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Design of Microgravity Space Environments to Enhance Crew Health, Morale, and Productivity

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DESIGN OF MICROGRAVITY SPACE ENVIRONMENTS TO ENHANCE CREW HEALTH, MORALE, AND PRODUCTIVITY

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ABSTRACT

This paper discusses habitability issues and design concepts which apply to large and small space stations. Special emphasis is placed upon opportunities and constraints posed by microgravity and upon special problems and needs associated with long-term isolation under confined conditions. Designed concepts are illustrated through photographs of drawings and models. (Many more are presented in the live talk than in this publication). Types of functional areas addressed include crew quarters, food preparation/dining areas, work areas, and exercise/recreation facilities.

INTRODUCTION

Development and operation of a manned space station is the next logical and essential step to extend practical utility of NASA's Space Transportation System (STS). Creation of a space station can stimulate private sector investment needed for benefits of commercial space industrialization to be realized. Opportunities for US businesses to sieze upon advantages afforded by the Space Shuttle to compete for international space markets are becoming rapidly eroded by a lack of full government commitment to move ahead in this area. In the meantime, while NASA awaits authorization and funding to proceed, it is still relevant to undertake research and planning which will facilitate expeditious and effective space station development when a go-ahead finally materalizes.

Two general camps of thought are likely to influence ultimate space station design. The Marshall Space Flight Center in Huntsville, Alabama has advocated a "Space Platform" concept with an emphasis upon supporting unmanned space science missions. The Johnson Space Center (JSC) Houston, Texas has favored a multi-purpose "Space Operations Center" (SOC) approach (although the term is no longer being applied) which emphasizes more diverse functions including assembly/deployment of large space structures, Orbital Transfer Vehicle (OTV) base operations...for transfer of large satellites from low-earth orbit (LEO) to geosynchronous orbit (GEO), satellite servicing, materials processing, and support for long-duration manned scientific missions on-orbit. In short, a key intended feature of both concepts is to enhance practical utilization of the Space Shuttle by extending and expanding manned and unmanned activities in space, freeing the Orbiter for its intended primary role as a delivery system. It is reasonable to expect that the space station which ultimately comes into being will comprise some features presented in both the Marshall and the JSC proposals.

ENVIRONMENTAL CENTER ACTIVITIES

The Environmental Center has undertaken a variety of space station studies under contract with JSC since the University of Houston-based research organization was founded in Fall, 1982. Common themes of these investigations have revolved around construction/configuration alternatives and habitability issues.

Two major Environmental Center projects which have influenced observations and conclusions in this paper are "Spacehab", a proposed 100-person-plus LEO space station concept; and habitability analysis related to the JSC Space Operations Center.

The Spacehab project has explored issues related to possible development, deployment, and operation of second or third generation space stations which can support labor intensive activities on-orbit (such as construction/assembly of large space platforms and satellites). The study assessed various overall space station architecture approaches and also examined design requirements and options for key interior crew areas, including

food preparation and dining facilities, sleep stations, waste management and hygiene facilities, exercise and recreation areas, and medical/health maintenance provisions.

Selection of an overall architecture and configuration approach has many important influences upon crew support factors:

- The approach determines internal volumes which will be available in any given area (or module) for crew functions and equipment.
- It influences the degree to which flexibility will be afforded to optimize interior design in any given module. (This is particularly critical for space stations due to compactness dictated by launch constraints and unique opportunities to take advantage of microgravity conditions to divide and use interior spaces in innovative ways that will be discussed later).
- It determines circulation patterns and constraints upon functional relationships between activities, facilities, and equipment.
- It affects safety and crew emergency procedures by determining the degree of accessibility to "safe heavens".

Since Spacehab was intended to support a relatively large crew, the notion of applying a conventional build-up approach which used Orbiter cargo bay-sized modules to be connected together on-orbit was rejected as being too restrictive. The interior 14 foot diameter by 50-60 foot length limitations would not permit adequate group assembly spaces, and internal circulation through and between the many modules would be too complicated, constricted and inconvenient to be workable. Use of the Orbiter's external tank as a habitat structure was considered, but ultimately rejected, primarily due to on-orbit retrofitting requirements and problems. Also considered but discarded was a geodesic strut and panel ("tinker toy") approach which would be assembled on-orbit around Orbiter-sized mechanical/logistics service cores. It was originally envisioned that the panels comprising the outer envelope would be made up of laminated sandwiches of radiation reflective, micrometeoride resistive, and thermal insulative materials, and would be sealed against the geodesic frame with the aid of internal pressurization of much the same manner that tubeless tires are sealed against automobile wheel rims. (In this case, an interior bladder would have been added for extra leak protection). The approach was later abandoned for two main reasons. The many struts and panels involved would make the system too complicated and time consuming for EVA astronaut assembly operations...and thermal expansion-contraction would be likely to eventually cause seal failures and leakage at the numerous joints. The Spacehab team ultimately selected a concept utilizing inflatable envelopes ("pods")...into which modularized mechanical/logistics service cores similar to those planned for the tinker toy concept would be inserted. The pod approach provides many advantages:

- The membranes can be light weight and highly compactible for launch.
- Most systems can be integrated prior to launch, avoiding retrofitting and minimizing on-orbit assembly of the large (60-90 foot diameter) structures.
- Structural joints that can leak and require maintenance can be minimized.
- The pods can take many forms to adapt to a wide variety of special dimensional and configuration requirements.

CREW PLANNING CONSIDERATIONS

Planning for a large space station like Spacehab must take most of the same type of factors into account as holds true for smaller stations, with some differences:

- Future space station users in second and third generation missions are not likely to be as selectively chosen or as extensively prepared as previous astronauts and cosmonauts, and will be less likely to endure hardships without complaint.
- Missions are apt to be much longer in duration, and space crews in orbit for weeks and months at a time conducting research, attending to microgravity manufacturing processes, and undertaking construction and assembly of space structures such as large communications satellites are likely to experience significant physiological and psychological changes and become bored.
- Internal conditions may be quite crowded, and reducing tension between a diverse mix of inhabitants living in close quarters with limited privacy will be essential.
- Enforcement of procedures and conduct while maintaining high crew morale when crews are mixed and from non-military backgrounds may call for new, innovative leadership and authority delegation techniques.
- Scheduling of facility utilization to accomodate demands for exercise time, food preparation and dining services, recreation facilities, etc. will require extensive attention.

- Opportunities to take full advantage of microgravity conditions in planning interior layouts are enhanced with larger space station volumes to work with..."walls" and "ceilings" can be put to good functional use, two levels can share a common floor, and movement from one level to another without need of stairs. (Similar possibilities in smaller Orbiter cargo bay-sized space station modules exist, but are much more limited).

General habitability considerations that apply to all space stations have been revealed through the US Skylab and Russian Salyut program experiences:

- Conventional thinking about furniture must be put aside. Without gravity to hold the body into a bent, seated position, one can sit in a standard chair only by continuously tensing and straining stomach muscles. Consequently, chairs aren't needed. Space-consuming beds aren't required either since sleeping bags can be attached to "walls" or "ceilings" with covers pulled tight to simulate pressure felt under bedding. Horizontal surfaces for tables are arbitrary since nothing will stay in place unless anchored. Vacuum-top tables... tables with pores through which a suction simulates gravity...might be used on work benches to keep small hand tools and hardware from drifting away.

- Body posture changes in microgravity should be taken into consideration. Without gravity to compress the spinal chord, the torso elongates a few inches, but is not so stiffly erect as on earth. It makes sense to raise and tilt work surfaces accordingly, to an appropriate crouching height. Dining tables, if provided, might be raised to minimize the distance between food containers and the astronauts' faces to reduce risks that food will "get away" enroute to mouths. The result will be adaptation to a "Chinese style" of eating. Dining tables in space stations are really not essential at all since crewpersons can eat while in a weightless free-float condition.

- Possible reach envelopes for standing astronauts increase under conditions of weightlessness. Assuming that an individual's feet are anchored to a "floor" in some fashion (e.g., shoes with cleats or suction cup soles), the person can lean forward past his normal center of gravity without experiencing a loading stress on his ankles or fear of falling on his face. Providing necessary anchorage for persons performing stationary tasks is, of course, very important.

- Storage systems should be designed to avoid the Jack-in-the-box effect that frustrated Skylab crews. Putting items in pockets of transparent storage bags rather than in drawers where contents fly out when opened is one solution. Clothing pockets become valuable portable stowage places for a wide variety of items.

- Equipment should be designed to avoid small loose parts such as nuts and bolts which can float away and get lost. Use of mechanical latches for fastening is one approach.

- Loss of muscle mass and deconditioning of cardiovascular systems must be reduced through active exercise programs and effective equipment. New ways to combine exercise with recreation to encourage health fitness should be explored.

- Special hygiene provisions are needed. A quick shower on earth can become a "bird bath" in orbit with water particles floating randomly in all directions. And while soaping up in microgravity is relatively easy, rinsing off is tedious and time consuming. NASA is considering a special shower to simulate gravity using an air flow to move water so that it will drain. The Environmental Center is proposing another approach...a "car wash" for humans complete with wash, rinse, and drying cycles. While no laundry facilities were provided on Skylab, the crews believed they would have been highly desirable and future space stations should have them if at all possible.

- Diverse psychological issues and needs must be taken into account. For example, while microgravity conditions enable use of "walls" and "ceilings" as floors, work, and storage areas, disorientation and confusion can result unless a "local vertical" reference is provided. This can be accomplished through the selective use of colors, lighting, and positioning of dominant focal elements to help astronauts maintain spatial orientation. Colors and lighting can also effect how large/small, active/restful, and cold/inviting interior areas appear. Variety achieved through changes of appearance and use of areas, activity schedule changes, and avoidance of monotonous colors can very likely reduce boredom on long missions.

- Personal privacy should be provided for. We at the Environmental Center advocate separate (but small) sleep stations for each astronaut. Dimensions for the stations might be approximately 4 feet x 4 feet x 7 feet tall...and each cubicle might be outfitted with a sleeping bag,

limited personal storage, a retractable writing desk, and a television screen. The TV consoles will enable occupants to tune in views of the earth, sun, and moon; take advantage of pre-recorded information programs; receive live announcements; and watch taped (and possibly live) earth broadcast networks. Toilets, laundry facilities, vending machines, and first aid cabinets should be located nearby.

- Eating is important both physically and psychologically. Future space stations might provide some fresh foods as well as frozen and pre-cooked varieties. However, microgravity presents interesting complications for space gardening. Plants will probably have to be grown in revolving drums to simulate gravity through centrifugal force so root systems will know which way to grow.

- Medical facilities will also require more complicated support systems to handle preventive health care, diagnosis, and medical emergencies. Surgical procedures and equipment, for example, are radically affected by microgravity conditions, since blood and other body fluids must not be allowed to float away and cover room surfaces. Controlled, directed air flows and special operating envelopes are under study, along with means to secure people and instruments in place during operations.

NEXT GENERATION SPACE STATIONS

At the time of this writing, eight aerospace companies are undertaking a "Space Station Needs, Attributes and Architectural Options" study sponsored by NASA Headquarters which will begin to lay the groundwork for near-term space station planning (if and when NASA receives necessary Congressional funding to move ahead). When the results are in, it is anticipated that NASA will re-examine the Marshall Space Platform and JSC SOC concepts and determine which, if either, approach is best suited to guide future space station development efforts. It is quite possible that the approach ultimately selected will be some hybrid form of the two.

Regardless of the overall design and configuration, it is probably safe to assume that some form of efficient system of SOC-like modules will be utilized to provide crew quarters and related support system, and that those modules will be sized to fit into the Orbiter's cargo bay.

The Environmental Center has analyzed interior configuration possibilities and trade-offs for Command Modules and Habitation Modules associated with the SOC approach. Important goals have been to enhance habitability and performance and also optimize efficiency of space utilization. The study has involved three basic types of activities.

- Crew area configurations proposed by JSC and Boeing were analyzed to identify strengths and weaknesses of each scheme.

- Alternative configurations were proposed by the Environmental Center to provide additional options for study.

- Drawings and transparent scale models were prepared to present most promising alternatives.

Given the constraint that the modules must fit into Orbiter cargo bays, allowable internal module dimensions were assumed to be a 13 foot diameter cylinder approximately 35 feet long (not including colonical ends or docking ports). Three general approaches for dividing the modules into smaller functional volumes were obvious:

- Each cylinder can be divided into "bologna slice" segments which produce a stack of shorter 13 foot diameter cylinders. This approach lends itself to creating a radially clustered arrangement of small spaces which might be used, for example, as sleep stations. Circulation areas that are required to move people and equipment between and through these stacked levels substantially reduces the 13 foot diameter floor space available for discrete functional use.

- The cylinders can be divided longitudinally to provide a floor/ceiling area which is rectangular in plan. This approach can open up much larger functional floor area volumes that can potentially be 13 feet wide and 35 feet long.

- The cylinders can be divided in a combination fashion so that some of the spaces are radially clustered and some space is longitudinally extended.

COMMAND MODULES

Key elements of Command Modules were assumed to include a command and control console, a small galley and dining area, waste management hygiene facilities, exercise equipment, sleep stations for at least two people, storage and equipment areas, and airlocks. Functional relationships between these general elements were studied along with internal configuration options and constraints posed by module dimensions.

While the results of the several trade-off studies are too case-specific to warrant exten-

sive elaboration here, some general observations follow:

- A predominately longitudinal space division approach appeared to have merit for Command Module planning applications. All schemes given serious consideration, however, had at least one bologna slice element. Longitudinal slicing provided means to optimize floor areas in wardrooms and enhance an appearance of spatial openness.

- The Environmental Center proposed a new and beneficial device to provide visual contact with the outside...an observation bubble that can be attached to berthing ports from the outside, or alternatively, deployed from the inside using atmospheric pressure to fix the perimeter seal tightly in place. Skylab experience attests to the importance of providing "windows" to the outside. The bubble approach can facilitate and complement development of standard module cannisters with interchangeable berthing/observation port accommodations to increase versatility.

- The command/control area might be located in a bologna slice segment with the console encircling a wall area containing one or more observation bubbles...enabling direct eye contact with EVA and docking/berthing operations.

- Areas located under the floor and above the ceiling in longitudinal slice wardroom areas can offer convenient mechanical, utility, and stowage spaces.

HABITATION MODULES

Crew accommodation requirements for Habitation Modules were assumed to include sleep stations, food preparation and dining, physical fitness and health maintenance equipment, personal hygiene and waste management facilities, and stowage. Again, while the results of the several trade-off studies are too extensive to discuss in detail here, a few general observations follows:

- Four sleep stations can be radially positioned in a bologna slice section, or placed in a longitudinally oriented segment...each approach offering advantages. The radial arrangement will create a special sleep station environment which might tend to isolate the area from noiser, more active functions. The longitudinal approach will produce a more open (spacious) overall feeling within the module.

- Personal stowage areas should be placed between individual sleep stations to provide noise barriers which will enhance privacy. (The sleep stations should be located in an area which is relatively removed from noises and other disturbances associated with wardroom activities).

- Food preparation/dining areas might be oriented longitudinally to optimize open floor space. Demountable tables (or tray mounts) might be provided to enable this area to be converted to an exercise space between meal periods. Substantial stowage should be provided nearby for food, exercise equipment, and other items. Precautions should be taken to avoid odors emanating from waste management and exercise functions from permeating dining and sleeping areas (e.g., through proximity avoidance and/or special air handling provisions).

- Two waste management areas should be provided for emergency and back-up use.

ULTIMATE CONCLUSION

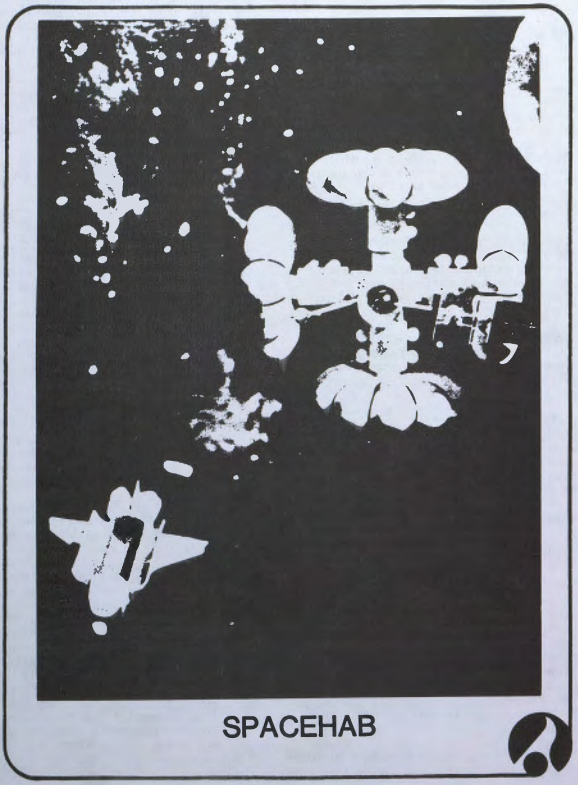
Designing to optimize crew health, morale and productivity necessitates common sense processes which prioritize the importance of human conditions and functions. Human considerations have not been a primary concern in previous missions due, quite understandably, to preoccupations with basic systems development to meet mission requirements. Man, after-all, has proven to be very adaptable...able and willing to tolerate inconveniences and discomforts in the interest of advancing critical program objectives.

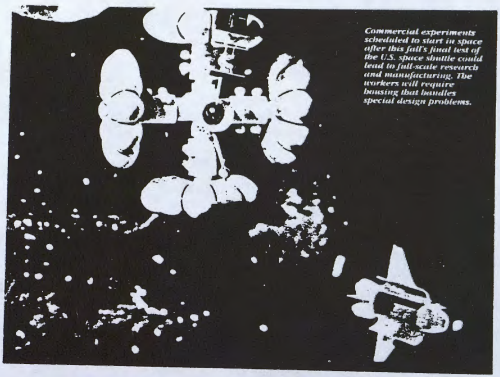
If a "permanent manned presence in space" espoused by national policy is to be realized, it is incumbent upon spacecraft planners to reassess the importance of human requirements for future missions:

- As manned orbital missions are extended in time, maintenance of crew health, morale and productivity will become more problemmatic and critical.

- Future space station crews are likely to present a broader population mix than previous missions, including older and younger people, both men and women, representing a broader range of professional and cultural backgrounds. Many will probably come from non-military backgrounds, will be less carefully screened, and will receive less fanfare upon return to earth than present and past astronauts. They are likely to be less tolerant of inconveniences and discomforts and overall, less highly disciplined and prepared to conform.

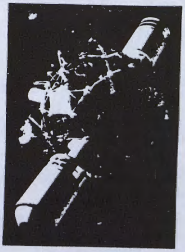
- The costs of transporting crews to and from orbit and supporting them while there will be substantial. Economic benefits of keeping crews in orbit as long as possible and maximizing performance will also be substantial. Efforts to optimize habitability, therefore, will be a practical necessity...not just a humanistic nicety.





Commercial experiments scheduled to start in space after this fall's final test of the U.S. space shuttle could lead to full-scale research and manufacturing. The workers will require housing that handles special design problems.

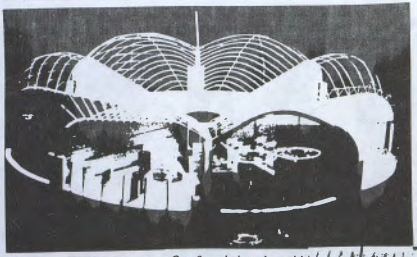
Pods for space workers



'Tinker-Toy' approach

Spacehab Project

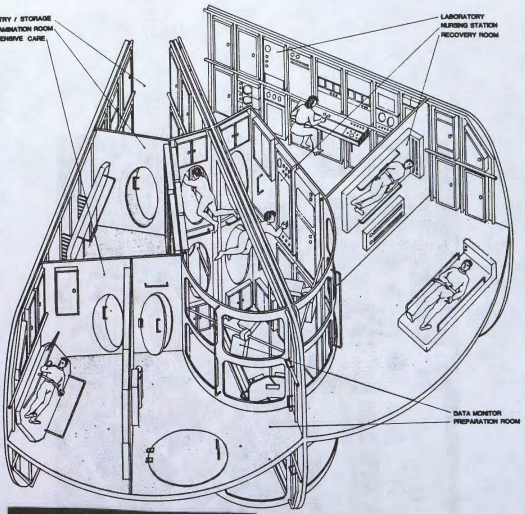
Conceptualized by the Environmental Center : Houston under contract with NASA.

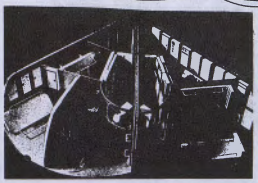


One Spacehab pod would enclose kitchen and dining area. Astronauts would plug trays into circular mounts (inset), then hook feet in the rings below.

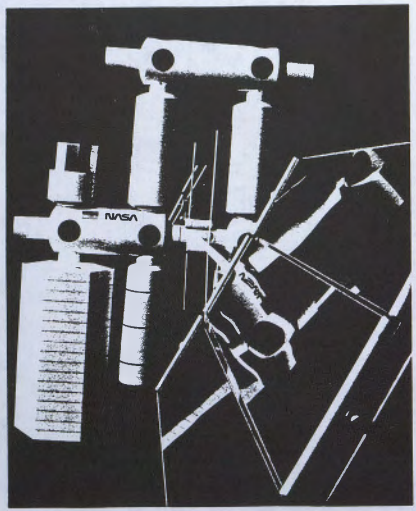
Crew quarters have private cubicles separated by personal storage areas, ranged around central laundry, vending machines, even an electronic A/V library (inset).

Spacehab Project

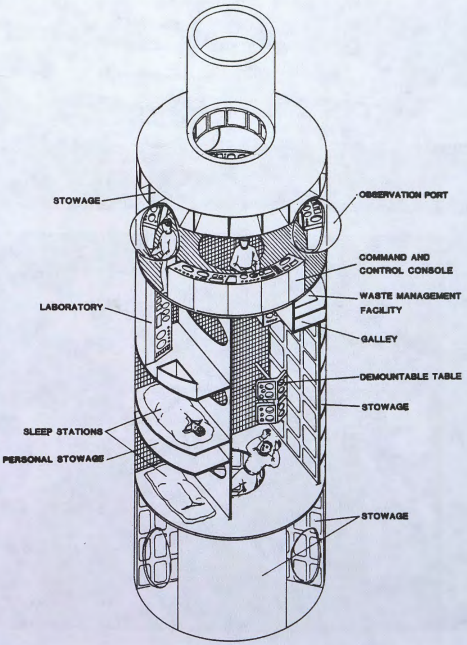




MEDICAL FACILITY

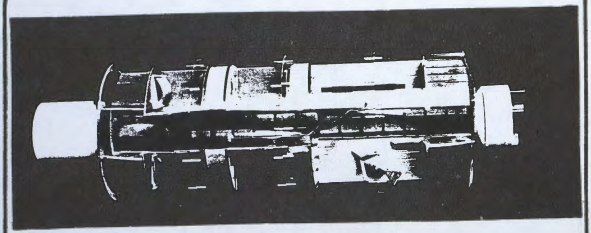


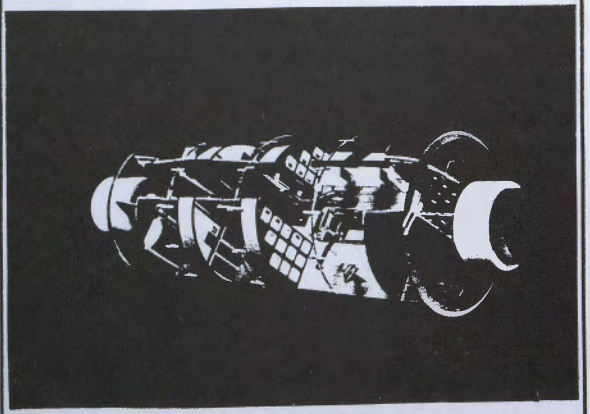
NASA – JSC Space Operations Center (SOC) Concept
Environmental Center Model



Command Module - Scheme 4

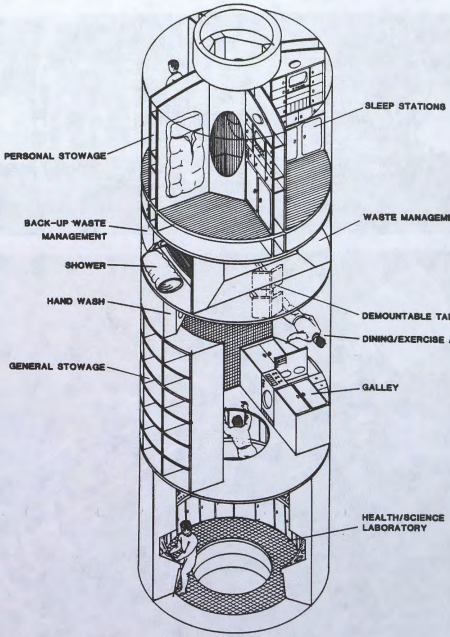
Environmental Center Concept





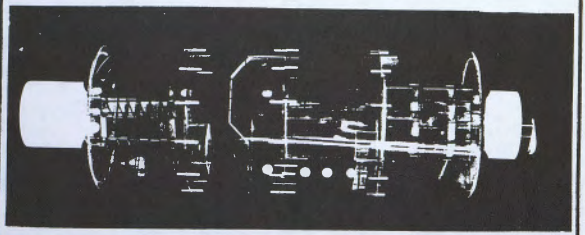
Habitation Module - Scheme 2

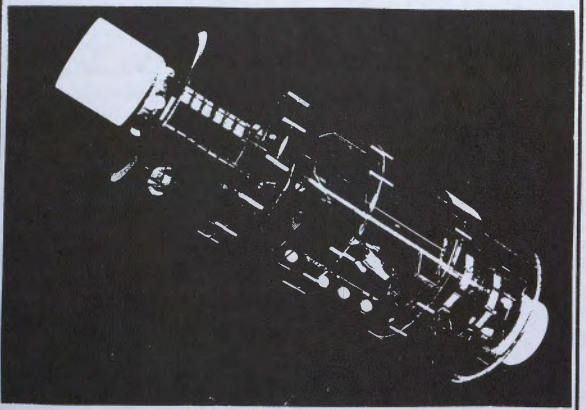
Environmental Center Concept



Habitation Module - Scheme 3

Environmental Center Concept





Habitation Module - Scheme 3

Environmental Center Concept