Vol. 1, No. 9: Oct.-Dec., 1988
Special Information Topic Issue

SICSA OUTREACH
Sasakawa International Center for Space Architecture

Living in Space: Considerations for Planning Human Habitats Beyond Earth

New frontiers have historically created needs for architectural innovations. Sod houses used by North American prairie settlers and Quonset huts used by arctic explorers are examples. Expeditions and settlements in space present demanding challenges for habitat planners.

Architecture in space is fundamentally different in many respects than on Earth. Planners must be aware of unique human adaptation, performance and safety requirements. Zero- or reduced-gravity produces changes in body posture and influences the way most physical activities are accomplished. Launch payload constraints impose severe restrictions upon the allowable weight and volume of all structures and equipment. The life-safety-critical nature and remoteness of space missions demand that all systems be extremely reliable and easy to repair. Only nonflammable and nonpolluting materials can be allowed.

Planning for space missions should consider which functions can be performed best by people versus machines. Good design can enhance crew effectiveness, productivity, health and safety. Important priorities are to make tasks easier, more time-efficient and enjoyable. Properly planned and designed equipment can prevent errors associated with confusion and fatigue, and can avoid morale problems related to long-term isolation and boredom. Benefits will support overall mission success.

Life in a New Frontier
NASA Photo

Key Planning Objectives

Optimize Safety and Reliability

- *Prevent unnecessary safety hazards.*
- *Provide emergency intervention means.*

Promote Resident Morale and Satisfaction

- *Accommodate private and social needs.*
- *Provide interest and variety features.*

Enhance Productivity/Performance Quality

- *Apply space human factors knowledge.*
- *Plan convenient and efficient labor use.*

Manned Space Program Background

The development of a capability for space habitation has been one of NASA's most important objectives since the creation of the agency. Shortly after the Mercury Program was initiated in 1958, consideration was given to two possible initiatives, a small space station and a manned lunar mission. Active space station planning was temporarily halted when President Kennedy advocated that a lunar landing (the Apollo Program) should be a primary national goal for the 1960s. Nevertheless, a space laboratory operating in conjunction with the Apollo spacecraft was examined by NASA as a secondary objective. This study never progressed beyond a preliminary planning stage.

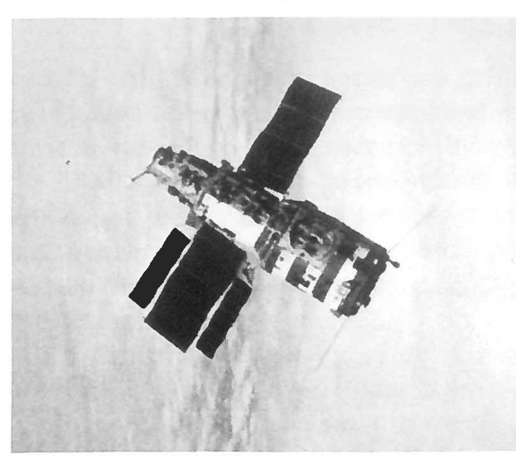
After the development phase of the Apollo Program was completed, NASA began to explore ways that Apollo hardware could be used in connection with an Earth-orbital laboratory. This effort culminated in *Skylab* (1969-1973) which was successfully launched and visited three times by three-man crews. During this period, design studies were conducted which produced other space station concepts, ranging in size from 6 to 24 person facilities.

Associated with space station planning was a proposed vehicle to transport crews and materials to and from Earth. As studies for a space station and a Logistics Vehicle progressed, emphasis was shifted to the vehicle, since transportation would be needed as a prerequisite for space station development. The Logistics Vehicle concept ultimately evolved into the present day Space Shuttle.

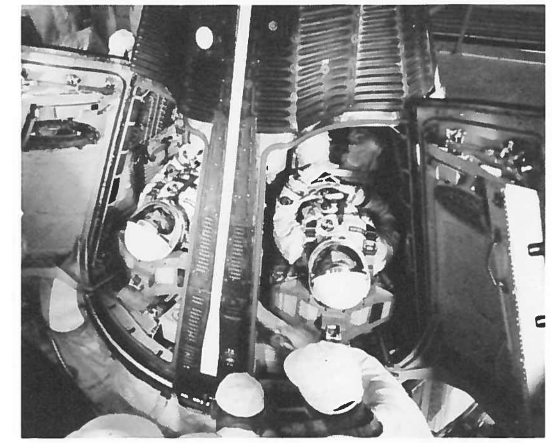
Following the Skylab Program, while the U.S. was delaying a commitment to develop an orbiting laboratory, the Soviet Union pressed ahead with an active space station program. The *Salyut 6* stayed aloft for four years and 10 months, hosting 30 cosmonauts and receiving 33 flights of manned and unmanned supply ships. Its slightly larger successor, *Salyut 7*, became the world's first modular space station.

Apollo-Derived *Skylab*
NASA Photo

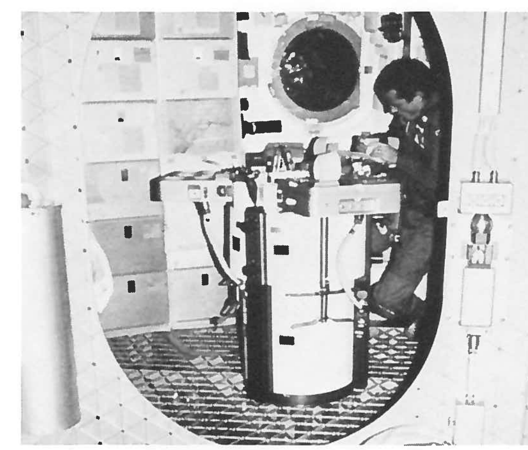
Logistics Vehicle-Derived Shuttle
NASA Photo



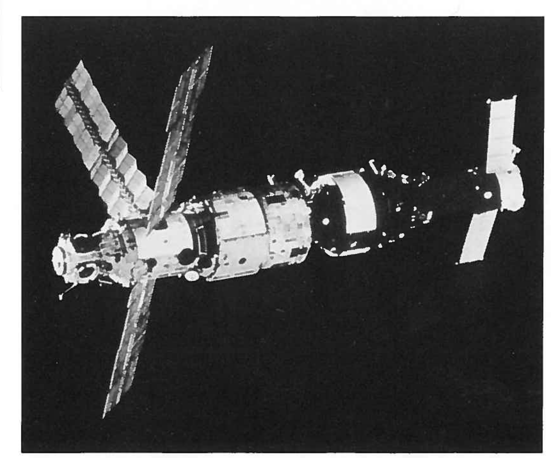
Salyut 7, First Modular Space Station
Soviet Photo-Courtesy James Oberg



Gemini Astronauts in Capsule
NASA Photo



Skylab Module Interior
NASA Photo



Kvant Module Docked to *Mir*
Soviet Photo-Courtesy James Oberg

Human Roles and Accommodations

Human roles and accommodations have advanced significantly during our short history of space flight. Mercury astronauts, functioning primarily as passive passengers, endured remarkably tight 40 cubic foot capsules. Gemini capsules, which enabled astronauts to pilot their spacecraft through complex orbit change and rendezvous maneuvers, were only 50 percent larger than Mercury, and carried two very cramped people. Apollo Command Modules provided four times the volume of Gemini capsules for their three-man crews. Apollo navigators and explorers visually guided spacecraft to safe lunar landing sites, surveyed the Moon's remote surface on foot and in rover vehicles, and brought back materials of great scientific value.

Provisions for crew comfort improved dramatically as capabilities to lift larger payload volumes into orbit increased. The 9,950 cubic foot Skylab offered nearly 45 times the amount of space available on Apollo missions. Its Orbital Workshop was divided into two levels, with ample volumes for working, sleeping, eating, personal hygiene and exercise.

Crew comfort takes on added importance as mission durations are extended. The third and longest Skylab mission lasted 84 days. Soviet space stations have supported cosmonauts on much longer missions. A 326 days-in-orbit record set onboard *Mir* was recently broken by Vladimir Titov and Musa Manarov who are scheduled to return in late December after a full year in orbit. *Mir* is the core module of a space station which is permanently manned. A Kvant astrophysics module is currently attached to *Mir*.

Present day Space Shuttle crews are willing to accept cramped quarters without privacy and with few amenities during short one to two week-long excursions. Future Space Station and lunar missions lasting several months, or Mars missions lasting years, are a far different matter. Means to optimize crew satisfaction will be essential for accomplishing successful programs.

Considering the Human Factor

Careful planning must be undertaken to optimize crew satisfaction and performance through attention to special "habitability" requirements in space. Proper design of living and work environments can have a positive influence upon how effectively and safely people accomplish mission tasks, how rapidly and thoroughly they adapt, how they feel about their surroundings, and even how healthy they remain over protracted periods of time.

Human factors planning must consider means to maintain the psychological and physical well-being of the crews under isolated and confined circumstances. Interior areas should be as comfortable and attractive as possible, emphasizing flexibility and convenience. Equipment design should reflect a good understanding of changes in body posture, leverage, procedures and other conditions imposed by zero- or reduced-gravity.

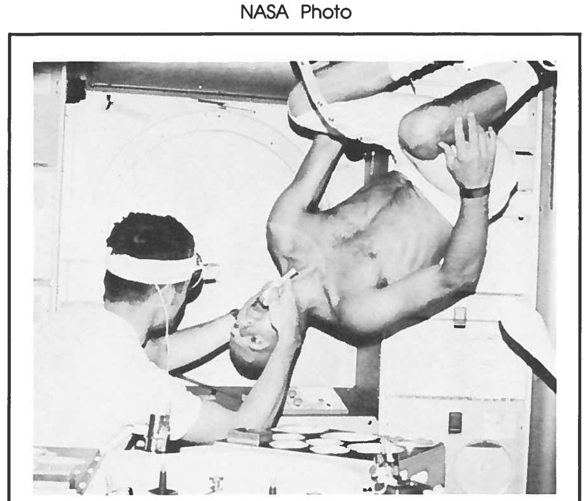
Variety is important to prevent boredom and depression. Means to change and personalize the appearance of interior areas and incorporate color and interest into the surroundings will be helpful. Menus should offer the widest practical range of choices, emphasizing enjoyment as well as nutrition. Schedules and accommodations should encourage exercise, recreation and social activities to help free time pass pleasantly.

People require time and places for private leisure. Sleeping quarters, for example, should be conducive environments for reading, listening to music and other solitary activities, incorporating devices to avoid intrusions of objectionable sounds, odors and other disturbances.

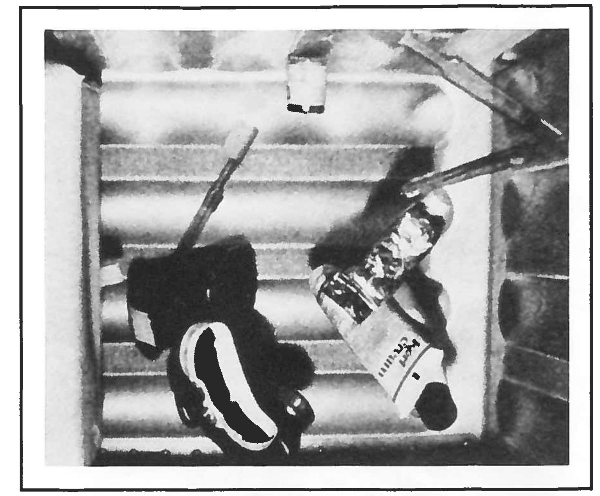
Means to maintain good hygienic conditions are extremely important. Since space habitats are closed systems, microbial growth can occur and spread rapidly, potentially causing human infections and foul odors. Problem areas and surfaces should be accessible and should be designed to facilitate easy cleaning.

Improvised Recreation in *Skylab*
NASA Photo

Meal Time Mixed with Play in Space
NASA Photo

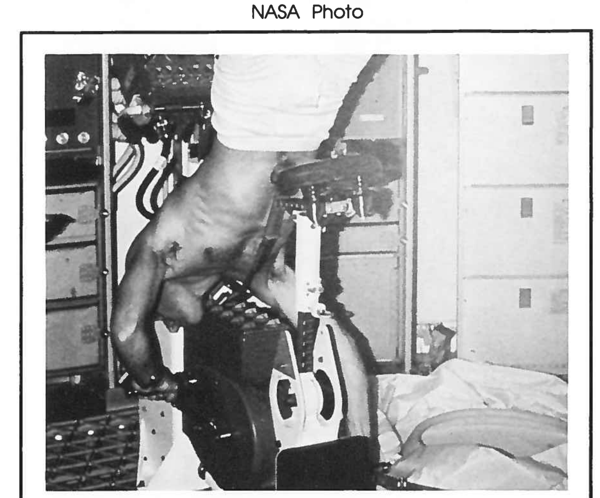


Health Maintenance in Space
NASA Photo



Contents Escaping from Drawer on *Skylab*
NASA Photo

Typical "Neutral Bouyancy" Body Posture
NASA Photo



Excercise on *Skylab*
NASA Photo

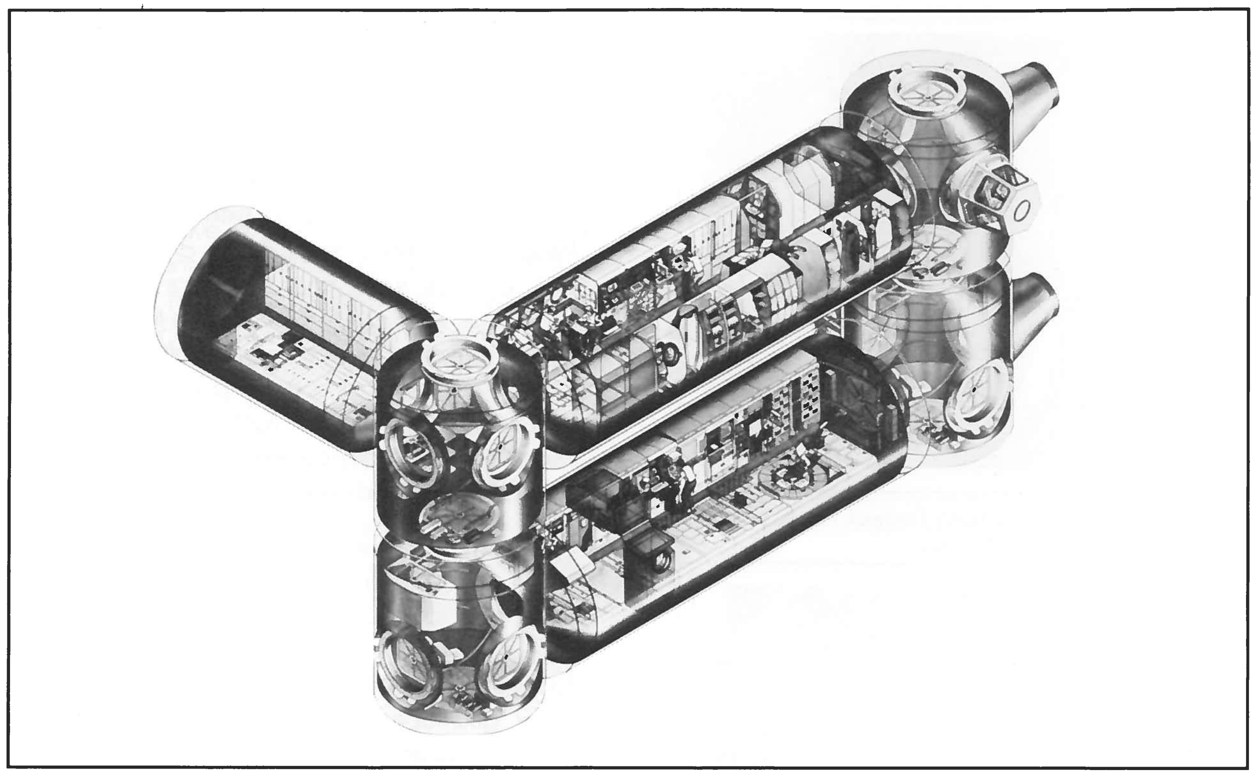
Influences of Zero-Gravity

The absence of gravity in orbiting habitats strongly affects most human activities. For example, in microgravity, the directions of "up" and "down" are established by the interior layout of the facilities, not by the orientation with respect to Earth. People can move freely in all directions. Therefore, ceilings, walls and floors can all serve as functional work areas. Since most interior surfaces are likely to be used as push-off places when people float from one area to another, switches and fragile items such as lighting elements should be protected. Sharp corners that can cause injuries when bumped should be avoided.

Anchorage devices are needed to hold people in place while they are performing stationary tasks, and to secure loose items which will otherwise float away. *Skylab* crews had cleats attached to their shoes that were inserted into triangular grid openings in floors for this purpose. Storage systems should be designed to keep contents from escaping when opened.

Body posture is altered significantly under weightless conditions. Without gravity to compress the spinal chord, the human torso elongates a few inches, but is not as stiffly erect as on Earth. Sitting in standard chairs is uncomfortable because without gravity, people need to constantly tense stomach muscles to keep their bodies bent. Accordingly, tables and other work surfaces should be raised to crouching heights of users since chairs are not needed. Table tops can be tilted since items placed on top must always be secured to keep them from drifting away.

Rigorous exercise regimes are necessary to help offset physical deconditioning effects of prolonged weightlessness. Life in zero-gravity leads to loss of muscle mass and weakened heart-lung systems. Bones leach calcium and become more brittle. Blood and other body fluids which normally collect in the legs under the pull of gravity collect in the chest and head, causing swollen faces, nasal congestion and occasional shortness of breath.



U.S. Space Station Modules Proposed by Boeing
Drawing by UH Experimental Architecture Program Graduate Li Hua

The U.S. International Space Station

Current planning for the U.S. International Space Station *Freedom* scheduled for operation in the 1990s emphasizes human safety, morale and convenience. While offering smaller interior volumes than *Skylab* astronauts enjoyed, the 14.5 ft. diameter, 42 ft. long habitat and laboratory modules will provide ample accommodations to support crews of six to eight people in relative comfort during missions lasting three months or more.

Individual quarters containing sleeping bags attached to walls will provide quiet, private places where astronauts can enjoy leisure time working at personal computers, watching taped programs, and simply relaxing. A galley-wardroom area with generous windows for Earth and space gazing will facilitate social interaction and shared experiences during meals and other free periods. A window will also be provided in the exercise area for crew enjoyment while completing important daily conditioning workout requirements. Installation of windows in sleeping quarters is under consideration.

Crew Quarters for Japanese Exhibit
Design by Li Hua

Space Station Galley Proposed by ILC Space Systems
Rack Exterior and Table Design by Li Hua and Francis Winisdoerffer

Space Station Wardroom Mockup Built for Japanese Exhibit
Design by Li Hua

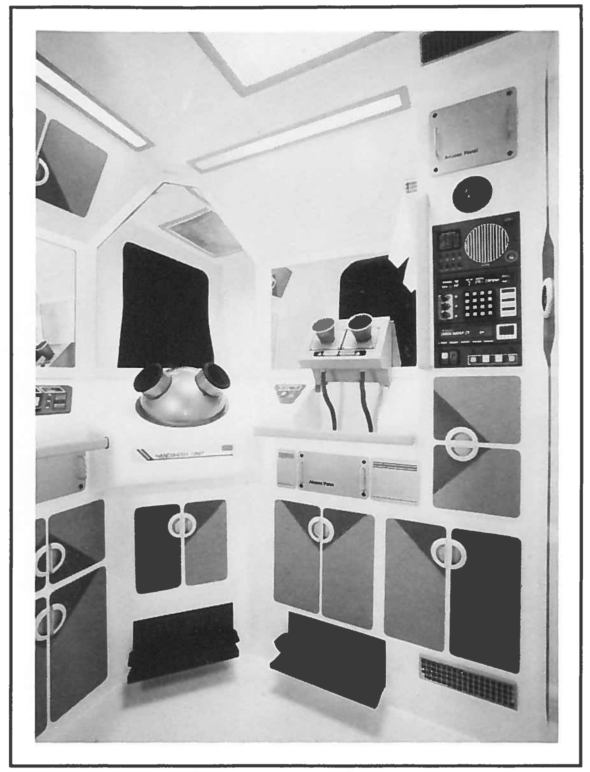
Interior Layout and Elements

The two basic interior Space Station module components are: racks for equipment; and functional units for crew occupancy. They are aligned along wall, floor and ceiling areas. The central circulation plan created by this arrangement will be configured with an Earth-like, normal gravity layout which presents a consistent up and down to prevent crew disorientation. An exception to this rule may be sleeping quarters, which might include transverse units located in the floor and ceiling.

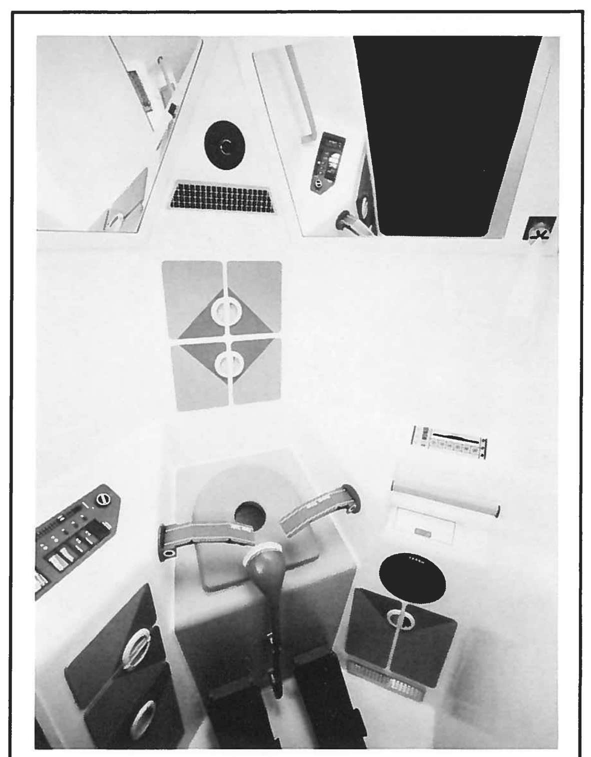
Space Station racks will contain health maintenance equipment, food preparation systems, storage units, life support and waste management devices, environmental controls, laboratory experiments and other items essential to safe and productive operation. Hinged connections and quick-release latches will enable the racks to be rapidly pivoted or slid out for routine and emergency rear access servicing of subsystems, utility interfaces and the pressure hull.

Functional units will offer private enclosures for such crew activities and systems as sleeping, showers, personal hygiene and toilets. Since the units' relatively small 41.5 inch wide, 40 inch deep, 80 inch tall size is very restrictive, it is essential to utilize all available space as efficiently and effectively as possible. Means may be incorporated to expand sleeping quarters a few inches into the central aisle area when in use to help relieve this space constraint.

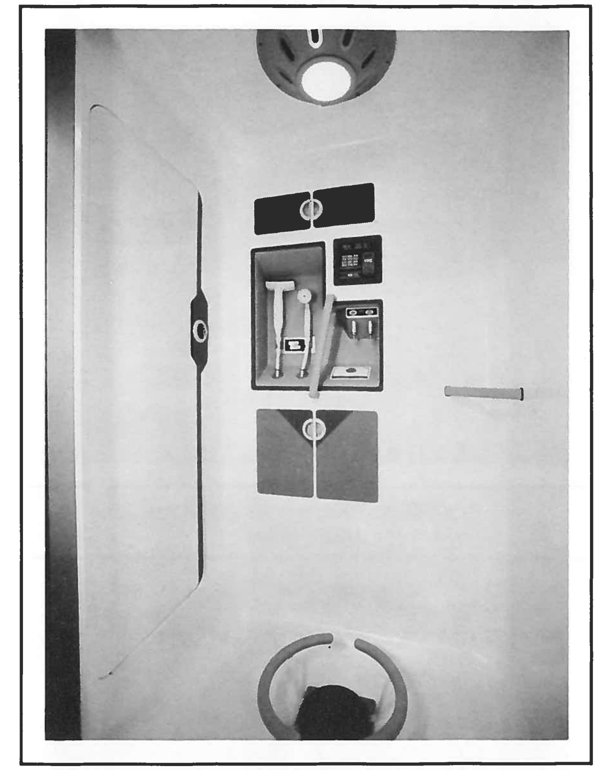
Lack of gravity will simplify some design and use requirements while complicating others. Since crew members can easily move about in all directions, ceilings can be accessed as useful work and stowage areas. Equipment items that would be very heavy and immobile on Earth can be effortlessly manipulated. Showers, on the other hand, require use of laminar air flow to replace the role of gravity in guiding water into floor drains. Similarly, toilets will use strategically positioned and directed air jets to move waste materials away from the body.



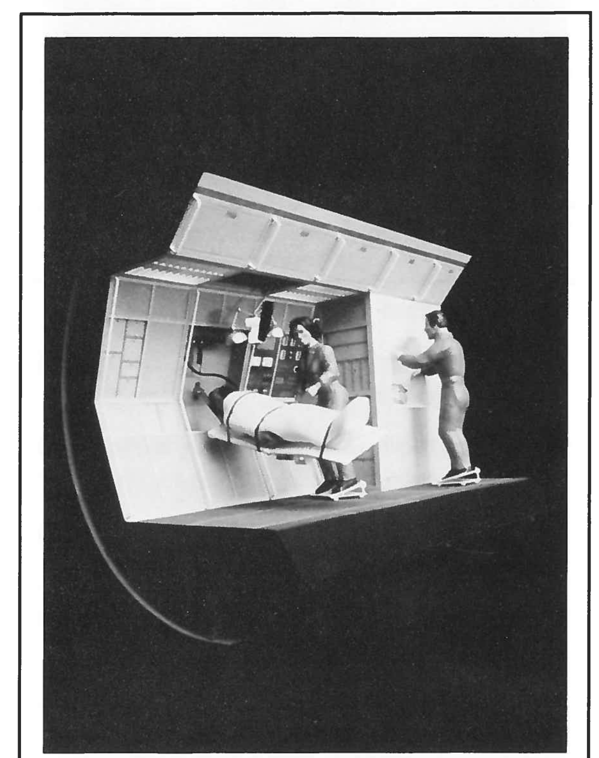
Hygiene Area Mockup Built for Japanese Exhibit
Design by Li Hua



Toilet Mockup Built for Japanese Exhibit
Design by Li Hua



Shower Mockup Built for Japanese Exhibit
Design by Li Hua



Health Maintenance Facility Concept
Design and Model by SICSA

Crew Accommodation Systems

Sleeping Quarters

- *Sleeping bag attached to "wall".*
- *Personal computer and VCR viewing.*
- *Deployable keyboard and writing desk.*
- *Personal clothing and general stowage.*

Wardroom and Galley

- *Multipurpose area with outside viewing.*
- *Table(s) with foot restraints.*
- *Oven and liquid/beverage dispensers.*
- *Cold and ambient food stowage.*
- *Cooking appliances and stowage.*
- *Handwash unit and dishwasher.*
- *Inventory control computer system.*

Toilet and Hygiene

- *Commode and urinal units.*
- *General and emergency showers.*
- *Handwash and facewash units.*
- *Laundry and waste containment systems.*

Health Maintenance Facility

- *Patient restraint system.*
- *Diagnostic and monitoring equipment.*
- *Medical information system.*
- *Instrument and medicine stowage.*
- *Autoclave and centrifuge.*
- *Hyperbaric/isolation chamber(s).*

Exercise and Recreation

- *Area with outside viewing.*
- *Exercycle, treadmill and other equipment.*
- *Towel, clothing and equipment stowage.*

Ancillary Support

- *Fixed/portable general and task lighting.*
- *Restraint systems and mobility aids.*
- *IVA communication systems.*
- *Crew-operated temperature controls.*
- *Hazard detection and warning systems.*
- *Emergency safe haven rations.*
- *Maintenance work stations and tools.*
- *Housecleaning tools and supplies.*

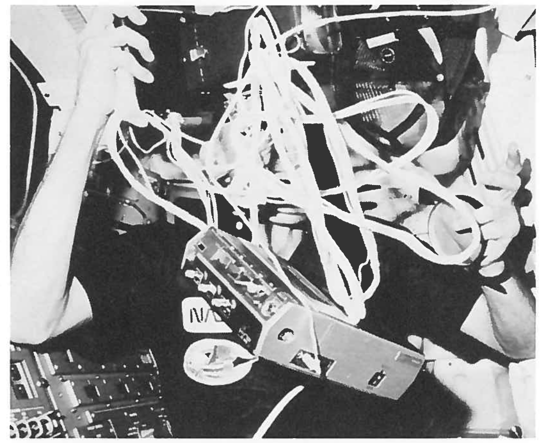
Hardware System Requirements

Stringent restrictions imposed by launch constraints, power conservation needs and safety requirements significantly influence many crew system planning and design aspects. Accommodations for people must compete with mission-critical flight and scientific equipment for severely limited payload weight, interior volume and power/cooling allowances. Materials and devices that present fire hazards, offgas or leak noxious substances, or impose excessive repair problems are unacceptable.

Design to optimize reliability and ease of maintenance is of urgent importance. Structures and equipment components must be made as simple to repair as possible. Users will not be able to "shuttle down to the nearest hardware store" for replacement items when there is a problem. Critical areas and equipment systems, including interior pressure hull surfaces, should be accessible for periodic inspections and maintenance.

Space habitat design must accommodate evolutionary changes associated with facility growth and reconfiguration, system upgrades and redefinition of functional support requirements. While it is difficult or impossible to anticipate the exact nature of all of the changes which might occur over decades of use, planning must incorporate a high level of modularity and variability. Simplicity of element changeouts must be emphasized since in-orbit and planetary crew time is very expensive. Operations will be constrained by limited onboard spare parts and tools, and by restrictions on procedures for safety reasons.

System planning must consider which functions can best be achieved by people, and which should be undertaken by machines. Automated and tele-operated systems, including robotic devices, can offer important advantages in undertaking tasks which are predictable, repetitive, and hazardous to health. Humans remain the option of choice for functions demanding versatility, mobility, judgement and creative improvisational abilities.

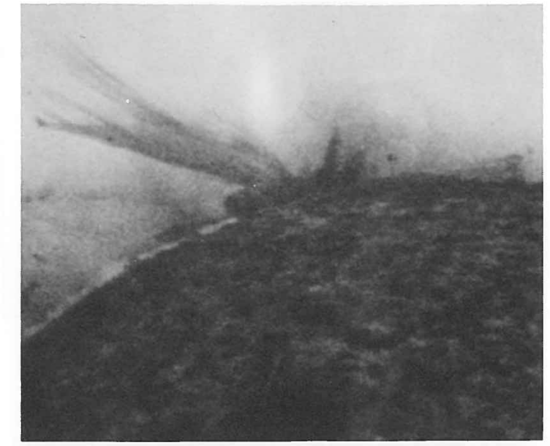


Difficult Repair Situation
NASA Photo

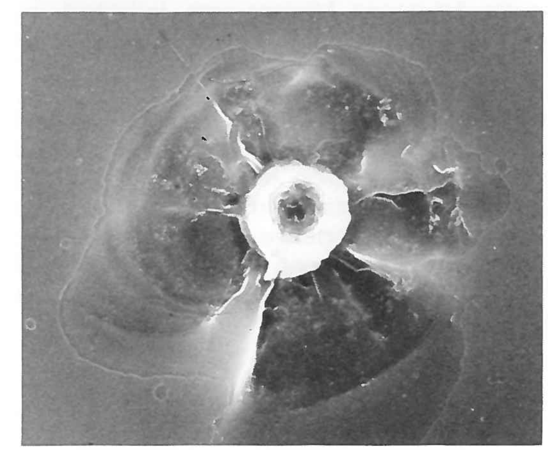
Easily Accessible Equipment Compartment
ILC Space Systems Photo

System Planning Priorities

- *Select materials and design systems to minimize volume, weight and power.*
- *Avoid materials and systems that are flammable or chemically unstable.*
- *Design structures and equipment to be rugged and easily repaired.*
- *Emphasize modular design approaches that facilitate evolutionary changes.*
- *Apply automation where possible to reduce labor and to avoid safety hazards.*



Solar Flare Detected on *Skylab*
NASA Photo



Micrometeoroid Damage to*Skylab* Window
NASA Photo-Courtesy Chuck Wheelwright

Hazard Intervention Strategies

- *Design outer walls/shields for space debris and radiation protection.*
- *Provide a solar flare warning system and special protective clothing/shelters.*
- *Provide ready interior access to pressure hull walls for leak inspections and repairs.*
- *Provide effective and safe methods to repair pressure hull penetrations.*
- *Provide rapid means to evacuate crews to safe refuges for rescue.*

Special Safety Hazards

Long-term exposure to ionizing radiation, even at relatively low levels, can have harmful effects on people and sensitive electronic equipment. The natural radiation environment in space consists of galactic cosmic rays (GCRs) and solar energetic particle (SEP) events.

For spacecraft, the altitude of the vehicle and inclination of the orbit are important determinants of GCR dose rates. Low-Earth orbit spacecraft receive substantial shielding benefits from the Earth's magnetic field. At an altitude of approximately six Earth radii (geosynchronous orbit) the geomagnetic shielding effect disappears.

High GCR levels also exist on the Moon where there is no radiation-absorbing atmosphere or magnetic field to deflect radiation transport of cosmic ray nuclei. Safety hazards increase dramatically during solar flares. Specially shielded "storm shelters" may be needed for supplementary crew protection when these events occur.

NASA's *Man-System Integration Standards* (NASA-STD-3000, Volume I, March, 1987) allows an annual 50 rem radiation dose. This greatly exceeds the maximum annual 5 rem dose set for U.S. occupational radiation workers. A typical meter of lunar surface receives an annual dose equivalent to 30 rem during solar minimum.

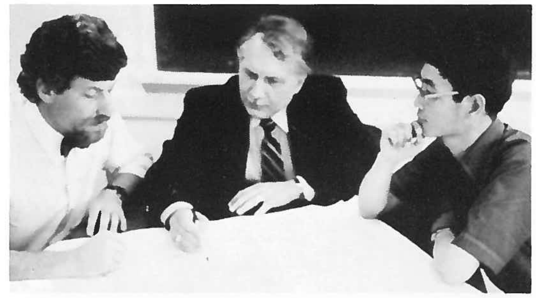
Space debris represents an ever increasing hazard. Incidents of micrometeoroid hits have been studied in connection with Apollo and Skylab Program experiences. Low collision probabilities projected during those missions did not appear to warrant high priority countermeasures. This situation is changing, however, as a result of the growing population of man-made rocket explosion fragments that currently constitute a major, very troublesome debris source. Exterior shields may be required to protect vulnerable and critical spacecraft elements. The best long-term strategy, however, is to establish international agreements that will put an end to the proliferation of man-made debris in space.

SICSA Background

SICSA is a nonprofit research, design and education entity of the University of Houston College of Architecture. The organization's purpose is to undertake programs which promote international responses to space exploration and development opportunities. Important goals are to advance peaceful and beneficial uses of space and space technology and to prepare professional designers for challenges posed by these developments. SICSA also works to explore ways to transfer space technology for Earth applications.

SICSA provides teaching, technical and financial support to the ***Experimental Architecture*** graduate program within the College of Architecture. The program emphasizes research and design studies directed to habitats where severe environmental conditions and/or critical limitations upon labor, materials and capital resources pose special problems. Graduate students pursue studies which lead to a Master of Architecture degree.

SICSA Outreach highlights key space developments and programs involving our organization, our nation, our planet and our Solar System. The publication is provided free of charge as a public service to readers throughout the world. Inquiries about SICSA and Experimental Architecture programs, or articles in this or other issues of *SICSA Outreach*, should be sent to Professor Larry Bell, Director.



Guillermo Trotti, Larry Bell, and Li Hua

SICSA management and staff have provided planning services aimed at enhancing human conditions in space for more than a decade. A continuing NASA-sponsored study titled *Analysis of Medical, Life Sciences and Habitability Systems for Advanced Missions* was initiated by SICSA's predecessor, the ***Environmental Center***, in 1982.

Other projects headed by Director Larry Bell and Associate Director Guillermo Trotti have involved numerous Space Station requirements definition and design proposals for major U.S. aerospace companies and Japanese space exhibition sponsors. Li Hua has been the lead designer for many of these projects. Some examples appear in this issue.

SICSA
Sasakawa International
Center for Space Architecture

Room 122 ARC, University of Houston
4800 Calhoun, Houston, Texas 77004

Budget No. 3310

1440008

Non-Profit Organ.
U.S. Postage
PAID
Houston, Texas
Permit No. 5910