hoop-Column Antenna Concept consists of a telescoping antenna mast which supports cables connecting to an outer compression ring. Thus all members of the structure are in tension except for two compression members. The antenna mast is attached to the outer compression ring. The curved shape of the mesh is affected by a cable network connected to the central mast. This structure has been built to a diameter of 15 meters and will be tested electronically and then tested at the NASA Langley Research Center.

Test definition of the vibration characteristics of this structure obviously is complicated by the presence of so many tension members which will be difficult to instrument. In addition, access to the mesh modes is inhibited by the presence of these cables. The presence of gravity significantly affects the vibration effects of the cables in a known way, increasing frequencies of the upper support cables while decreasing those of the lower cables. Natural frequencies associated with the modes involving motion of the compression ring will be affected, but to a lesser extent.

Exact Member, Repeating Segment Analysis. Analysis of such a structure as the Hoop-Column antenna concept by usual finite element methods is very difficult because of the large number of degrees-of-freedom in this structure. An analysis has been developed however, which makes use of the repetitive nature of the structure and exact member theory. In this analysis only one repeating member is analyzed using exact member theory. Only the repeating segment is described in the analysis computer program but natural frequencies for the complete structure can be generated. Cable motion and beams with significant preload are treated. Analysis of a typical repeating structure is indicated in which a structure similiar to a bicycle wheel is analyzed. Because of the exact nature of the elements, no intermediate nodes are needed between connections for analysis of the repeating segment. Results for this analysis show the lowest frequency as a function of preload. Thus, as preload is increased, the cable frequencies rise as indicated in the left portion of the figure while frequencies associated with the ring motion become the lowest frequency and eventually drops to zero as indicated in the right portion of the figure. When this frequency becomes zero, buckling occurs. This analysis will be the primary tool used to analyze the 15m Hoop-Column Antenna for comparison with ground test data.

Certification Issues for Large Space Structures

Projects that require that very large structures be assembled or deployed in space present many perturbations to usual engineering development procedures. For example, orbital assembly requires that scenarios and timelines be known with confidence in order to plan for the necessary resources on orbit. Such data at present are almost non-existent. Development of reliable mathematical representations of structural behaviour also becomes much more difficult. The presence of gravity and atmosphere cause much of the ground test data to become suspect or invalid. Thus a thrust of research should be to improve the ability to perform ground tests. This can be done by improving suspension systems, extending the ability to predict gravitational effects, and callibrating ground test data through carefully planned orbital experiments. Several of the options are incorporated into the proposed space station mathematical model development logic. The program begins with more fundamental information being generated early. More focused, complex testing is accomplished later in the program. Options include both full-scale component and subassembly tests, and scale model tests in a comprehensive ground test program. Probably the only fully assembled vehicle data obtained prior to flight will be the model data. Certainly this is the case for evolutionary configurations.

The generic space station model consists of a cylindrical habitation module, two solar arrays, each containing six panels providing a total span of 9m tip-to-tip, and a simulated thermal control panel vertically in the figure. The central joint is specially designed so that various relative orientations of the components can be realized. Slewing of the solar arrays will be accomplished with various torque motors located at the root of each solar array.

Actuators. A major difficulty in the implementation of most of the new technology in active vibration control in the presence of large slewing motions is the absence of specially designed actuators for this application. A mast actuator with internal electronics will produce a force proportional to the negative of the velocity. The sensor electronics and the effector all are contained within the one device. At the right of the figure is a grillage structure on which several of these vibration suppressors will be placed to act simultaneously to demonstrate their effectiveness for closely spaced modes. A typical output of the device is shown at the right of the figure as a time history. These actuators will be used in several laboratory test programs including the space station model just described and the control of flexible structures (COFS) program. Another difficulty in the certification of large structures is confirmation of the joints' structural integrity. In this figure typical test data is shown in the upper right. This data is taken from a static test of a typical structure joint. As shown in the figure the joint is nonlinear and has hysterisis.

This hysterisis is the source of most damping in large structures, but the nonlinearity introduces an unknown which must be accounted for analytically in the structural prediction. Because of the presence of gravity, interactions occur in ground tests and unknown preloads will occur during these tests on the joints which may alter the joint stiffness and thus the overall dynamics of the joint dominated structure. A ground test program to improve the ability to predict structural dynamics of joint dominated structures is now underway. This ground test program is part of the COFS program which has resulted from a NASA-industry assessment of the state-of-the-art for dynamics and control of large space structures. Other work emphasizing control of space structures has been underway in recent years. This work involved ground tests correlated with analysis and emphasized control design which accounts for the suppression of vibration of flexible structures.

The structure from which a mast is deployed is a reusable modified spacelab pallet being developed for use in the NASA Space Technology Experiments Program (STEP). The modifications are being made to provide several options to the experimenter. Experiments will be in the structures, structural dynamics, and controls disciplines. Reusable electronics for experiment control and data recording are part of the STEP pallet, thus effecting a large cost savings to the experimenter.

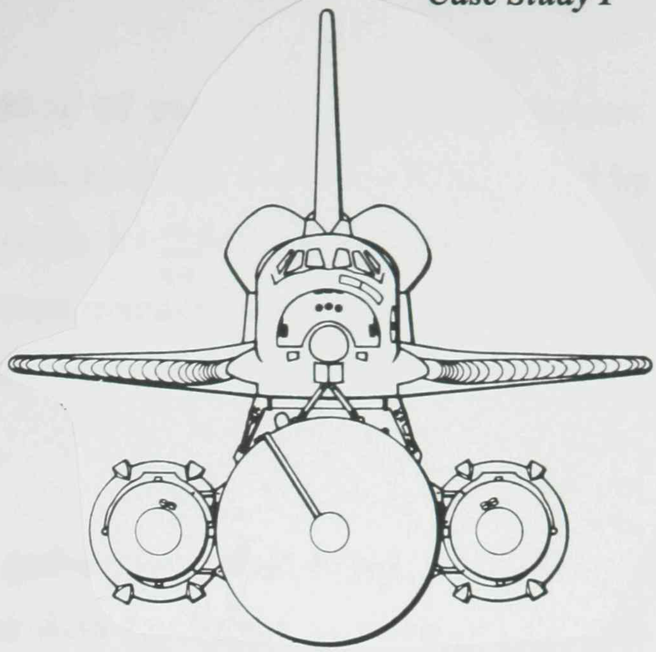
Careful tests and comparison with ground tests and associated analysis will produce a verified capability for the accurate prediction of joint dominated structures. A hoped for result of this program will be a capabilty to predict with some degree of confidence the damping of a joint dominated structure in the orbital environment. The mast used in this first flight will be reflown with increasing emphasis on control technology development. The mast is the first experiment which will be conducted in the STEP program. Contractor proposals for the mast are now being reviewed and the STEP pallet is under development. The NASA Langley Research Center will provide laision between the shuttle project and the experimenter.

Concluding Remarks. In reviewing status and progress in the area of dynamics of large space structures, system identification, analysis of flexible structures, and certification of large space structures have been discussed. A new and promising technique for system identification utilizing free-decay time domain responses of large space structures has been developed and applied to both laboratory models and flight hardware with favorable results. The method is intended not only for applications in ground tests, but will be used in the analysis of flight data both on the OAST-1 Solar Array Flight just completed and in the mast program which is underway.

Facilities and instrumentation are in preparation for a challenging ground vibration test and analysis program on a new antenna concept called the Hoop-Column to be conducted in mid-1985 (this test was a part of the unsuccessful flight of the Space Shuttle Challenger, mission STS-51L). This antenna concept will be analyzed using an analysis which has been developed to the point of readiness for production applications. This analysis utilizes exact member theory, takes advantage of structural repetition, and can be applied in a much more efficient manner than usual finite element procedures. In addition, initial work to develop an advanced deployment and large motion simulation program has been described.

Implementation of vibration suppression techniques in tests has necessitated the development of actuators. One such actuator has been described which was developed in a coordinated NASA-university effort.

A comprehensive program in the area of structural dynamics and control of large space structures, Control of Flexible Structures (COFS) has been initiated which addresses the use of subscale models, subassemblies, and full-scale ground tests in the certification process, and compares results of these ground tests with results from flight tests in the orbital environment. Parallel analysis programs will aid the understanding of the experimental data and a capability to predict joint-dominated structures with confidence will result from this program.



The Space Shuttle
The shuttle has three main units: the orbiter, in which people and cargo travel between Earth and orbit; two solid rocket boosters that, together with the orbiters three main rocket engines, launch the entire system; and external fuel tank which supplies fuel to the orbiter engines. The orbiter returns to Earth like an airplane and can be used up to one hundred times. The boosters parachute into the sea and can also be reused.

Many commercial, scientific, and ecological services are provided by unmanned spacecraft carried into orbit by the orbiter and by experiments conducted onboard the orbiter. Many of these experiments will be accomplished by the use of a Spacelab, a complete scientific laboratory that remains bolted into the orbiter's payload bay. Spacecraft requiring higher orbits than the Shutles maximum altitude of about 1000 kilometers or intended for interplanetary missions are sent on their way by attached upper stage rockets.

Among the many services and benefits anticipated from Shuttle payloads are: timely and frequent global crop surveys that are fundamental to accurate crop forecasts; locating potential petroleum and mineral deposits; alerting officials to air, land, and water pollution; location of potential fish concentrations; aiding ship transport bt pinpointing storms, icebergs, and other hazards and by discovering navigation passages through icefields; providing watershed information to aid in better water resource management; inventorying timber to help maintain renewable forest resources; and providing current pictures of urban areas for land use planning.

Other rewarding activities include: gathering global temperature, cloud, moisture, air pressure, wind and other data for better weather and climate forecast; placing domestic aand international communications satellites into their operational orbits; improving observations of near and far space to gain knowledge about the Earth, Solar System, and Universe; experimenting with the manufacture of new and lower cost pharmaceuticals, crystals for electronics, metal alloys, and other products made possible by the weightlessness of space; and transporting technicians and materials to build vast space structures that may be needed for possible future solar electric power stations or for huge communications satellites.

The frequent availability of inexpensive standard cannisters for small self contained payloads makes it possible for students and individual researchers to have their experiments flown on Space Shuttle missions.

Getting into space requires the complex equipment shown on this wallsheet. The Space Shuttle uses the most advanced aerospace technology available to achieve economical and useful space flight.

Spaceflight, as it now occurs, is characterized by a physiologically restrictive environment. The restrictions are made up of weightlessness, and the extreme isolation encountered by the space traveller.

The first ten years of the space experience have been dedicated to the technical excellence of the spacecraft itself. Very few provisions have been made for the comfort and psychological well being of the space traveller. Perhaps the only reason these missions have been bearable to the astronaut is because of the relative brevity of the missions up to this date. In the future of space travel and manufacture, the environment will have to be very carefully delineated in order to meet the human factor requirements necessary for efficiency in space manufacturing. One very important factor is the relationship of the physical dimension of the human body to the necessary functions it must perform. The single most important factor is the volume requirement per person necessary to make the participants feel comfortable. Presently there are no given generic man/ft^3 requirements. In the past, the astronaut was allocated from 300 to 700 ft^3. However these requirements were based upon rocket booster capabilities, and not on known habitability requirements.

Human space requirements are not absolute. Norms for individual space have increased historically and are known to vary culturally as a function of industrialization and social affluence. A characteristic has been for luxuries to become necessities, and this has been true in the case of normal and minimum standards for individual space.

The general space list found in the appendix of this program is to be used solely as a guide. It should only be used as a reference point to a beginning. The figures are derived from NASA anthropometry standards, but are not tested and in no way apply to the artificial gravity portion of the space station.

Microgravity Sector	*feet* ^{3}	*total*
Crew Support		
Crew Quarters 30		
Study	220	6600
Personal Kitchen	n/a	n/a
Sleeping	68	2040
Entertainment / anthropometric exercises	145	4350
Bath (to be shared by 2 to 4 crewmates)	85	850
	518	15540
Kitchen Galley Area (service for 22 crewmen)		
Food Prep	390	390
Serving Area	360	360
Clean-up	500	500
Dining Area	210	4620
	1460	5870
Teleconferencing Area		
Private Conference		1800
Satellite Conference		1600
Satellite Television Viewing		2300
		5700
Mission Operations		
Research Facility		
Equipment Housing		3500
Human Interface Laboratories		1380
Extravehicular Platforms (feet^2, and do not add to gross req)		7600
Remote Manipulator System		675

Control Room (Canadarm)		
Astronomic Laboratories		2400
Life Science Laboratories		2760

Materials Processing Facilities *

Industrial Work Station (16)	760	12160
Directional Solidification of Silicon (25 units)	300	7500
Electromagnetic Levitators (7 units) Containerless Processing (crystals, indium antimonide)	350	2450
Monodisperse Latex Reactors (4 units)	300	1200
°Packaging and Transport (12% of the net)		1338
°Payload Support (220% of the package & transport)		2944
		<u>27592</u>

°figures taken from Earth-bound material processing standards. These values are close as the difference between the technologies require virtually the same space.

*at present these capabilities do not exist, the research equipment has been modified and the space summaries have been adapted from the gross required area needed for efficient operation of the equipment.

Station Operations

Planning and Scheduling	650
Subsystem Monitoring and Control	600
Pre/Post-EVA Operations	1200
IVA Support of EVA Operations	400
Proximity Operations	400
General Housekeeping	450
ORU Maintenance and Repair	450
Logistics and Resupply (30% of the net)	1245
	<u>5395</u>

Artificial Gravity Sector

Crew Support

Crew Quarters (40)

Study	288	11520
Personal Kitchen	288	11520
Sleeping	512	20480
Entertainment / anthropometric exercises	480	19200
Bath (to be shared by 2 to 4 crewmates)	375	7500
	1943	70220

Commanders Quarters (2)

Study	370	740
Kitchen	400	800
Sleeping	625	1250
Entertainment	630	1260
Bath	540	1080
	2565	5130

Kitchen Galley Area (service for 65 crewmen)

Food Prep	9200	9200
Serving Area	850	850
Clean-up (partially shared with the prep area)	1200	1200
Dining	20150	20150
		31400

Teleconferencing Area

Private Conference	4230
Satellite Conference	5400
Satellite Television Viewing	7385
Public Discussion	6750
	<u>23765</u>

Medical Facility

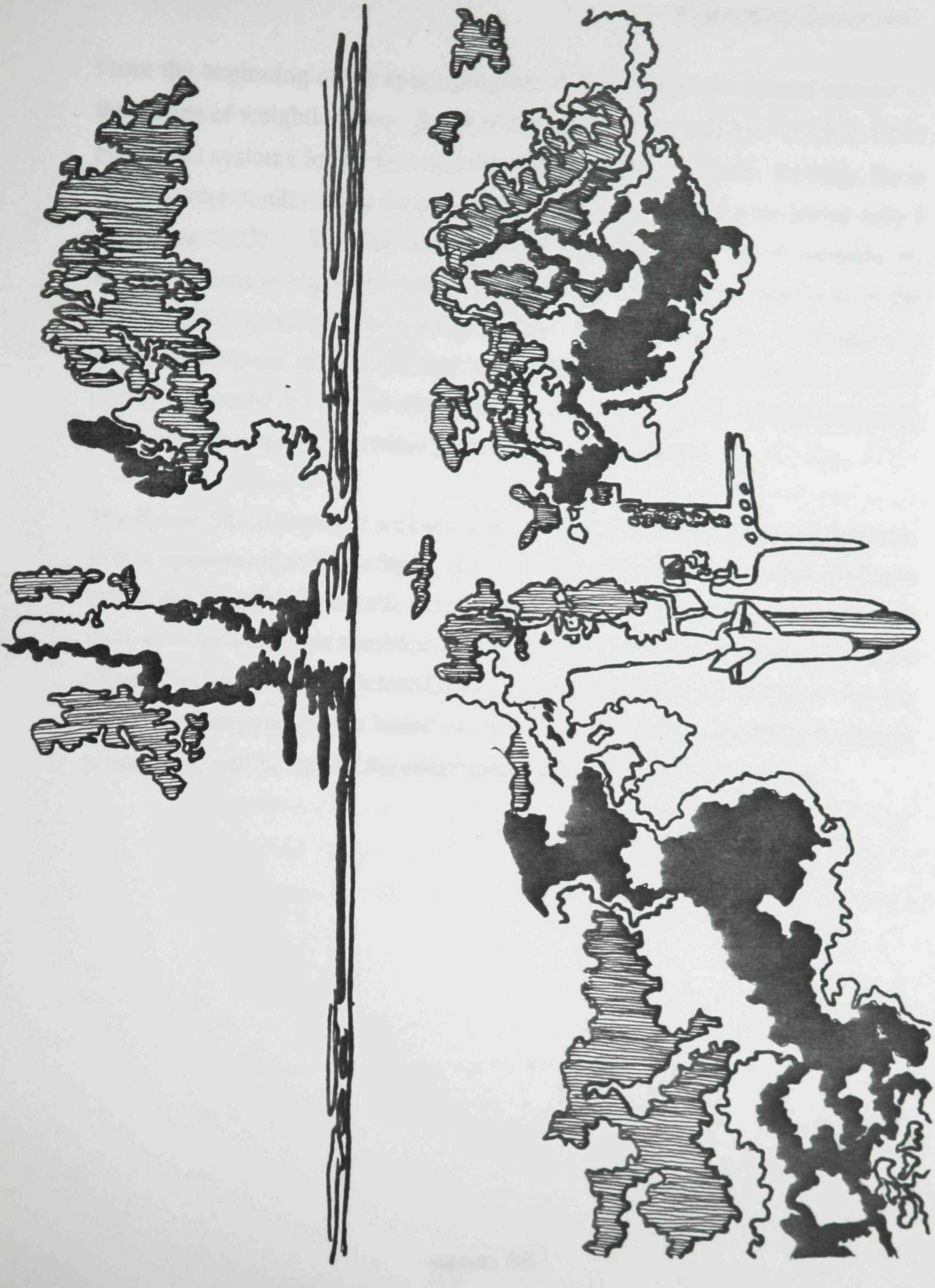
Diagnosis Room	1600
Therapy Room	3280
Pharmacy	1450
Downlink Communication to Earth Medical Facility	1200
Medical Material Referance Room	2250
	<u>9780</u>

Station Operations

Planning and Scheduling	1950
Central Navigation and Control (docking & EVA)	4300
Subsystem Monitoring and Control	1800
Pre/Post-EVA Operations	3600
IVA Support of EVA Operations	1200
Proximity Operations	1200
General Housekeeping	1350
ORU Maintenance and Repair	1350
Logistics and Resupply (30% of the net)	3735
	<u>20485</u>

Totals ==

Crew Support.....................................	*27110*
Mission Operations...............................	*45907*
Station Operations...............................	*5395*
Microgravity ---	*78412*
Crew Support.....................................	*130515*
Mission Operations...............................	*n / a*
Station Operations...............................	*20485*
Artificial Gravity ---	*151000*
Totals--	*229412*



From the beginning of the space program, NASA has had a special interest in the effects of weightlessness. Some of NASA's earliest studies were directed at propellant systems for rockets and structural welding in space. Initially, these studies were conducted in drop towers on Earth. Weightlessness lasted only 5 to 10 seconds. By the mid-1960's, however, the brief periods of weightlessness available in drop towers or on aircraft flights gave way to the longer microgravity experiments of the Apollo program. Microgravity experiments were also conducted on Skylab and the Apollo-Soyuz project, jointly operated by the United States and the U.S.S.R. Most recently, microgravity research has taken place on the space Shuttle.

The Space Shuttle opened a new era in microgravity science and applications. While opportunities for reflight and recovery of test samples were available before the Shuttle, the Shuttle permitted larger and more complex experiments than ever before. This combination of heavier payloads and repeated missions allows NASA to expand scientific and commercial research in space. For the 1980's and beyond, space based microgravity research, especially materials processing, will be one of the centerpieces of the U.S. space program.

Many space modules will have a microgravity environment. The following are general considerations that must be made when designing the overall layout of the space module for microgravity:

a. Access - Microgravity allows greater access to places that would otherwise not be possible in one-g.

b. Restraints - Many of the activities in microgravity require that the individual be restrained or tethered. These restraints or tiedowns are not as "portable" as gravity. Layout of crew stations must consider the extra time for the member to secure himself or herself. Activities which require restraints should be grouped as much as possible within the same reach envelope.

(Refer to Paragraph 8.9, Mobility Aids and Restraints Integration, for additional information on restraints and to Paragraph 3.3.3.3.1, Functional Reach Design Requirements, for information on reach limits.)

c. Pre-Mission Training - Training and simulation done on EArth will be conducted in one-g. The design should be such that the transition from Earth to space environment does not completely negate the effects of this training.

d. Work Flow - Although a space module may be at microgravity, one-g rules apply for arrangement and grouping of activity centers for efficient workflow.

It is often more efficient to design the workspace so that it can be used for a number of different activities. It may be possible to use a volume which is dedicated to a specific activity and which would otherwise be wasted space when that activity is not being performed. Multipurpose utilization of volume can increase the efficiency of the space module. The activities should be compatible with the surrounding area and with each other. Possible limitations for multipurpose, utilization of a volume include:

a. Hygiene and Contamination - One activity may contaminate another, such as body waste management and food preparation.

b. Time - It may take too much time to efficiently convert the volume from one function to another.

c. Privacy Infringement - An activity may infringe on the privacy of a crew member. This is the main objective to having two persons on different workshifts sharing the same quarters.

The space module must support mixed crews with different skills living and working together in space for months at a time. The design goal of a space module should be to provide a facility that, within some understandably necessary size constraints, provides a comfortable and functionally efficient environment. In order to achieve this goal, consideration must be givin to the physical dimensions of the human. The design must accomodate from the smallest in size to the largest of the selected design crew-member population.

Equipment arrangement, grouping, and layout of the space module should enhance crew interaction and facilitate efficient operation. The module layout and arrangement should be based on detailed analysis using recognized human factors engineering techniques. This analysis process should include the following steps:

a. Functional Definition - Definition of the system functions that must occur in the mission.

b. Functional Allocation - Assignment of these functions to equipment, crew members, and crew stations.

c. Definition of Tasks and Operations - Determination of the characteristics of the crew tasks and operations required to perform the functions, including:

1. Frequency.
2. Duration.
3. Sequence.
4. Volume required.
5. Special environmental requirements.
6. Privacy and personal space requirements.

d. Space Module Layout - Using the information determined above, the layout of the space module should:

1. Minimize the transit time between related crew stations.
2. Accomodate the expected levels of activity at each station.
3. Isolate stations when necessary for crew health, safety, and performance, and privacy.

4. Provide a safe, efficient, and comfortable work and living environment.

The following requirements apply to the overall architecture of the space module.

a. Crew Station Size - Each crew station shall be sufficiently large to accomodate the anticipated crew and their activity level.
(Refer to Paragraph 8.6, Envelope Geometry for Crew Functions, for detailed requirements.)

b. Transit Time Minimization - Unproductive crew transit times shall be minimized.
(Refer to Paragraph 8.7, Traffic Flow, for detailed requirements.)

c. Station Accessibility - Appropriate cues shall be provided for the location and identification of crew stations. Translation Paths and crew station entry and exits shall be sized and located to accomodate anticipated traffic patterns and volume.
(Refer to Paragraph 8.5, Location Coding, Paragraph 8.8, Translation Paths, and Paragraph 8.10, Hatches and Doors, for detailed requirements.)

d. Crew Station Location - Stations that perform related functions shall be adjacent to each other, if possible. Activities performed at a station shall be compatible with surrounding activities and facilities (i.e. non-interference in terms of physical, visual, or auditory tasks). Crew stations shall be seperated or isolated if it improves the

overall performance and or safety of the crewmembers.
(Refer to Paragraph 8.3, Crew Station Adjacencies, for detailed requirements.)

e. Microgravity - Appropriate mobility aids, restraints, and orientation cues shall be provided throughout the space module to accomodate living and working when in a microgravity environment.

f. Reconfiguration - The space module shall have design features that minimize expenditure of crew skill and time in the event of space module reconfiguration.

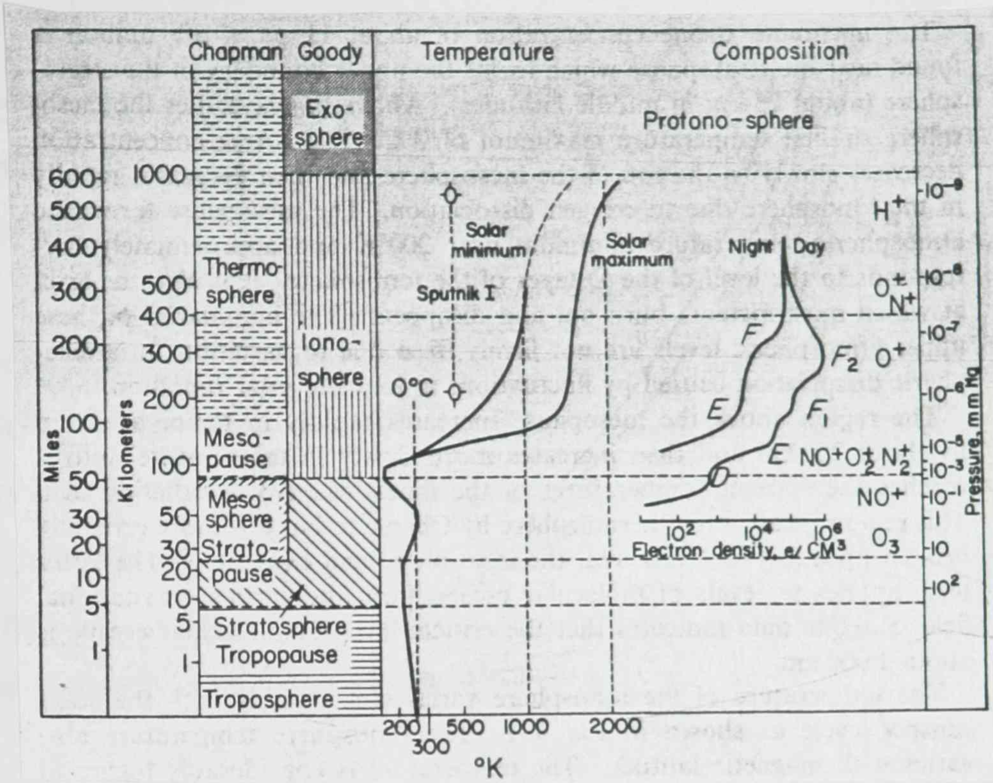
g. Decor and Lighting - The design, decor, and lighting of the space module interior shall be configured to enhance the performance, safety, and comfort of the crewmembers.

h. Dedicated vs. Multipurpose - Space Utilization Design Requirements. The interior accommodations shall be designed so that multipurpose utilization of the space meets the following requirements:

1. Compatibility of the Activities Within Crew Stations - Activities that occur within the same station shall not interfere with each other. It is best if the different activities occur at different times.

2. Compatibility With Surrounding Activities and Facilities - Each of the activities performed at a station shall be compatible with surrounding activities and facilities.

Environment can be defined as the summation of the physical and chemical forces acting on materials which are exposed within the boundaries under consideration. This section considers the environment extending from the Earth's upper atmosphere throughout interplanetary space. (see Figure 25)



The lower atmosphere or troposphere has beeen quite well characterized for many years. The chemistry of this layer is relatively constant but pressure and temperature decline with increasing altititude. The moisture variation in the troposphere coupled with convection forces and winds cause our familiar weather phenomena.

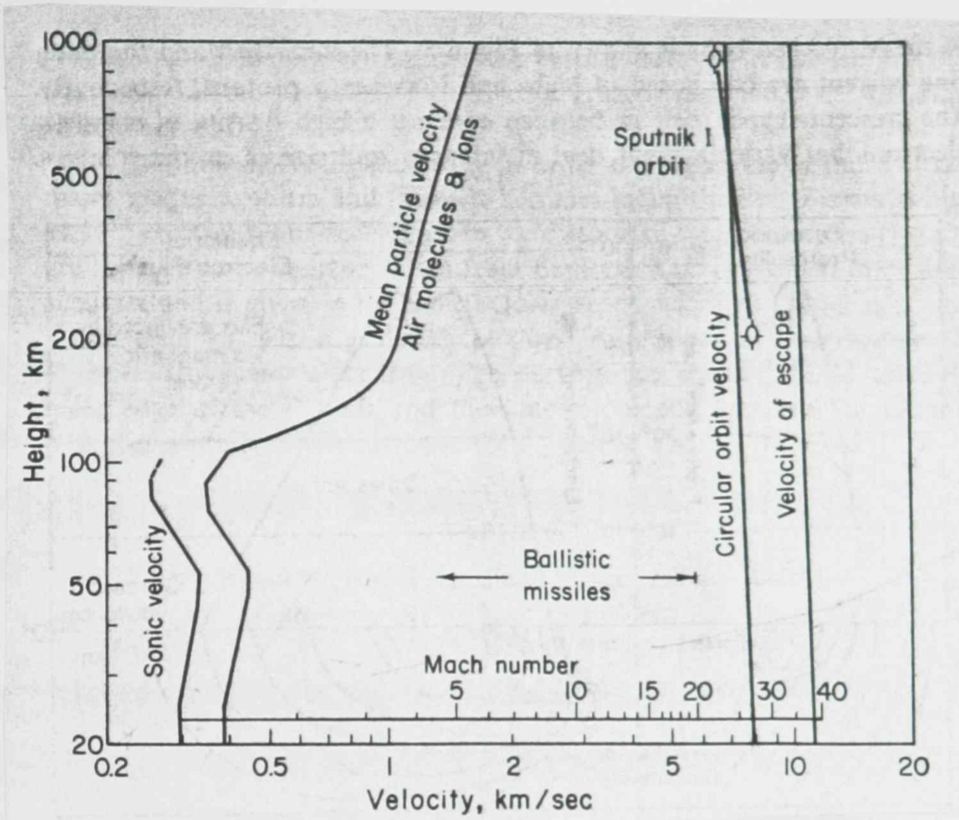
The next atmospheric layer is the stratosphere or region of constant temperature of about -56°C. This is the altitude at which there is significant increase in solar ultraviolet light and an accompanying increase in ozone concentration.

The maximum ozone concentration of about 11 parts per million is found near the stratopause which forms the upper boundary of the stratosphere (about 25 km in middle latitudes). Above this layer lies the mesosphere or first temperature maximum of 0°C. The mesopause forms the atmospheric temperature minimum near -73°C and approximately corresponds to lower layer of the ionosphere. It is also the layer where most meteors burn out and disappear.

The next layer is the thermosphere. Temperatures increase rapidly in this layer until they begin to taper off in the inner layers off the ionosphere and the exosphere.

The space station will be sited approximately 225 miles above sea level. At this level, or altitude, all traces of the Earths' atmosphere are indistinguishable. Meteor activity is at a minimum. Temperatures are determined only by the reflectance coefficient of the material exposed to the exterior. All oxygen and nitrogen have been long since ionized.

The velocity necessary to maintain a circular orbit is 15,120 miles per hour (mach 27). Artificial gravity is determined by the diameter of the spacecraft. Therefore the angular momentum and centripetal acceleration will be computed at the documentation phase of the thesis process. (see Figure 26)



This section discusses the orientation of crew stations (workstations, crew activity centers, etc.) within the space module. The information in this section applies to a microgravity environment where there is no gravity to define a single orientation.

In a 1-G or partial gravity environment, orientation is not a particular problem. "Down" is the direction in which gravity acts and the human is normally required to work with feet down and head up. In a microgravity environment, the human working position is arbitrary. There is no gravity cue that defines up or down. In microgravity, orientation is defined primarily through visual cues which are under the control of the system designer. The orientation within a particular crew station is refered to as a *local vertical*. There are several orientation factors to be considered when designing a microgravity environment.

a. Work Surfaces - Microgravity expands the number of possible work surfaces (walls, ceilings, as well as floors) within a given volume. This could result in a number of different "local verticals" within a module.

b. Training and Testing - Some of the working arrangements that are possible in microgravity will not easily be duplicated on Earth. Pre-mission training and testing will suffer with these arrangements. Additional training might have to be conducted during the actual mission. This could drastically reduce the effectiveness of a short duration mission.

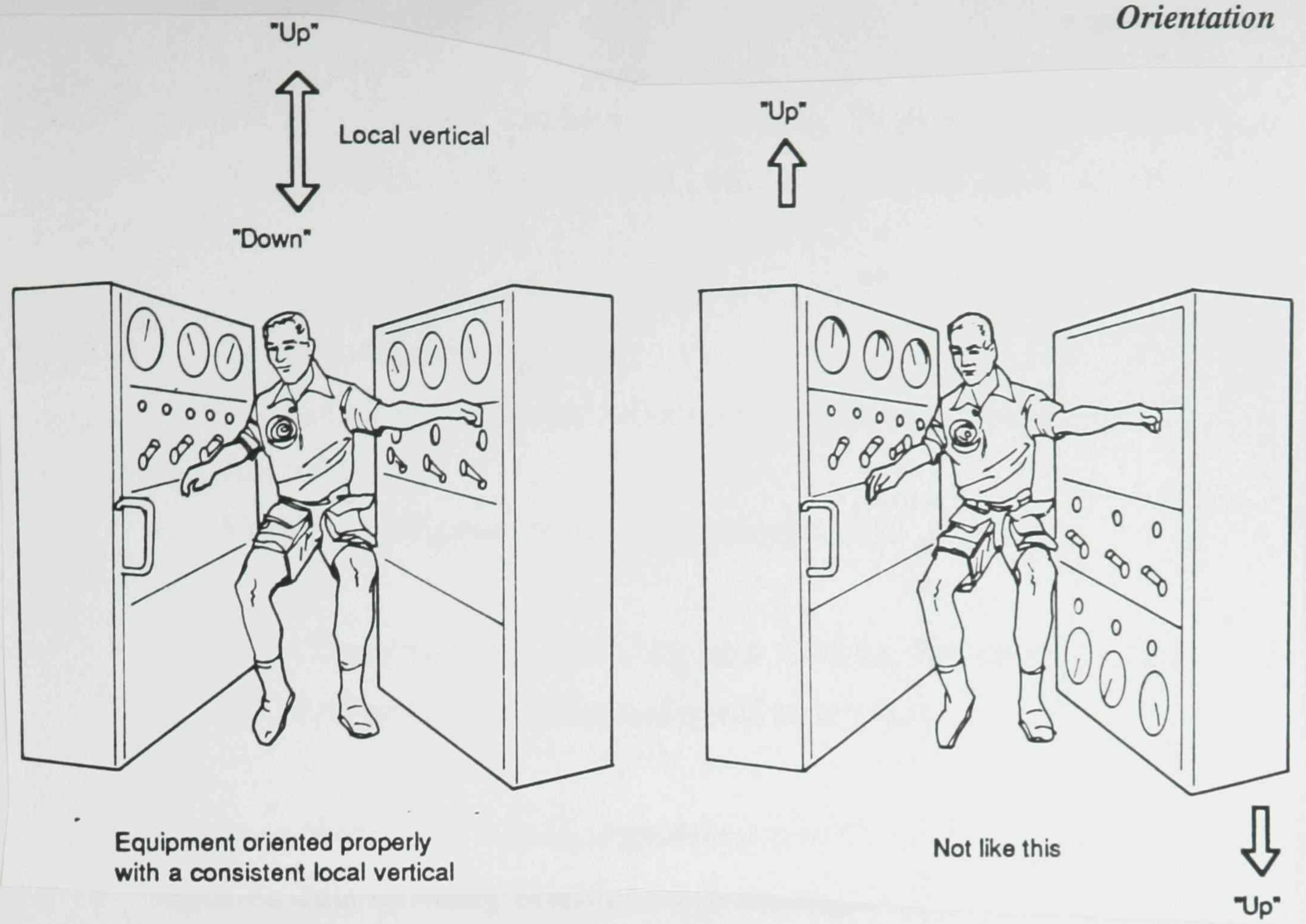
c. Disorientation - Humans, raised in a 1-G environment, are accustomed to forming a mental image of their environment with a consistent orientation. People locate themselves and obvjects according to this mental image. If the person is viewing the environment in an unusual orientation, this mental image is not supported. This can promote disorientation, space sickness, temporary loss of direction, and overall decreased performance.

d. Visual Orientation Cues - Visual cues are needed to help the crewmember quickly adjust his or her orientation for a more familiar view of the world. These visual cues should define some sort of horizontal or vertical reference plane (such as the edges of a CRT or window). Of the two, it appears that the horizontal cue is being conducted by Nasa to determine additional guidelines for the design of visual orientation cues.

e. Equipment Operation - Due to prior training and physical characteristics of the human, some pieces of equipment are more efficiently operated in one specific orientation. Labeling must also be properly oriented to be readable. Direction of motion stereotypes exist for most controls. For instance, in the U.S. power is turned on when a switch is positioned "up" or toward the head. If equipment items, labels, and controls have different orientations within the same crew station, human errors are likely to occur.

The following are design requirements for establishing an orientation within a space module:

a. Consistent Verticle Orientation - Each crew station shall have a local verticle so that the verticle orientation within a specific work station or activity center shall remain consistent. (see Figure 45 for illustration).



b. Visual Orientation Cue - A visual cue shall be provided to allow the crewmember to quickly adjust to the orientation of the activity center or workstation.

c. Seperation - When adjacent workstations or activity centers have verticle orientations differing by 90° or more, then clearly definable demarkations shall separate the two areas.

This section discusses the standards for defining locations on or within a space module. The location coding system shall apply to all crew interface areas including:

a. Control and display panels.
b. Stowage areas, lockers, subcompartments, and containers.
c. Access panels.
d. Systems, components, and equipment.

(Refer to Paragraph 9.5, Labeling and Coding, for specific labeling and coding design requirements and considerations.)

(Refer to Paragraph 8.4, Compartment and Crew Station Orientation, for requirements defining orientation in microgravity.)

Color	Vehicle location	Luminous intensity * candella (candlepower)	Chromaticity (CIE chromaticity diagram coordinates)
Aviation red	Port (left) side	2.5 (0.2)	Y = not greater than 0.330 X = not less than 0.650
Avitation green	Starboard (right) side	6.3 (0.5)	Y = not less than 0.390 X = not greater than 0.270
Aviation yellow	Bottom	2.5 (0.2)	Y = not less than 0.380 X = not greater than 0.630
Aviation white	Aft (preferred)	2.5 (0.2)	Y = 0.300 to 0.400 X = 0.300 to 0.400
Aviation blue	Aft (not preferred)	6.3 (0.5)	Y = not greater than 0.200 X = not greater than 0.245
Dual aviation white/ aviation yellow	Forward	See above	See above

The following analytical process can help to optimize traffic flow and crew functioning:

a. Analyze Functions and Tasks - Determine the type and level of activity that occur at each of the crew stations and the required movement of crew and equipment between the stations.

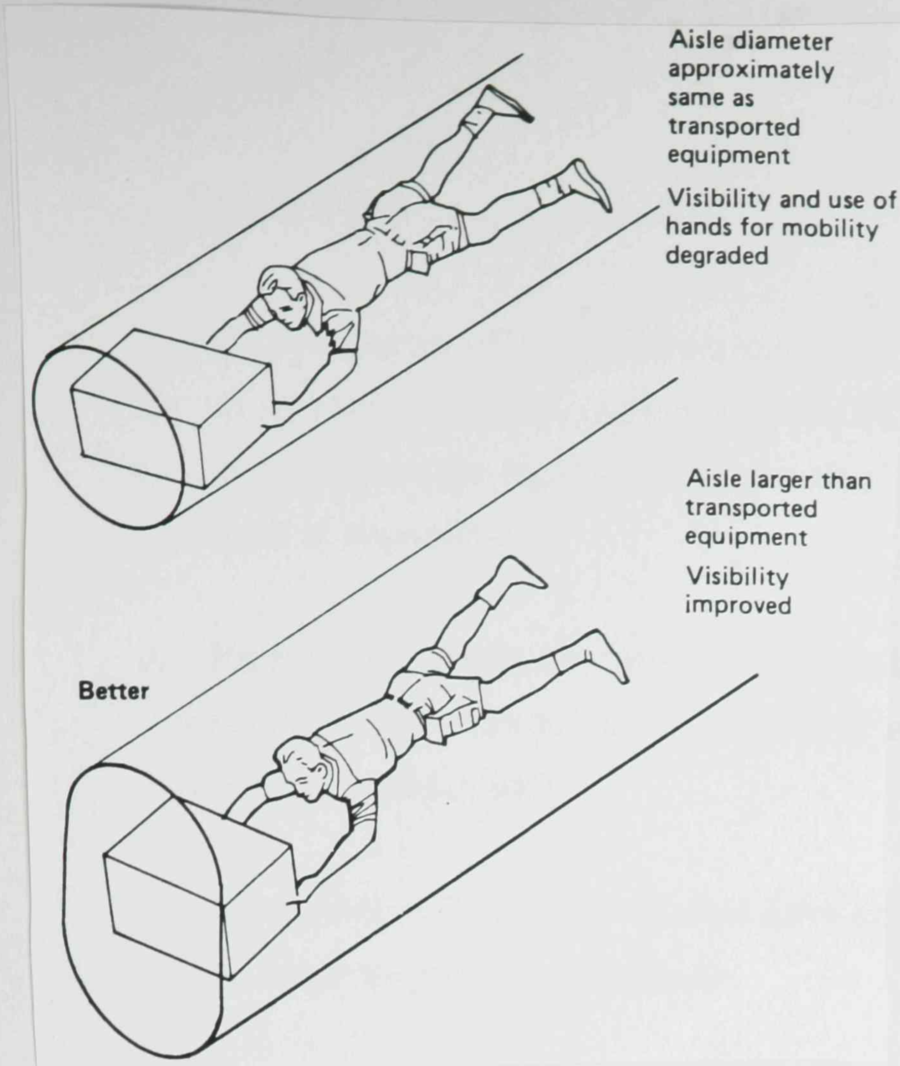
b. Locate Crew Stations - Locate crew stations to minimize the traffic flow.

c. Design Translation Paths - Once the crew stations are located, design the translation paths for efficient traffic flow. First, design the paths to accomodate the traffic flow requirements of the worst case conditions. Then, complete the design to meet other traffic flow requirements.

1. Define traffic flow details: number of persons, number of transits, type of packages, speed of transit, type of activity surrounding the path, etc.

2. Use the information above and Figure 46 to determine the required translation path.

3. Accomodate possible congestion at intersections through scheduling, increase of path size, provision for visibility of crossing traffic, etc.



The following factors must be considered in designing for equipment and package transfer in microgravity conditions:

a. Task Constraints - The planning of equipment transfer traffic routes must take into account task constraints such as time, safety requirements, required positioning accuracy, other trafic, and gravity conditions.

b. Translation Path and Equipment Size - A translation path approximately the size of the equipment being transported will degrade visibility and use of hands and feet for translation mobility and stability (see Figure 47)

The design for traffic flow shall take into account the possibility of a space module or subsystem failure or damage that could require evacuation.

Specifically, the following requirements apply:

a. Escape Routes - Crewmembers shall be provided with escape routes for egress and/or isolation in the event of a hazardous condition. Where practical, dual escape routes shall be provided to serve in the event that one route is impassable.

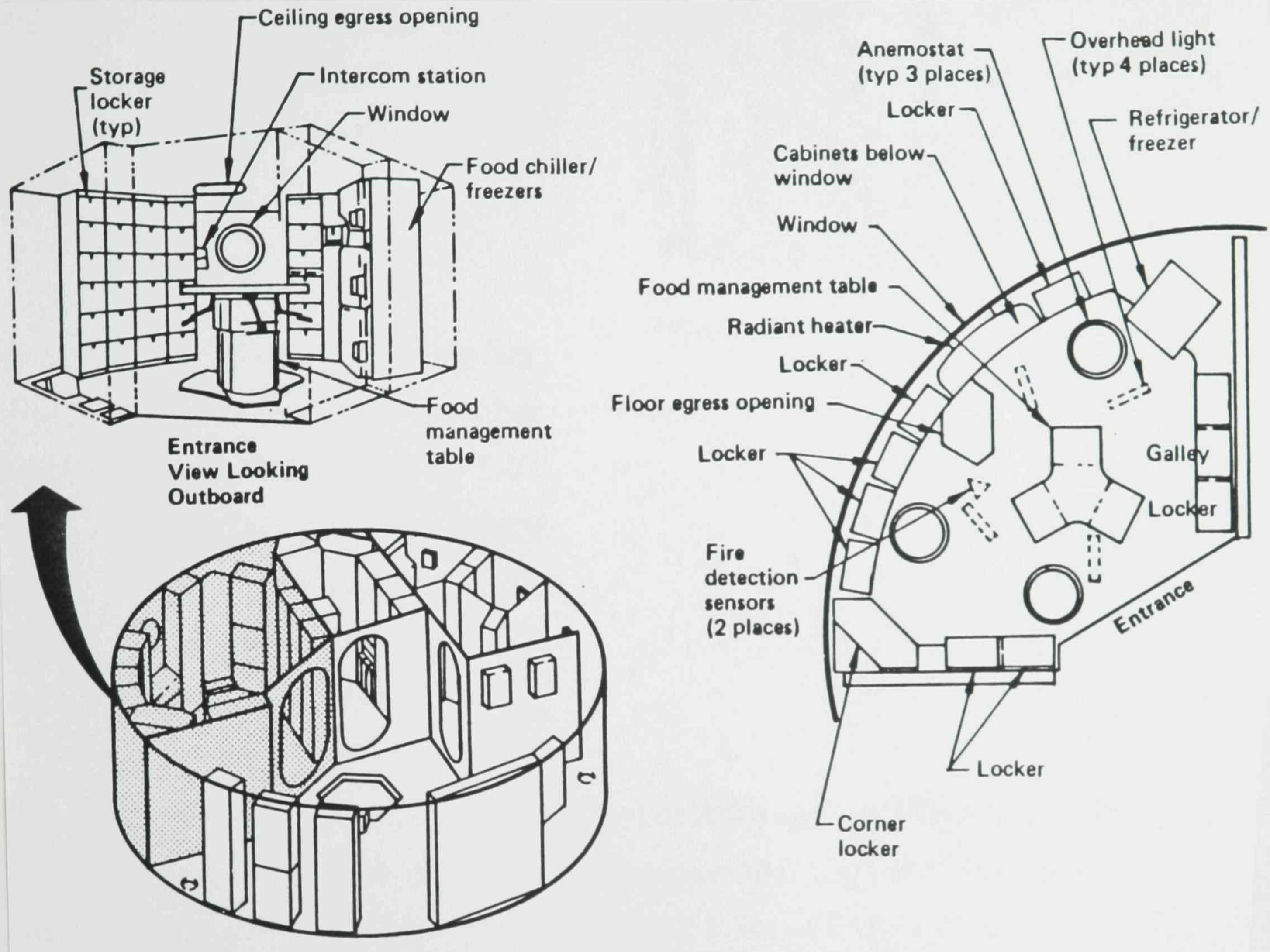
b. Protection of Entry/Exit Path - Provisions shall be made to protect compartment entry/exit paths in the event of an accident (fire, explosion, abrupt accelerations, etc).

c. Crew Station Size - Crew Station openings and egress paths shall be large enough to permit rapid egress.

d. Emergency Regulation and Route - Emergency traffic regulations and appropriately marked emergency routes shall be established for safe and efficient movement of personnel and equipment.

e. Emergency Rescue and Return Route - An emergency rescue and return route shall be available for all planned IVA activity areas. The route shall be capable of accomodating an EVA suited individual.

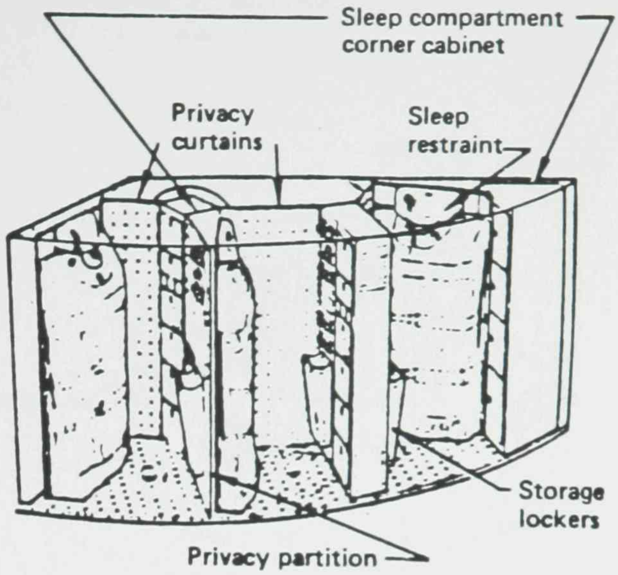
The Skylab Food Management Compartment for a crew of three was combined with a wardroom (see Figure 8.6.4.1-1). The area measured 2.29 meters (7.5 feet) long by 2.44 meters (8 feet) wide by 1.98 meters (6.5 feet) high. Total combined habitable volume was 11.1 cubic meters (391 cubic feet).This compartment was used by three crewmembers for a mission of 84 days.



Reference: 130, Figure 7, page 11

Figure 8.6.4.1-1. Skylab Food Management Compartment

Access to the dining position for the crewman next to the freezer was judged not adequate when the other positions were occupied. The crewman in the inboard dining position could not reach the food storage area without disturbing the other diners.

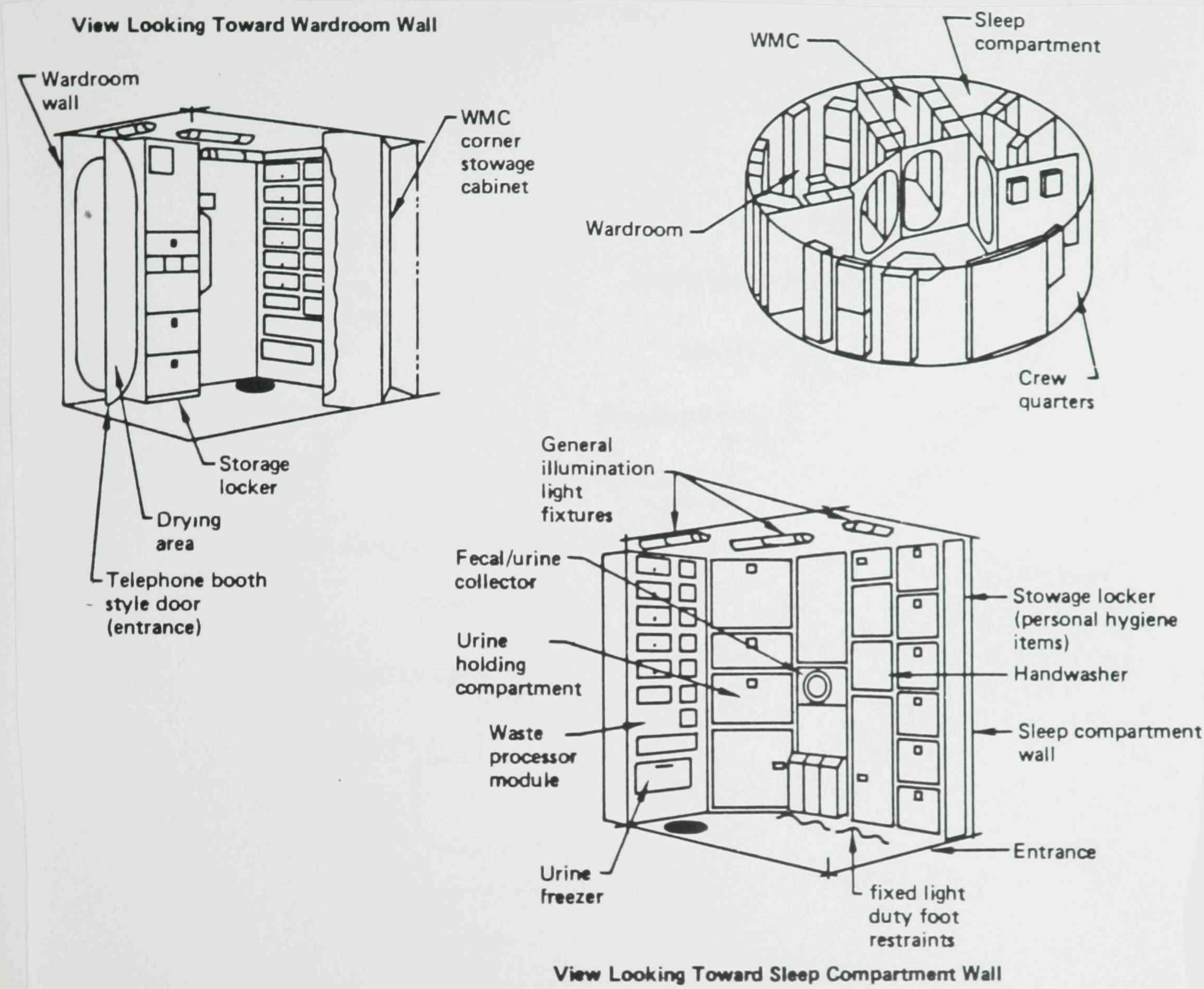


Reference: 155, page 3-4

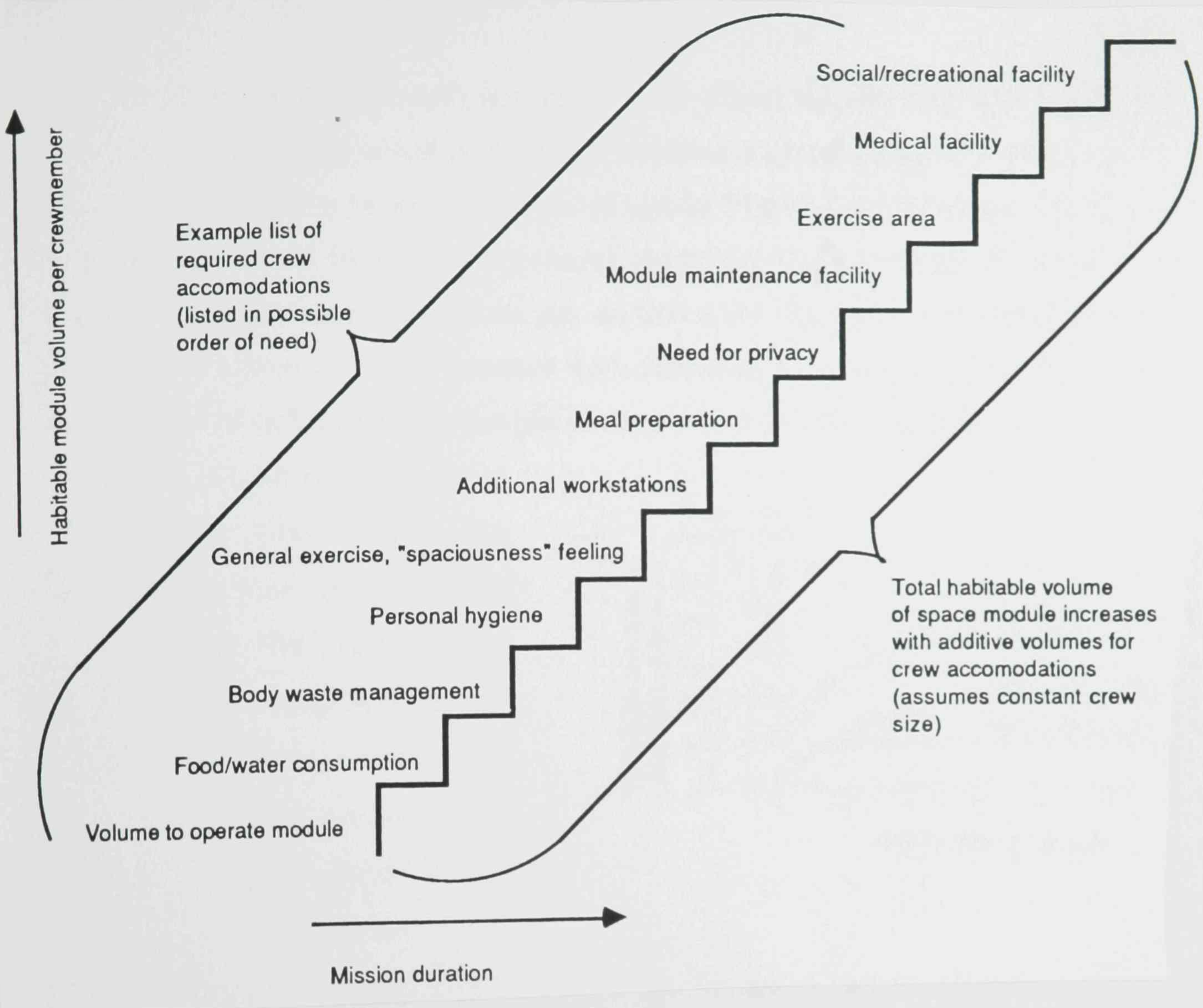
The Skylab sleep compartment (Figure 37) for one crew member was 0.92 meters (3 feet) long by 1.07 meters (3.5 feet) wide by 1.98 meters (6.5 feet) high. The total habitable volume was approximately 1.92 cubic meters (68 cubic feet).

The volume of this sleep compartment was satisfactory for a mission of 85 days. The Skylab combined both the waste management and hygiene functions in a single compartment (see Figure 38). The dimensions were 1.98 meters (6.5 feet) long by 0.92 meters (3.0 feet) wide by 1.98 meters (6.5 feet) high. The total combined free volume was 3.57 cubic meters (126 cubic feet). The total habitable volume utilized by the hygiene function was approximately 2.42 cubic meters (85 cubic feet). The total habitable volume utilized by the waste management function was approximately 2.42 cubic meters (85 cubic feet).

This compartment was satisfactory for three crewmembers for 85 days, but interference between crewmen doing both functions simultaneously led to their suggesting separate compartments.

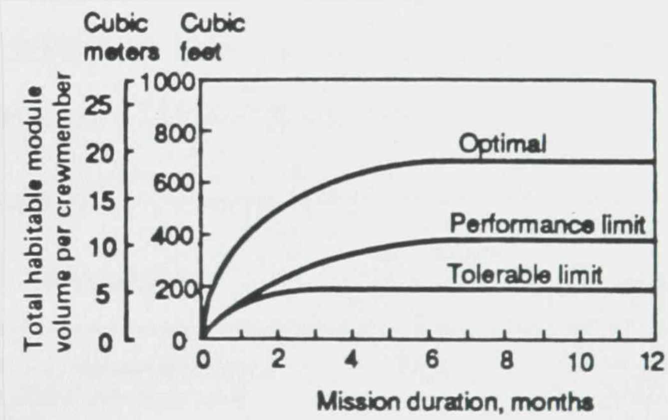


This section provides information for sizing the space module for human work and habitation. Physical *body envelopes* for various crew functions are given. The information in this section can be used to develop a preliminary overall layout of the space module.



(Refer to Section 9.0, Workstations, and Section 10.0, Activity Centers, for detailed design requirements and consideration for specific crew stations).
(Refer to Section 3.0, Anthropometrics and Biomechanics, for additional information on human size and work envelope.)

The duration of the mission has an overall effect on the required envelope geometry. Increasing mission duration requires a greater physical envelope to accomodate mission tasks and personal needs. Figure 40 illustrates this. Crew accomodations are listed in the general order that their need might occur in a mission. These accommodations are additive, so the total required habitable volume per crewmember increases with duration. Guidelines for determining the amount of habitable volume per crewmember for varying misssion durations are shown in Figure 41. As the mission duration increases, there is a greater tendency for the crew to feel confined and cramped. This can effect psychological health and crewmember performance. The judged physical space is not necessarily relative to the physical size of the room. The feeling of spaciousness can be achieved visually through the arrangement, color, and design of the walls and partitions of the space module. Some of the facts that are known about visual spaciousness are listed below:



a. Distance from Viewer - Errors of overestimation of space increase as the distance from the viewer increases. This indicates desirability of long view axes.

b. Room Shape - Irregular shaped rooms are percieved to have more volume than compact or regular shaped rooms of equal volume.

c. Viewing along a surface - Distances judged along surfaces are overestimated with respect to those judged through empty space. If an observer looks along a wall, the boundary wall would be judged as further away than if it is seen from the same physical distance across the empty space of the room.

d. Lighting and Color - The effects of brightness, color saturation, and illumination levels on perception of volume are listed in Figure 8.6.2.2-1. (Refer to Paragraph 8.12.2, Interior Design and Decor Design Considerations, for details of the effects of lighting and color.)

Volume perception (roominess)	Brightness*	Color saturation	Illumination level	Color
Enlarge	Areas will be enlarged by lightness. (Use to alleviate feelings of oppression or "closed-in".)	Pale or desaturated colors "recede" and open up a room	High	Cool colors (green, violet, blue, lilac, aqua)
Close-in	Areas will be closed-in by darkness.	Dark or saturated hues "protrude", and close-in a room	Low	Warm colors (red, yellow, brown, pink, ivory,cream, peach)

e. Clutter - Clutter, or items that visually detract from long view axes, decrease the perceived room volume.

f. Windows - Windows allow the crewmember to focus on objects (such as Earth) outside the space module. This can significantly increase the sense of spaciousness and psychological well being of the crewmember. (Refer to Paragraph 8.11, Windows Integration, for additional information on the use of windows in architecture.)

Some of the social factors that should be considered in the layout of the interior volume of the space module are discussed below:

a. Privacy - Visual privacy is a major concern for some activities such as body waste management and personal hygiene. Volumes devoted to these functions must be visually isolated. In addition, it has been found that a general sense of privacy increases when visual exposure of the individual decreases and the individual has controllable visual access to the outside world. In other words, the individual feels private if he or she has the ability of observing without being observed. This should be considered when designing individual crew quarters.

b. Leadership Role - The size of and role of a crewmember's private quarters can impart a sense of status to other crewmembers. If desirable for organizational purposes, this fact can be used in configuring the space module.

c. *Proximics* - Proximics is the study of space as a communication medium. Some of the factors to consider are:

1. When conversational or recreational space is necessary, the space

should be configured so that the crewmembers can be at distances of 0.5 to 1.2 meters (1.5 to 4.0 feet) and at angles of 90 to 180 degrees from each other. In general, 90 degrees is preferred for casual conversation while180 degrees is preferred for competitive games or negotiations.

2. Equal relative heights among social conversants should be maintained through spatial configuration and placement of restraints.

3. In a socially communicating group it should be possible for all to position themselves in relatively similiar body orientation and limb location. Maintaining the same verticle orientation is desirable.

Design of any system or facility should be based on the logical sequence and smooth flow of activities that are to occur in the facility. Generally, the most effecient layout is to place crew stations adjacent to each other when they are used sequentially or in close coordination. There are some limitations to these general rules, however. Adjacent positions should not degrade any of the activities in the surrounding stations. General adjacency considerations, beyond simple active flow, are listed and discussed below.

a. Physical Interference - Some crew stations require a high volume of entering and exiting traffic (both personnel and equipment). Placement of these stations adjacent to each other could result in traffic congestion and loss of efficiency.

b. Noise - Activities such as communications, sleeping and rest, and mental concentration are adversely affected by noise. Activity centers generating significant noise levels should not be placed adjacent to those activity centers adversely affected by noise.

(Refer to Paragraph 5.4, Acoustics, for Specific noise tolerance levels for various activities.)

c. Lighting - Ambient illumination from one activity center may either interfere with or benefit the activity of a different center. Activities that require illumination will benefit from the "spillover" ambient illumination. Activities adversely effected by light could be:

1. Certain experiments or lab activities such as photographic development.

2. Sleeping.
3. Use of some optical equipment (such as windows) and self illumination displays (such as CRT).

(Refer to Paragraph 8.13, Lighting, for further information on lighting.)

d. Privacy - There are cultural and individual requirements that should be considered. Certain personal activities such as sleeping , personal hygiene, waste management, and personnel interactions require some degree of privacy. These private areas should not be placed in passageways or highly congested activity centers.

e. Security - Many of the experiments and production processes will be confidential to a specific industry or organization. These activity centers may require visual, audio, or electrical isolation from the rest of the space module.

f. Vibration - Certain personal activities such as relaxation or sleep, will be disturbed by vibrations and jolts. In addition, many production, experimental, and control functions will require a stable and vibration free platform. Crew stations of these types should be isolated from sources of vibration.

(Refer to Paragraph 5.5, Vibrations, for vibration exposure limits.)

Specific Adjacency Design Considerations

Analysis have been performed on typical space module crew functions to determine adjacency considerations for specific crew stations and functions. The functions considered in the analysis are listed in Figure 33. The following criteria were used to evaluate adjacency of the functions. Each of these criteria were given equal weighting:

Crew support
- Meal preparation
- Eating
- Meal clean-up
- Exercise
- Medical care
- Full-body cleansing
- Hand/face cleansing
- Personal hygiene
- Urination/defecation
- Training
- Sleep
- Private recreation and leisure
- Small-group recreation and leisure
- Dressing/undressing
- Clothing maintenance

Station operations
- Meetings and teleconferences
- Planning and scheduling
- Subsystem monitoring and control
- Pre/post-EVA operations
- IVA support of EVA operations
- Proximity operations
- General housekeeping
- ORU maintenance and repair
- Logistics and resupply

Mission operations
- Payload support
- Life sciences experiments
- Materials processing experiments

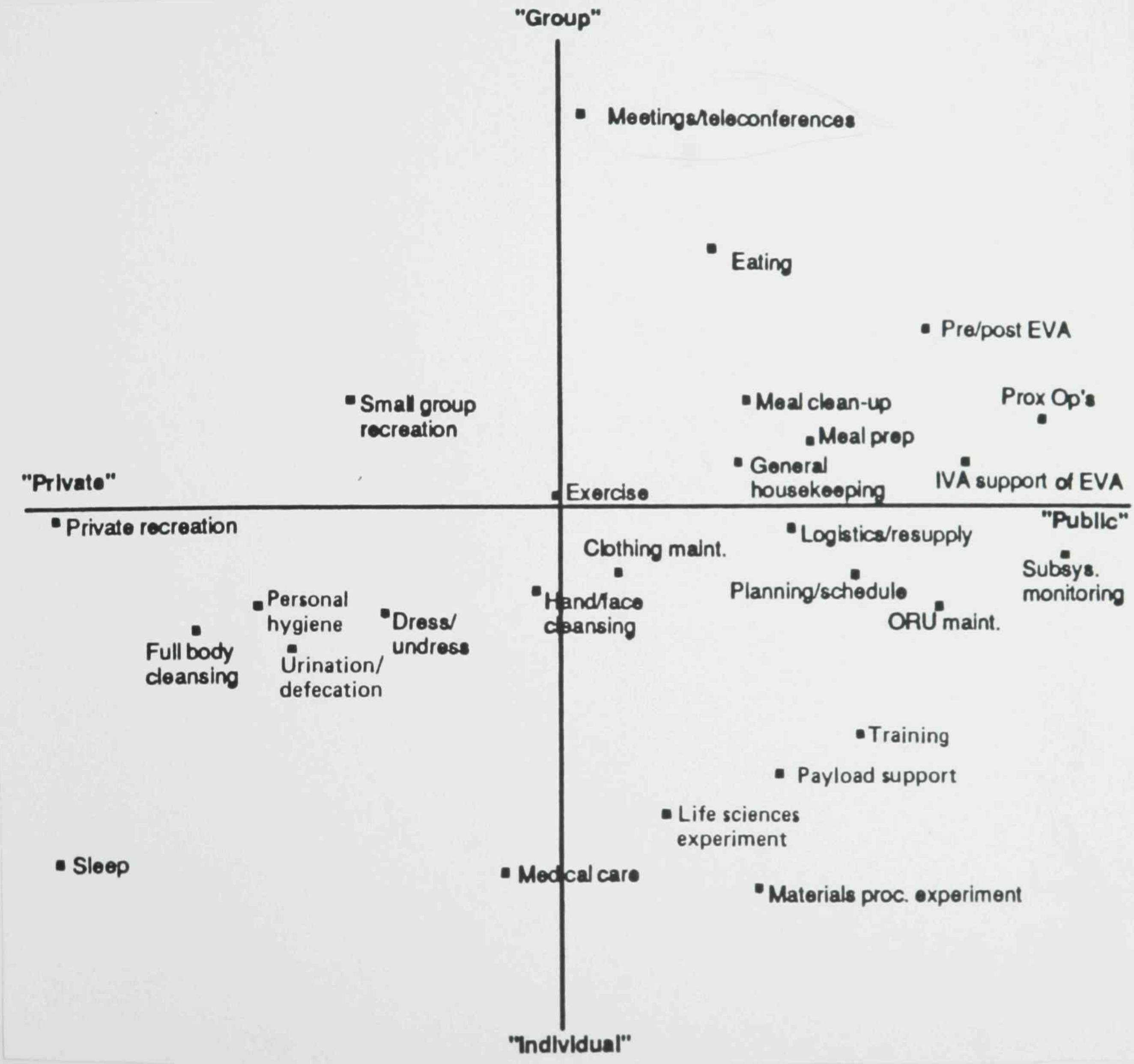
a. Transition Frequency - The frequency with which crewmembers switch from performing one function to another.

b. Sequential Dependency - The extent to which one function provides the reason, or need, to perform another function.

c. Support Equipment Commonality - The percentage of support equipment shared by the functions.

d. Noise Output and Sensitivity - The potential for noise generated by crew activities and support equipment associated with one function to interfere with the performance of another function.

e. Privacy Requirements - The similarity of the privacy requirements (both audio and visual).



The results of the study are shown in Figure 34. Crew functions are plotted in the chart. The chart describes the functions on two scales: Public Functions/Private Functions and Group Functions/Individual Functions. The relative position of the functions on the chart indicate the relative compatibility of these functions. Consider grouping stations which support the functions that are close together on the chart. Consider seperating stations which support the functions that are seperated on the chart.

This section on workstation layout covers the following areas: general workstation design factors, control /display placement and integration, human/workstation configuration, and specialized work station requirements.

Design considerations for generic workstations are presented below.

a. Interchangeable Components - Workstations should be designed to incorporate interchangeable components and common interfaces to the greatest extent practical.

b. Reconfigurable workstations - Workstations should be capable of being reconfigured to accomodate as wide a variety of uses as practical.

Workstation illumination requirements shall consist of the following:

a. Illumination - Workstation illumination shall be determined by tthe tasks to be accomplished. Illumination requirements are given in Figure 35.

Design requirements pertaining to workstation congestion and distractions are presented below.

a. Traffic - Workstations shall be located so as to minimize interference with and from traffic areas.

b. Distractions - Workstations shall be designed such that all external distracting stimuli to the operater are minimized.

Workstation color selection requirements are specified below.

a. Color Selection - Neutral colors shall be used in workstations.

b. Reflections - Workstation surface colors shall be lusterless.

Illumination levels

Work area or type of task	LUX* (ft-C) Minimum
Assembly, general	
Course	325 (30)
Medium	540 (50)
Fine	810 (75)
Precise	1075 (100)
Bench work	
Rough	325 (30)
Medium	540 (50)
Fine	810 (75)
Extra fine	1075 (100)
Business machine operation (calculator, digital, input, etc)	325 (30)
Console surface	215 (20)
Circuit diagram	325 (30)
Dials	215 (20)
Panels	
Front	215 (20)
Rear	110 (10)

Work area or type of task	LUX* (ft-C) Minimum
Inspection tasks, general	
Rough	325 (30)
Medium	540 (50)
Fine	810 (75)
Extra fine	1075 (100)
Meters	110 (10)
Office work, general	325 (30)
Ordinary seeing tasks	215 (20)
Reading	
Large print	110 (10)
Newsprint	325 (30)
Handwritten reports in pencil	325 (30)
Small type	325 (30)
Prolonged reading	540 (50)
Repair work	
General	325 (30)
Instrument	810 (75)

Design requirements pertaining to workstation congestion and distractions are presented below.

a. Traffic - Workstations shall be located so as to minimize interference with and from traffic areas.

b. Distractions - Workstations shall be designed such that all external distracting stimuli to the operater are minimized.

Workstation color selection requirements are specified below.

a. Color Selection - Neutral colors shall be used in workstations.

b. Reflections - Workstation surface colors shall be lusterless.

c. Controls:

1. Controls shall be black or grey unless special functions dictate otherwise (e.g., emergency evacuation controls are striped black and yellow).
2. Toggle switch handles shall have a satin metallic finish.
3. Control colors shall provide good contrast between controls and background.

d. Panel Color Finish - The panel color shall provide good contrast between the labels and the background. Label/background colors shall be consistent within a functional area.

e. Consoles and Pedestals - The color of structural members of control consoles and pedestals and overhead mountings for control units shall be consistent with surrounding areas.

f. Meter Bezels - The meter bezels shall be the same color specified for the particular panel on which the meter will be used.

The following are general considerations for the design of the interior decor:

a. Simplicity - Interior design should be simple, i.e., too many colors, complicated visual patterns, large areas of extremely saturated colors or too many fabric variations may result in visual or sensual oversaturation. Such treatment becomes an annoyance to most observers, especially over long periods of exposure.

b. Variety - Extreme simplicity can be carried too far. Drab, singular color or completely neutral color schemes and smooth, untextured surfaces are monotonous and lead to boredom and eventual irritation with the bland quality of the visual environment.

c. Personalization - The ability of a crewmember to personalize certain portions of her or his environment is often a morale booster. This option should be limited to an individual's personal quarters. A simple feature could be a simple bulletin board on which the crewmember could display memorabilia.

d. Maintenance of Decor - Use of a wide variety of colors, textures, materials, and accessories can exaggerate housekeeping, repair, and replacement problems.(refer to Figure 48 for possible color schemes)

	Only use these colors in small amounts or as trim in areas indicated with dot																										Use in any amounts in areas indicated with dot															
Space module areas	Pale pink	Reddish pink	Red	Red orange	Maroon	Orange	Apricot	Yellow orange	Chamois	Yellow	Yellow green	Green	Blue green	Blue	Violet	Royal blue	Purple	Magenta	Reddish brown	Buff	Burnt sienna	Brown	Olive drab	Gray	Dark gray	Black	Champagne	Cinnamon	Beige	Salmon	Peach	Straw	Ivory	Cream	Maise	Pale yellow	Pale green	Pale blue	Lavender	White	Off white	Light gray
Living areas																																										
• Rest area/crew quarters	●					●	●	●	●	●	●	●	●	●	●	●			●	●	●	●					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
• Recreation	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
• Lounge	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
• Personal hygiene, shower	●	●		●		●	●	●	●	●	●	●	●	●		●				●		●					●	●	●	●	●	●	●	●	●	●	●	●		●	●	●
• Passageways						●	●	●	●	●	●	●	●	●		●			●	●	●	●		●	●		●	●	●	●	●	●	●	●	●	●	●	●		●	●	
Work areas																																										
• General workstations							●	●	●	●	●	●	●	●		●			●	●	●	●		●			●	●	●			●	●	●	●	●	●	●		●	●	●
• Data processing						●	●	●	●	●	●	●	●	●		●			●	●	●	●		●	●		●	●	●	●	●	●	●	●	●	●	●	●		●	●	●
• Communications						●	●	●	●		●	●	●	●		●			●	●	●	●		●	●		●	●	●	●	●	●	●	●	●	●	●	●		●	●	●
• Maintenance													●	●		●				●								●	●			●	●	●	●	●		●		●	●	●
• Mechanical equipment/													●	●		●			●	●	●	●		●				●	●			●	●	●	●	●		●		●	●	●
power generation																																										
• Security									●	●	●	●	●	●		●			●	●	●	●		●				●	●	●	●	●	●	●	●	●	●	●		●	●	●
• Logistics									●	●	●	●	●	●		●			●	●	●	●		●	●			●	●	●	●	●	●	●	●	●	●	●		●	●	●
• Administration					●	●	●	●	●	●	●	●	●	●		●		●	●	●	●	●			●		●	●	●	●	●	●	●	●	●	●	●	●		●	●	●
Food Preparation																																										
and serving																																										
• Kitchen			●			●	●	●	●	●	●					●			●	●	●	●	●				●	●	●	●	●	●	●	●	●	●		●		●	●	
• Dining					●	●	●	●	●	●	●					●			●	●	●	●	●				●	●	●	●	●	●	●	●	●	●		●		●	●	●
Service areas																																										
• Laundry						●	●	●	●	●	●	●	●	●		●				●					●			●	●	●	●	●	●	●	●	●	●	●		●	●	●
• Health maintenance										●	●	●	●	●															●	●	●	●	●	●	●	●		●		●	●	●
Assembly areas																																										
• Conference/briefing			●		●	●	●	●	●	●	●	●	●	●		●			●	●	●	●		●	●		●	●	●	●	●	●	●	●	●	●	●	●		●	●	●
• Training						●	●	●	●	●	●	●	●	●		●			●	●	●	●		●			●	●	●	●	●	●	●	●	●	●	●	●		●	●	●
Storage areas																																										
• Food storage							●	●	●	●																			●				●	●	●					●	●	●
• General Storage/supplies												●	●																●				●	●	●					●	●	●

A summary of the effects of microgravity on the human body, possible countermeasures, and considerations for the design of facilities to support these countermeasures is shown in Figure 10.8.2-1.

Zero gravity effect	Possible countermeasures	Facility and equipment	Notes
Cardiovascular deconditioning	Low intensity, high freq. exercise of large muscle groups (aerobic exercise)	• Exercise device (aerobic ergometer) • Heart rate and metablic monitoring system • Adequate ventilation, cooling • Timer • Diversion from boredom • Post exercise body wash	• Need volume for storage and use Heart rate and metabolic monitoring systems could be part of Space Medical Facility (see Para. 10.9). Heart rate monitoring should be routine; metabolic monitoring could be periodic (weekly). • (See Para. 10.2, Personal Hygiene)
		• Athletic games • Game equipment • Adequate ventilation, cooling • Post game body wash	• Could be in Recreation Facility (see Para. 10.7) • (See Para. 10.2, Personal Hygiene)
Fluid loss	Fluid loading prior to I-G entry	• Storage area for fluids and fluid administration supplies	• Could be part of Galley (see Para. 10.5) or Space Medical Facility (see Para. 10.9)
	Drugs	• Storage area • Inventory system	• Would be part of Space Medical Facility (see 10.9)
Bone mineral loss	Skeletal loading through low frequency, high intensity exercise (anaerobic exercise)	• Exercise equipment • Centrifuge	• Need volume for storage and use • Considerable impact on vibration, dynamics, volume, and cost
	Drugs	• Storage area • Inventory system	• Would be part of Space Medical Facility (see Para.10.9)
Disorientation, space adaptation syndrome neuromuscular patterning not adapted to zero gravity	Perceptual-motor exercise	• Padded surfaces • Mobility aids and restraints for practicing body movements and placement • Visual orientation cues	• Could be part of Recreational Facility (see Paragraph10.7)
	Drugs	• Storage area • Inventory system	• Could be done in Health Facility (see Para. 10.9)
Loss of muscle mass, strength and endurance Loss of one gravity neuromuscular patterning	Exercise of specific muscle groups; 1. High frequency, low intensity aerobic exercise (primary emphasis) 2. Low frequency, high intensity anaerobic exercise	• Exercise devices (both isotonic and isokinetic devices)	• Need volume for storage and use

The following is a further discussion of these considerations:

a. Mission Duration - This section assumes a mission duration of at least 10 days. For missions less than 10 days, an exercise facility is desirable for crew morale and well-being. The anticipated physiological decrements of a short mission can be countered by compensatory conditioning programs prior to the mission.

b. Multi Facility Function - The effects of microgravity can be counteracted in a number of different facilities in the space module. The primary function of the microgravity countermeasure facility would be to serve as an area for exercise and for strorage of this equipment.

c. Scheduling Capability - The microgravity countermeasures facility should have means to control the type and quantity of countermeasures administered to each crewmember. This would include a means to track the effects of the countermeasure and provisions for revising the countermeasure protocol and/or schedule.

d. Boredom and Crew Productivity - Microgravity countermeasures such as exercise may be boring because of a lack of mental stimulation. The following are ways in which a facility may reduce the boredom and increase the crew productivity:

1. Recreation facilities - provide supplemental facilities for listening to music, news, video entertainment, etc.
2. Social interaction - Locate fixed countermeasure facilities near each other or near points where people are congregated to allow

social integration.

3. Workstation facilities - Add compatible workstation facilities to the countermeasure facilities so that the crewmember can perform productive work while undergoing countermeasure activities.

4. Mobile facilities - Some countermeasure facilities can be made mobile (such as the elasticized body suit) so that they can be used at other crew stations.

e. Facility Location - The following considerations should be made when locating a fixed facility within the space module:

1. Vibration and noise - Some exercise equipment is noisy and causes vibration. This equipment should be isolated from sensitive areas such as crew quarters or sensitive workstations.

2. Personal hygiene area - post exercise whole or part body washing facilities should be close to the countermeasure facility.

3. Galley or potable water dispenser - Liquids should be available for crewmembers during strenuous exercise.

f. Microgravity Considerations - The design of the countermeasure facilities should account for the effects of microgravity. Some of these considerations are listed below:

1. Drying of perspiration - Perspiration will not drip from the body

but will pool on the body and then float into the atmosphere. There should be some way of drying perspiration before it contaminates the module.

2. Convection cooling - In 1-G, warm air around the body will rise providing cooling. In microgravity this will not occur. Ventilation for cooling must be provided through forced air.

3. Debris containment - Debris, such as hair lint, will not fall to the floor where it can be swept up. There must be a means, such as a vacuum system, to collect such material.

The following equipment and supplies shall be provided as microgravity countermeasures:

a. Exercise Equipment - The following exercise equipment shall be provided:

1. Cardiovascular exercise equipment.

2. Muscular strength maintenance exercise equipment - Equipment to maintain strength in major muscle groups that imposes resistive forces from 10 to 300 lb.

3. Skeletal loading equipment.

b. Monitoring Equipment - The following capabilities shall be provided for monitoring the microgravity countermeasure program:

1. Routine monitoring - The capability shall be provided to monitor the following parameters on a periodic basis:

   a) Electrocardiograph output - 12 Lead ECG.

   b) Blood pressure - Automated indirect systolic and diastolic blood pressure.

   c) Maximal and submaximal oxygen uptake (V02).

   d) Muscle strength - Muscle strength measurement of major muscle groups.

c. Pharmaceuticals - Pharmacological agents to help maintain homeostasis, counter bone mineral loss, mitigate space motion sickness, or otherwise counter the negative effects of microgravity shall be included in the space medical facility's pharmaceutical inventory.

Exercise facilities shall meet the following environmental requirements:

a. Cooling and Ventilation - Provide cooling and ventilation controls and capacity to handle increased metabolic rate during exercise.

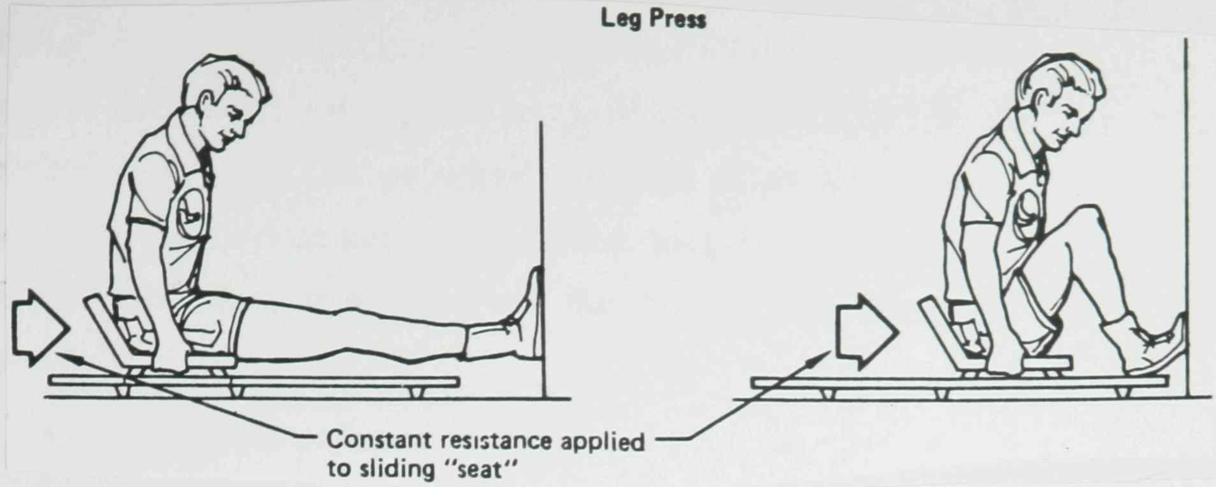
b. Noise and Vibration Control - Control noise and vibration output from exercise facilities to minimize disturbance to other crew stations.

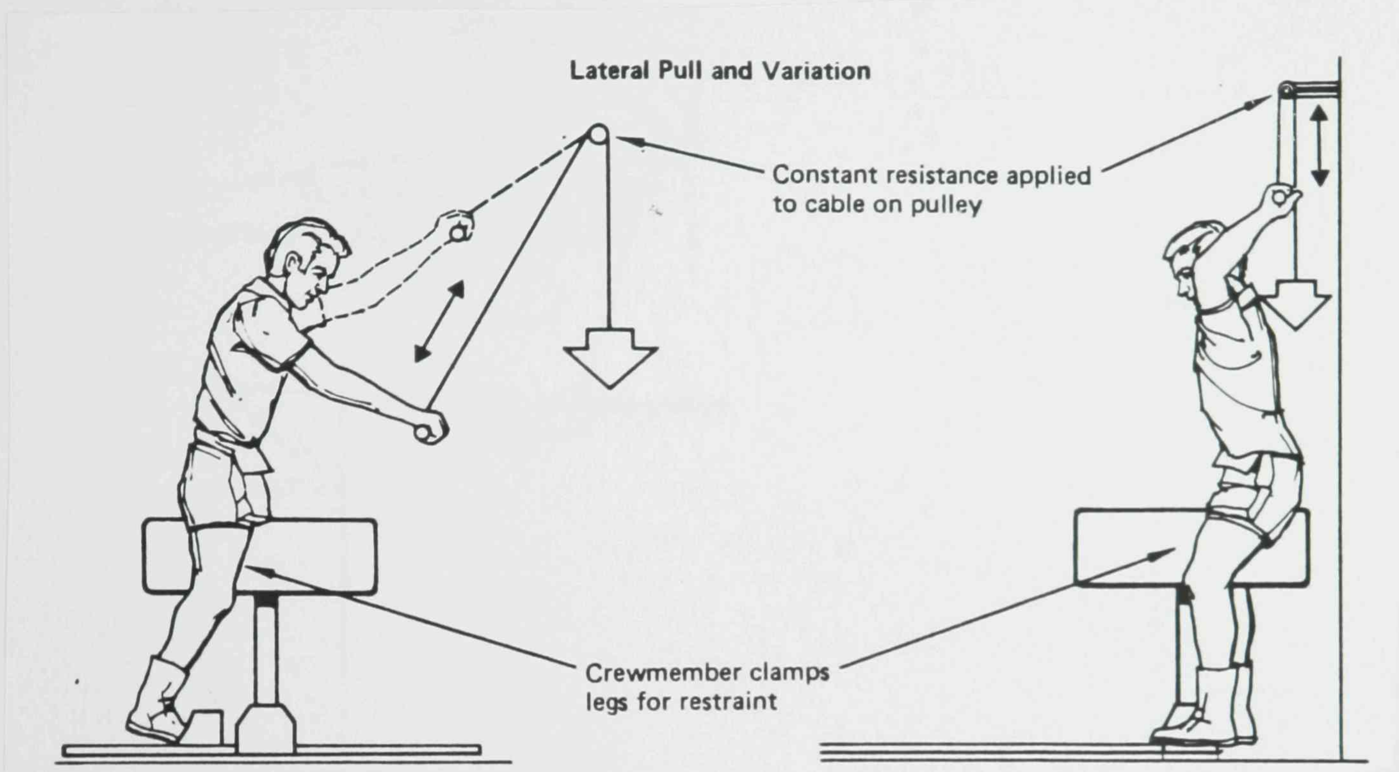
c. Minimize Boredom - Provide an environment to minimize boredom while exercising.

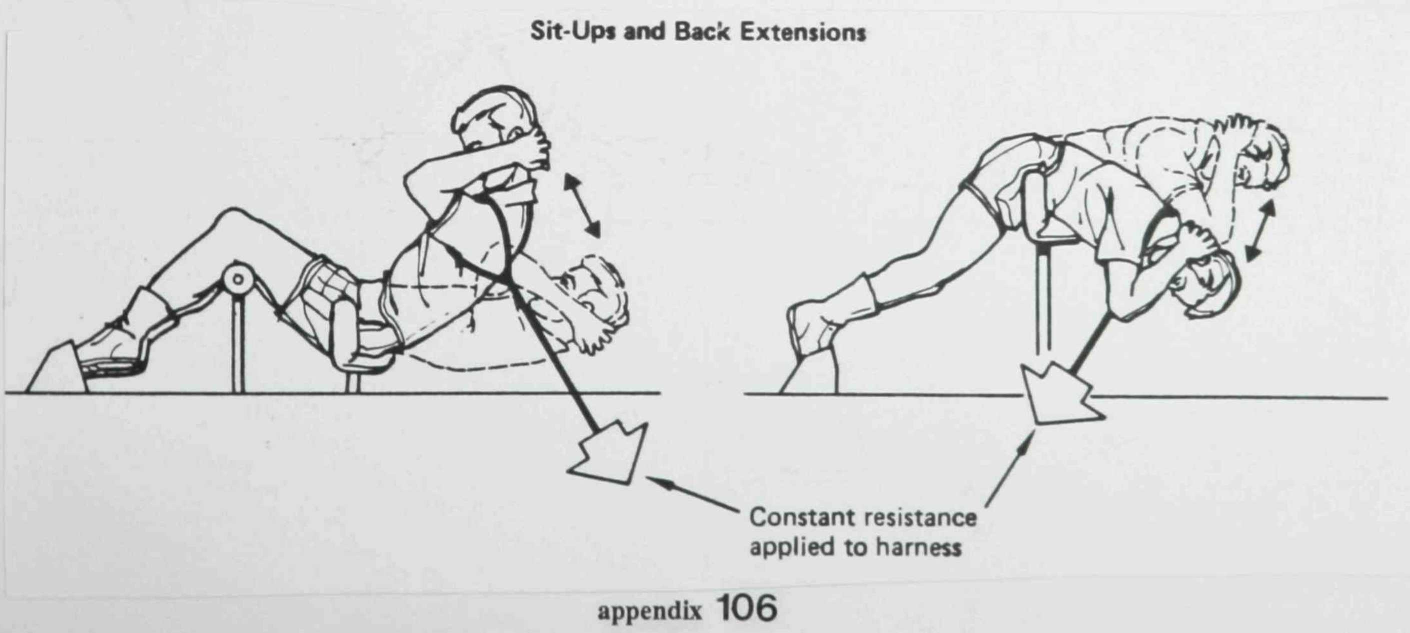
The following are example design solutions to the microgravity exercise requirements.

a. Strength Exercises - Several devices that utilize an electromagnetic brake or hydraulic mechanism to impose resistance equivalent to those of a 1-G environment have been developed. With a cable/pulley system and proper positioning, all major muscle groups of the body could be exercised (see Figure 10.8.4-1). The exercises include leg extension, military press, bench press, sit-ups and back extensions, plus leg curls, and arm curls; these exercises constitute an exercise for the major muscle groups of the body and should maintain the strength of the arm extensors and leg flexors (which the programs during Skylab 4 failed to do) as well as the arm flexors and leg extensors which were adequately maintained during Skylab 4. The abdominals and back extensors are included because of their importance as antigravity muscle groups for maintaining an erect posture in a 1-G environment. These are not adequately stressed by the natural body position assumed during microgravity exposure.

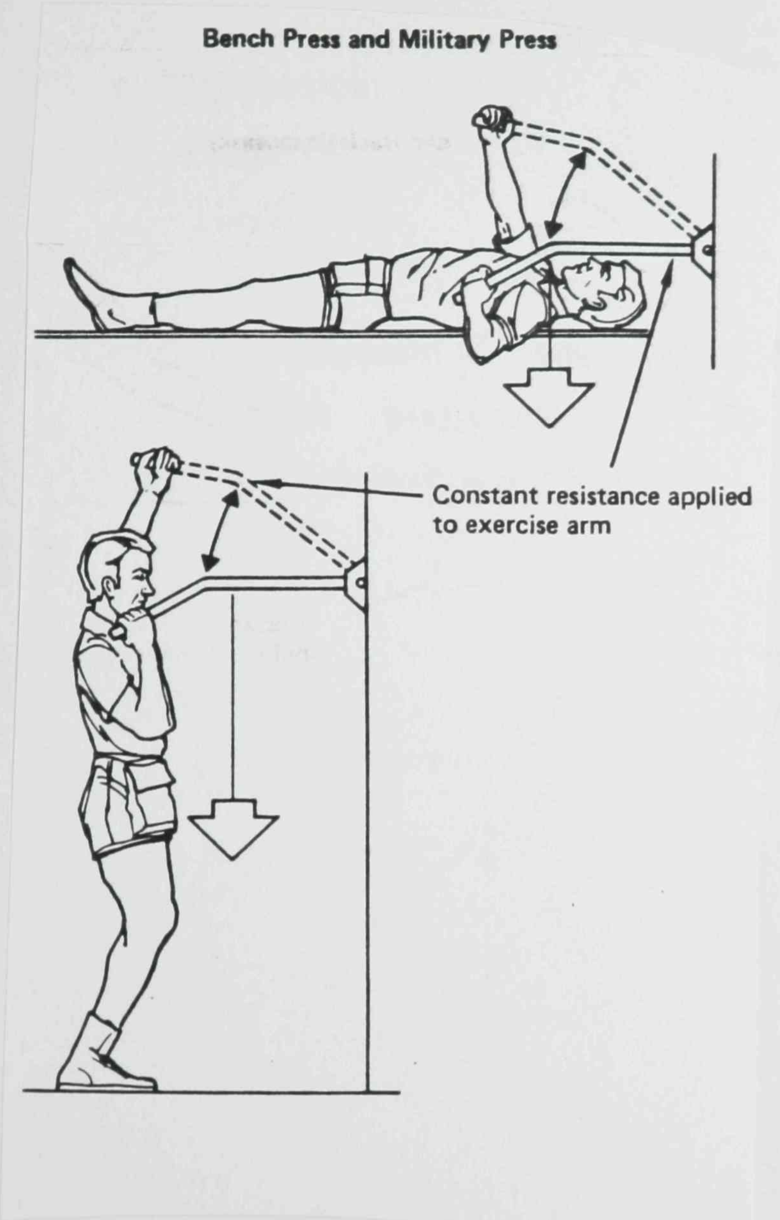
b. Aerobic Exercise Equipment - A bicycle ergometer similiar to that used in the Skylab series will provide aerobic exercise. It could be modified to include a video display terminal and computer programs (both commercially available) to simulate bicycle touring in Earth environments (through Yellowstone Park, coast to coast, hilly terrain, etc). Data storage, allowing each crewmember to keep performance and status records, should be included. These modifications, while not essential to the physiological performance, will greatly enhance motivation to exercise and adherence to required regimens.


Leg Press
Constant resistance applied
to sliding "seat"


Lateral Pull and Variation
Constant resistance applied
to cable on pulley
Crewmember clamps
legs for restraint


Sit-Ups and Back Extensions
Constant resistance
applied to harness

c. Skeletal Loading Exercises - A treadmill similiar to that used on Skylab 4 and the Shuttle could be provided as an adjunct to the other exercise equipment. Its principal attribute is as an impact device to potentially counter mineral loss in the long bones of the leg. Some crewmembers may prefer it over the bicycle ergometer for aerobic exercise.

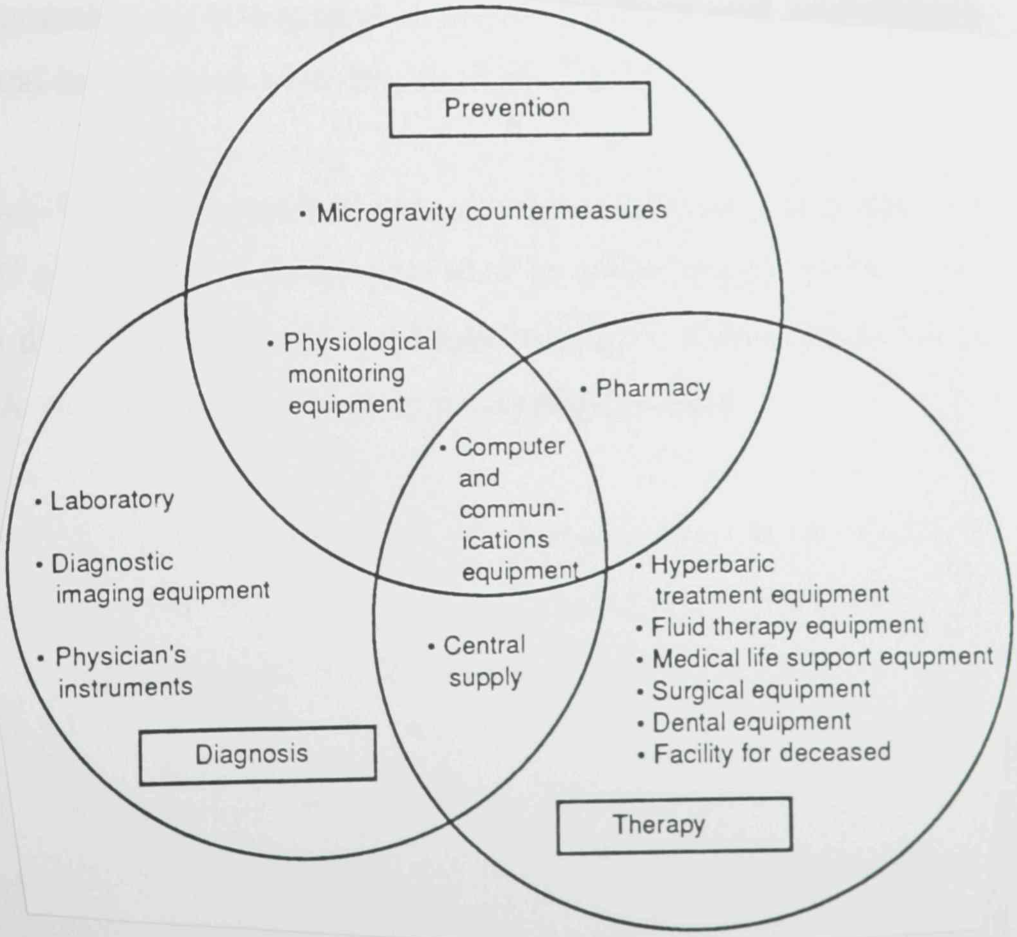


This section deals with the design of a Space Medical Facility (*SMF*). This section addresses both the environmental and physical requirements of the SMF.

The SMF must provide the following equipment and supplies to perform the following functions:

a. Prevention.
b. Diagnosis.
c. Therapy.

Some of the equipment and supply items suppport two or all three of these functions. The relationship of the medical functions and the equipment/supplies is shown in Figure 44.



The equipment in the SMF must be operable by the crew members. The final selection and design of the SMF equipment must be consistent with the medical training of the crew.

A SMF is a dedicated space module area that shall be set aside primarily for medical treatment of crewmembers on long term missions. The following detailed equipment parameters are based on current clinically acceptable medical standards. Future advances in clinical medicine may change many of these requirements.

The following communications and computing capabilities shall be provided in the Space Medical Facility:

a. Medical Database - An onboard medical information management system, incorporating an integrated medical database and appropriate levels of medical information security, shall be provided.

b. Private Two-Way Communications - A voice communication channel between SMF and Earth shall be provided to allow crewmembers the opportunity to discuss their health problems/concerns with crew medical officers, NASA physicians, and other concerned personnel.

c. Data Downlink - Data communication channels shall be provided to ensure downlinking of medical information/data to assist ground personnel in determining actual conditions of ill or injured crewmembers.

d. Medical Management Algorithms (Computer Assisted) - Preventative, diagnostic, and therapeutic computer assisted medical management algorithms shall be provided as a part of the medical database.

e. Medical Reference Materials (Computer Assisted) - Computer assisted medical checklists, procedures, and indexed medical reference materials shall be provided as a part of the medical database.

f. Air-to-Ground Electronic "Mail" - Secure and nonsecure electronic mail service shall be provided between the SMF and the ground based crew surgeon.

g. Inventory Management - A computerized inventory management system for medical supplies and pharmaceuticals shall be provided. Information from this inventory management system shall be available within the space module and on the ground.

The following are design consideration for space module laundry facilities:

a. Crew Productivity - Laundry processing is a potentially significant use of crew time and every effort should be made to reduce the level of crew involvement. The following are means of reducing crew time:

1. Elimination of the need for pressing laundry.

2. Elimination of the need to sort laundry prior to washing due to different processing requirements.

3. Automation of the collection, processing, and distribution functions.

4. Use of disposable clothing.

b. Laundry Collection, Processing, and Distribution System - There are a number of different options for laundry collection, processing, and distribution. Each of these options require different human factors considerations. Some of these options and their human factors implications are listed below:

1. Central collection, processing, and distribution laundry area - This might save overall module volume but could result in loss of crew time to making daily trips to the laundry area.

2. Several small collection points and central processing and distribution area - This would increase module volume devoted to the

laundry function but may improve crew efficiency. An automated transfer of dirty laundry (through conveyor or piping system) would further increase crew efficiency.

3. Several small collection, processing, and distribution areas - Would save crew time in collection and distribution but may require more volume and more crew time in actual laundry processing.

c. System Capacity - Clothing types and laundering frequency rates are estimated in Figure 10.10.2-1. These rates and the size of the crew can be used to estimate the required capacity of the system. Additional laundry capacity will be required for towels, washcloths, bedding, etc. Landering of these items will depend on the design of the personal hygiene facility, use of disposable materials, housekeeping techniques, etc. Once the system is sized, procedures will have to be established to ensure the laundering frequency does not exceed the system capacity.

Item	Estimated mass grams (oz)	Estimated laundering frequency
Shirt	110 (4)	1 per 2 days
Jacket	370 (13)	1 per 14 days
Trousers	370 (13)	1 per 7 days
Shorts or panties	57 (2)	1 per day
T-shirt of brassiere	40 (1.5)	1 per day
Socks	14 (.5)	1 per day
Handkerchief	7 (.25)	1 per 2 days
Sleep/gym shorts	85 (3)	2 per 7 days
Sleep/exercise shirt	110 (4)	2 per 7 days
Slipper socks	85 (3)	1 per 90 days

d. Noise - Laundry facilities are a potential source of high noise levels. They must be isolated or insulated as required to ensure that the noise requirements in Paragraph 5.4 are met.

The following are considerations to be made in the design of personal hygiene facility:

a. Psychological Effects - Good grooming can enhance self image, improve moral, and increase the productivity of the crewmember. Adequate and comfortable bathing and body waste management facilities have been high on the list of priorities of participants in various space missions. Some modification of personal hygiene practices and procedures may be necessary due to equipment design limitations and water supply restrictions. Too great a modification, however, could impact negatively on crew self image and productivity. It would be unwise to expect optimum performance unless optimum conditions are provided.

b. Odor - Objectionable body odors can rapidly build without adequate personal hygiene facilities. This is a predictable source of interpersonal conflict.

c. Ease and Comfort of Use - The personal hygiene facilities will not be used, or will be used infrequently, if they are awkward, uncomfortable, or take an inordinate amount of time to use. This was a problem with the Skylab shower design.

d. Privacy - It is desirable to have privacy for crewmembers for whole body and partial body cleaning (including donning and doffing of clothing).

e. Feedback - Unfamiliar and inadequate facilities and environment can result in crewmembers falling into patterns of substandard hygiene. The results are likely to be reduced productivity and interpersonal conflict. Provision of full length mirrors or other means of feedback can help to maintain personal image and hygiene habits.

f. Mission Duration - Shorter missions generally require less extensive personal hygiene facilities. Each of the facility design requirement paragraphs provide guidelines for determining facility requirements based on mission duration.

g. Microgravity Considerations:

1. Cleanup - in microgravity, water and debris, such as hair, do not fall to a fixed surface as they do on Earth. Water and debris float. Water cannot be simply drained away and hair cannot be swept up. Collection of water and debris become both an engineering problem and an operational problem for the crew member. Functions that require relatively little time on Earth, such as a shower, can require much more time and be less relaxing because of the cleanup requirements due to microgravity. This can impact negatively both on mission schedule and personal motivation to use the facilities. Designs should minimize the time and discomfort penalties resulting from microgravity.

2. Restraints - Restraints should be provided so that the crewmember does not compromise the personal hygiene operations by having to stabilize himself or herself. These restraints should be compatible with the personal hygiene operation. For example, foot

restraints in a whole body wash facility should not be damaged when exposed to water.

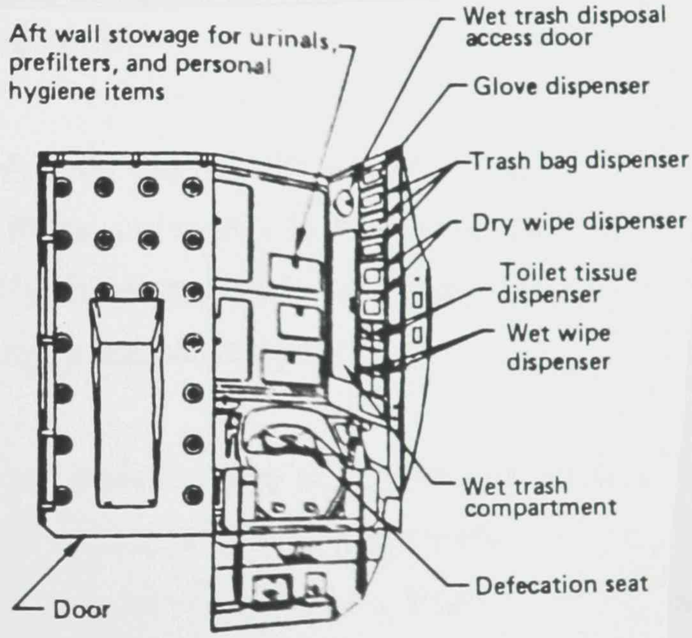
The STS urination and defecation facility contains the following features which have proven successful:

a. Spring loaded thigh bars that press the user against the opening used for defecation.

b. A toe bar at the front of the system for stand up urination.

c. Velcro footstraps to stabilize the body for cleanup after defecation.

(see Figure 49 for arrangement of toilet supplies and cleanup materials).



Reference: 312, page SS2

Figure 10.3.4-1. Overall Layout of the STS Waste Management Station

Some of the benefits of materials processing are the new developments that arise from government sponsored research. These benefits include new technologies and new materials. One of the most extraordinary new materials is "foam steel". Collectively these materials are known as fiber reinforced composite materials.

Some of the strength adding elements are boron or graphite, and "whiskers" - needle shaped single crystals.

These materials could make possible a skyscraper one mile high, (if one is necessary) or a suspension bridge twice as long as the ones now in existence. Airplane weights can be reduced by as much as one third, allowing light weight, faster, more fuel efficient aircraft.

Ironically, these materials are slated to be the workhorses of the space station structural systems. The irony of these materials is that they can only be produced in microgravity (presently these materials are being processed in drop tubes and KC-135 aircraft flying parabolic trajectories).

The production of these materials are possible due to directional cooling, or directional solidification. The space station will be a regenerative process to an extent, in that it will produce the materials to allow itself to grow and expand in capabilities and physical scale.

General Purpose Rocket Furnace

Experimental Capability The General Purpose Rocket Furnace (GPRF) provides three independently controlled cavities for melting and resolidifying experimental specimens in a microgravity environment. Each cavity can be operated to provide near-isothermal or gradient temperature profiles. Samples can be cooled at specific rates with a cold gas quench through a common manifold or water-cooled heat sink integral with each cavity while maintained in a sealed atmosphere.

Mode of Operation Each cavity consists of a three zone furnace with heat extraction at one end, capable of operating in an isothermal or gradient mode. The temperature gradient is maintainedby programmable control of the three heating elements and a heat exchanger in the cavity. The isothermal environment is provided by operating the three heating elements at or as near the same temperature as possible.

Operational Parameters

Operating Temperature Range..............................	100°C-900°C
Maximum Power...	1600 watts

Sample Parameters

Maximum Length...	7.8 cm
Maximum Diameter...	2.0 cm

Physical Characteristics

Furnace length..	50.80 cm
Furnace diameter...	43.18 cm

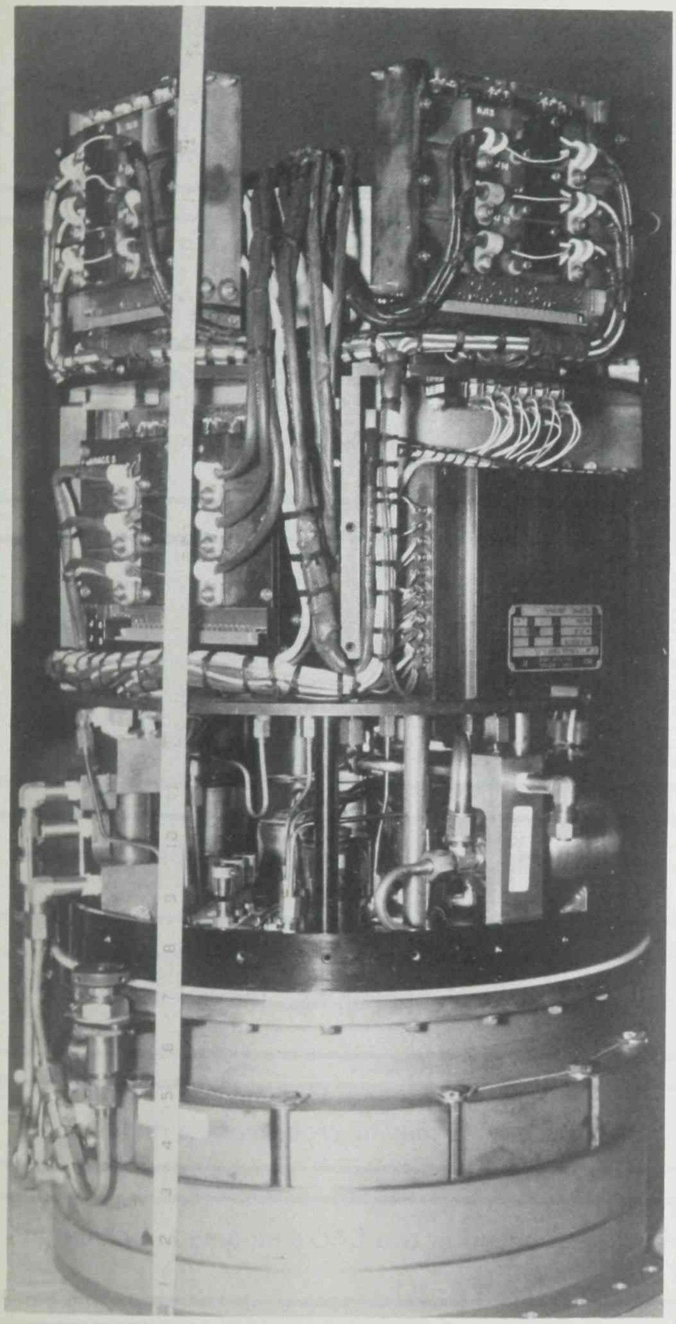
Integral Instrumentation Maximum of two thermocouple measurements per sample.

Data Acquisition Capabilities Real time data acquisition is not applicable to this unit. Analaysis is performed on the finished samples and on the digital temperature data provided by the thermocouples.

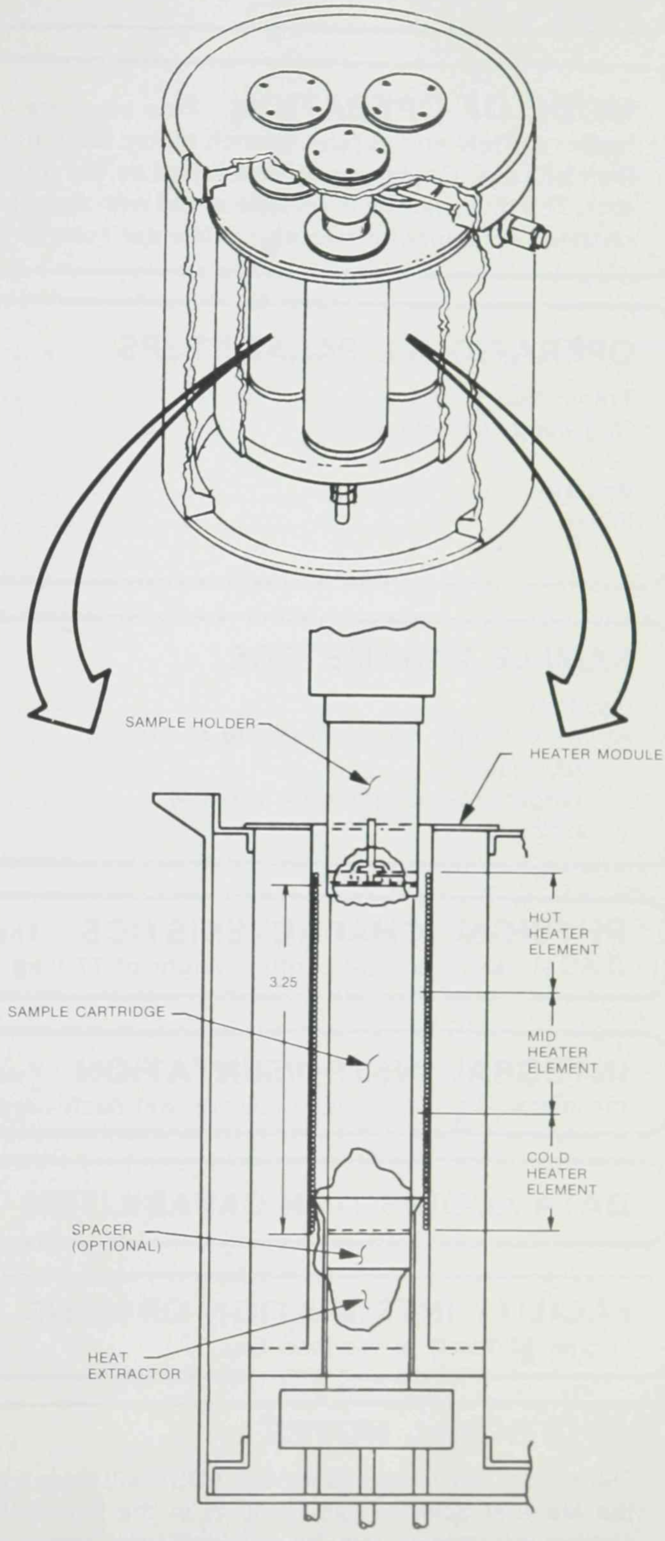
Facility Integration Options Presently the GPRF is designed to operate in the Materials Experiment Assembly (MEA) in the Orbiter payload bay.

Additional Notes
NASA plans to modify the two GPRF's to increase their operating time and temperature capability after the MEA-A3 (D-1) Mission which is scheduled in the latter part of 1985.

PHOTOGRAPHIC VIEW



SCHEMATIC VIEW



HEATER MODULE WITH SAMPLE CARTRIDGE INSTALLED

Advanced Automated Directional Solidification Furnace

Experimental Capability This advanced design of a directional solidification furnace (AADSF) has a sophisticated controlled gradient region between the hot and cold zones. The furnace may be configured to an individual experimenter's sample and operated to compensate for changes in solidus temperature as the sample adjusts to its steady state value, changes in thermal conductivity between solid and melt, and energy deposition from translation and release of latent heat. The unit is capable of maintaining the solidification front in optimum postition for obtaining a nearly planar interface.

Mode of Operation The microprocessor controlled gradient region consists of one or more wafer thin booster heaters, an adjustable length adiabatic zone, and a controllable heat sink. The booster heaters and the use of a heat transfer medium between the sample and the heating module provide much steeper thermal gradients than conventional Bridgeman furnaces in the solidification region. The furnace thereby allows stabilization of the interface against constitutional breakdown.

Operational Parameters

Power	500 watts max.
Voltage	28 ± 4 vdc
Cold zone operating range	ambient to 600°C
Hot zone operating range	ambient to 1000°C
Booster heater range	ambient to 1400°C
Thermal gradient*	0 to 900°C
Translation rate	1.0 to 50 mm/hr

Sample Parameters

Capacity	two samples/flight
Ampoule outer diameter	3.5 cm max.
Ampoule length	25.0 cm

Physical Characteristics

Overall dimensions:

Diameter	17.8 cm
Length	56.0 cm
Weight	approx. 68 kg

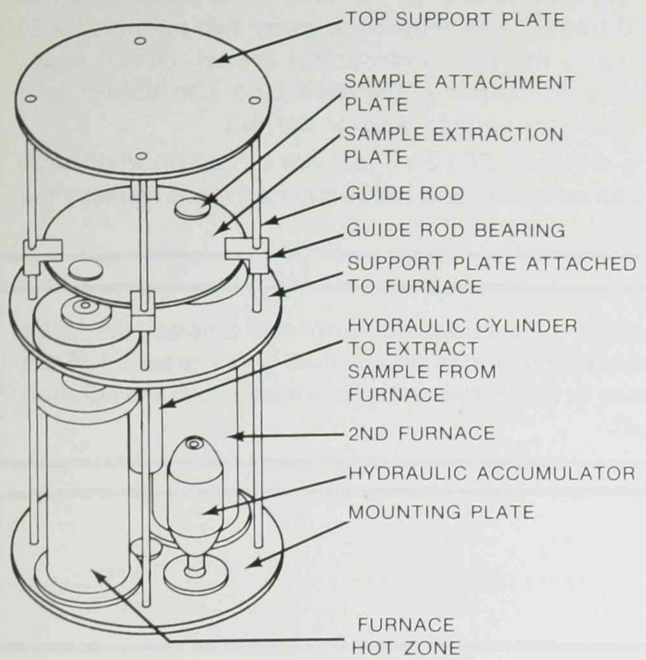
Integral Instrumentation A motion control programmer for sample positioning and control, and an AADSF controller for CPU, power electronics, and housekeeping will be provided.

Data Aquisition Capabilities Temperature at various control points vs. time, temperature rate vs. time.

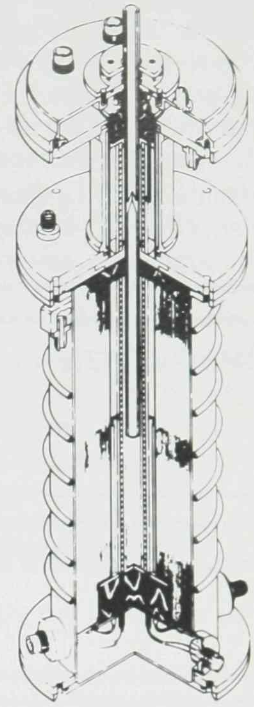
Facility Integration Options Each AADSF will be housed in an Experiment Apparatus Container (EAC) and mounted on the Material Science Lab (MSL) in the Orbiter Payload Bay.

Additional Notes *Dependent on sample material. An engineering prototype has been completed; first flight is planned for 1986.

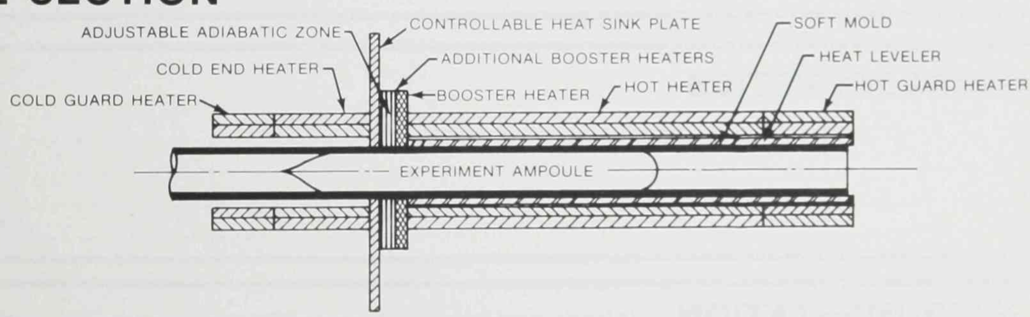
APPARATUS



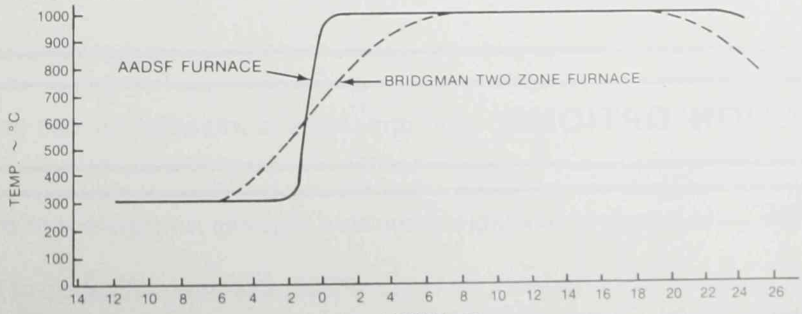
FURNACE MODULE



FURNACE SECTION



TEMPERATURE PROFILE



Isoelectric Focusing Experiment

Experimental Capabilty This apparatus was developed to determine the best isoelectric column configuration for a recycling isoelectric focusing (RIEF) apparatus designed for operation in low-g. Ground-based RIEF is possible only through the use of screen elements which assure laminarity of flow by minimizing electro-osmosis and limiting convection. The isoelectric focusing experiment contains eight column assemblies. The first use of the apparatus had columns with different combinations of three kinds of partitions, two kinds of buffers, and one kind of antielectro-osmosis coating.

Mode of Operation Seventy volts direct current is simultaneouosly applied across (end-to-end) each column to produce a pH gradient in the buffer and focusing of the materials to be separated. Movement of the colored samples to their isoelectric points (the point where the pH of the sample and the pH of the buffer are the same) is recorded photographically.

Operational Parameters

Constant voltage to each column............................	70 vdc
Total current limited to.......................................	40 ma

Sample Parameters

Sample capacity..	8 column assemblies

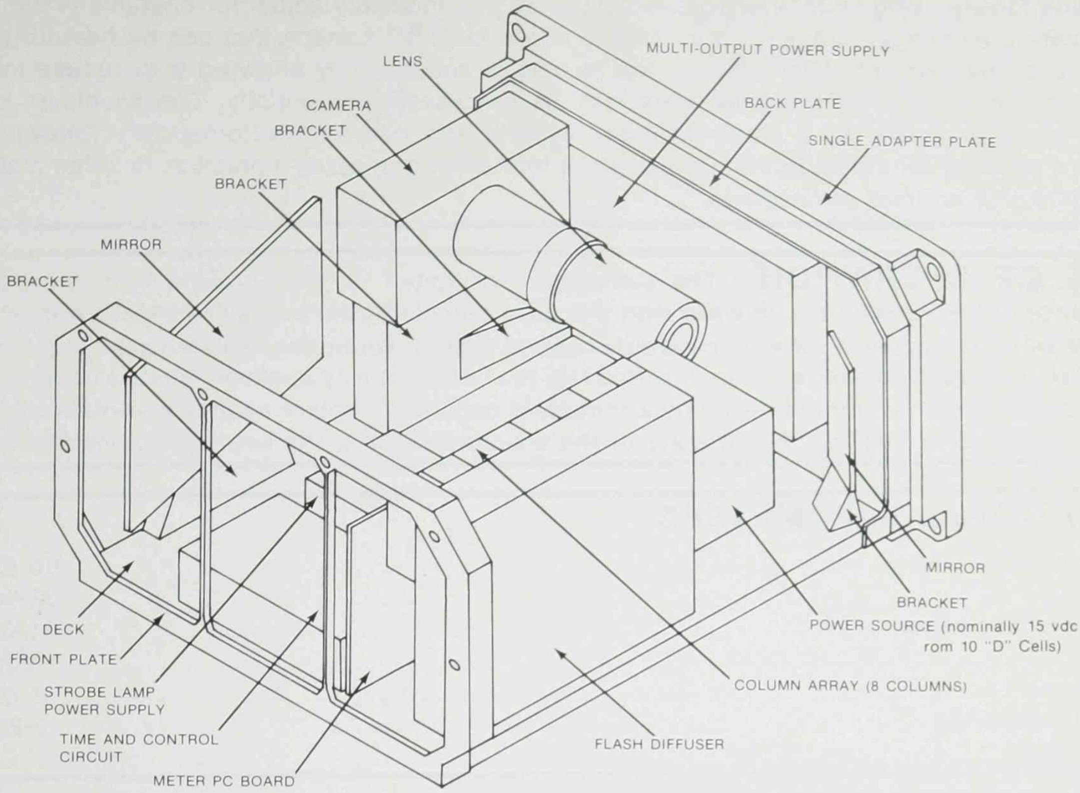
Physical Characteristics The apparatus is configured to replace a standard middeck storage locker.

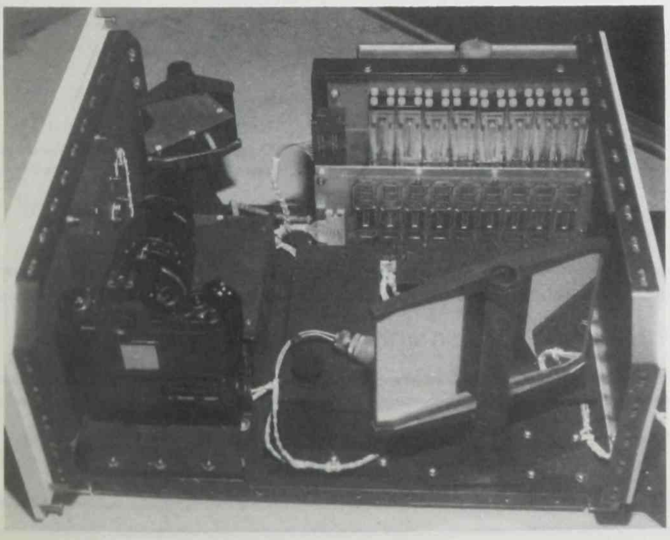
Integral Instrumentation LED display of voltage and current is turned on for each photograph.

Data Aquisition Capabilities Forty 35mm photographs, first 10 taken at 3 minute intervals, remaining 30 taken at 2-minute intervals.

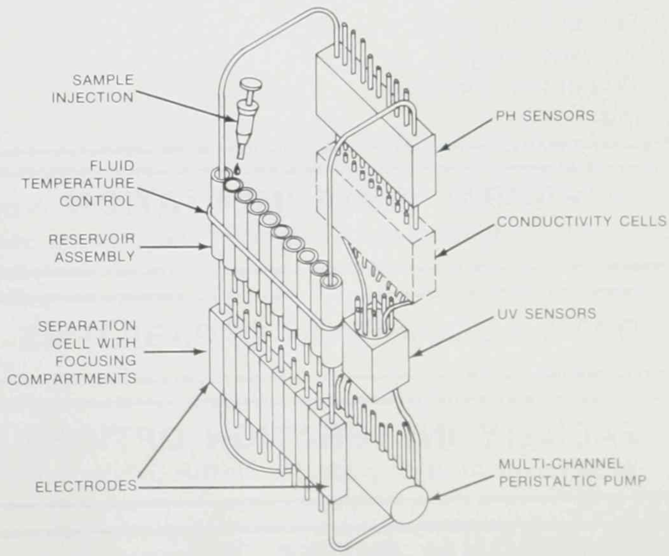
Facility Integration Options The apparatus is designed to mate with a single adaptor plate in the Orbiter middeck.

APPARATUS





PLANNED RECIRCULATING IEF SYSTEM



Single Axis Acoustic Levitator

Experimental Capability The single Axis Acoustic Levitator (SAAL) is a containerless processing facility using an interface technique to automatically adjust for changes in the speed of sound as the temperature changes. Samples are injected into a hot-wall furnace that can be heated up to 1600°C in an atmospheric environment. After melting, the sample is solidified by allowing it to radiate in an acoustically transparent heat sink. Additional samples may be processed sequentially. The specimen can be positioned without physical means by a weak acoustic levitator and operated automatically following activation. The apparatus is useful for studying the containerless formation of glasses, ceramics, or other materials that require the presence of an inert atmosphere.

Mode of Operation The sample is positioned in the acoustic energy node formed by the interference of the incident sound wave with the wave reflected from a small reflector inserted into the insulated chamber with the sample. Four silicon carbide heating rods surround the levitated sample during the melt phase, and an array of stainless steel rods are inserted into the heating cavity to allow radiative cooling and solidification. The solidified sample is then retrieved by a retracting cage and another sample automatically inserted. A quartz window serves as a port for photography of the specimen during the processing sequence.

Operational Parameters

Operating temperature	up to 1600°C
Voltage	32 vdc
Power	3100/2600 watts
Pressure	1 atm
Atmosphere	air or inert gas
Levitator frequency	15-20 kHz
Cooling rate*	15°C/sec

Sample Parameters

Capacity	up to 8 samples
Spherical diameter	up to 1.5 cm

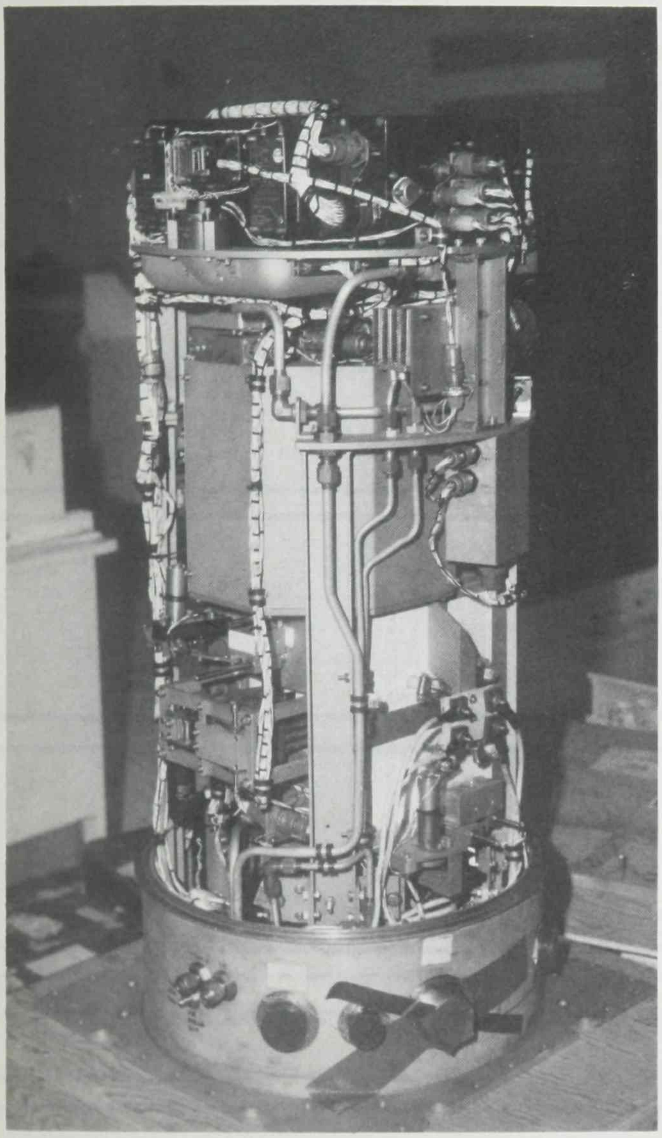
Physical Characteristics

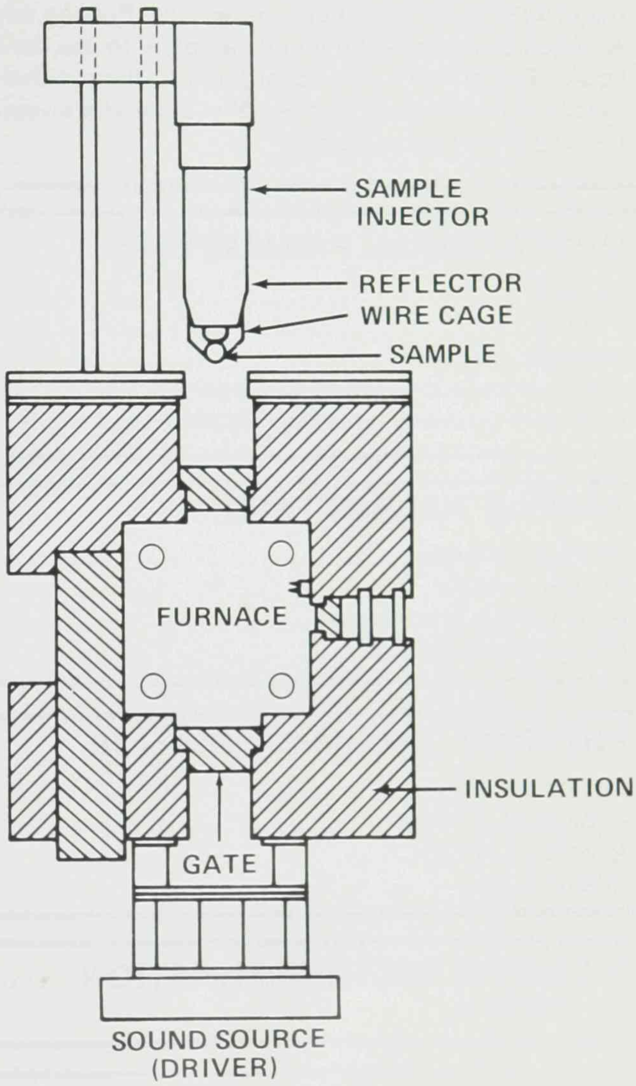
Furnace length	71 cm
Furnace diameter	43 cm
Furnace weight	61.3 kg
Processing chamber	10.2 x 10.2 x 11.4 cm
Injector cage	2.5 x 2.5 x 2.85 cm

Integral Instrumentation A pyrometer records sample temperature while a movie camera provides a photographic record of the process sequence.

Data Aquisition Capabilities Temperature and photographic record.

Facility Integration Options Operation of this apparatus is restristed to the Materials Experiment Assembly located in the Orbiter payload bay.




SAMPLE
INJECTOR
REFLECTOR
WIRE CAGE
SAMPLE
FURNACE
INSULATION
GATE
SOUND SOURCE
(DRIVER)

Automated Directional Solidification Furnace

Experimental Capability The Automated Directional Solidification Furnace (ADSF) is used to individually melt up to four different material samples. Each sample can then be cooled at a controlled rate with 50/50 ethylene glycol/water in a manner which will promote directional solidification. Up to two rate changes can be achieved during the processing of each sample. The process allows investigation into the anisotropic properties of metals and the unusual electrical, magnetic, and optical properties of unique directionally solidified molecular structures.

Mode of Operation Four separate furnace heating units are present, consisting of an individual heater module and copper quench block. Each heating unit is translated along the axis of the sample during the melt process. The drive system is variable speed with microprocessor control of the translation speed and any required rate change. Atmospheric and environmental control are maintained by the sealed furnace enclosure.

Operational Parameters

Translation speed	0.1 mm/hr. to 500 mm/hr.
Operating temperature	200-500°C (middeck)
	200-1500°C (cargo bay)
Voltage	28 vdc ± 4 volts
Power	1,175 watts*

Sample Parameters

Capacity	4 samples
Ampoule length (high temperature version)	135 mm
diameter	6 mm
length (low temperature version)	135 mm
diameter	6-8 mm

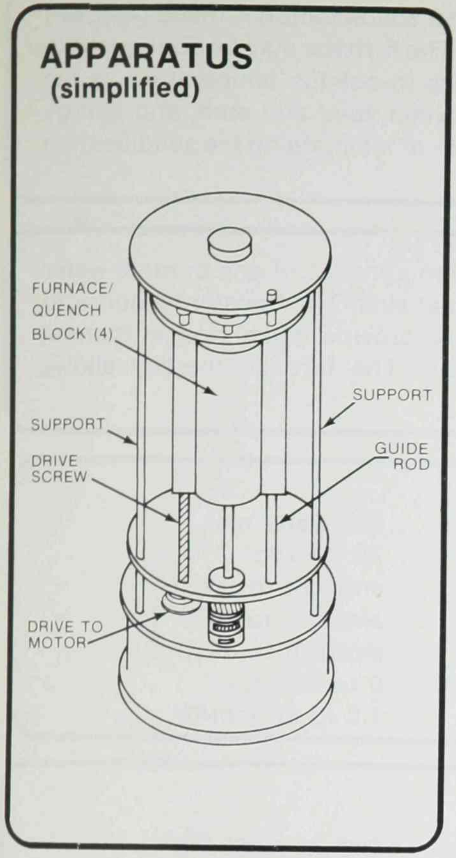
Physical Characteristics The ADSF will include two Experiment Apparatus Containers (EAC's) having a total control weight of 77.1 kg.

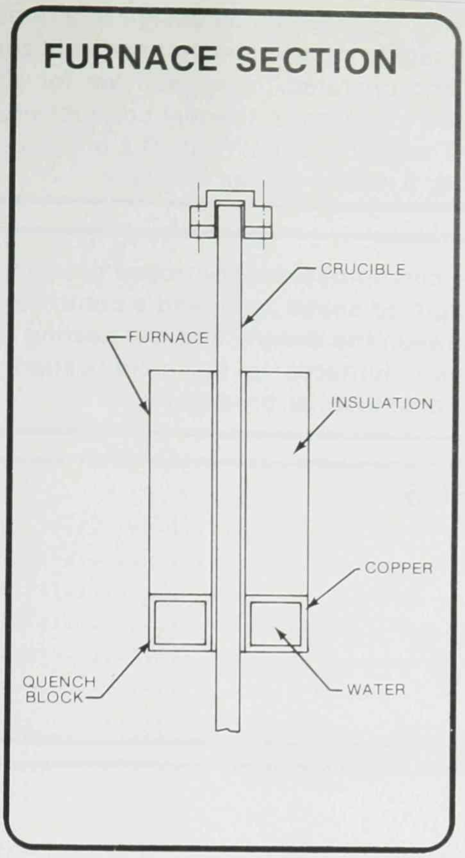
Integral Instrumentation Two furnace cavities will each contain four thermocouples while the remaining two furnace cavities will each contain one thermocouple.

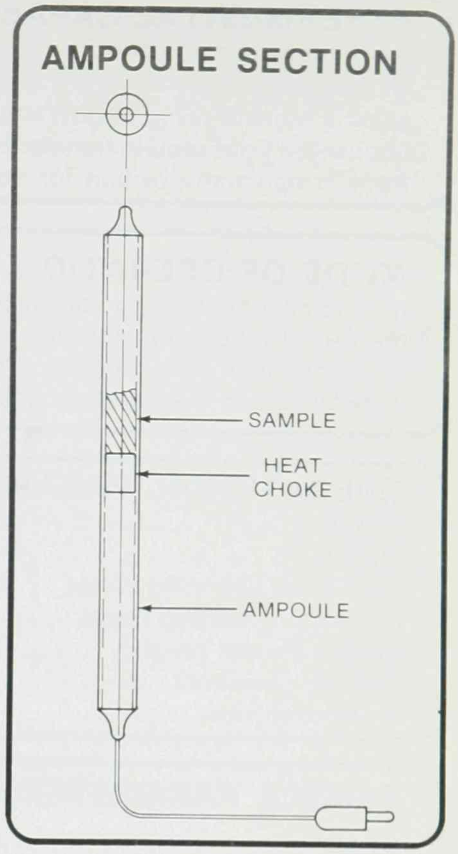
Data Aquisition Capabilities Up to 22 channels of data may be recorded at a rate of 1 sps.

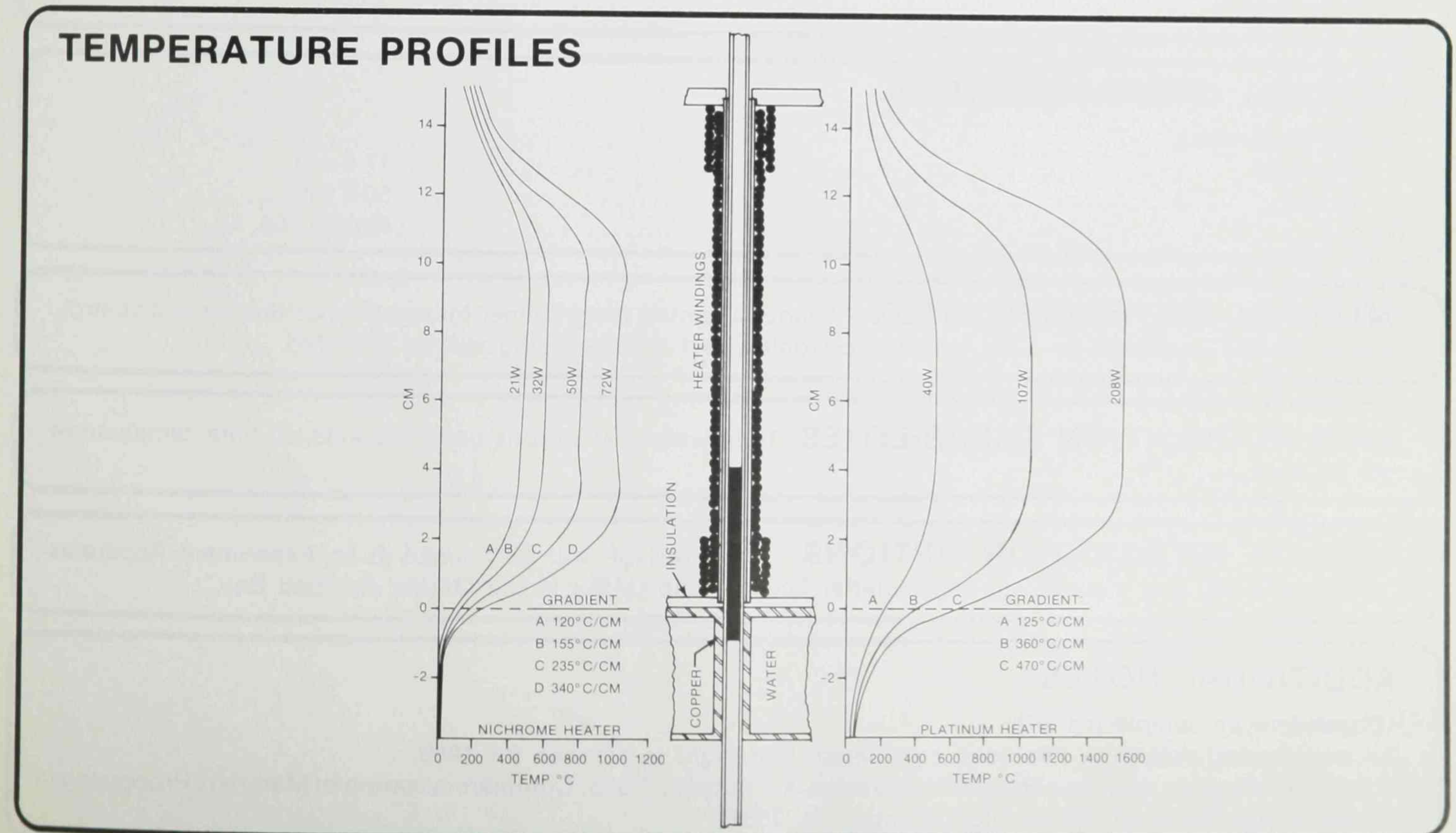
Facility Integration Options The unit will be housed in two EAC's mounted in either the Orbiter Middeck or Payload Bay.

Additional Notes
*Maximum power capability; the ADSF will have a peak power of 357 watts when configured in EAC's mounteds on the Material Science Lab (MSL-2) in the Orbiter Payload Bay. The ADSF is planned for flight in 1985.


APPARATUS
(simplified)
FURNACE/
QUENCH
BLOCK (4)
SUPPORT
SUPPORT
DRIVE
SCREW
GUIDE
ROD
DRIVE TO
MOTOR


FURNACE SECTION
CRUCIBLE
FURNACE
INSULATION
COPPER
QUENCH
BLOCK
WATER


AMPOULE SECTION
SAMPLE
HEAT
CHOKE
AMPOULE


TEMPERATURE PROFILES
CM
21W
32W
50W
72W
A B C D
GRADIENT
A 120°C/CM
B 155°C/CM
C 235°C/CM
D 340°C/CM
NICHROME HEATER
0 200 400 600 800 1000 1200
TEMP °C
HEATER WINDINGS
INSULATION
COPPER
WATER
CM
40W
107W
208W
A B C
GRADIENT
A 125°C/CM
B 360°C/CM
C 470°C/CM
PLATINUM HEATER
0 200 400 600 800 1000 1200 1400 1600
TEMP °C

Continous Flow Electrophoresis System

Experimental Capability This system has been developed to permit exploratory separations of biological materials. The cell handling facilities allow the separation of living cells as well as macromolecules. A large cross section chamber permits a high continuous rate of flow, consequently increasing the potential process volume of the sample material. Sample temperature can be maintained for several hours, permitting the recovery of living cells.

Mode of Operation The sample is injected into the electrophoresis chamber and carried into an electric field by the buffer. Under the influence of the field, in microgravity, the various subfractions of the sample are deflected according to their respective mobilities and enter a channel collector at the end of the chamber. Ideally each fraction segregates into a different channel where it is then moved through tubing by a peristaltic pump to collection bags in a thermally controlled chamber.

Operational Parameters

CFES Input Voltage.. 28 ± 4 vdc
CFES Input Power, Maximum................................ 600 watts

Sample Parameters The apparatus is capable of multiple sample operation. In addition a small thermoelectric refrigerator is provided for storage material before and after processing.

Physical Characteristics (Fluid Systems Module)

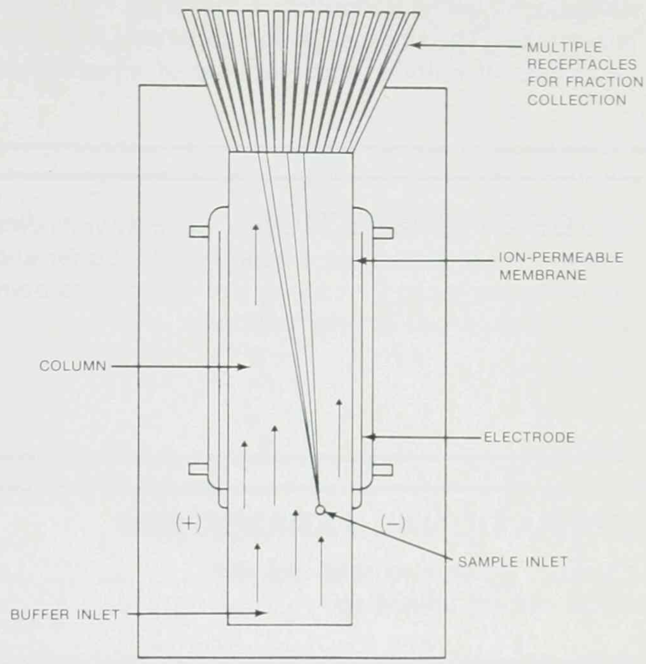
height... 183 cm
width... 61 cm
depth... 46 cm
weight (Block III, entire system)............................ 376 kg

Integral Instrumentation Microcomputer for experimental control and monitoring is included

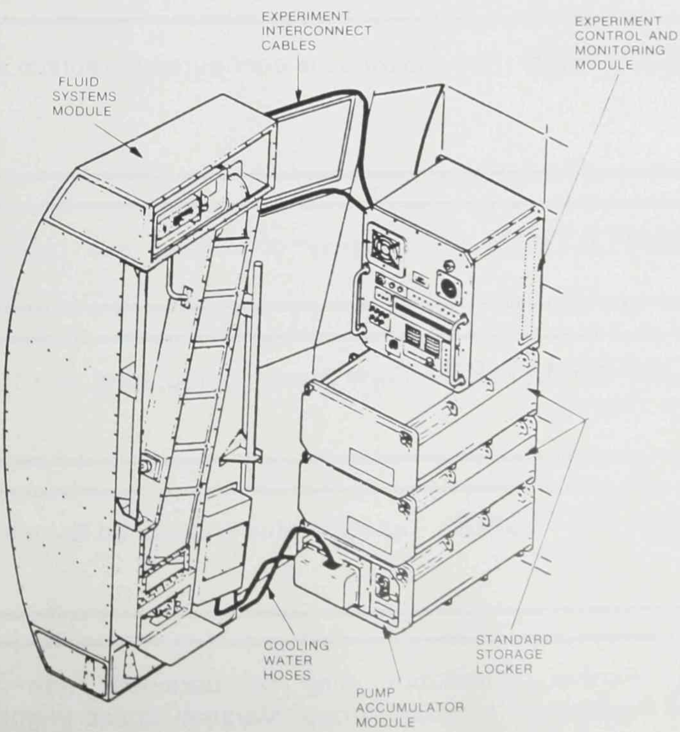
Data Aquisition Data analysis is performed on the finished product. A Nikon F-2 camera is available to obtain process photographs.

Facility Integration Options The experiment control and monitoring module, and the sample storage module are located in middeck lockers, while the fluid systems module is mounted adjacently in the middeck.

ELECTROPHORESIS PROCESS



ORBITER MIDDECK EQUIPMENT ARRANGEMENT (BLOCK III)



Static Column Electrophoretic Seperator

Experimental Capability Up to eight column asemblies can be operated and photographed in each apparatus. A constant voltage (nominally 70 vdc) power supply in the apparatus is used to apply potential to a maximum of eight columns. The output of the 70 vdc power supply is 40 ma. Once the apparatus is manually turned on, it operates for 90 minutes and then shuts itself off. During the 90 minutes of operation, 35 mm photographs are taken once every three minutes for the first 10 frames, and then once every two minutes for 30 frames. This photography sequence can be changed by changing the time-and-control printed circuit board assembly. Columns which require no power can be flown without modification of the apparatus. The multi-output power supply would have to be modified to provide different column voltage and/or current.
The meter printed circuit board assembly has nine light emitting diodes (LED) on it that are turned on when each photograph is taken. One LED displays the potential applied to all columns, and the remaining eight display the current passing through each column.

Mode of Operation Each column contains a mixture of a buffer solution and ampholytes to be separated. Once the 70 vdc is applied to each column assembly, the buffer astablishes a pH gradient. Each ampholyte to be separated has its own pH. It migrates to the point in the buffer solution where it and the solution have the same pH, which is known as its isoelectric point (pl).

Operational Parameters

Voltage	115 vac
Power	32 watts

Sample Parameters

Capacity	8 samples
Sample container length	15 cm
diameter	0.477 cm

Physical Characteristics

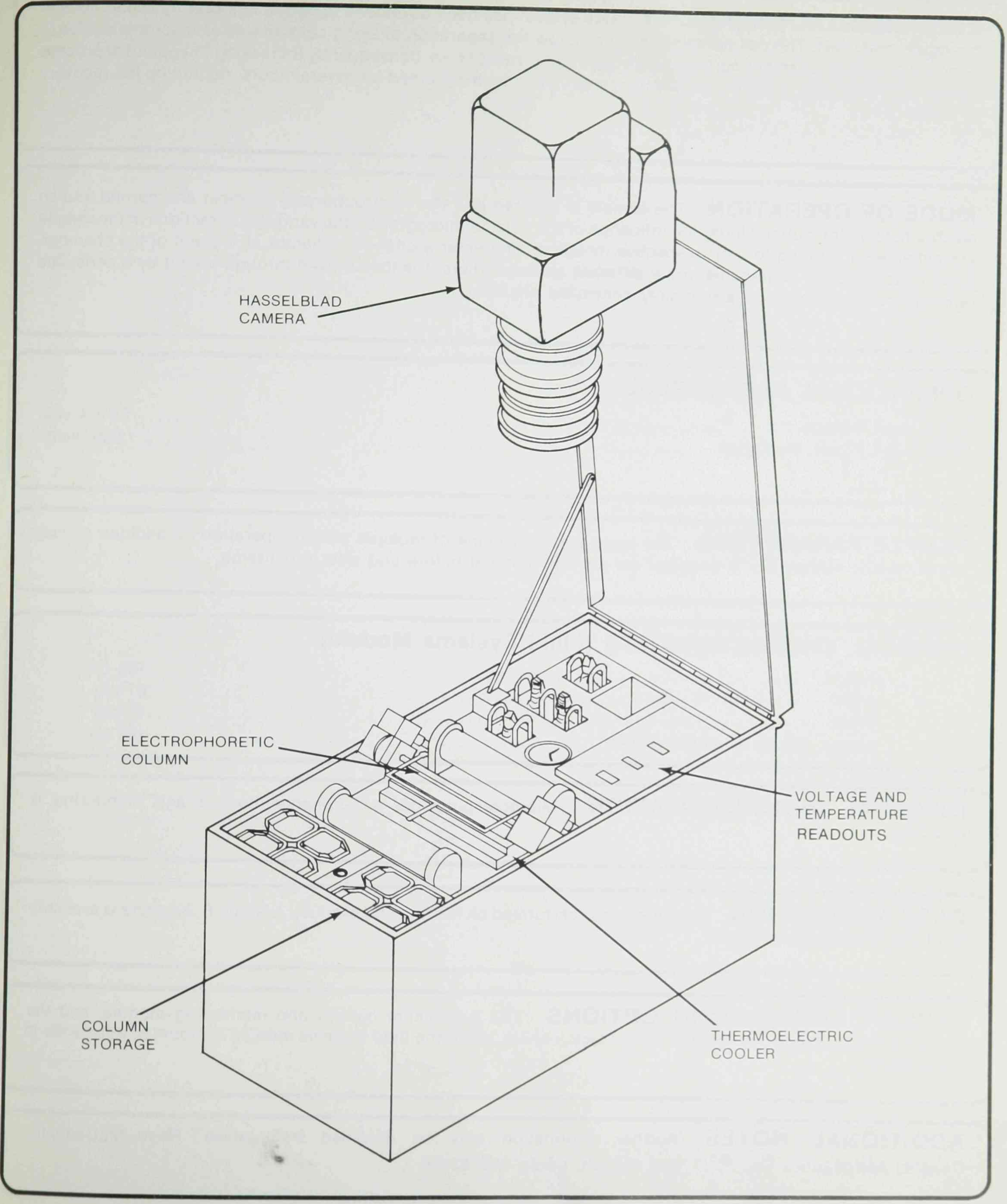
length	34 cm
width	17.5 cm
height	12.5 cm
weight	3.4 kg

Integral Instrumentation Voltage and temperature readouts are provided with high quality photographic recording.

Data Aquisition Capabilities Sample behavior, voltage, column temperature, and time are photographically recorded.

Facility Integration Options The apparatus is intended for use on the Orbiter middeck.

Additional Notes The presently available apparatus requires refurbishment and modifications to suit specific experiments.


HASSELBLAD
CAMERA
ELECTROPHORETIC
COLUMN
VOLTAGE AND
TEMPERATURE
READOUTS
COLUMN
STORAGE
THERMOELECTRIC
COOLER

Three Axis Acoustic Levitator

Experimental Capability This Three Axis Acoustic Levitator (3AAL) apparatus permits a liquid specimen to be positioned and manipulated by a three-dimensional acoustic energy well. Manipulations include rotation, oscillation and drop fusion/fission. The oscillation and rotation can be used to stir the liquid as well as center the gas bubbles in the liquid drop. Multiple samples can be injected and controlled while color or black and white motion pictures are obtained, which provide one direct view and two reflected views on orthogonal axes. Temperature, acoustic pressure and driver power can be monitored. The apparatus permits the investigation of a variety of fluid dynamic properties and particle interaction.

Mode of Operation Three acoustic drivers positioned along orthogonal axes are used to suspend the droplet in an acoustical energy wall. Pulsing or phasing of the drivers permits controlled oscillation or rotation. An injector deploys the liquid sample into the containment area with low velocity and little circulation within the liquid. The primary data recorder is a 16mm movie camera which employs a mirror system to obtain a three view record. Synchronized strobe lights allow the investigator to obtain either a color or a black and white rendition of the experimental sequence.

Operational Parameters

Voltage..	28 vdc
Power..	126 watts
Acoustic pressure...	150 dB max
Disturbance acceleration tolerance........................	10^{-4}g
Estimated acoustic pressure (fundamental mode)........	1 dyne/cm^2

Sample Parameters

Sample diameter...	0.3-2.5 cm
Sample volume...	0.14-8.0 cm^3
Max. sample translation..................................	3 cm
Max. sample ratation......................................	30 rps

Physical Characteristics

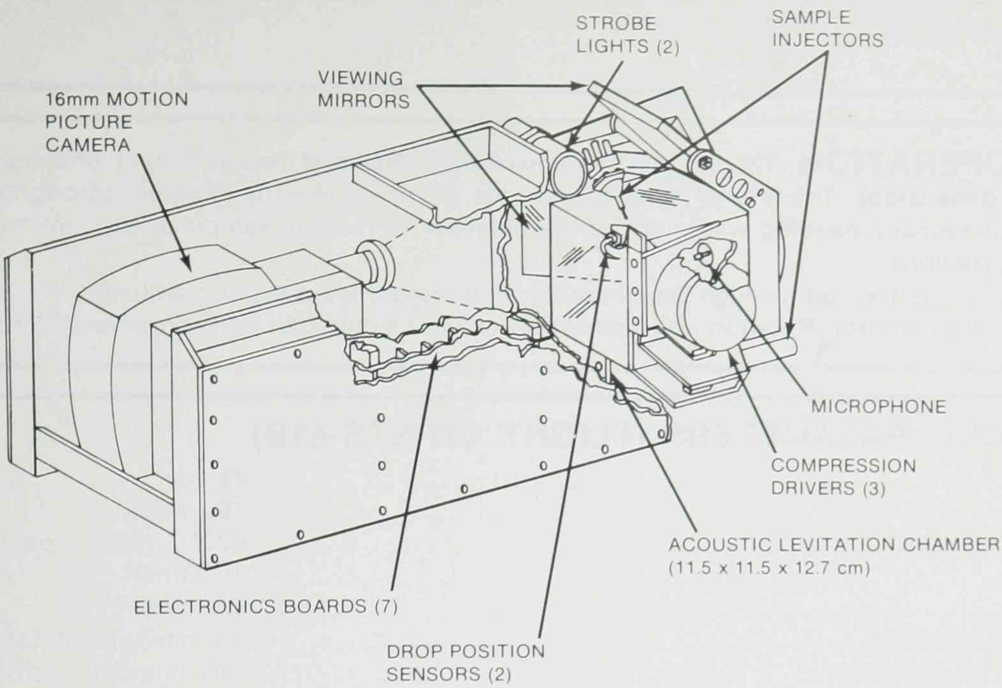
Apparatus length..	68.58 cm
Apparatus diameter...	38.74 cm
Aparatus weight..	70.82 kg
Chamber size..	11.5 x 11.5 x 12.7 cm

Integral Instrumentation Drop positioning sensors (2) and a 16 mm video camera with a mirror system.

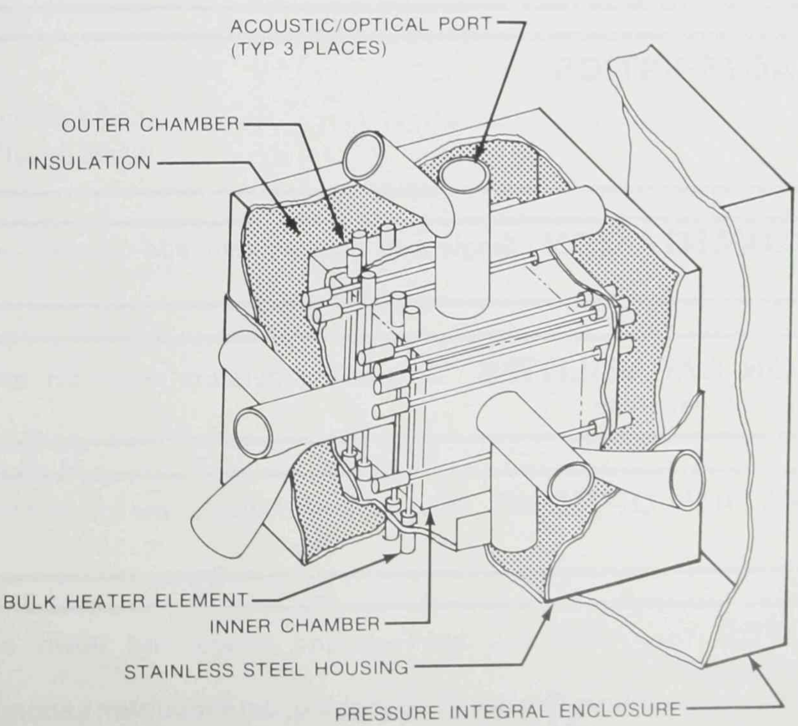
Data Acquisition Capabilities Color or black and white video record of the processing sequence.

Facility Integration Options The apparatus is housed in an Experiment Apparatus Container and mounted in the Orbiter payload bay.

ACOUSTIC LEVITATION SYSTEM



LEVITATION CHAMBER



Acoustic Containerless Experiment System

Experiment Capability The Acoustic Containerless Experiment System (ACES) is a flight facility that will melt and acoustically oscillate a single sample of glass, ceramic, or metal while it is acoustically restrained within the central area of a resistance heated rectangular furnace filled with an inert gas. The experiment is monitored by thermal sensors and a video recording system during the 120 minute duration which provides about 15 minutes at the present limitation of 620° C.

Mode of Operation The furnace is an insulated resistance heated Inconel chamber of 6.3 by 6.3 by 7.0 cm internal dimensions. The energy of the three acoustic drivers enters the chamber through three orthagonal ports and forms resonant standing waves within the chamber to restrain sample excursions from the effects of external g perturbations.
Resonant frequency is tracked through the chamber temperature changes and adjusted to maintain resonance and sample location control. Rotation and oscillation of the sample can be programmed into the experiment.

Operational Parameters (Flight on STS-41B)

Voltage	28vdc
Power	160 watts
Operating temperature	620°C (900°C potential)
Heating rate	10°C/min.
Cooling rate	4.5°C/min.
Furnace gas environment	dry nitrogen at 14.7 psi
Electronics gas environment	30% humidity nitrogen/10% He

Sample Parameters

Sample capacity	1 sample/flight
Sample size	approximately 1.0 cm diameter

Physical Characteristics

Two cannisters:	inside diameter 42.16 cm inside length 44.07 cm

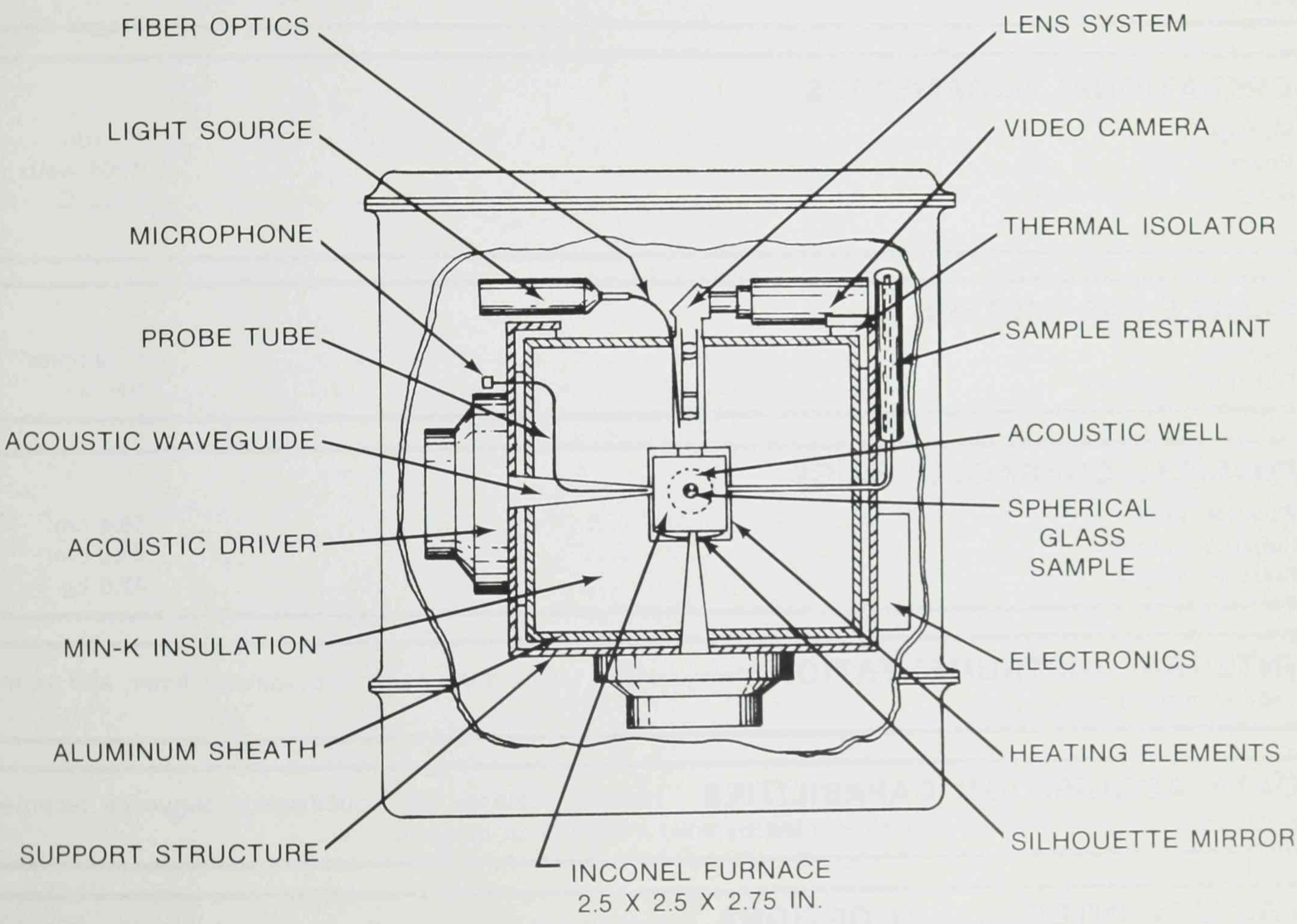
Integral Instrumentation Single axis video system, add-on micro-accelerometer externally mounted.

Data Acquisition Capabilities Data for temperature, electrical, and acoustic performance recorded on audio portion of videotape.

Facility Integration Operations This unit was located in the forward locker array of the Orbiter on flight STS-41B.

Additional Notes The ACES has been ground tested and flown on STS-41B. Post flight modifications are now progressing.

FURNACE CANISTER



Electromagnetic Levitator Furnace

Experimental Capability The Electromagnetic Levitator Furnace (EML) allows a conductive sample to be positioned in the levitation coil aned melted by inductive heating in a vacuum or controlled gaseous environment. Following the melt phase, power may be reduced at a rapid rate, allowing radiative cooling and solidification of the specimen. Additional cooling is possible through the use of a quench gas. Pyrometric apparatus is useful for performing undercooling and nucleation studies, preparation of amorphous and metastable phases in metallic systems, and thermophysical measurements.

Mode of Operation The sample is suspended in the electromagnetic field of a cusp coil and is heated and melted by induction from the coil's electromagnetic field. The cusp coil consists of adjacent coils having opposing alternating magnetic fields. An active servo positioning system maintains the electrically conductive specimen in the center of the coil system against acceleration during flight and damps oscillations of the specimen. The experimental sequence is controlled by a timer allowing fully automatic operation following initiation of the timer sequence.

Operational Parameters

Voltage	28 vdc
Power	1204 watts
Operating temperature*	1300° C

Sample Parameters

Capacity	6 samples
Spherical diameter	0.9 cm

Physical Characteristics

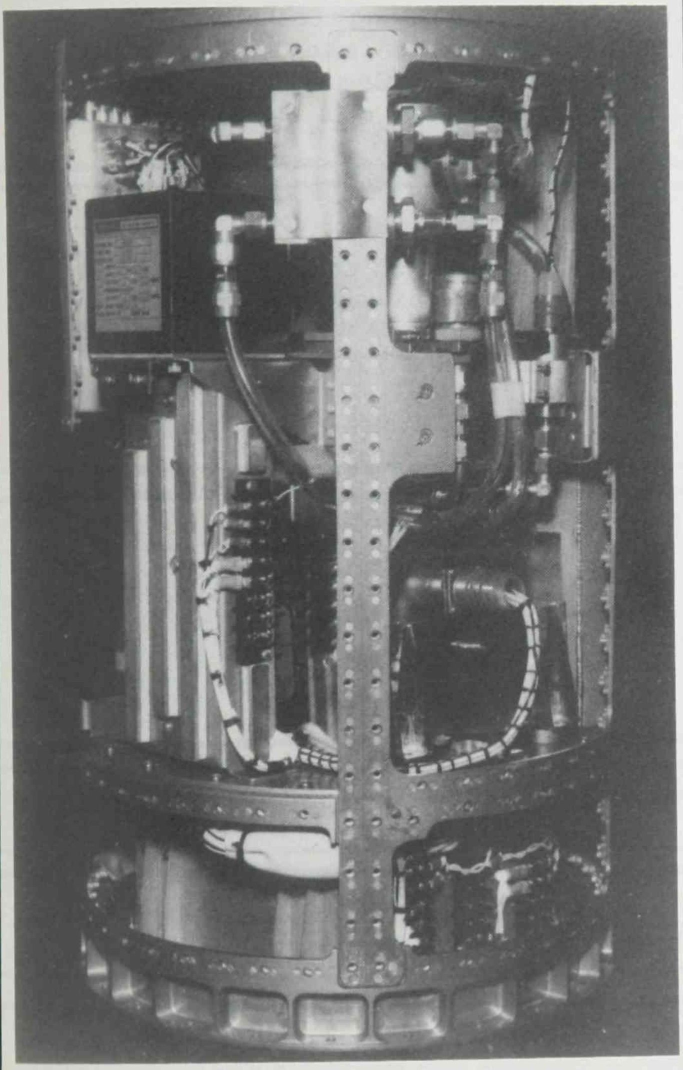
Furnace length	58.4 cm
Furnace diameter	35.6 cm
Furnace weight	42 kg

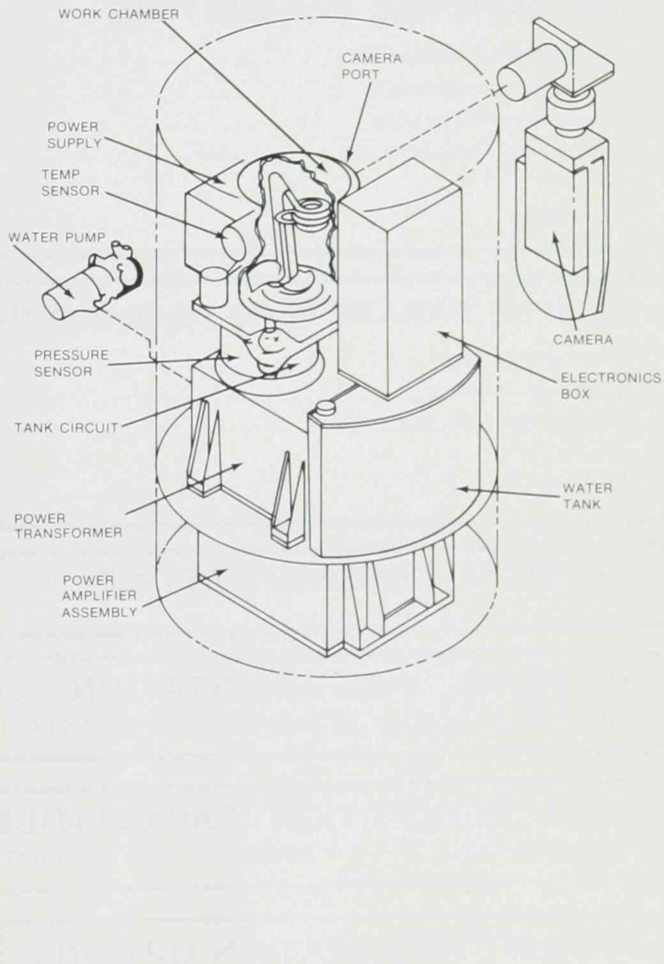
Integral Instrumentation Pressure and temperature sensors, pyrometer, timer, and 16 mm motion picture camera.

Data Acquisition Capabilities Heating , melting, and solidification sequence recorded photographically; temperature data recorded by solid state silicon detector.

Facility Integration Options Operation of this apparatus is restricted to the Materials Science Lab located in the Orbiter payload bay.

Additional Notes *Actual temperature achieved as a function of sample size, emissivity, and resistivity.




WORK CHAMBER
CAMERA PORT
POWER SUPPLY
TEMP SENSOR
WATER PUMP
PRESSURE SENSOR
TANK CIRCUIT
POWER TRANSFORMER
POWER AMPLIFIER ASSEMBLY
CAMERA
ELECTRONICS BOX
WATER TANK

Fluids Experiment System

Experimental Capability The Fluids Experiment System (FES) is a multi-purpose fluids research facility used to investigate crystal growth phenomena in microgravity through utililzation of the grown crystal and holographic records of the growth process. It can accommodate a variety of experimental cells for performing a broad range of fluid experiments in areas such as fluid convection, phase transition, surface physics, and bubble behavior. Samples can be processed for post-flight analysis, and real time flow visualization can be obtained using a schlieren technique. The facility will allow confirmation of the advantages of microgravity environment and evaluation of the feasibility of producing solution grown crystals on orbit.

Mode of Operation The system includes an optical bench for making holograms of a test cell from two orthogonal views. Real time viewing in schlieren or shadowgraph modes is provided by means of a video degree of saturation at the growth interface. Composition profiles can be mapped using holographic interferometry. The system is designed to be used in combination with the Vapor Crystal Growth System (VCGS) and, as such, provides support to the VCGS for microprocessor control, and data acquisition, display and transmission.

Operational Parameters

Holographic resolution	< 20u @ 10:1 contrast ratio
Holographic capacity	450 photos each, transverse and primary
Heating/cooling rate	0.5° C/min
Operating temperature of test cell	ambient to 70° C (SL-3 only)
Power	1.0 kw max average
Cooling	10-20° C Water, 10-35° C Air

Sample Parameters (Spacelab III Mission)

Crystal isolation	< 8° C/cm gradient
Residual fluid	2.0 cc
Crystal growth duration	2 test cells @ 24 hrs 1test cell @ 60 hrs
Test cell fluid	triglycine sulfate 1.8-2.5 pH

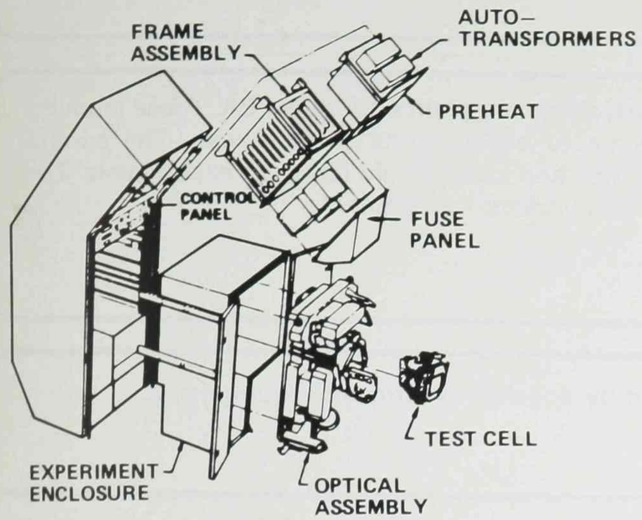
Physical Characteristics The FES is configured within a Spacelab double rack.

Integral Instrumentation Closed circuit television with remote to ground, 70 mm holographic recorder, accelerometer, and Process Control and Data Acquisition (PCDA) microprocessor.

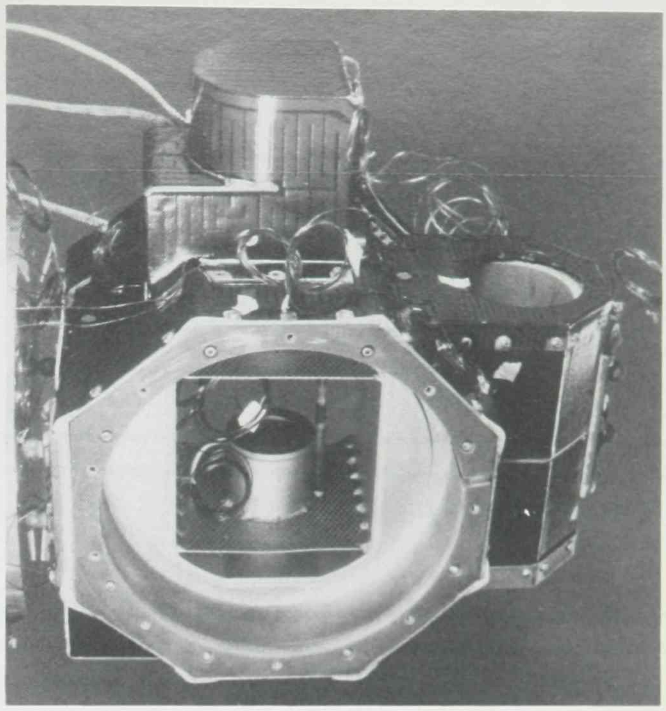
Data Acquisition Capabilities PCDA microprocessor provides all data processing requirements (up to 1sps/parameter) and transmits directly to the Spacelab high rate multiplexor for ground link.

Facility Integration Options The system is designed for installation in a Spacelab double rack.

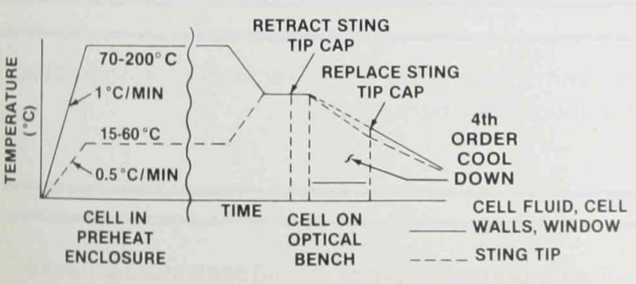
EXPLODED VIEW



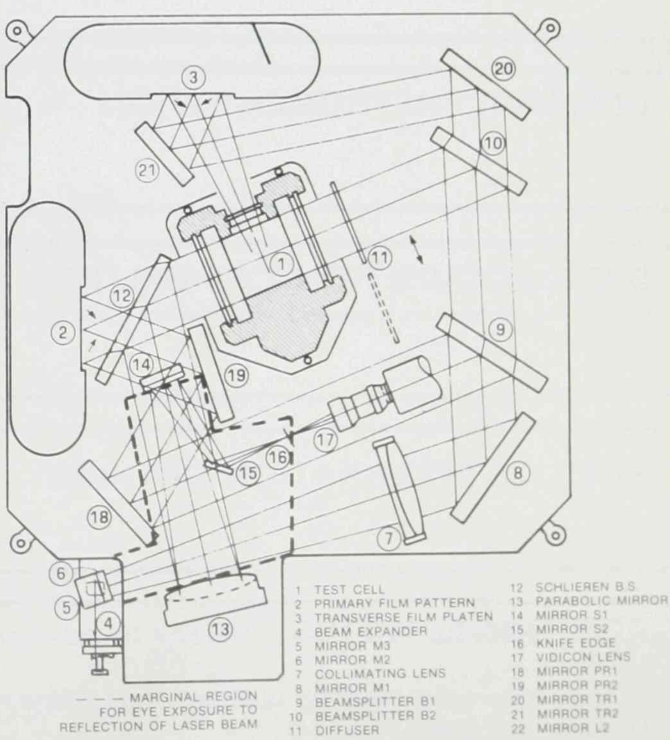
TEST CELL



TEMPERATURE PROFILE (SL-3)



HOLOGRAPHIC VIDEO SYSTEM



Fluid Experiment Apparatus

Experimental Capability The Fluid Experiment Apparatus (FEA) is a modular microgravity chemistry/physics experiment system to support fundamental space processing research. It is designed to conduct basic and applied process or product development experiments in general liquid chemistry, crystal growth, fluid mechanics, thermodynamics, cell culturing, and additional areas.

Mode of Operation A number of specialized subsystems are planned for the FEA. These modules will allow the FEA to be configured to support a wide range of experimental requirements. The current configuration (FEA-1) will accommodate float zone crystal growth and certain fluid handling experiments. The mode of operation will vary greatly dependent upon specific experiment requirements.

Operational Parameters To be determined by specific experiment requirements.

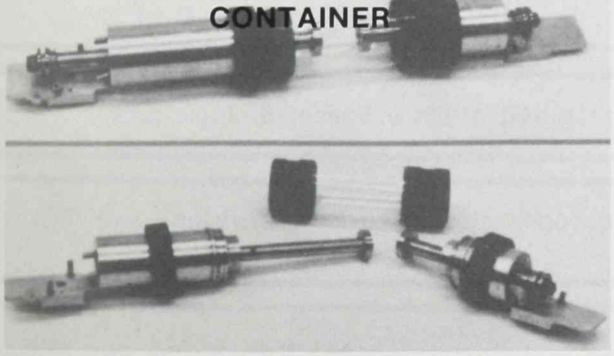
Sample Parameters To be determined by specific experiment requirements.

Physical Characteristics The FEA is completely self-contained and configured to replace a standard Orbiter middeck storage locker.

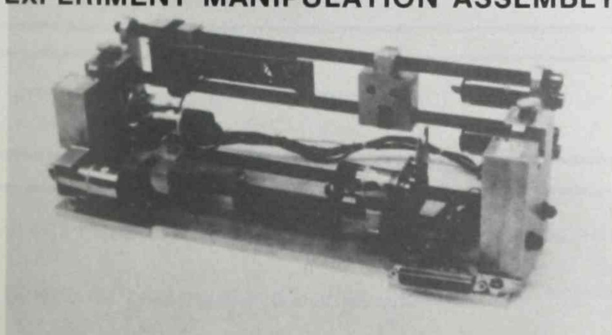
Data Acquisition Capabilities A variable frame rate (1/60 to 36 seconds) photographic recording system is included. Additional data acquisition capabilities can be provided.

Facility Integration Operations The unit will be mounted in place of middeck storage locker.

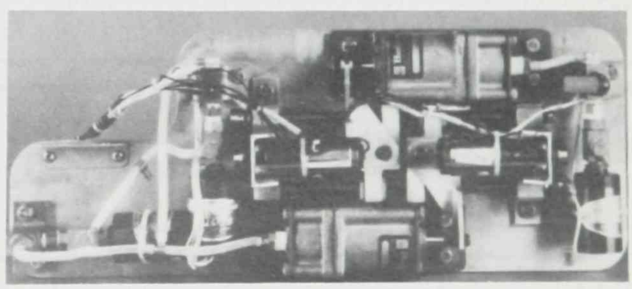
FLUID MANIPULATION EXPERIMENT CONTAINER



EXPERIMENT MANIPULATION ASSEMBLY



FLUID STORAGE AND PUMPING ASSEMBLY



Vapor Growth Crystal System

Experimental Capability The Vapor Growth Crystal System (VGCS) is a special purpose facility emulating vapor crystal growth ground experimentation hardware, providing both the grown crystal and in-flight microscopic observation of the growth process via closed circuit television. The apparatus is useful in comparing the structural and spectrographic properties of microgravity grown crystals with Earth grown crystals to determine low-g growth effects. It meets the objective of growing single crystals by vapor transport while inhibiting polycrystalline nucleation.

Mode of Operation The VCGS furnace contains three separate heating elements. The growth ampoule contains a temperature controlled pedestal which positions and controls the seed temperature. Source material for the vapor transport process is positioned on the ampoule sidewall. A binocular microscope is used by the Payload Specialist to monitor the growth process and modify the growth parameters as required. The VCGS is designed to be used in conjunction with the Fluids Experiment System (FES) and relies on the FES for support in the areas of data entry/display, process control, and power control/distribution.

Operational Parameters

Source heater range	100-120° C
Source heater modulation	±2.5° C
Source heater rate	5° C per 2 min
Ring heater range	120-180° C
Ring heater rate	0.005-0.500° C/hr
Sting heater range	40-80° C

Sample Parameters

Test ampoule diameter	8.0 cm
Test ampoule length	11.0 cm
Test ampoule strength	1.5 atm @ 180° C
Test chamber air loop	20-30° C ±1° C

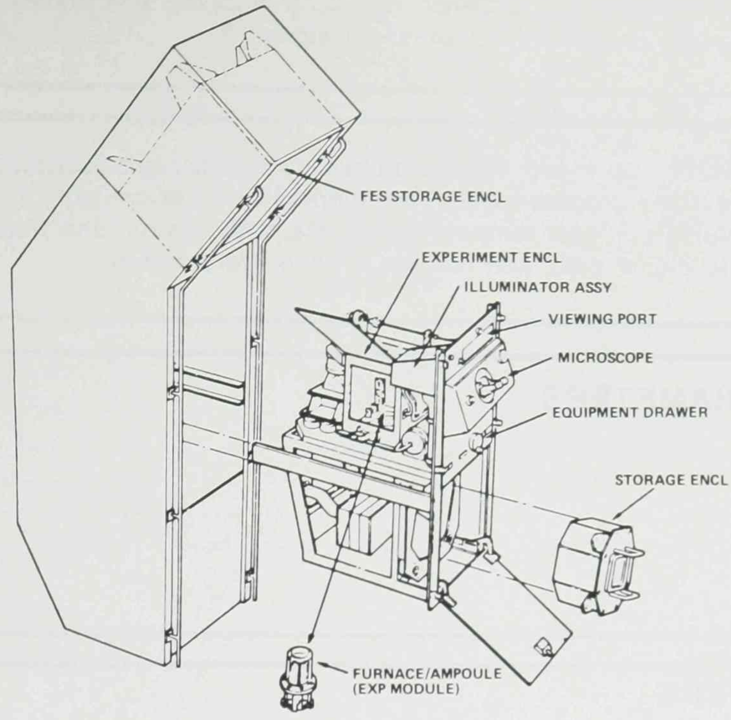
Physical Characteristics The VCGS is configured within a Spacelab single rack.

Integral Instrumentation 10-30x microscope, closed circuit television, and PCDA microprocessor when used in conjunction with FES.

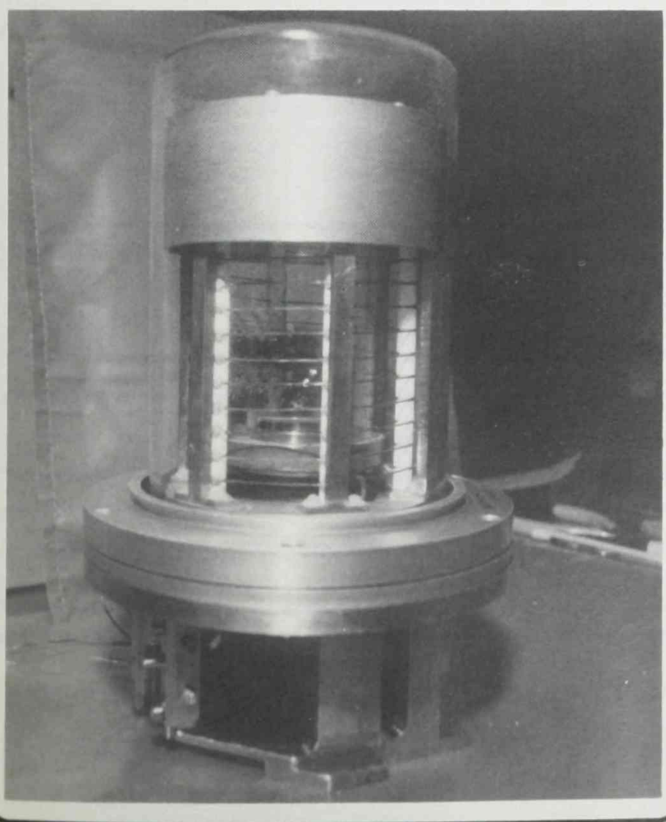
Data Acquisition Capabilities When used in conjunction with FES, and the FES PCDA microprocessor handles all data processing requirements and transmits directly to the Spacelab high rate multiplexer for ground link.

Facility Integration Options The VCGS is designed for installation in a Spacelab single rack located adjacent to the FES facility.

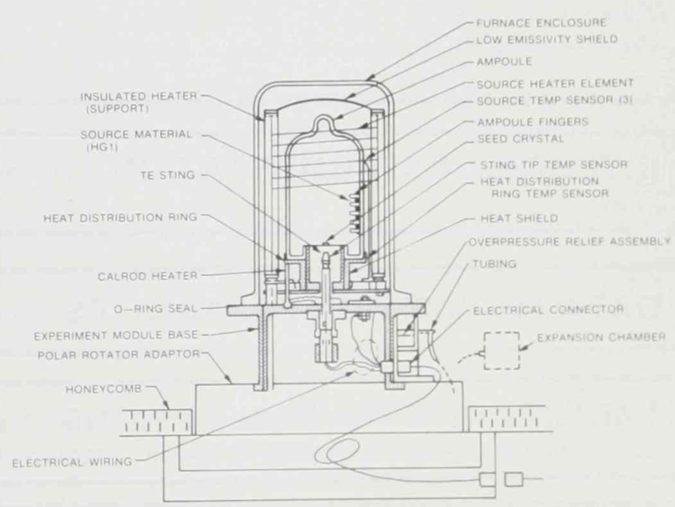
EXPLODED VIEW



VCGS RACK ASSEMBLY



FURNACE/AMPOULE ASSEMBLY



Monodisperse Latex Reactor System

Experimental Capability The Monodisperse Latex Reactor System (MLRS) consists of four reactors in an Experiment Apparatus Container (EAC), a Support Electronics Package (SEP), and two interconnecting cables, one for power and the other for signal.

Mode of Operation Up to four 100 ml batches of material can be stirred only in the preprocess mode, or stirred and heated in the process mode. Two temperatures are available, nominally 70 to 90° C. During the process mode, one volume and four temperatures (base, wall, piston, and fluid) are measured. The SEP converts this analog data to digital data and records it once every minute.

Operational Parameters

SEP input voltage	28 ± 4vdc
MLR input voltage	36 vdc
SEP input current	13 amp (max)
MLR input curent	6 amp (max)

Sample Parameters

Capacity	4 samples
Sample volume	100 ml
Cylinder inner diameter	4.1 cm
Cylinder length	7.8 cm

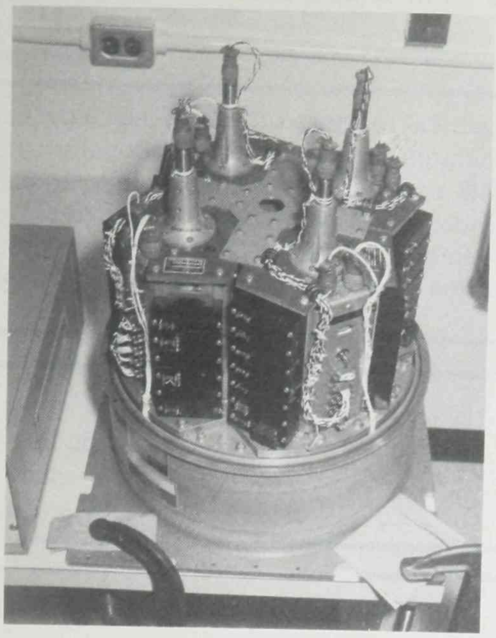
Physical Characteristics

Reactor length	38.1 cm
Reactor diameter	20.6 cm
Reactor weight	6.8 kg

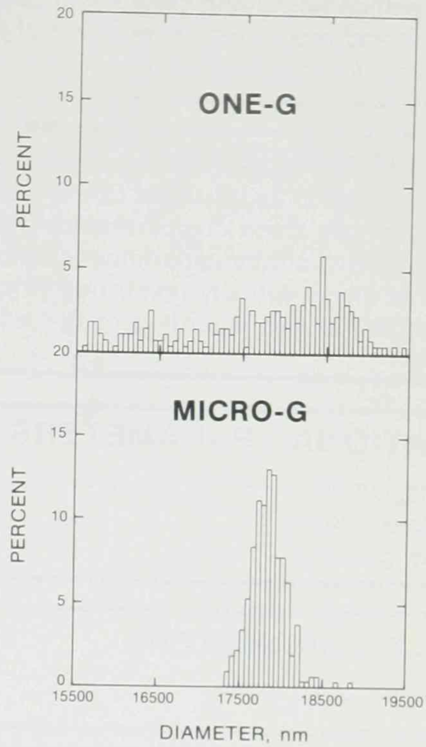
Integral Instrumentation
Volume change (1), temperature probes (4)

Data Acquisition Capabilities The SEP can record up to 22 channels of data at a rate of 1 sps.

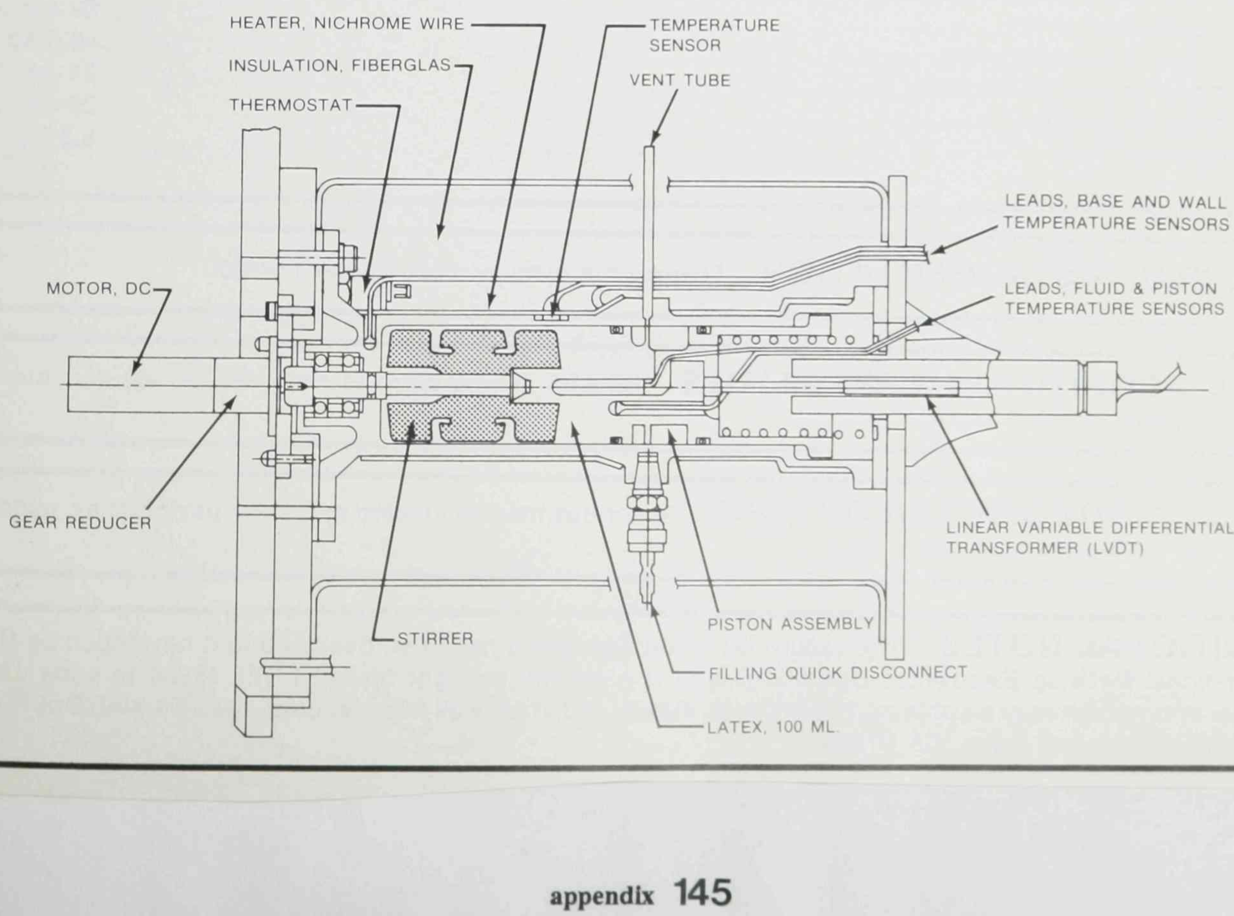
Facility Integration Options The MLR is designed to be housed in an experiment apparatus container and attaches to a double adaptor plate in the Orbiter middeck.



TYPICAL PARTICLE SIZE DISTRIBUTION



FULL SECTION OF ONE REACTOR



Solute Diffusion Apparatus

Experimental Capabilities The Solute Diffusion Apparatus can keep liquid reactant solutions separated until established in earth orbit, and then open the valves separating them to allow the solutions to diffuse together slowly and react chemically to form single crystals without gravitational effects. The apparatus can control and record the temperature of the solutions and provide for their thermal expansion or contraction. The solution volumes are variable.

Mode of Operation The apparatus consists of four cylindrical reactors surrounded by a cylindrical resistance heater in an insulated cylindrical enclosure and a microcomputer in a separate cylindrical enclosure. Each reactor has three compartments. The two outer compartments contain the reactant solutions and are designed to cause virtually no stirring when they are opened. The microcomputer controls the entire process, including control and recording of the temperature and opening of the valves. Electric power is supplied by batteries.

Operational Parameters

Operating temperature	260-320° K
Power consumption	5 watts
Maximum power	37.5 watts

Sample Parameters

Total volume per reactor	2 liters

Physical Characteristics

Reactor outside diameter	7.6 cm
Reactor length	71 cm
Reactor enclosure outside diameter	30 cm
Reactor enclosure length	82 cm
Reactors and enclosure mass	48.6 kg
Microcomputer outside diameter	21 cm
Microcomputer length	28 cm
Microcomputer mass	8.5 kg

Integral Instrumentation Thermistors with microcomputer control.

Data Acquisition Capabilities Reactor temperature is recorded at regular intervals in microcomputer random access memory.

Facility Integration Options Apparatus may be located in Orbiter payload bay, middeck, or free-flying retrievable satellite.

The idea that people other than highly trained astronauts would someday live and work in space has long fascinated science fiction fans. Today it interests professional space scientists and engineers as well. The Space Shuttle, in which anyone in ordinary good health can ride into orbit, was the first step in turning this dream into reality. The Space Station, planned for initial operation in the 1993-1994 time frame, will provide a permanent facility in orbit for continuing technical and scientific work. It will be operated by rotating crews from Earth, including personnel who are not career astronauts.

The Space Shuttle takes much larger crews into orbit than any prior launch vehicle. The work these crews perform varies greatly, according to the particular mission. Some tasks are similiar to those done every day on Earth, but most are unique to the requirements of spaceflight. Early missions were devoted primarily to verifying the performance of the Space Shuttle and its associated equipment. Crews on later flights have operated instruments to perform extensive observations of the Earth, studied objects of interest in astronomy, processed materials in microgravity, and performed biological experiments with seeds, plants, insects and small animals. A very important part of the work has been launching satellites for scientific and commercial use, and repairing spacecraft in orbit. Some satellites have been recovered from orbit and returned to the ground, ready to be refurbished and launched again.

The Space Shuttle and the Space Station are the largest components in NASA's Space Transportation System, of STS. The system will eventually include other small reusable vehicles and stations as well. The Space Station is now in the design phase, and should be operational by 1994. The first of two small reusable support vehicles that will be used in conjunction with the Space

Station is also in work.

The private sector is also working on a space facility. Bell and Trotti, a Houston based architectural firm have joined with Westinghouse earlier this year to build and launch the Industrial Space Facility, the first privately owned space facility. The ISF is scheduled to go into orbit in 1992, a full two years before the NASA space station goes up. NASA has promised to donate two and a half payloads of cargo space on the next available Space Shuttle flights to Space Industries, and is allowing the company to pay on credit.
Perhaps one of the important questions that must be asked is, Why in Space? Just as materials processing on Earth made the leap into space a reality, the space program today offers unique opportunities for materials processing. The most important benefit of processing in space is extended weightlessness. On Earth, gravity causes materials of different densities and temperatures to separate and materials to deform under their own weight. In the microgravity of an orbiting spacecraft, however, scientists can use unique materials processing techniques, techniques that are all but impossible on Earth. The results may lead to a material or a processing approach of scientific or commercial value. Among the commercial, scientific, and military benefits of space-based processing are:

Electronic Materials (crystals). Pure, nearly perfect crystals are required in computers, lasers, and numerous other optical and electronic devices. Space processing permits crystal purity and uniformity far beyond those possible on Earth.

Metals, glasses, and ceramics. High-strength metals and temperature-resistant glasses and ceramics are essential to power generation, propulsion, aviation, aerospace, and related applications. Containerless processing in space permits scientitsts to mix and solidify metals and ceramics in forms and at levels of purity that cannot be obtained on Earth and offers a better understanding of solidification processes on Earth.

Biological materials. Seperation of macro-molecules (proteins, enzymes, cells and cell components) is fundamental to all fields of biological research. Weightless processing permits scientists to separate and purify biological materials more effectively than can be done on Earth.

Fluids and chemicals. Virtually every physical science depends on an understanding of the effects of gravity on convection, buoyancy, sedimentation, and the like. Investigations of fluid physics and combustion processes under weightlessness can help reveal subtle interactions among atoms and molecules that are not observable under normal gravity.

The field of materials research has always been hindered by gravity induced disturbances that restrict observation and limit understanding and control of pertinent phenomena occurring a gaseous or a liquid phase. Thermal gradients in molten materials give rise to gravity driven convection currents which, in turn, prevent solidifying materials from attaining the desired structure and composition. Gravity also intrudes in other ways: it creates hydrostatic pressure, causing hot materials to deform under their own weight; it distorts wetting and surface tension effects; and it causes seperation of materials having different densities.

Although use is commonly made of high acceleration fields such as in centrifugal seperation of fluids, very little attention has been paid to material processes in an environment of less than one gravity. Microgravity (weightlessness) occurs in free-fall in our Earth environment. Environmental factors such as temperature and pressure are controlled and used in materials processing. They are applied at much higher and lower values than are naturally available at the Earth's surface. Variations in gravity, on the other hand, have been used only at higher values because microgravity has been difficult to attain.

Some microgravity experimentation has been performed with promising results. For example, it has been demonstrated that crystals grown in microgravity can be more uniform in compositionand, in some circumstances, freer of defects than crystals grown in otherwise comparable conditions on the ground.

Materials Processing is one of the central elements of NASA's microgravity program. A simple definition cannot adequately explain the term. Materials processing is the conversion of sand to silicon crystals for use in semiconductors. It is the separation of ordinary biological materials into invaluable drugs and chemicals. It is the production of high-strength, temperature resistant alloys and ceramics. It is, in short, the science of processing ordinary and comparatively low-valued raw materials into crystals, chemicals, metals, ceramics, and countless other manufactured products.

Materials processing enables us to build modern computers to process information and communication systems to transmit it. Materials processing enables us to build turbines for aircraft and electric power plants. Materials processing makes possible revolutionary advances in the production of chemical and biological compounds, such as insulin. And, not surprisingly, materials processing, by producing high-strength alloys and heat resistant ceramic tiles, makes the space program possible.

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One of the most exciting areas of microgravity research is biological materials processing. Processing biological materials typically requires separating specific cells, cell components, antigens, hormones, and proteins from a biological medium.

On Earth, one of the most widely used analytical technologies is electrophoresis. In electrophoresis, a gel or another supporting medium is used to suppress convective flows. Small batches of materials are separated by differences in net electrical charge, size and shape. Positive and negative potentials are applied to either end of a medium containing the materials to be separated. As the electrical potentials are applied, materials migrate through a gel or other supporting media toward the attracting potential. Scientists can concentrate some of the desired materials.

To extend this process to a preperative scale or apply it to cells, cell components, or other particles, the supporting media must be eliminated. Such "free-flow" electrophoresis techniques have met with limited success on Earth because of gravity driven convective flows, which tend to remix the separated components.

In space, the convective flows are virtually eliminated. Separation techniques such as continuous flow electrophoresis (CFE) permit separation of biological materials in quantities and levels of purity unattainable on Earth.

In CFE, which is efficient only in a weightless ennvironment, a continuous flow of biological material is separated. Without the effects of gravity to distort the separation process or the separation medium, gels or other supporting media are no longer required. Larger quantities of purer materials can be produced. Cells and cell components that would not pass through the pores of the gell can be separated in space by this process. The potential commercial benefit of space-based CFE is sufficient that a U.S industrial consortium has already sponsored a commercial CFE experiment aboard the Shuttle.

The potential benefits from weightless electrophoresis and other biological materials processing techniques are enormous.

The importance of biological materials processing in space can be understood by considering the quantities and values of desired materials. On Earth, many essential biological materials can be produced only in gram or millgram quantities and then only at costs of tens of thousands of dollars per unit. The value of these materials per unit of weight and the ability to produce greater quantities in the weightless environment of space mean that commercial-scale production in space may prove to be very economical. In addition to commercial-scale production of proven materials, space offers the opportunity for extended research into new and promising biological techniques commercially unattainable in the gravity on Earth.

Crystals are at the heart of the electronic revolution. Crystals, made of sisicon or other materials, are the basis of semiconductors, computers, radiation sensors, and lasers. Crystals enable us to operate satellites for worldwide communications, weather reconnaisance, and military surveillance. Crystals allow us to explore frontiers -- for example, artificial intelligence -- that were once thought unreachable.

The structure and purity of the crystals that support these technologies are remarkable. Inpurities measured in the parts per billion can render a cryatal useless. Structural defects at the molecular level can have the same effect. On Earth, these problems are partially overcome only with complex and costly processes for growing crystals and obtaining the desired electrical properties. Space offers at least two highly desirable conditions for crystal growth:

*Weightlessness permits scientists to grow large, nearly perfect crystals. Gravity-driven flows that deform the face of the growing crystal or distort the crystallizing zone are absent in a weightless environment.

*In a weightless environment, objects like crystals can be processed without a containerm Containerless processing permits scientists to melt and solidify crystals without the crystals absorbing impurities from a container.

Metals, glasses, and ceramics

If crystals provide the electronic basis for the future, metals, glasses, and ceramics provide the structural bases. Advanced metals, glasses, and ceramics are essential to such products as jet engines, nuclear power plants, electro-optical devices, and the Space Shuttle itself.

In the case of the Space Shuttle, for examble, the heat of reentry (up to 3,000°F) is enough to destroy every metal known. The solution? A ceramic made of silica fibers, offering exceptional heat resistance. When formed into a tile at high temperature and low pressure, the silicon fiber becomes a low density solid that resists the heat of reentry. Such ceramics offer a wide range of opportunities for high-temperature applications.

Where high temperatures are combined with high stress, however, ceramics can crack. For these types of applications, including the turbine blades of jet engines, special metals are needed. These metals are cast under exacting conditions to ensure the precise structure recquired.

The weightlessness of space offers scientists an opportunity to investigate and improve the methods for creating advanced metals, glasses, and ceramics. While no one expects giant space foundries to turn out quantities of manufactured products in the near future, scientists do expect this research to uncover compounds whose properties are of great value.

Another important benefit of space processing may be the development of lower-attenuation glass fiber for use in the optical communication systems, these fibers would allow more signals to be sent over a longer distance than do conventional fibers.

Among the important methods that could benefit from weightlessmess is directional solidification. Under directional solidification, metals can be given enhances properties along a preferred direction. For applications that place a great strain on the metal in a known direction, as in a jet turbine, directionally solidified metals are invaluable.

Another important process that can be studied extensively in space is rapid undercooling. In this process, a metal is solidified so rapidly that its atoms cannot organize themselves into their normal metallic structure. The result, a disordered structure similiar to that of glass, gives the material unusual properties. This process, studied in space, is advancing casting technology on Earth.

thesis statement

Architecture is the physical embodiment of the spirit of the need it serves. Architecture is a servant of mankind. At its best it serves to inspire and instill civic identity.

The built environment is the culmination of technology, cultural aesthetic, and personal values. Architecture is a planned, carefully conceived integration of the built environment and these expressions. When the spirit is present, architecture becomes something which is bigger than life; regardless of its scale. Architecture can never provide the "spirit", but intrinsically presents a medium for the clear transmission and enhancement of the "spirit".

Because architecture is not limited to just 'places' for activities it affects us on every scale - from the design of the key ring for our car, to the road system which moves us into the city we eat, sleep, and play in. Architecture is intuitively obvious only to the most passionate observer.

thesis proposal

The spirit of twenty-first century america is best described as one of competitive internationalism. And in no other facet of american life is this competitive drive more intense than in the American Space Program. The space shuttle is a necessary first step toward permanently manned space stations. The space shuttle will serve as the building platform for an orbitting pharmaceutical research and manufacturing lab in space. This facility will explore the possibility for the advancement and production of medical and pharmaceutical materials. Due to the prohibitive costs involved in the transport of people and materials, this facility will have to serve as a community for interrelated researchers, engineers, and medical technicians. The need for an architectural solution to the problems encountered in a dehumanized environment is enormous. We can not abandon this field to depersonalized functionally trained engineers. The persons involved in the activities of this research and manufacturing facility most be afforded all the benefits of a well planned city.

programming strategies

I will pursue the research for this thesis program in two major directions. Because of the fantasy nature of this project and the possibilities of exploring new twenty-first century technologies, much of my research will be done by personal correspondence with science fiction writers. I am currently attempting to obtain any technical material available from the Institute for Future Studies, (a NASA sponsored student program). The technical portion of the pharmaceutical research will be done with the help and guidance of the faculty and students of the Texas Tech University Health Sciences Center.

I look forward to the possibilities and opportunities this proposal will give me. The fantasy and technological aspects of this project will be the best possible vehicle for the advancement of my thesis; Architecture is the physical embodiment of the spirit of the need it serves, the need is a vehicle for the enhancement of America's competitive internationalism.

At present, the principle means of conducting orbittal research is via NASA's Space Shuttle. Experiments aboard the shutttle may be conducted in the middeck area of thee Orbitter cabin, in the cargo bay, using either the Materials Science Laboratory; and in the Spacelab module. Each of these Shuttle payload ares offer certain special characteristics.

Middeck payloads are carried in one or more of the 42 middeck storage lockers, each about 2 cubic feet in size with a maximum experiment weight of 60 pounds. Crew involvement with middeck experiments is possible.

Payloads using the Materials Experiment Assembly are self-contained and operate independently of the Shuttle itself. Payloads on the Materials Science Laboratory (MSL) use the resources provided by the Orbiter. The experiments can be large (up to 12 cubic feet [on an upcoming flight] and heavy (up to 2,100 pounds [on the same flight]). The total weight of the experiments in the laboratory is more than 3,300 pounds.

Spacelab experiments are similiar to MSL experiments in size and character, except that the crew can be more involved in experiments conducted in the Spacelab module. As Spacelab missions evolve, it is expected that each will be dedicated to a specific scientific discipline, such as materials processing, life sciences, or environmental observations. Use of dedicated discipline laboratories will reduce flight costs and intergration requirements and will permit increased coordination among experimenters.

Apparatus and equipment available or under development for these experiments include many types of furnaces for crystal growth and directional solidification, electrophoresis equipment, acoustic levitators, fluid experiment systems, and vapor crystal growth systems. Several of these systems are intergated into Spacelab racks and provide advanced multiuser processing. If the existing equipment and apparatus are not suitable for an experiment, investigators may build their own, using a low-cost approach made possible by the Shuttle's opportunities for reflight.

Recent accomplishments in NASA's Microgravity Science and Applications program range from theoretical to ground investigations to large experiments aboard the Shuttle. The June 1983 flight of the Shuttle carried six microgravity experiments: three sponsored by the United States and three sponsored by West Germany. The U.S. experiments are:

Containerless processing of glass. Glass samples were injected into a furnace, positioned by accoustic pressure, melted, and cooled. This containerless processing method can be used to better understand glass formation and to improve glasses for optical and electrical applications.

Miscibility-gap materials. An immiscible alloy is a mixture that separates rapidly under gravity. Before the molten metals solidify, density differences cause the less dense metal to float on the denser metal. The miscibilty problem for metals is very much like trying to mix two common liquids, oil and water. In the zero gravity of space, however, immiscible metals can be alloyed with the desired distribution constituents and studied. Such new alloys may lead to improved structural, electrical, and magnetic materials.

Among the German-sponsored experiments, two involved miscibility gap alloys and one involved solidification of composite materials. The fact that foreigh governments and U.S commercial investigators are willing to pay to develop the experiments they fly aboard the Shuttle indicates its importance to microgravity research.

Continuous flow electrophoresis. A recent commercial microgravity experiment, the Mcdonnell Douglass continuous flow electrophoresis, is being watched closely by other researchers. This experiment offers the potential for commercial production of biological materials, such as pharmaceuticals, in space. NASA plans continued space based research to refine and improve biological separation techniques for potential applications.

Over the next 5 to 10 years, microgravity research will stress both scientific and commercial goals. Products will include crystals, metals and ceramics, glasses, and biological materials. Processes will include containerless processing and fluid and chemical transport. As research in these areas develops, the benefits will become increasingly apparent on Earth: new materials, more efficient use of Earth's nonrenewable fuel resources, new pharmaceuticals, advanced computers and lasers, and better communications. Like space, the opportunities offered by microgravity science and applications are vast and are only beginning to be explored. The NASA program will evolve over the next decade to take maximum advantage of our planned Space Station capability.

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