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Special Information Topic Issue

SICSA OUTREACH
Sasakawa International Center for Space Architecture

Experience, Analogs and Simulations to Guide Planning for Prolonged Missions

Lengthy manned space missions such as lunar base initiatives and voyages to Mars and back will impose severe social and psychological demands upon crews. Failures of individuals and groups to adapt and perform effectively under difficult, sometimes perilous, conditions will put lives, and even major programs, in jeopardy. It is essential that all practical means be used to anticipate and address problems long before they occur. Precautions and interventions must be incorporated into all stages of crew selection, training, mission planning and spacecraft system design. Previous space experience, along with analogs and simulations on Earth, can yield valuable insights.

Space-related behavioral research and training programs conducted since the early 1960s have made use of a variety of facilities and methods. Isolation studies have utilized high altitude surface chambers, underwater habitats and submarine crew data. Mission task simulations have made use of large water tanks for neutral buoyancy tests, spacecraft mockups with realistic operational control and feedback features, and special aircraft that fly in parabolic paths producing short periods of weightlessness.

This report presents an overview of representative methods that are used to identify space habitat design requirements, operational procedures, and crew selection and training guidelines. Important lessons drawn from the various approaches are highlighted.

Former SICSA Student Laurie Weaver
Space Station Mockup Photo by NASA

Key Mission Planning Activities

Prolonged Isolation and Stress Research

- *Psycho-social adaptation mechanisms.*
- *Optimization of crew selection and mix.*

Habitability and Human Factors Studies

- *Factors influencing crew comfort/morale.*
- *Means to enhance performance/safety.*

Mission Planning and Analysis

- *Task and procedure definition.*
- *Scheduling of work and leisure activities.*

Crew Selection and Training

- *Preflight preparation for mission tasks.*
- *Readiness for emergency events.*

Prolonged Isolation Effects

The current Presidential Directive on National Space Policy establishes a goal to *"expand human presence and activity beyond Earth into the Solar System"*. This ambitious endeavor will challenge the willingness and abilities of crews to cope throughout long periods of isolated confinement with few amenities or recreational diversions. Some missions, such as voyages to Mars and back, may last more than two years.

Anxieties regarding ever-present dangers, in combination with physiological deconditioning caused by reduced gravity and other factors, are likely to erode morale and performance over time. Interpersonal relationships and teamwork may suffer as a result, affecting crew performance and even safety.

Previous Mission Data

Soviet cosmonaut experiences onboard the *Mir* spacecraft have demonstrated that humans can adapt to life in space for relatively long periods. While much of the scientific psycho-social data yielded by these missions is not available, some useful information has appeared in Soviet books and news articles. Three carefully monitored U.S. *Skylab* missions, one lasting 84 days, remain to be the best sources of U.S. data.

Soviet space program experts are known to attach great importance to issues associated with long-term confinement. A NASA report titled *Soviet Space Stations as Analogs* by B. J. Bluth and M. Helppie (1986) discusses a comprehensive battery of monitoring approaches used to observe cosmonaut psychophysiological conditions and work productivity. Television monitors and voice analysis are primary methods used along with self-assessments and visiting onboard medical observers. Evaluation considerations include moods and motivation levels, behavioral tactics, intragroup relationships, work attention and activity effectiveness, ability to receive and act upon information, and changes in sensory motor reactions.

Isolation Experiments

Extrapolations of Inflight Experiences

U.S.S.R. Salyut *and* Mir *(1971 to present)*

Have supported main crews of two, performing tours of duty lasting from several months to one year with intermittent short visits by other cosmonauts. Extensive data on crew behavior and interaction has been recorded but much has not yet been released.

Project Skylab *(1973-74)*

Represents the longest duration U.S. spaceflights. Three crews of three astronauts each participated in missions lasting 29, 59 and 84 days. Extensive information was collected about crew health, performance and habitability responses.

Terrestrial and Underwater Analogs

Antarctic Bases (1957 to present)

The U.S. currently operates three stations that accommodate people year-round. Observations yield information about crew sleep/work schedules, recreation, privacy, and relationships. Experimental controls, however, are generally lacking.

Nuclear Submarines (1946 to present)

The U.S. Navy currently has approximately 3,500 crewmen aboard nuclear ballistic submarines at any given time. Informal studies have been conducted to provide information about optimal work/sleep schedules and behavior/work motivation factors.

Controlled Isolation Experiments

Manned Life Support System Tests (1968-71)

McDonnell Douglas conducted 60 day (1968) and 90 day (1971) tests in which crews of four were enclosed in sealed cabins to test regenerative life support systems. Abilities of crews to maintain physiological and psychological health were evaluated.

Tektite *(1969-1970)*

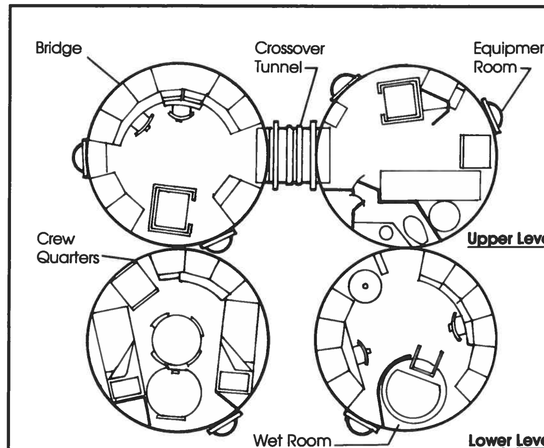
The U.S. Office of Naval Research sponsored an experiment in which four crewmembers were housed in an undersea habitat for 60 days. A purpose was to study small group behavior and effectiveness during real work, stressed, isolated conditions.

MESA (1964)

Boeing conducted a Manned Environmental System Assessment (MESA) program in which five crewmembers were confined in a high altitude (low pressure) chamber for 30 days. Studies included crew psychology/behavior in a closed-atmosphere life support system.

Spartan Field Camp Conditions in Antarctica
Photo by Dr. Chris McKay, NASA

Typical Submarine Crew Accommodations
Official U.S. Navy Photo– ca. 1960



Tektite I and *II* Habitat
Drawing by Tom Polette-Adapted from ONR Report DR 153

Small Antarctic Stations as Analogs

Small antarctic research stations, such as the 20-person U.S. South Pole facility, present conditions which are similar in many respects to those that will be encountered on future lunar and planetary surface missions. Heterogeneous teams of highly motivated and trained military and civilian personnel on such facilities must learn to live together and depend upon one another as they perform difficult, sometimes hazardous tasks under remote, dark and extremely cold conditions. Controlled monitoring of crew adaptation and behavior under these circumstances can yield important lessons. Unfortunately, few such studies have been conducted to date.

Nuclear Submarines as Analogs

Submarines are often mentioned as analogs from which behavioral data can be extrapolated for planning prolonged space missions. Crew populations for modern U.S. ballistic missile submarines are somewhat large for direct comparison, typically maintaining approximately 140 officers and enlisted personnel. These people may also be more homogeneous, younger on the average, and less scientifically-oriented than future space voyagers. Still, the large quantity of submarine psychological data that has been collected since 1953 lends useful knowledge about human adaptation and performance under adverse and stressful conditions.

Controlled Isolation Experiments

Relatively long duration (30-90 day) experiments conducted in closed chambers have studied the effects of isolation, artificial life support systems and other space-pertinent factors using carefully planned and monitored research procedures. NASA-sponsored 60 and 90 day **Manned Life Support System Test** programs by McDonnell Douglas, and a **Manned Environmental System Assessment** by Boeing, utilized small high altitude chambers for this purpose. ***Tektite I***, a 60 day experiment, used two interconnected underwater habitat-laboratory vessels. Each of these tests has expanded understanding of human and life support system requirements for space and undersea operations.

Habitability/Performance Influences

Experiences on U.S. and Soviet spacecraft, antarctic stations and nuclear submarines reveal a variety of problems that erode the abilities of people to cope and perform over time. Familiar manifestations include irritability leading to crew and ground-crew conflicts, depression and lack of motivation, fatigue, reduced alertness, and troublesome changes in sleep patterns. Some of these difficulties may be avoided or reduced through improved habitat design, expanded comfort and recreation amenities, variety and choice of menu selections, and balanced scheduling of work and leisure activities. A great deal has been learned about such needs and approaches since the advent of the U.S. Apollo Programs more than two decades ago. Much more must be learned, however, before it is prudent to send people on multi-year missions to the Moon and Mars.

A "habitable" environment is one which enables people to maintain physiological and psychological well-being, good levels of performance and acceptable social relationships. Habitability studies within a space mission context, must consider factors involving the individual, responses to his/her environment and colleagues, interactions with machines and general surroundings, and unique requirements imposed by the mission.

Detailed understanding of human roles and needs is of vital importance. Experiences with spacecraft and undersea habitats have demonstrated that morale and performance are enhanced when people feel that they are important, are interested in their work and are able to fulfill personal goals. Simulations which treat humans simply as test subjects without appealing to personal motivations and interests are likely to have limited validity and value. Caution must be applied in generalizing observations of one type of population group to another. Planners should use methods that account for potential differences in professional and cultural backgrounds, goals and circumstances.

Important Habitability Lessons

Crew Living Accommodations

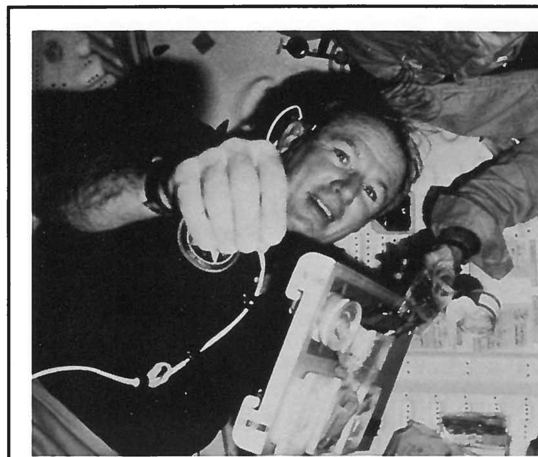
- ***Privacy and leisure.*** Skylab *demonstrated the importance of private sleep areas as places to be alone, away from fellow crew and ground monitoring.*
- ***Dining menu selection.*** *Meal times on-board* Skylab *were important social periods and broke up the day. Food variety is necessary. Tastes change in space.*
- ***Exercise and recreation.*** *Exercise in space is vital to health but becomes boring. The favorite* Skylab *recreation was window viewing of the Sun and Earth.*
- ***Toilet and hygiene.*** *Commode malfunctions in space can have serious consequences. Personal and facility hygiene is laborious, but vital to health and morale.*

Environmental Systems and Features

- ***Air quality and comfort.*** *Accurate control of breathing atmosphere, temperature and humidity has been demonstrated in spacecraft and undersea habitats.*
- ***Noise control.*** *Objectionable sounds from fans, thermal expansion/contraction of pressure hulls and other sources can interrupt sleep and task concentration.*
- ***Lighting systems.*** *Highest illumination levels are required for hygiene activity and workstations. Cosmonauts wanted more and more light as time passed.*
- ***Color and decor.*** *Some crewmembers criticized the drab, monotonous colors on* Skylab. *Aesthetics and means to provide variety should be considered.*

Crew Organization and Schedules

- ***Size and composition.*** *Small crews often have high levels of interdependency. The mix of skills, cultural/professional backgrounds and personalities is important.*
- ***Sex and role identity.*** *Crews must avoid stereotypic views and behavior. They must be versatile to adapt to changing circumstances and needs as required.*
- ***Leadership and motivation.*** *Teams can be organized around democratic or authoritarian models. Mutual respect and confidence must be common to both.*
- ***Activity schedules.*** *All experience demonstrates that good crew morale and performance requires a proper balance between work and leisure.*



Mealtime Onboard the Space Shuttle Orbiter
NASA Photo

Cosmonauts During Leisure Time
Soviet Photo Courtesy of Jim Oberg

Mixed Gender Crew Onboard STS-7
NASA Photo

Crew Living Adjustments

Confined conditions onboard spacecraft, at small antarctic stations and in nuclear ballistic submarines challenge crews to adjust expectations and lifestyles. Privacy, personal belongings and recreation options are severely limited by constraints upon interior volume. Meals take on special importance as times to talk and as events to help structure daily work and leisure schedules. Simple activities such as viewing of outside splendors through windows and other solitary pursuits are often most valued. Periscope viewing is of similar importance to submarine crews.

Importance of Lighting, Color and Music

Effective use of lighting, color and music can offer needed variety and interest, influence positive moods and facilitate task performance. Soviet space station experience indicates that the desire for brighter illumination increases with mission length. The higher lighting levels appear to help counteract fatigue and decreases in visual and mental acuity over time. Some *Skylab* astronauts emphasized the importance of having good adjustable task lighting and color variety to offset monotony. Antarctic crews and Soviet cosmonauts have stated that music becomes very important on long missions. Soviets often program music to complement activities.

Crew Composition and Relationships

Attitudes and performance on long-duration missions depend a great deal upon: the professional and cultural backgrounds of individual crewmembers; their maturity, competence and personalities; the way they and others perceive their roles; with whom they are confined, and the leadership structure with which they must comply. Heterogeneous crew mixes present challenges. Soviet experiences have revealed that language and cultural differences within multinational crews can present significant interpersonal problems. Potentials for conflict increase with time due to mission fatigue and the limited outlets for emotional relief that strain tolerance levels.

Designing for the Human Factor

Successful planning for manned space missions, and particularly those of extended duration, must consider the human as an interdependent part of a very complex man-machine system. This does not imply that people should be relegated to cyborg-like roles and characteristics that deny full expression of human potentials and needs. Instead, mission planning should recognize, apply and facilitate unique and expansive contributions afforded by human intellect, creativity, versatility and dexterity.

A prerequisite in attaining this goal is to determine and assign appropriate functions to humans and to machines relative to the special capabilities and limitations of each. Optimum man-machine interfaces must then be examined within the context of mission objectives and conditions imposed by the surrounding environment.

Proper design to optimize performance of the total man-machine system must be responsive to all human senses. Included, are factors which affect visual activity, sensitivity to temperature and touch, pleasant and objectionable tastes and odors, and beneficial uses and control of sounds.

"Human engineering", a term often attached to efforts aimed at enhancing living comfort and task performance, suggests an image of trying to fit man to the machine and to his environment. "Engineering for humans", reflecting the reverse objective, might be a better title. Realities in space, however, do demand that people adapt and adjust to many restrictive and demanding circumstances which cannot be avoided. Examples are severe limitations upon living space and privacy, weight-dictated restrictions on personal belongings, and strict behavioral protocols demanded by performance and safety requirements. Added to these adjustments are major changes in living and work procedures imposed by reduced gravity and other conditions in space. Good planning can assist these adaptation processes.

Human Engineering Influences

Micro- and Reduced Gravity Conditions

Anthropometric and ergonomic factors

- *Influences on design and dimensioning of equipment and work surface heights.*
- *Influences on reach envelopes and general task procedures/performance.*
- *Influences on force requirements and leverage constraints for various tasks.*

Internal equipment layouts and designs

- *Optimum utilization of walls, floors and ceilings with orientation references.*
- *Avoidance of sharp corners/protrusions that can cause injuries when bumped.*
- *Protection of fragile fixtures and control surfaces that can be bumped.*
- *Design for maintenance procedures that take weightlessness into account.*

Restraints and mobility aids

- *Hand-holds, foot restraints and body leverage devices for various tasks.*
- *Means to secure diverse items while stored and in use.*

General Space Conditions

Habitat and equipment layout

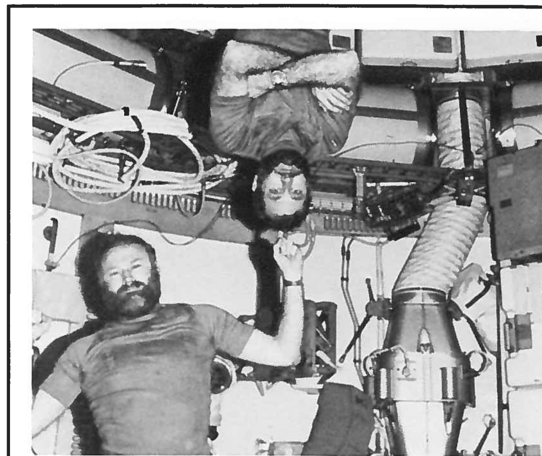
- *Avoidance of traffic obstacles and circulation bottlenecks.*
- *Separation of living and work areas, quiet and noisy areas, and private areas.*
- *Rapid and easy crew emergency egress and critical equipment repair access.*
- *Convenient arrangements of related functions and equipment.*
- *Ample volumes for group gatherings and maintenance operations.*

Equipment operability

- *Standardization of monitors and controls to optimize coherence and familiarity.*
- *Adequate lighting, contrast and controls for precise and critical tasks.*
- *Simplicity of operations with clear, complete instructions.*
- *Avoidance of electrical, toxic and burn hazards to users.*
- *Good inventory management systems.*
- *Legible graphic readouts and labels using color coding when possible.*

Maintenance and servicing

- *System/subsystem accessibility with quick and easy disconnects.*
- *Adequate spares, tools and instructions.*
- *Close-outs to keep debris out; durable and easy to clean surfaces.*
- *Audible and visible malfunction indicators and alarm systems.*
- *Backup systems and procedures covering critical human and system failures.*



Weightlessness Onboard *Skylab*
NASA Photo

Maintenance Operation in Microgravity
NASA Photo

Health Care Onboard *Skylab*
NASA Photo

Adaptation to Reduced Gravity

U.S. *Skylab* and Soviet space station missions have yielded substantial data about physiological effects and design requirements associated with weightless periods lasting from a few months to a year. Temporary and permanent deconditioning effects of weightlessness associated with much longer voyages to Mars and back are not known and are a matter of great medical concern. Also not understood, is the length of time humans can remain healthy in the reduced gravity of the Moon and Mars (about 1/6 and 1/3 Earth gravity, respectively). Future rotating space laboratories may provide needed answers.

Optimizing Maintenance and Safety

Minimizing perceived and actual safety risks is essential to crew morale and well-being. Limited spare parts, tools and repair specialty skills on long duration missions will require an emphasis on system reliability. Possible illness or death of a crewmember with a needed technical background will exacerbate periodic maintenance and critical repair problems. Such operations must be planned to be as simple as possible, using standardized fittings and tools. Comprehensive instructions should cover all contingencies and be presented in a clear form.

Preventative and Emergency Health Care

Planning and accommodations should provide means to prevent and respond to crew health problems. Special space-related concerns include: deconditioning effects of reduced gravity; airborne infections; exposure to toxic substances and radiation; chemical and electrical burns and shocks; lacerations and fractures; and cases of "the bends" following extravehicular activities. Surgery and other radical procedures may be precluded by constraints imposed by limited equipment, expertise and sanitary conditions. Crewmembers, however, will require general training to perform tooth extractions and other paramedical procedures on one another.

Crew Selection and Training

Previous inflight, analog and simulation experiences have produced at least as many questions as answers about complex variables influencing human performance and behavior under prolonged isolation and stress. We have learned that individuals vary greatly, and that responses to surrounding circumstances are highly conditional. Important influences include their psychological and physiological states, who and how many people they are with, their attitudes about themselves and others, the importance they attach to their work, and their preparedness for conditions and challenges they encounter.

Since the beginning of their space program, the Soviets have applied rigorous social and psychological testing and training prior to flight. They have also carefully monitored and evaluated psychological changes and interpersonal relations during the flights. Important crew selection criteria include:

- A low general anxiety level.
- Emotionally well balanced outlook.
- Extrovert personality.
- High level intellectual/perceptive abilities.
- Steady voluntary attention span.
- Good attention separability/changeability.
- Good memory for details.
- Capability to control personal reactions.

Mission performance predictors selected by analogous programs differ markedly. Crew selection criterion variables were analyzed against adaptation and work performance during three 15 day saturation dives in *Sealab* (1965). Results ranked the highest predictors as age, diving experience, birth order, and size of home town. Experiments on Project *Tektite* (1969-1970), another underwater study, concluded that individual gregariousness most strongly correlated with performance. Both studies indicated that crews which enjoyed good social relationships were most inclined to work effectively together when difficult conditions demanded cooperation.

Research and Training Facilities

Microgravity Studies and Simulations

Shuttle Orbiter (1981-present)

Supports up to eight crewmembers on missions lasting as long as ten days. Research uses include human physiology studies, animal and plant research, space construction demonstrations, remote sensing, and diverse space physics and microgravity experiments.

Spacelab (1983-present)

Pressurized module that converts the Shuttle Orbiter payload bay into a habitat and laboratory. It is used for space life science experiments, microgravity material processing, and other experiments to expand Orbiter uses. It was developed by ESA.

Neutral Buoyancy Simulators (1966-present)

Large water-filled tanks located at NASA's Marshall Space Flight Center and Johnson Space Center to simulate operations that are to be performed under weightless conditions in space. Purposes are to demonstrate and evaluate procedures and to train crews for mission tasks.

Modified Boeing KC-135 (1960s to present)

NASA aircraft designed and operated to fly in a series of parabolic flight paths, each providing approximately 30 seconds of weightlessness. Purposes include human factors studies, psycho-physiological experiments and astronaut training.

One-G Simulators and Mockups

NASA Space Station Mockups (1985-present)

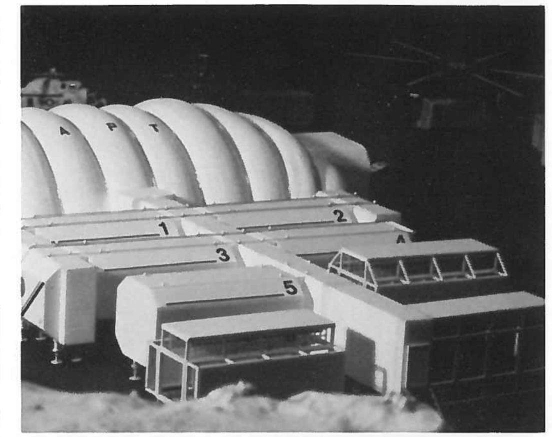
NASA's Johnson Space Center and Marshall Space Flight Center maintain and periodically update habitat Space Station Freedom module mockups which are used for presentation and evaluation of interior design elements and human interfaces.

SMEAT (1973)

A mockup of the Skylab crew quarters was used for a Skylab Medical Experiments Altitude Test (SMEAT) involving three crewmembers for 56 days. Purposes included systems operation and experiment demonstration, time and motion studies, and human factors/habitability research.

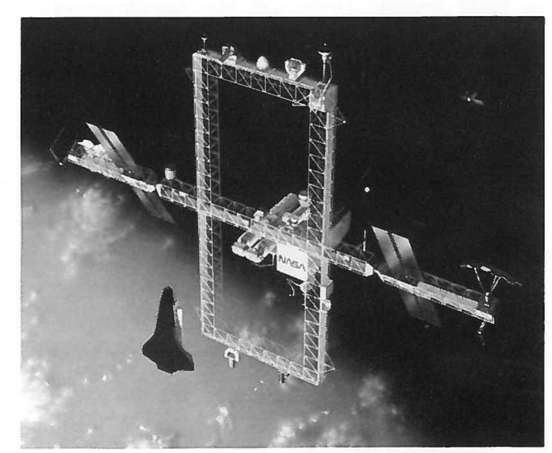
Apollo Command Module Simulator (1969-72)

Elaborately accurate mockup of the Command Module interior with working instruments linked to computers with programmed spacecraft flight characteristics, subsystem status feedback and simulated failures. Used extensively for training.



Conceptual APT Configuration
SICSA Photo

Cosmonaut Undergoing Water Survival Training
Soviet Photo Courtesy of Jim Oberg



Space Station Freedom at Full Configuration
Denise Watt-Artist

Simulations to Assist Crew Selection

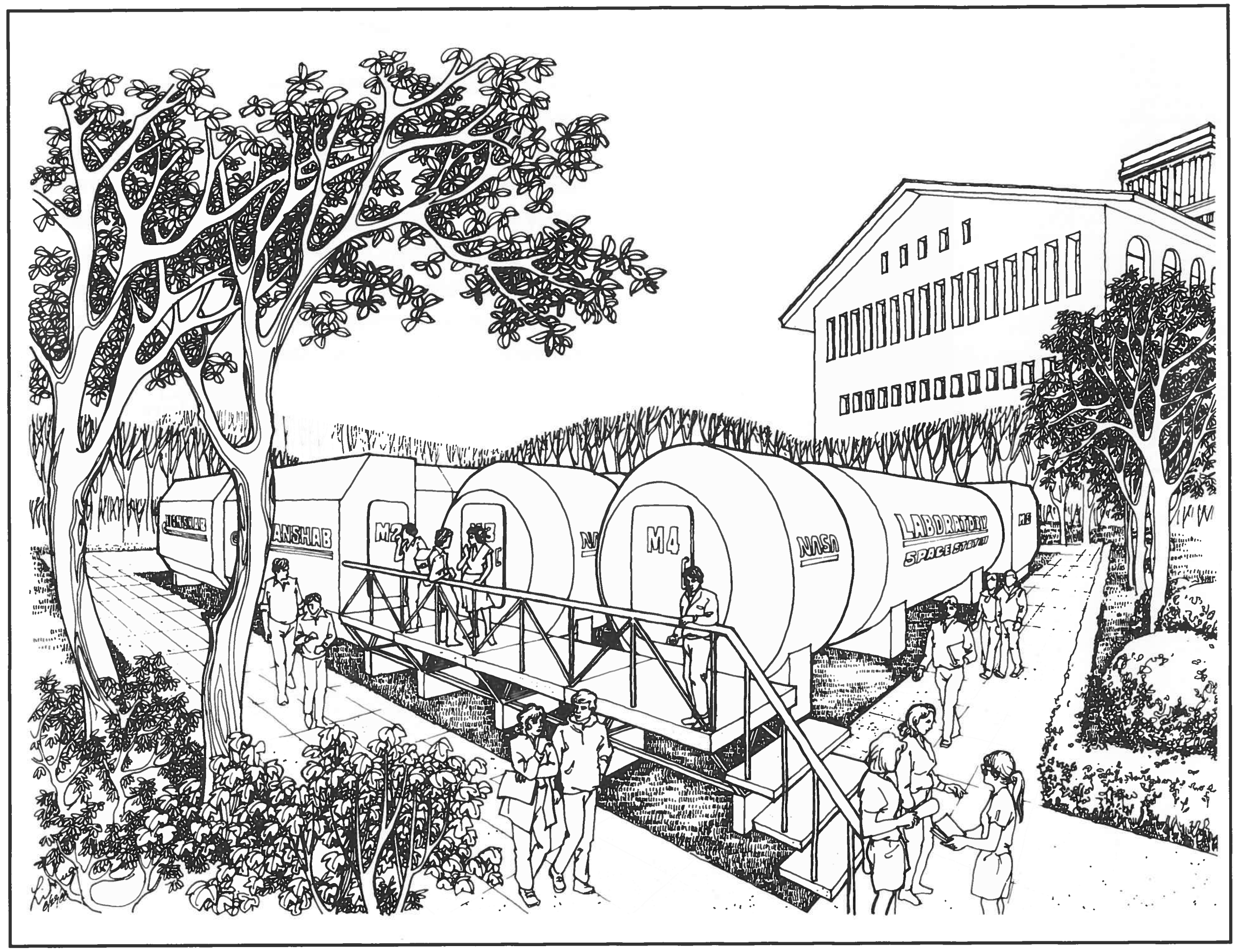
There is a great need to develop more comprehensive and reliable criteria for selecting individual and group candidates for future prolonged space missions. Experience has demonstrated that the longer the flight, the greater the likelihood that small personal and interpersonal problems become large ones. Of critical importance is to increase understanding of how crews will react in isolated, harsh environments.

SICSA's planned **Antarctic Planetary Testbed (APT)** will provide an excellent means to evaluate crew requirements and performance under rigorous simulated mission conditions. Located in an extreme environment where isolation is real, the conditions will closely parallel many found in space. Implementation is scheduled for 1992 (*SICSA Outreach* , Vol. 1, No. 8: July-Sep., 1988).

Psychological and Technical Training

Soviet training programs subject cosmonauts to survival challenges aimed at building self confidence and discipline. Early training involves more than 100 parachute jumps, many requiring cosmonauts to complete check lists or other tasks during free fall periods. Later tests abandon trainees in remote, environmentally hostile locations where they suffer extreme temperatures, loneliness, hunger and thirst for days. Training also includes intensive self-programming courses to prepare them for interpersonal pressures, isolation, and performance of any necessary task without hesitation. Evidenced by extended and productive Soviet *Soyuz* and *Mir* flights, the training appears to be very successful.

Absent a space station, the U.S. currently has no means to match Soviet preparations for long duration missions. The most practical near-term strategy to address this disadvantage involves cost-effective simulations to achieve research and training priorities. U.S. *Space Station Freedom* planning has produced useful crew system reference data to guide simulation facility design. SICSA's APT plan embodies this approach.



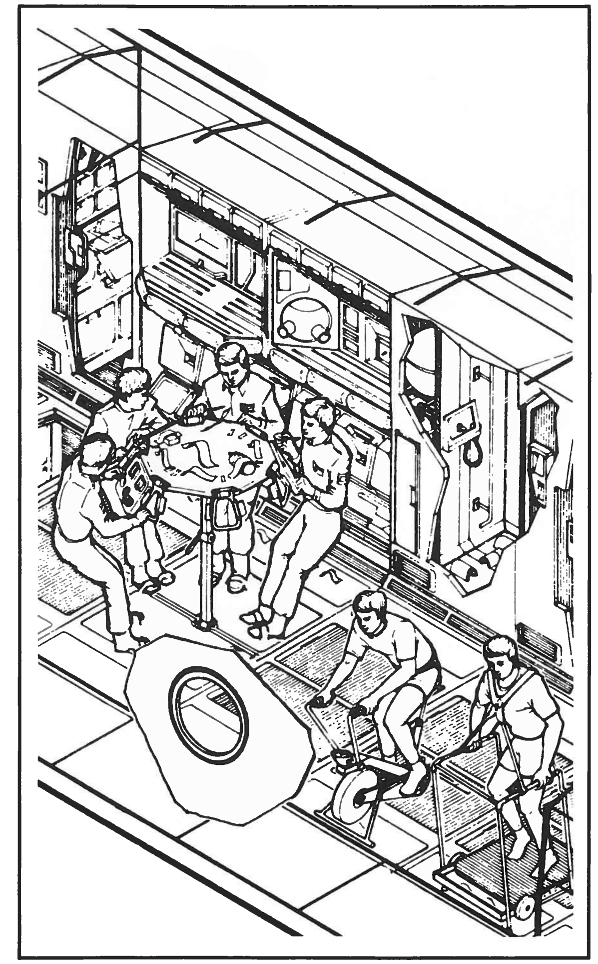
Proposed Systems Integration and Mission Simulator (SIMS) Facility at the University of Houston
SICSA Drawing by Li Hua

SICSA's Planned SIMS Facility

SICSA plans to establish a **Systems Integration and Mission Simulator (SIMS) Facility** in a park setting adjacent to the University of Houston College of Architecture. Comprised of units which are similar in size and character to space station modules, the SIMS Facility will house full-sized mockups of living and work environments for space station and lunar/planetary applications. These replicas will be used to demonstrate and evaluate design concepts, and will support work task simulation experiments such as time-motion studies. Functioning utility systems will also enable the units to be outfitted for confined living experiments and crew training program planning.

Some SIMS Facility units will be constructed as working prototypes of SICSA's Antarctic Planetary Testbed modules. These **Transhab Modules** are being designed for compact, efficient transport to remote sites where they can be easily and quickly assembled by a small crew.

Cylindrical modules are also planned to be incorporated into the complex to accommodate standard *Space Station Freedom* utility and equipment systems. This will enable equipment system mockups, prototypes and flight hardware to be interchangeable with simulation facilities operated by NASA and its contractors.



SIMS Interior Concept Example
Drawing by Li Hua

SIMS Facility Purposes

Habitability/Human Factors Research

- *Mockup accommodations to support design and evaluation of interior layouts and systems.*
- *Simulation settings for mission task procedure and time-motion studies.*
- *Controlled living environments for confinement behavior experiments.*

Teaching and Training Center

- *Space habitat education and exhibit center for visiting students and scholars.*
- *Mission and procedure planning resource for NASA and other interested users.*

Architectural Prototype

- *Demonstration and evaluation of Antarctic Planetary Testbed Transhab Modules.*

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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.

P. I. Larry Bell and Researcher Tom Polette

SICSA's Simulator Planning for NASA

SICSA is undertaking studies to determine design requirements for a one-gravity space life sciences simulator. Foundation work has been conducted as part of a NASA Johnson Space Center study contract titled ***Analysis of Medical, Life Sciences, and Habitability System Requirements for Advanced Missions.*** This activity is being continued with support from a recent $60,000 award from the NASA Regional University Grant Program. Dr. Patricia Santy is the NASA Project Monitor. Means to examine factors associated with psycho-social dynamics of individuals and groups during long periods of confinement are being accorded special emphasis. This report highlights important information sources and considerations.

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