YOU MEAN I HAVE TO LIVE UP THERE?
HUMAN FACTORS IN SPACE

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The recent Space Shuttle flight has reawakened us to the enormous potential that can be tapped from future missions requiring manned space craft. The Space Transportation System can act as a supporting vehicle for numerous future programs such as space stations, space manufacturing facilities, power satellite systems, space settlements, and other concepts that we may have yet to formulate. As science uncovers new technologies or new applications to old technologies that are advantageous in space, a probable shift will occur in which the impetus for space utilization will be provided less by the regulatory block (NASA) and increasingly on the part of the private sector.

This shift will represent a correspondingly greater diversity of types and sizes of space structure configurations and require a broad spectrum of personnel duties and requirements to support the various missions. Furthermore, the rapid technological growth of information systems promises a reduced dependence on massive ground stations and a correspondingly greater operational potential for future personnel in space. These duties may include inspecting, maintaining, beam building, updating or actually living and working in a space structure. Both short term and long term personned space ventures will be required and different levels of requisite skill, training and motivations will be evidenced. These conditions will necessitate alternative design solutions. For example, a highly motivated crewmember on a short trip to replace a satellite component would not require as large a living space in his habitability module as a beam builder on a long term stay in a space station, but more attention would be needed to minimize the effects of space motion sickness characteristic of the first few days of space flight. Therefore, although there will probably not be any one design solution, a number of issues requiring different priorities for each mission must be considered for future successes in personned space activities. This paper will describe a few of these issues and how the U.S. space program has addressed them.

ANTHROPOMETRIC CONCERNS

Design for the fifth to ninety-fifth percentile population in space represents a much more complex issue than is required for "normal" terrestrial design. During the initial launch of space craft the acceleration induced by takeoff results in compressive forces on the spine that alter the normal viewing angle of the crewperson and must be accounted for if manual activities are required at that time. Subsequent to takeoff and during weightlessness the human body progressively increases in height up to one or two inches caused by the absence of gravitational compression on the spine, underscoring an even greater range of design that must be accommodated to.

Utilization of female crew members for space operations appears advantageous due to such attributes as a smaller mean volume and weight and requirements for less food, oxygen, and other items than are required by male crew members. However, this represents corresponding problems associated with designing for the fifth to ninety-fifth percentile for both men and women under stringent standards of performance. The Space Shuttle flights represent the first time that both males and females will be used for space ventures. Shuttle design was largely able to accommodate for these design requirements with the exception of providing for the full range from five feet to more than six foot four inches in the forward control station. These design strictures were not fully met in this case because of the lateness of the decision to use females, although platforms and stilts were provided as aids.

A major finding that was not determined until the Skylab flights was that in microgravity conditions the body assumes a different posture than the standard 1g position on earth. This was termed the Neutral Body Posture and represents that position the body assumes in the absence of external forces. The Neutral Body Posture is a semicrouch, somewhere between the normal standing and sitting position, in which the neck and head drops forward, the feet evidence a fifteen degree droop and the thighs and knees are slightly bent. Deviation from this posture resulted in extreme discomfort and fatigue for the Skylab astronauts. There was a strain on the stomach muscles as they attempted to maintain the 1g seated position and on the neck muscles in counteracting the reduced line of sight from head droop. The forward postural shift also resulted in a greater reach envelope. Measurements of the posture were determined from Skylab photos and implemented for the first time in the design of the Space Shuttle. The design was subsequently tested in Neutral Buoyancy Water Tanks to substantiate its adequacy.

ORIENTATION

On earth one's orientation is taken for granted because down is in the direction of the gravitational force and maintained by our vestibular system of balance and visual cues. Under conditions of weightlessness, only the visual system provides information regarding up and down, and down is generally considered wherever the feet are located. Consequently, in microgravity conditions disorientation is likely to occur and curious perspectives of normal surroundings often emerge. Orientation to one's surrounding can be augmented by designing a strongly defined local vertical into the craft. A local vertical is created by provision of a clear up/down reference in design corresponding to that normally found on earth. A uniform reference may improve performance because it is easier to train in and presents more familiar and less confusing information in an environment largely interpreted from visual cues but presents the obvious disadvantage of inefficient use of very valuable space.

Skylab was the first U.S. space craft large enough for design of local vertical to be consequential. NASA intentionally designed Skylab with three orientations. Although the workshop where crew members lived and worked was designed with a standard 1g orientation, the Docking Adapter it was attached to provided no local vertical with fixtures protruding from the entire wall and the Command and Service Module which mated with the Docking Adapter had a strong vertical opposite of the workshop. Providing two opposite orientations did not appear to present a great imposition for crew members but much frustration was expressed over the Docking Adapter, which most astronauts never became accustomed to. Even with a strongly defined local vertical in the living quarters of Skylab orientation was difficult and the crew would occasionaly get lost, particularly by entering a room sideways or upside-down. Confusion would disappear within thirty to fifty degrees of the normal vertical and the surrounding would regain its predictive quality.

Despite the fact that the relatively smaller room below which was easier to interpret was preferred and most of the astronauts were the most comfortable when oriented to the vertical, it was generally felt that a specific 1g orientation should not be the primary design goal. Rather traffic patterns and volume considerations should take precedence in formulation of criteria. It was recommended that within a specified task all of the task elements (equipment, lighting, restraints) be arranged around a local orientation but did not need to be correspondingly oriented to other tasks. Future crew members, perhaps less highly motivated and trained, may feel differently and more understanding needs to be gained on this phenomena. The Space Shuttle is designed with a local orientation and provides smaller quarters, so orientation should not represent a problem.

NOISE

Provisions for noise attenuation has represented a major design problem because of substantial resultant weight penalties and the large number of noise generating components. However, noise can cause performance decrements induced from psychological stress, particularly since some astronauts indicated that sleep was not as restful in space. Decibel levels were considerable until noise abatement methods were implemented after the first Apollo Lunar Landing upon the astronauts' insistence that they needed it for sleep. Even with this proviso in the subsequent Skylab, sound levels reached 64 dBA at one point. The Space Shuttle design discontinued the noise attenuation because of stringent cost and weight demands, but additions may be incorporated in future flights to reduce noise levels. One of the fans in particular provided an extremely high noise level and will require a solution. These provisions appear particularly desirable for those missions that shift work is designed for.

MOBILITY/RESTRAINT SYSTEMS

The imposition of weightlessness presents obvious problems in locomotion and manipulation of equipment. Crew members need to be continually restrained to prevent floating away. Once an astronaut started moving along a path he was unable to speed-up or slow-down or change direction on his own. Consequently, if a crew member found himself drifting from a wall he often had to resign himself to floating until he touched the opposite wall (two hours in one instance). Each force exerted created an equal and opposite force so items such as the pushbuttons for squirting water in the Skylab wardroom table provided exasperation when crewmen would find themselves pushed away if they hadn't restrained themselves.

Foot Restraint Systems

The Mercury and Gemini space craft were too small to allow mobility. Apollo Modules were slightly larger but foot restraints were not provided for intra-vehicular traversal. The much greater size of Skylab resulted in a variety of foot restraint systems. The primary system was a triangular cleat that could be attached to shoes and inserted into triangular grids that constituted the floor and ceiling of most of the crew quarters area and forward dome. The restraints were engaged by rotating the shoes slightly and disengaged by reverse rotation. An option in Skylab was three sizes of conical mushroom shaped cleats. The triangular cleats were found to be time consuming to operate and would periodically malfunction, but generally provided a stable restraint system. Conical cleats were easier to engage, but the astronaut had to use continuous pressure in the grid to keep them from disengaging. Flexible velcro lined toe straps were provided in front of the Waste Management Compartment and doughnut shaped restraints were placed in the shower and could be used barefoot. Both of these systems were found deficient because foot droop was not accounted for and effort was required for use.

Evaluation of these and similar restraints resulted in several recommendations. The use of a variety of types of foot restraints was undesirable and only one kind should be developed. This restraint should be passive, not require concentration, be quickly and easily engaged and disengaged, firmly hold the user and allow for installation at temporary work sites. These criteria resulted in the decision to use a suction cup attachment on conventional leather boots that would cover smooth surfaces of the Shuttle Orbiter deck. Such a solution is advantageous because it is more amenable to the ankle droop characteristic of the Neutral Body Posture.

Item Restraints

Weightlessness presented many problems for crew members attempting to locate and use articles. Astronauts frequently reported opening containers and releasing inumerable items into the air, floating in all different directions. The direction and distance of traversal could not be predicted, although large objects generally drifted at a slower rate than smaller objects. Location of specific items frequently appeared impossible. Skylab missions alone contained over twenty thousand items stowed in one hundred cabinets and astronauts quickly lost track of where many of them had been placed.

A number of restraint devices were used on the various missions. Mercury and Gemini flights only used velcro as a temporary restraint. Subsequently, one of the most successful item restraints proved to be bungee cords, or metal "screen door" type springs with snaps or hooks at each end. Pant pockets were inadequate as restraints because items frequently did not fit correctly and would float out.

The problem of restraint of items obviates a need for additional design strategies. Minimizing the number of separate items by use of multi-function tools and equipment alleviates the difficulty of attempting to capture many articles at once. The substitution of latches instead of screws is evidently superior. Color contrasts of figure and background can result in easier detection. Floating items can also be dangerous and should be too large to inhale and possess no sharp edges.

HYGIENE

Astronauts in space have required less frequent body cleansing than would appear necessary on earth because of an absence of virtually all dust and dirt. Filtering systems were continually purifying the air. A week is generally considered an adequate period between thorough cleanings. The primary cleanliness problem resulted from perspiration caused by exercise. This problem was exacerbated by the absence of gravitational convection currents that led crew members to overheat. A fan in close proximity to the exercise area can provide much relief.

The Mercury craft provided no allowances for cleansing because of the short duration of flight. Gemini was too confining for removal of the entire space suit but a water dispenser and towels were available for partial body cleansing. The greater size of the Apollo craft meant crewmen were able to perform whole body cleansing. Skylab was the only U.S. space craft to contain a shower. This was a collapsible suit system that required unpacking and assembly and had to be cleaned and dried out after use. Crewmen generally preferred sponge baths to this, indicating the cleaning of the shower defeated its purpose and was too time consuming. The Skylab crew washed themselves from a valve recessed in the wall of the hygiene station that provided sprays of hot and cold water. A suction drain close to the valve did not perform adequately and water splashing made washing difficult. The Space Shuttle presently only has provisions for sponge bath cleansing because very few missions are expected to exceed seven to ten days. Should longer flights occur in the future, additional systems will probably be accorded.

WASTE MANAGEMENT

The primary issue in management of human wastes under microgravity conditions is ensuring containment so that it does not float into the air. Mercury crewmen were fed a low residue diet for thirty days prior to and during launch to minimize this problem. An insuit urine collection system and a diaper-like insuit fecal containment system was the only provision. Gemini astronauts were less limited dietarily and were allowed plastic bags for fecal containment except during launch and reentry. A variation of the plastic bags for fecal matter was utilized during the initial Apollo voyages but a differential pressure relief tube with a funnel attachment represented a great improvement. Skylab's Waste Management compartment was totally enclosed with a folding door with aluminum sheeting. The triangle grid was not placed on the floor because designers felt that odors and spills would represent a problem. The astronauts disagreed and expressed displeasure at difficulty of performance without restraints. The fecal collector was a hatch like opening with a bag enclosed within and a little seat that folded over. Waste was collected by suction airflow. Urination was accomplished with a variation of the Apollo tube, except the tube caused reduction of pressure inside the bladder and could collect a twenty-four hour supply at one time. Major criticisms of the Skylab system were that the vertical orientation of the fecal collector forced the crew to look at the floor during use, and the lack of restraints. The Space Shuttle waste collector is designed for fifth to ninety-fifth percentile males and females in both zero and 1g with the vehicle oriented horizontally. The compartment contains a privacy curtain as well as top and bottom openings to avoid the expense of private ducting. Designers learned a lesson from Skylab and provided foot and waist restraints and handholds. The seat is more similar to those used on earth, with a vacuum suction for collection and a differential pressure tube. During the recent Shuttle flight a primary complaint of the astronauts was the inadequate force of suction flow. The facility accommodated for women by providing a cap-like protrusion at the front of the pressure tube that would be pressed against to prevent splatter. A potential problem may occur because of the constraint that both males and females use the same urination tube - protocol may also take precedence in space. The compartment was placed as far away from the sleeping compartment as possible because of prior complaints from the Skylab crew.

SLEEPING AREAS

Previous astronauts have reported that sleep is lighter in space, so issues such as privacy and noise barriers appear of particular consequence in a weightless environment. Virtually all of the Skylab astronauts indicated that private sleep compartments are necessary, and the longer the mission the more critical it was considered. Substantial ventilation must be provided in these quarters because in the absence of convection currents caused by gravity it is possible to suffocate in one's own CO_2 exhalations.

The Mercury and Gemini ventures required that astronauts sleep strapped to a form fitted couch with their pressure suits on. Apollo crewmen were still not provided private sleep areas, but could finally wear comfortable intravehicular garments and slept in restraints similar to hammocks under or above the couches. Skylab was the first space craft with private sleeping curtains, partitions and stowage lockers to separate sleep areas. Sleeping bags were oriented vertically to the floor with attendant body restraints. Initially one of the astronauts indicated it was difficult sleeping in this orientation, but he quickly adjusted and it was generally considered an efficient use of space. Astronauts preferred cooler temperatures while sleeping than during work. Temperatures were individually controlled in the compartments by monitoring the airflow rate in the floor, but the headward direction of ventilation caused drying of the nasal passages and general discomfort. Subsequent design evaluations recommended that future space craft avoid directing airflow towards the head during sleep. The Space Shuttle provided four sleep stations containing pallets with restraints, individual lighting, and curtains for privacy. Ventilation could be monitored from each station, but airflow was directed towards the feet. Three of the stations were oriented horizontally and one station was oriented vertically to the floor. Sleeping bags were similar to those used on Skylab. In the case of sleeping shifts required during the Spacelab flights extra sleeping bags will be provided.

CONCLUSION

This paper has addressed only a few of the issues related to design of space craft. However, it is evident that dramatic changes have occured in living quarter configurations in a short time period and this trend will probably continue. Much information has yet to be acquired related to human potential and requirements in space and technological changes will provide progressively new solutions as this information is acquired. For example, effects of long term weightlessness, high energy particle radiation, and sustained rotation for generation of artificial gravity need to be more fully understood and will represent new design implications.