

**Systems and Human Factors  
Concerns for Long-Duration  
Spaceflight**

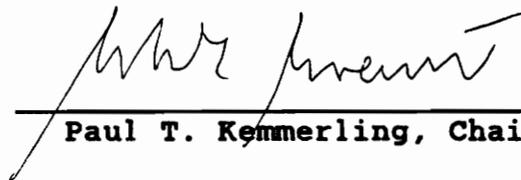
by

**Dwight A. Holland**

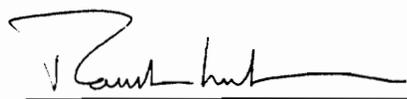
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**MASTER OF SCIENCE  
IN  
SYSTEMS ENGINEERING**

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**Committee Chairman : Professor P. Kemmerling  
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**(ABSTRACT)**

Long-duration spaceflight poses many challenging technical and non-technical problems that must be addressed. Past experience with long space missions has shown that the medical and psychological issues in the human factors realm that may arise are serious enough to require high-level consideration in the overall systems development process.

An essential aspect of the total systems development process for long-duration space missions entails the conception of a variety of countermeasures to combat the degradative effects of microgravity, isolation and confinement. These effects should be considered within a larger mission/systems framework. Additional factors within a broad systems perspective include the notion that context is an important attribute of the overall system state and may directly affect the astronauts' psychological health and the physical ability to perform required tasks.

A review of the literature in the psychosocial and medical realms is presented as these concerns impact the human factor within the macro-system goal of successful long-duration spaceflight mission completion.

## Acknowledgements

I wish to thank my advisor Professor Paul Kemmerling for his patience and wisdom during this process. I also would like to acknowledge the influence that Dr. R. Lickliter has had on my training and thinking in the systems realm. His graciousness and ideas will not soon be forgotten.

Also deserving thanks are my immediate family and my grandparents who have provided so much support and help throughout the graduate education process.

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## CHAPTER 1

## INTRODUCTION

As man seeks to stay in space for longer periods of time, the human factor becomes more and more important. In fact, manned space flight can be viewed as an interaction of three elements: the crewmember (selection, protection, training); spacecraft systems (function, design, performance); and the environment (internal, external, and combined). Proper integration of these mission elements is essential to ensure optimal mission success and productivity. Adopting an integrated systems perspective reveals that the three elements listed become extremely interdependent with the result that variations in one element of the system often have an effect on other system attributes, thereby affecting mission parameters (See Figure 1).

Within an overall systems context, there are many human factors/systems considerations that do not initially appear to directly affect systems decisions but that often indirectly "drive" the final mission goals and hardware requirements. Harris (See Figure 2, 1989) lists some of the "human factors" which impact space developments that are within the realm of the psychosocial, medical, economic, and political arenas, among others. When evaluated within a larger systems context, these factors are described generally in the figure as "Human Factors in Space Developments." The human factors in space developments all interact in complex ways that are often dependent upon context as the defining element of overall systems processes and functioning.

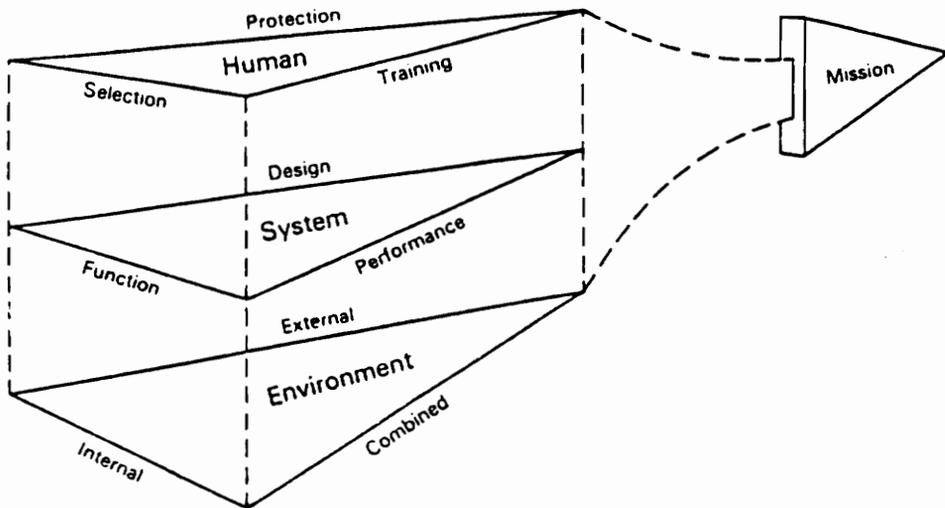


Figure 1. Elements of Mission Design  
(from Nicogossian, Huntoon, and Pool, 1989).

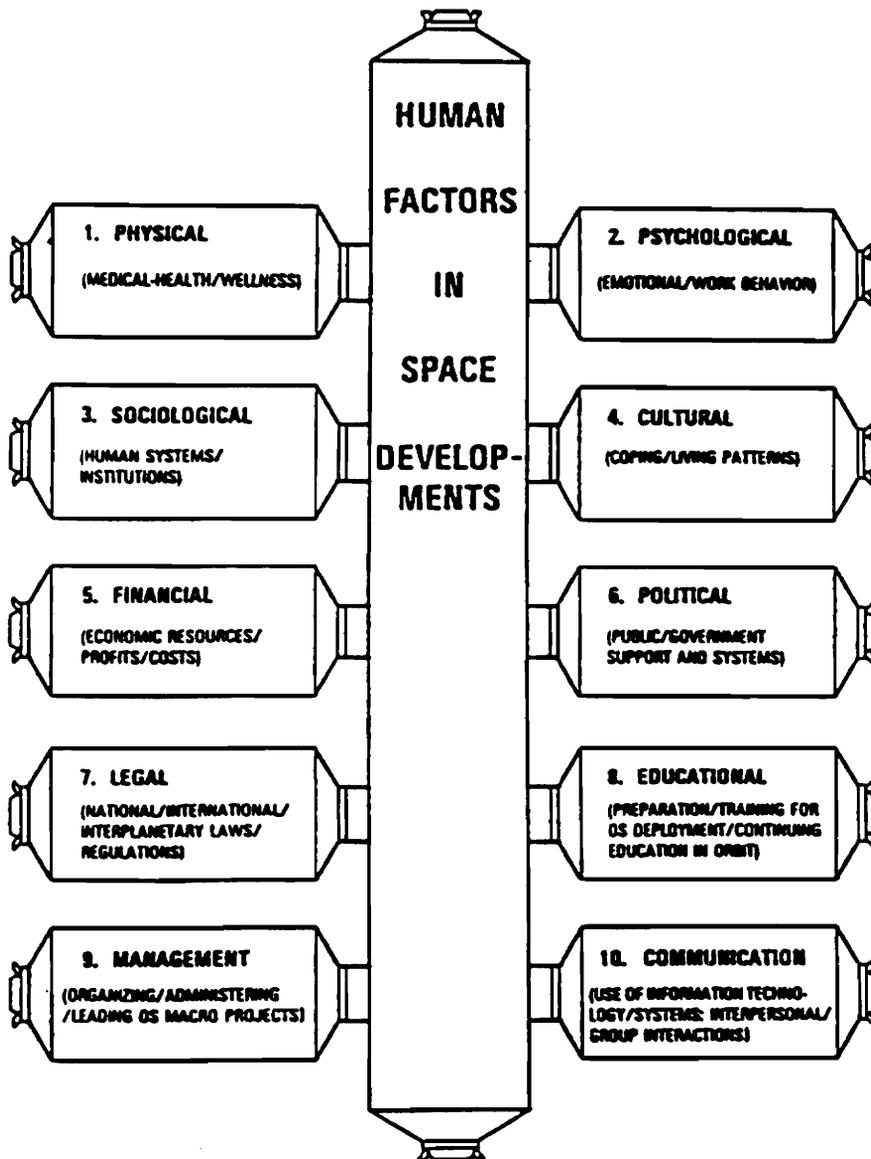


Figure 2. Human Factors in Space Development  
(from Harris, 1989).

## Scope

The organizational cultures of both NASA and its aerospace contractors have normally been dominated by science and engineering disciplines from a narrow, almost purely technical, perspective. The systems approach to solving problems, particularly within the human factors domain, has been spotty at best. One notable example of this has been the recent debate in the space community and halls of congress regarding the amount of Extra Vehicular Activity (EVA) that must be performed by humans for the construction and maintenance of Space Station Freedom. The recent studies which have been done have suggested that the EVA requirements for the station construction and later maintenance would take up so much of the astronauts' time that it would be difficult to justify such a station configuration. This consideration, along with budgetary issues and a host of other factors (review Figure 2), has lead to numerous design reviews and a still-evolving station configuration. Literally hundreds of millions of dollars have been spent on these reviews and mid-course changes, yet not one piece of hardware is in space yet and the "final" station configuration is just now evolving (Aviation Week and Space Technology, 1990a).

This paper will review some of the more pertinent issues within a human factors/systems context for long-duration spaceflight problems. The review will focus predominantly on the first three modules of the systems and human factors topics shown in Figure 2, i.e. the medical, psychological, and sociological issues regarding the crew. These factors are often considered to

be the most critical for long-duration spaceflight mission success. Degradation of either of these three components in the human factors area will lead to overall lowered system performance and reduced mission effectiveness.

## CHAPTER 11

### SYSTEMS ENGINEERING CONSIDERATIONS

#### Systems Engineering Perspective

Systems engineering stresses not only a life-cycle approach to the design and development of a system, but also emphasizes the interrelationships of the systems' components with each other and the external environment (note Figure 1 and its relevance to these comments). Figure 3 is an overview of the system life cycle process (Blanchard and Fabrycky, 1990). As the figure shows, after the definition of need comes the conceptual design phase which is characterized by feasibility studies and advance product planning.

A comprehensive systems developmental context for spaceflight requires that one of the key elements in the conceptual design phase should be the considerations given to the manability (human factors) of the proposed long-duration space facility. These human factors/systems issues are the focus of this review effort.

Figure 4 from Blanchard and Fabrycky (1990) illustrates the human factors considerations that should be evaluated at the conceptual and preliminary system design stages. Close

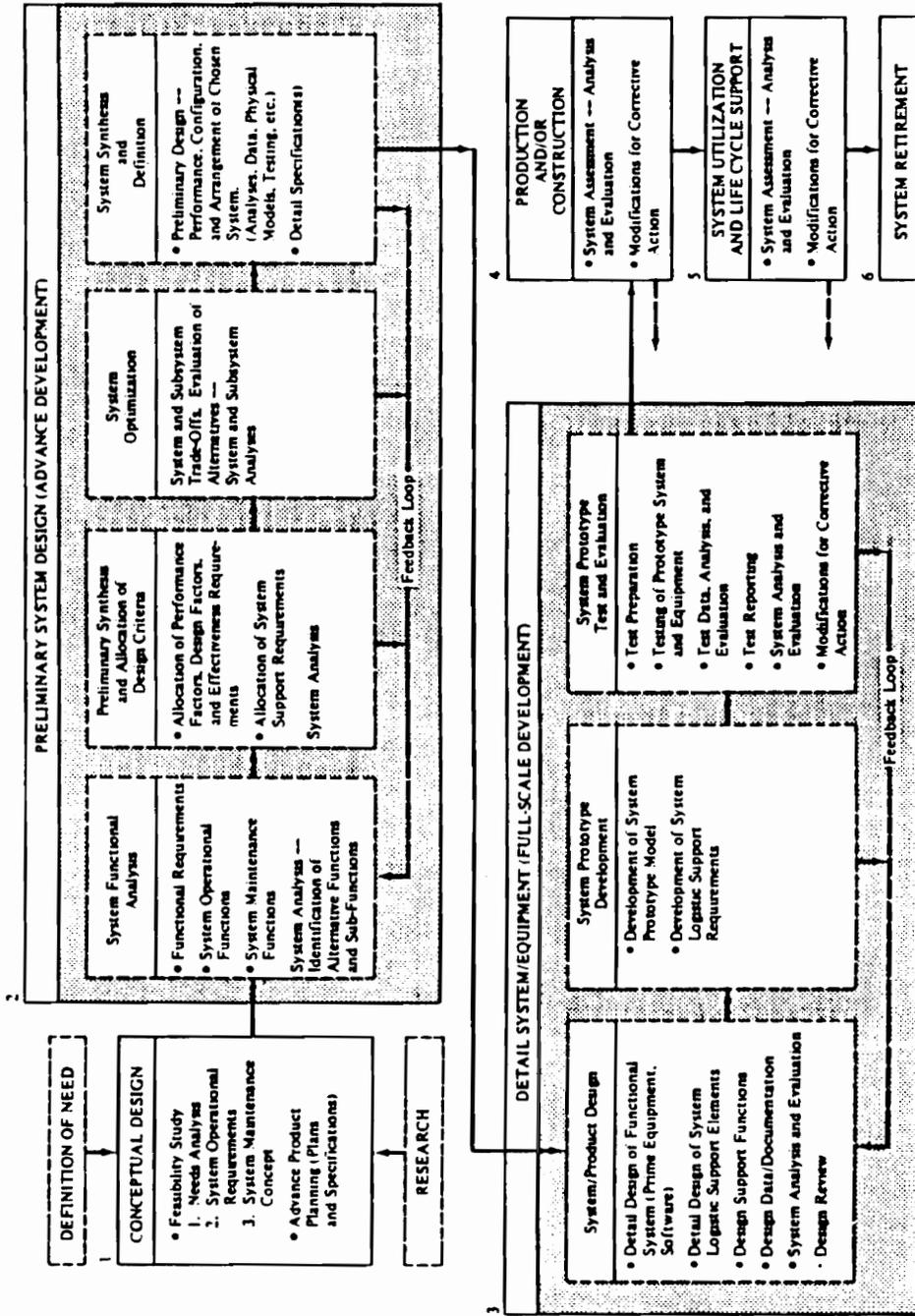


Figure 3. Overview of the Systems Life Cycle Process (from Blanchard and Fabrycky, 1990).

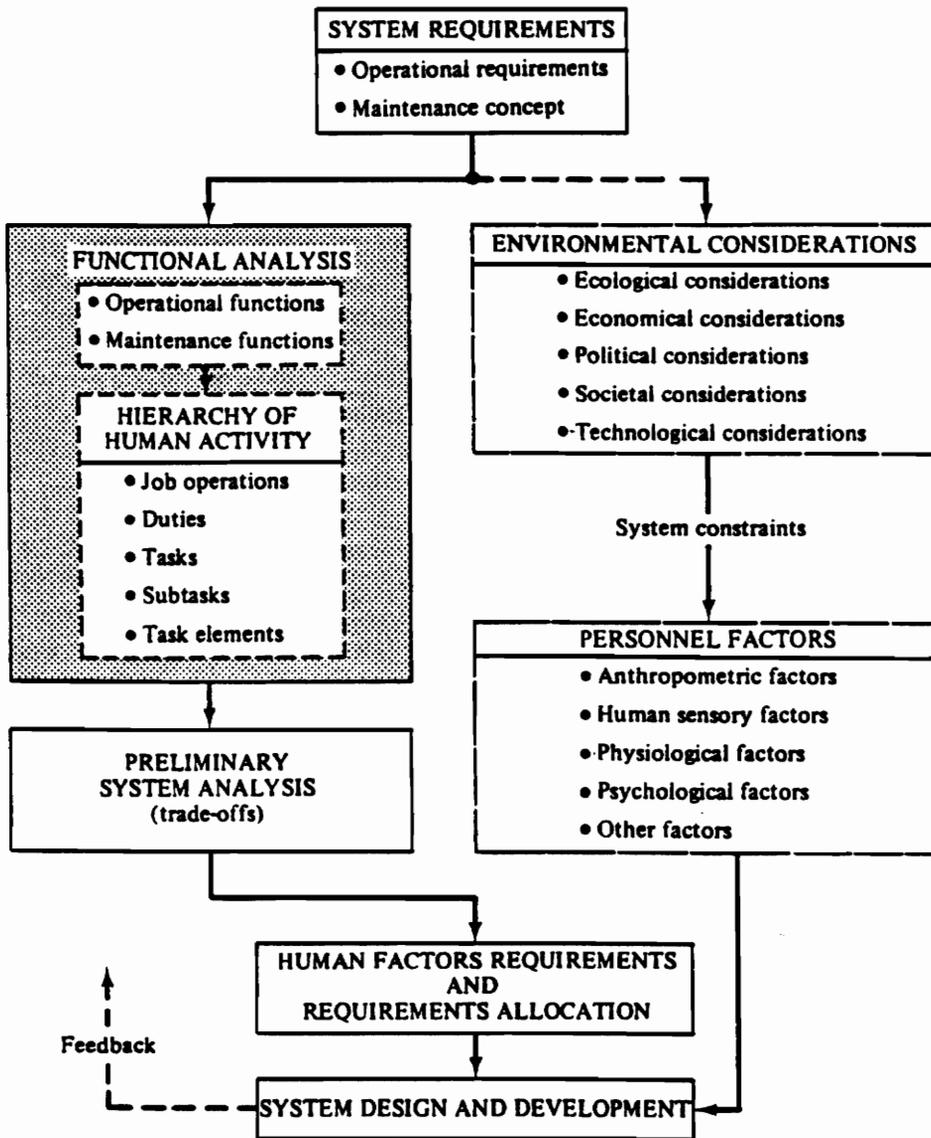


Figure 4. Human Factors Considerations in System Design (from Blanchard and Fabrycky, 1990).

examination of the figure reveals not only the classic functional analysis in a human factors context, but also some of the political, social, technological, and economic constraints that Harris (1989) also identified as relevant. Decisions made at the preliminary system design level may affect the human factor in ways that cannot be easily "fixed" later. Thus, if the human factor is considered early in the design process, more optimal human/system interaction can be expected later when the hardware is produced. Had many of these human factors issues been addressed earlier by NASA and the Congress during Space Station Freedom development, it is likely that several of the design reviews and forced changes in the system might not have occurred saving time, effort, energy and money. Figure 4 also delineates the "Personnel Factors" section as including: anthropometric, human sensory, physiological, psychological, and other factors. The psychological, and to a lesser extent, physiological issues are stressed in the body of this review, but brief mention of the other areas is warranted for completeness since these areas also directly impact systems development.

Blanchard and Fabrycky (1990) in Figure 5 outline how the human factors engineering aspects should be considered within the total systems development process. A detailed discussion of the ramifications of this process is far beyond the scope of this effort except to say that in a system as dependent upon the human factor for success as manned spaceflight--there had better be serious consideration given to this area or disaster might ensue.

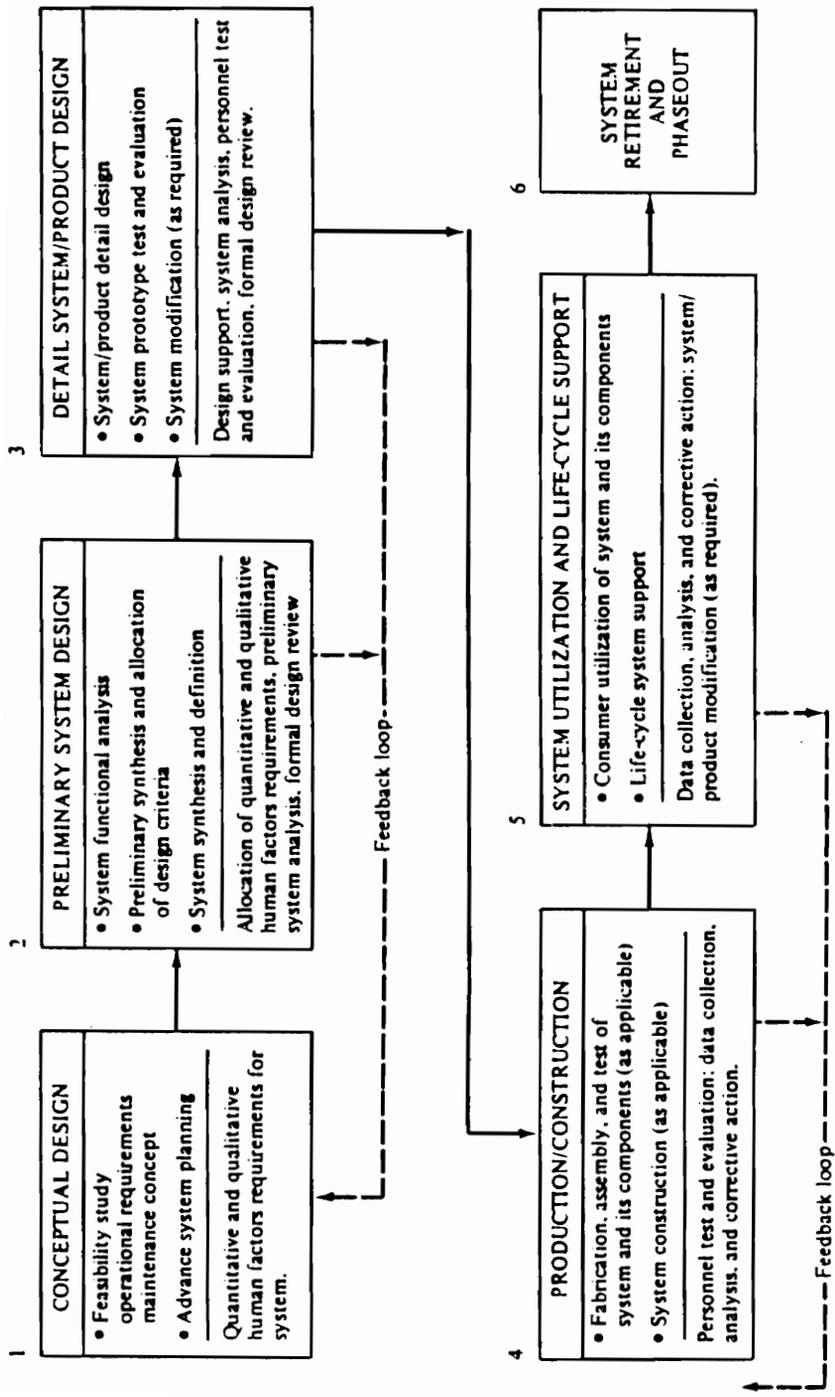


Figure 5. Human Factors Engineering Aspects within the Total Systems Context (from Blanchard and Fabrycky, 1990).

### Anthropometric/Human Sensory Factors

From a systems perspective, the correct application of anthropometric data is crucial to sustaining a high level of human performance without undue fatigue and error.

Anthropometric factors to be considered involve the correct design and placement of controls and panels for effective human utilization. This is a particularly bothersome area since in a zero-gravity environment, the body naturally assumes a semi-fetal position during most tasks as shown in Figure 6 (Johnston and Dietlein, 1977).

Anthropometric and biomechanical issues also to be considered include mass-moving capabilities, force-level parameters (especially for EVA tasks), and musculoskeletal task specific constraints. Thankfully, many of the anthropometric factors relevant to spaceflight have been chronicled in the voluminous NASA (1978) reference guide for this area of human/system integration. Human sensory factors that impact mission performance are many and varied. Table 1 from Hunt (1987) assesses the basic sensory, motor, and intellectual capabilities that are critical to perform in the space environment. All of these capabilities and the limitations that go with them must be addressed within a systems context when functions are being assigned to the human operator. Once the various functions are clearly stated in the process of system concept development, the next step is to allocate those functions to either human or machine. While it is important during the design process to have the physical engineering disciplines represented as key participants; it is equally important to have

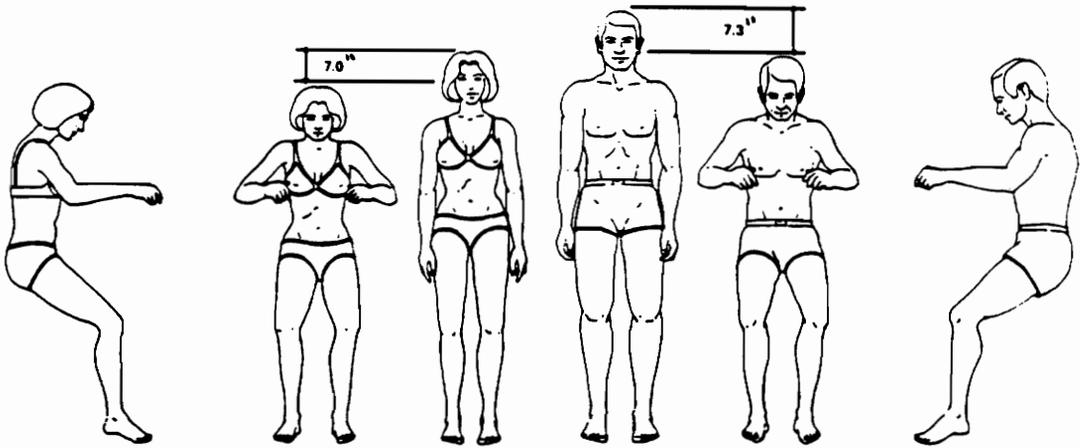


Figure 6. Two center figures show bodies at Earth positions, while four outer figures show neutral body positions of space.

**TABLE 1**  
**SENSORY, PSYCHOMOTOR, AND INTELLECTUAL FUNCTIONS CRITICAL**  
**TO HUMAN PERFORMANCE IN THE SPACE ENVIRONMENT**

**Sensory and Perceptual Functions**

Vision	Audition	Somesthesia
Visual acuity	Auditory threshold	Cutaneous
Brightness	Absolute	Shape
discrimination	Loudness	Texture
Contrast discrimination	Pitch discrimination	Vibration
Monocular/binocular	Sound localization	Temperature
depth perception		Pressure
Color/color contrast		Localization
discrimination		Kinesthesia and
Motion and rate of		proprioception
movement detection		Complex (e.g.,
		itch, oily,
		greasy)

**Psychomotor/Motor Functions**

Force application  
 Eye/hand coordination  
 Fine/gross movement  
 Overall body positioning and  
 limb relationships  
 Rate of movement

**Intellectual Functions**

Short-term memory  
 Long-term memory  
 Cognition  
 Emotional status

Adapted from Hunt, 1987.

the input of specialists in the human factors related disciplines--since these people know more about the capabilities, limitations, and behavioral characteristics of humans as they may be considered to perform particular functions. Guidelines regarding the functional allocation of human versus machine can be summarized by a comparison of human capabilities and machine alternatives as shown in Table 2.

Furukawa and Buchanan (1984) developed a list of functional requirements thought to be "vital" to systematic planning for a Low-Earth Orbiting (LEO) space station. An attempt was made to group major items and their hardware in a relational manner. Figure 7 from Furukawa and Buchanan (1984) represents an attempt to create a holistic space station systems overview as derived from functional and hardware requirements. Note that in the cluster of functions surrounding crew issues, two functions in particular seem to have many other interacting components. The complex interacting components just referred to regarding crew support are habitability and health maintenance/medical care provisions. These particular functions will be addressed in more detail later in this paper.

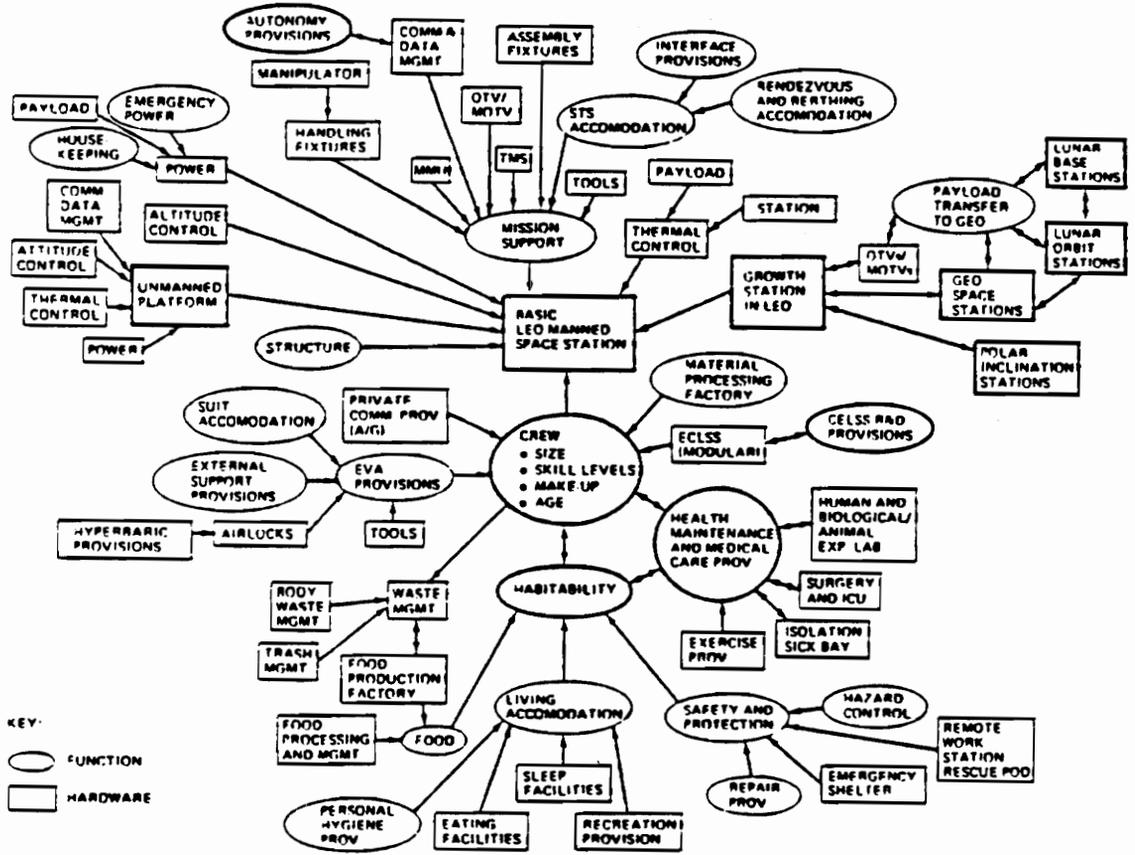
Hunt's (1987) Table 3 also summarizes the characteristics of human senses and indications for their use. From existing human factors and psychological engineering data it is possible to compare the basic human capability to meet systems requirements with the necessary level of performance for the space task. With the possible exception of the neurovestibular system, there apparently does not appear to be a change in the underlying

TABLE 2

## HUMAN VERSUS MACHINE

## Comparison of Human Capabilities with Machine Alternatives

Human	Machine
Can recognize and use information redundancy (pattern) in the real world to simplify complex situations.	Has limited perceptual constancy and is very expensive.
Has high tolerance for ambiguity, uncertainty, and vagueness.	Is highly limited by ambiguity and uncertainty in input.
Can interpret an input signal even when subject to distraction, high noise, or message gap.	Performs well only in a generally clean, noise-free environment.
Is a selecting mechanism and can adjust to sense specific inputs.	Is a fixed sensing mechanism, operating only on that which has been programmed for it.
Has very low absolute thresholds for sensing (e.g., vision, audition, and touch).	To have the same capability, becomes extremely expensive.
Has excellent long-term memory for related events.	To have the same capability, becomes extremely expensive.
Can become highly flexible in terms of task performance.	Is relatively inflexible.
Can improvise and exercise judgement on the basis of long-term memory and recall.	Cannot do this; is best at routine, repetitive functions.
Can perform under transient overload; performance degrades gracefully.	Stops under overload; generally fails all at once.
Can make inductive decisions in novel situations; can generalize.	Has little or not capability for induction or generalization.
Can generate only relatively small forces and cannot exert large forces for very long or very smoothly.	Can generate and exert forces as needed.
Generally requires a review or rehearsal period before making decisions based on items in memory.	Goes directly to stored information for a decision.
When performing a tracking task, requires frequent reprogramming; does best when changes are under 3 rad/s.	Has no such limitations.
Has a built-in response latency of about 200 us in a go-no-go situation.	Has no response latency.
Is not well adapted to high-speed, accurate search of large volumes of information.	Computers are designed to do this.
Does not always follow an optimum strategy.	Will always follow the strategy designed into it.
Has physiological, psychological, and ecological needs.	Has only ecological needs.
Is subject to anxiety, which may affect performance efficiency.	Is not subject to this factor.
Is dependent upon the social environment, both present and remembered.	Has no social environment.
Diurnal cycle imposes cyclic degradation of behavior.	The machine cycle may be whatever is desired.
Is subject to stress as a result of interpersonal problems.	Is not affected by such problems.
Great differences exist among unselected individuals.	There are no unselected machines.



**Key** OTV: Orbit transfer vehicle  
 TMS: Teleoperator maneuvering system  
 MMU: Manned maneuvering unit  
 PROV: Provision  
 A/G: Air (space)-to-ground  
 STS: Space Transportation System  
 LEO: Low-Earth orbit  
 GEO: Geosynchronous Earth orbit  
 ICU: Intensive care unit  
 ECLSS: Environmental control & life support system

Figure 7. Interactive Nature of Space Station Systems  
 Adapted from Furukawa and Buchanan, 1984.

TABLE 3  
CHARACTERISTICS OF THE SENSES

Parameter	Vision	Audition	Taste and Smell	Touch	Vestibular
Sufficient stimulus	Light-radiated electromagnetic energy in the visible spectrum. Heavy particles	Sound-vibratory energy, airborne or structural paths	Particles of matter in solution (liquid or aerosol)	Tissue displacement by physical means	Accelerative forces
Spectral range	Wavelengths of 400-700 $\mu\text{m}$ (violet to red)	20-20,000 Hz	Taste: salt, sweet, sour, bitter Smell: fragrant, acid, burnt, and caprylic	> 0 to < pulses/sec	Linear and rotational accelerations
Spectral resolution	120-160 steps in wavelength (hue) varying from 1 to 20 $\mu\text{m}$	~3 Hz (20-1000 Hz) 0.3% (above 1000 Hz)	—	$\Delta\text{PPS} = 0.10$ pps	—
Dynamic range	~90 dB (useful range) for $3 \times 10^{-4}$ $\text{cd}/\text{cm}^2$ (0.00001 mL) to 32 $\text{cd}/\text{cm}^2$ (10,000 mL)	~140 dB 0 dB = 0.0002 $\text{dyn}/\text{cm}^2$	Taste: ~50 dB $3 \times 10^{-4}$ to 3% concentration quinine sulfate Smell: 100 dB	~30 dB 0.01-10 mm	Absolute threshold = 0.2°/sec
Amplitude resolution $\Delta I/I$	Contrast = $\Delta I/I = 0.015$	0.5 dB (1000 Hz at 20 dB or above)	Taste: ~0.20 Smell: 0.10 to 50	$\Delta I/I$ nonlinear and large at low force levels ~0.15	~0.10 change in acceleration
Acuity	1° of visual angle	Temporal acuity (ciclets) = 0.001 sec	—	Two-point acuity = 0.1 mm (tongue) to 50 mm (back)	—
Response rate for successive stimuli	~0.1 sec	0.01 sec (tone bursts)	Taste: ~30 sec Smell: ~20-60 sec	Touches sensed as discrete to 20/sec	~1-2 sec synapse may persist to 2 min after rapid changes in rotation
Reaction time for simple muscular movement	~0.12 sec	~0.19 sec	—	~0.15 sec (for finger motion, if finger is the one stimulated)	—

Source: Loftus, Bond, and Patton, 1975, as used by Hunt, 1987.

TABLE 3 (Continued)

## CHARACTERISTICS OF THE SENSES

Parameter	Vision	Audition	Taste and Smell	Touch	Vestibular
Best operating range	500-600 $\mu\text{m}$ (green-yellow) 107.6 $\text{lm}/\text{m}^2$ (10 fc) to 2152 $\text{lm}/\text{m}^2$ (200 fc)	300-6000 Hz 40-80 dB	Taste: 0.1-10% concentration	—	-1 g acceleration directed head to foot
Indications for use	<ol style="list-style-type: none"> <li>1. Spatial orientation required</li> <li>2. Spatial scanning or search required</li> <li>3. Simultaneous comparisons required</li> <li>4. Multidimensional material presented</li> <li>5. High ambient noise levels</li> </ol>	<ol style="list-style-type: none"> <li>1. Nondirectional warning or emergency signals</li> <li>2. Small temporal relations important</li> <li>3. Poor ambient lighting</li> <li>4. High vibration or g-forces present</li> </ol>	<ol style="list-style-type: none"> <li>1. Parameter to be sensed has characteristic smell or taste</li> <li>2. Changes are abrupt</li> </ol>	<ol style="list-style-type: none"> <li>1. Conditions unfavorable for both vision and audition</li> <li>2. Visual and auditory senses</li> </ol>	<ol style="list-style-type: none"> <li>1. Gross sensing of acceleration information</li> </ol>

Source: Loftus, Bond, and Patton, 1975, as used by Hunt, 1987.

mechanisms of human sensory and perceptual processes as a result of residence in the space environment. The human sensory characteristics mentioned above will only be addressed in the body of this paper as they may affect and psychological and physiological factors for long-duration spaceflight.

Care must be taken when extrapolating earthbound task performance data to the space environment because the uniqueness of that environment does not always lend itself to highly reliable task performance data, thereby impacting mission timelines. Both the U.S. and Soviets have noted that the "average" task in space requires approximately twice the time that the same practiced task on earth takes (Bluth and Helppie, 1986; Cooper, 1976; Fay and Helmke, 1989). Accomplishing daily tasks must be done within a habitable environment or a degradation of human performance will soon occur. The concept of "habitability" will be discussed next from a systems viewpoint.

### Habitability

In their classic work, Living Aloft, Conners, Harrison, and Akins (1985) defined what habitability meant within a space operations context:

Habitability is a general term which connotes a level of environmental acceptability by potential users. The requirements for conditions to be "habitable" change dramatically with circumstances. For brief periods, almost any arrangement that does not interfere with the health of individuals or the performance of their jobs would be acceptable. Over the long term, conditions [in the system] must support not only individuals' physical, but also their psychological health.

Space habitability within a systems paradigm then implies

not only solid human/system performance, but also addresses the quality of life in space that allows for both survival and the development of human potential. The Conners et al. (1985) group adopted the recommendation of the Space Sciences Board to utilize a systems perspective to analyze spaceflight. Habitability is a part of that systems perspective. The systems perspective in this context reveals that missions are comprised of highly interdependent components (e.g. biological, social, technical), such that changes in one element may have repercussions on other mission elements. Figure 8 from the Hunt (1987) article mentioned earlier illustrates how habitability is affected by many systems factors from the biological to the purely social. Habitability in turn affects (or feeds back onto) many of the parameters shown in the figure thus reflecting the total system's dynamic nature among the factors involved in a complex way. This dynamism is not always predictable because the context within which a significant event occurs may change from one time to another.

One of the most important issues to consider within the habitability realm is that of crew quarters. According to the National Research Council (1986), one of the key negative habitation factors in undersea habitats, submarines, and polar stations has been the lack of privacy. Privacy becomes more important as the mission length increases.

Soviet research has shown that a lack of space (volume) may lead to negative physical and psychological problems (Bluth and Helppie, 1986). The need for privacy is related to the nature of

the stressful conditions imposed on the human being. The need to withdraw temporarily to "recharge one's batteries" can be a very effective coping mechanism.

The interior design of the Space Station or a vehicle going to mars is of utmost importance. The Skylab experience has shown that some factors are more important than others when designing personal crew quarters. The items that are of particular importance are: intrusive noises, ceiling height in confined areas, personal stowage needs, needs for acoustic, light and odor isolation, uncomfortable temperatures, and uncomfortable airflow direction, etc. (Fount, 1989).

Other design considerations to improve habitat aesthetics are to:

- \* Provide variation of visual stimuli through color changes, if wanted;
- \* Design interiors to accomodate personalization of decor;
- \* Discourage too personalized decor in common areas.

Fount (1989) did a survey of habitability issues from all nine Skylab astronauts and two current Space Shuttle astronauts. He found that eight of the respondents would like to spend between 25 and 60 percent of non-sleeping off-duty time in solitude. The other three respondents would also like to spend time alone, but a lower percentage of the time. Eleven of those questioned felt that the crew quarters be kept at a minimum of 150 cubic feet. One respondent felt that a quarters size of 80 cubic feet, like that of Skylab, was fine--but that there should be more recreational space to compensate for the smaller

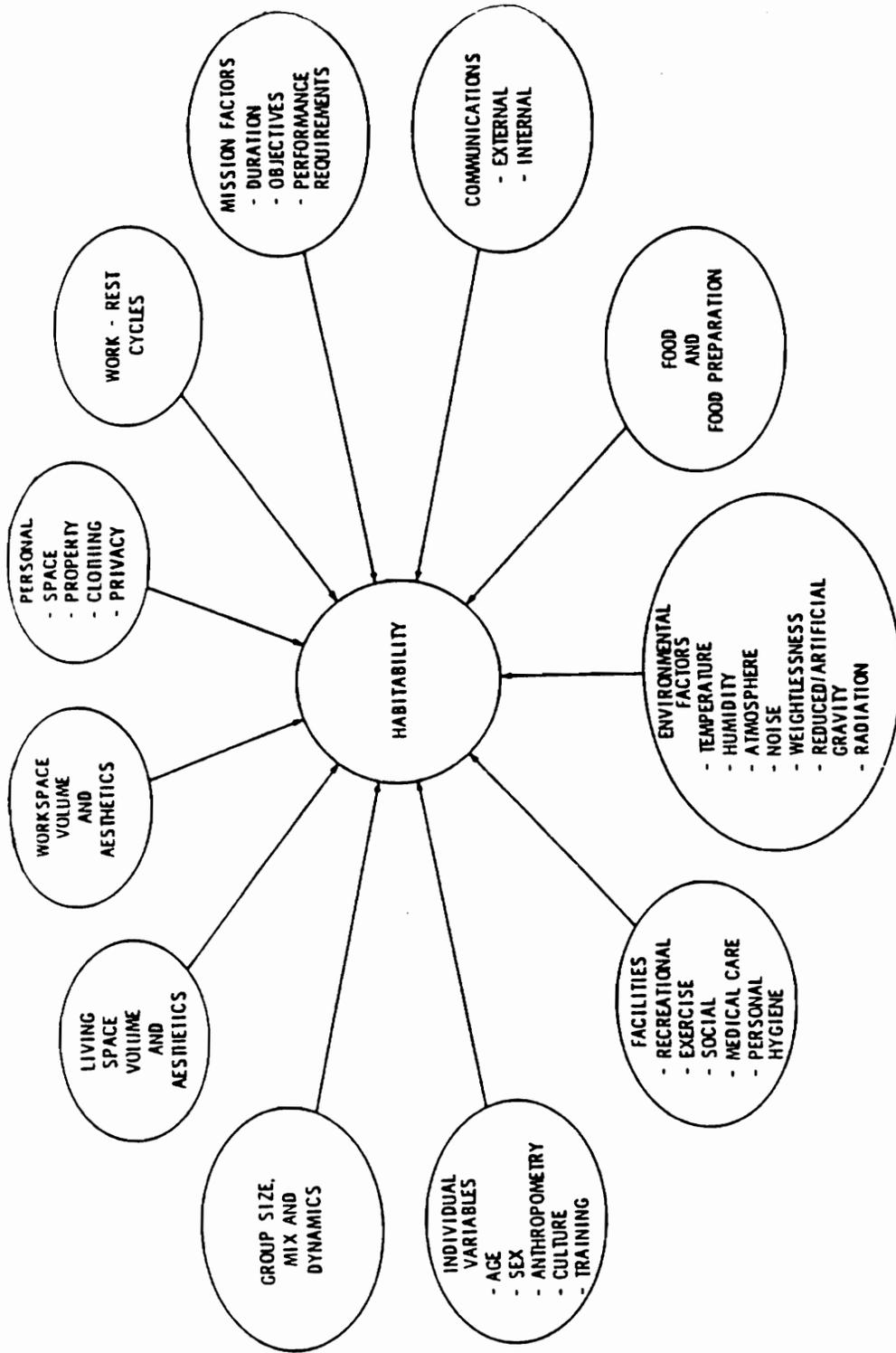


Figure 8. Factors Impacting the Habitability of Spacecraft  
Adapted from Hunt, 1987.

quarters. Nine of the eleven respondents felt that there was an absolute necessity for crew members' personal items to be included in the space of the individual crew quarters. There are many more habitability issues for space station design teams to consider during a systems design process (as Figure 8 illustrates) that are of significance that will not be reviewed here.

Some researchers have attempted to expand the interactional nature of systems components into a generalized theory incorporating aspects of open-systems theory. Open-systems theory has also been called Living Systems Theory (LST) and has wide applicability to the multi-dimensional problems of extra-terrestrial outposts and long-duration spaceflight (Miller, 1978), and it is this LST perspective that will be reviewed next.

### CHAPTER III

#### LIVING SYSTEMS THEORY

##### Applications

Dr. J.G. Miller, a psychiatrist/psychologist, began directing applications of his research on Living Systems Theory to the space realm in the mid-1980's. Another researcher named Finney (1985) confirmed Miller's approach and emphasized that in space studies, a living systems approach has biological, technological, and social components. Finney (1985) called for social scientists, biologists, human factors engineers, and architects all to work closely with the project managers and

engineers who design the whole space system. Perhaps without realizing it, Finney was actually calling for a complete systems engineering approach to the problem of long-duration spaceflight.

A paper entitled Living Systems Applications to Human Space Habitation (Miller and Miller, 1990) suggests that planning for extraterrestrial living requires an overall systems perspective with the primary design focus on the human beings that are to inhabit the base (or station). They propose that Living Systems Theory (LST) can aid in the planning and management of such a facility because it is an integrated conceptual approach to the study of biological and social living, the technologies associated with them, and the overall environmental constraints that affect the system's functional parameters. Living systems in the Miller's conceptualization are open systems that maintain a thermodynamically improbable energetic state by a continual interaction with the environment, in which these systems input substances of lower entropy and higher information content than they output.

### Theoretical Basis

James and Jessie Miller have developed a visual/conceptual representation of the 20 essential subsystems at each of the eight main levels of living systems. In this model, the eight levels of the vertical axis are--cell, organ, organism, group, organization, community, society, and supranational systems. The essential subsystems are depicted on a horizontal axis as reproducer, boundary, ingestor, distributor, converter, producer,

matter-energy storage, extruder, motor, supporter, internal transducer, channel/net, timer, decoder, and output transducer. The living systems theory thus facilitates cross-level research in terms of the various components of the system interacting with each other.

Each system can be identified with this methodology in terms of a set of variables, or parameters, describing its basic processes. At the level of groups or below, these represent aspects of flows of materials or matter, energy, and information of communications. At the level of organization and above, two additional flows are measured--personnel (individual or group), and money or its economic equivalent (i.e. costs).

P.R. Harris (1989) and Miller (1989) have separately argued for a general living systems theory to be applied to the development of the space station and lunar base. They both believe that using this strategy will improve space planning and management--which is desperately needed based upon past experience with the shuttle and space station systems. Examples summarizing the basic concepts and tenets of the living systems theory for spaceflight can be found in Figures 9 and 10.

Figure 9 depicts the systems applications in the space station Freedom with the five major flows for that open system using LST symbols (colors are also included for coding as part of the theory but cannot be reproduced here). Five major LST flows are also shown for the proposed lunar base which is slated to be operational before 2010 (Figure 10). The pattern for the lunar base illustrates a command center, generating station, habitation

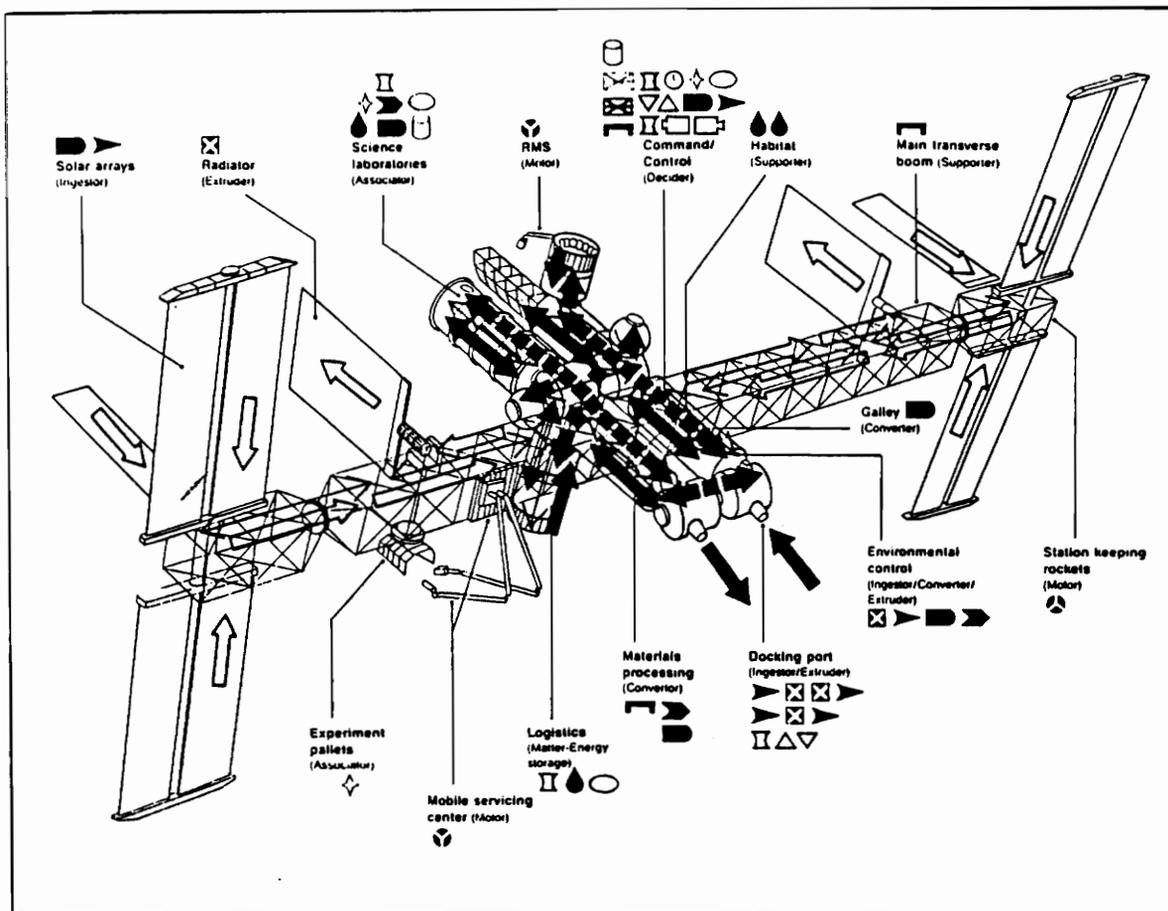


Figure 9  
Space Station Living System Theory Flows

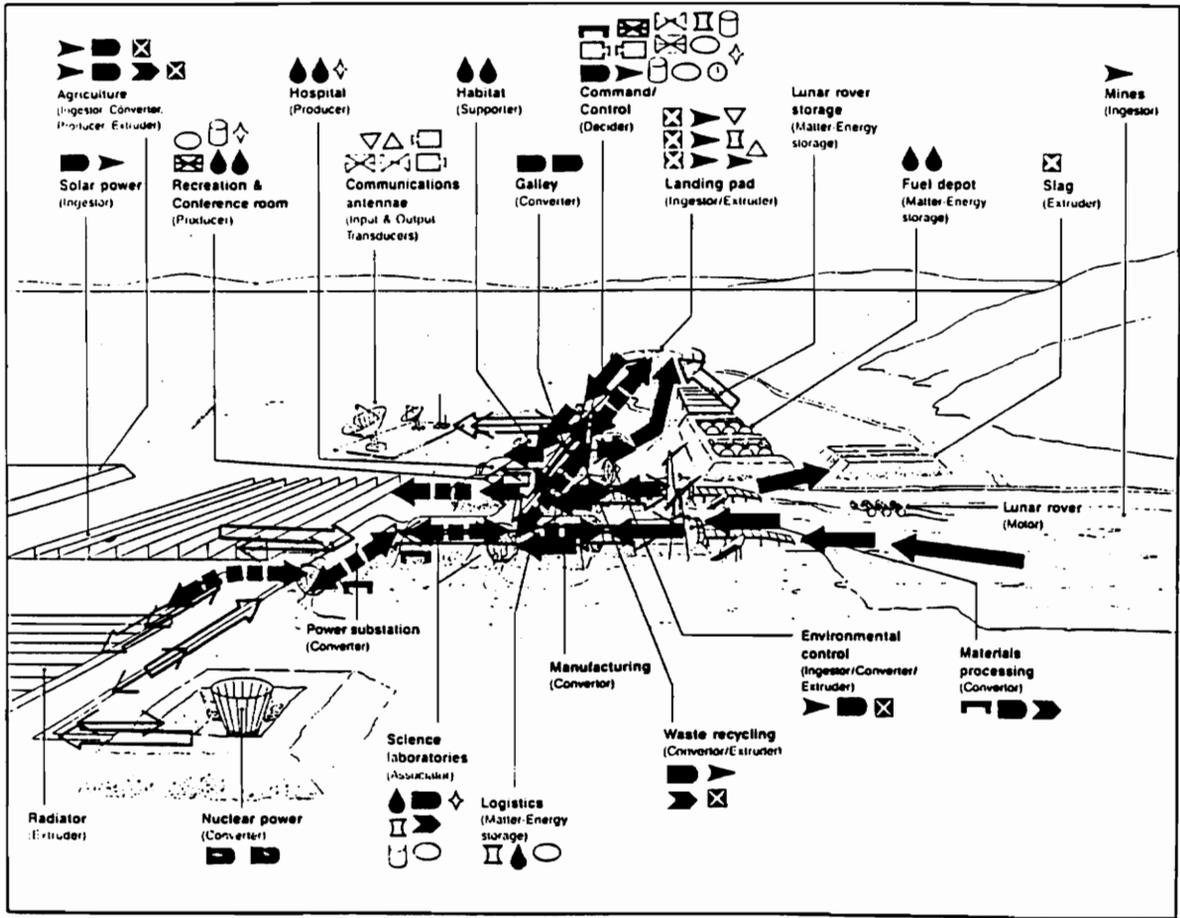


Figure 10  
Lunar Base Living Systems Theory Flows

unit, and several other system components.

Living systems concepts can aid in relating the complex factors which impact the success or failure of a space mission. An example of this would be how individual astronauts (organism) form into a mission group, serving the goals of an organization such as NASA, working together with the aerospace industry (community), to achieve the end-objectives of a nation, the United States of America.

LST has been applied with success for over thirty years on the earth by scientists in earth-bound setting. The next application of this style of systems engineering with a life sciences/behavioral emphasis is to improve human performance and habitation in extraterrestrial environments. If LST templates were used within the design and operational phases for space communities, it is possible that better planning information and macromanagement could occur (Harris, 1989).

One of the key components within the context of the systems theory just described is the human being. The major question is: Can performance levels be maintained during long-duration spaceflight to accomplish mission goals and return the astronaut to Earth in a relatively undamaged state? The term "undamaged state" refers to both physical and emotional statuses of the human being. This challenge remains one of the most difficult to overcome within a systems context. Hardware can be built to fly in space, but the addition of the human element into the system requires that many constraints be met that involving the habitability, psychological, and physiological realms. Each of

these contributors to the system has implications for the others by affecting the human factor, potentially endangering human performance and productivity.

## CHAPTER IV

### HUMAN FACTORS CONCERNS

#### Background and Issues

To preserve and enhance the productivity of humans in long-duration spaceflight, effective countermeasures against harmful or performance degrading effects of the space environment must be considered. Psychological issues are of fundamental importance for individual productivity, group cohesion, and quality of life. The main areas of concern in the physiological realm are reduced gravity and radiation. It is not clear at this time whether the physiological changes which occur during long periods associated with microgravity can be reversed quickly enough to allow for normal functioning immediately upon arrival on a planetary surface such as mars, or upon return to the Earth. There needs to be a better understanding of the physiological changes that occur during spaceflight such that countermeasures can be developed to circumvent these changes. The human being could quickly become the "weak link" in the system if better countermeasures are not found. Psychological factors also have been shown to be of serious concern on long spaceflights--along with such analog environments such as Antarctica and submarines. The associated literature within the psychological realm will be reviewed next within a spaceflight social systems perspective.

## PSYCHOLOGICAL FACTORS

### Crew Stress

An isolated and confined environment is going to produce crew psychological stress. Furthermore, the stress-induced dynamics of the group can substantially impact crew performance and morale as both NASA and the Soviets have found. During the longest Skylab mission, commander Gerald Carr and his fellow astronauts not only "plotted" to hide certain things from ground control, but also went on what might be considered a "strike" until some pressing issues could be worked out with the ground controllers (Cooper, 1976; Kanas, 1987). In this case, the group was unified against what they perceived as unreasonable demands by Houston, thereby directing some of the intragroup stress towards ground control. The Skylab mission lasted less than 100 days and was in LEO.

The Soviets have reported similar instances with overt, open, interpersonal conflict aboard their Salyut and Mir space stations. Bluth (1981) reports that cosmonauts have written that it becomes harder and harder to get along as a crew as time goes on and that things should not "...be allowed to explode." There are unofficial reports and whispers in the aeromedical community that during one particularly long flight, one cosmonaut attacked another with a hypodermic needle (Roanoke Times and World News, 1985). This would not be surprising since documented instances have occurred where remote antarctic team members have attacked each other verbally and physically (Harrison, Clearwater, and McKay, 1991). The recently published Harrison et al. work (1991)

just cited is a complete summary of how Antarctic studies on group and individual behavior can be utilized as models to develop a better perspective on human behavior under environmentally stressful conditions which may serve as reasonably good space habitation analogs.

Christensen and Talbot (1986) have done an excellent review on the psychological aspects of spaceflight. Their review examined the American and Soviet experience in space with regard to perception, performance, small group dynamics, and a host of other factors. Table 4 from their work summarizes the main issues which influence orbital behavior and performance from an environmental, space system, and support perspective. If many of the factors that Christensen and Talbot list in Table 4 were considered within a systems context, then there is a reasonable chance that psychological stressors could be mitigated to the extent possible. This approach would require all parties involved in the mission from ground support personnel to the astronauts families to be brought into the systems "loop." The Soviets, perhaps having had learned the hard way, have already been doing just this through their Group for Psychological Support (Santy, 1983; 1987).

A systems perspective on stress relevant to spaceflight has been analyzed by Steinberg and Ritzmann (1990) and is illustrated in Figure 11. Within a systems framework, stress is an overload or unload of matter, energy and/or information input to--or output from--a system. Amending this concept to an organism (astronaut) level reveals that the individual(s) has purposes,

TABLE 4

SOME FACTORS THAT INFLUENCE BEHAVIOR AND PERFORMANCE  
OF SPACECREW AND OTHER OPERATIONAL PERSONNEL

A. Psychological, Psychosocial, and Psychophysiological	B. Environmental	C. Space System	D. Support Measures
limits of performance (perceptual, motor)	spacecraft habitability	mission duration and complexity	inflight psychosocial support
cognitive abilities	confinement	organization for command and control	recreation
decision-making	physical isolation	division of work, man/machine	exercise
motivation	social isolation	crew performance requirements	selection criteria
adaptability	weightlessness	information load	work-rest/avoiding excess workloads
leadership	lack of privacy	task load/speed	job rotation
productivity	artificial life support	crew composition	job enrichment
emotions/moods	noise	spacecrew autonomy	preflight environmental adaptation training
attitudes	work-rest cycles	physical comfort/quality of life	social sensitivity training
fatigue (physical and mental)	shift changes	communications (intracrew and space-ground)	training for team effort
crew composition	desynchronization	competency requirements	inflight maintenance of proficiency
crew compatibility	simultaneous and/or sequential multiple stresses	time compression	cross training
psychological stability	hazards		recognition, awards, benefits
personality variables	boredom		ground contacts
social skills			self-control training
human reliability (error rate)			
space adaptation syndrome			
spatial illusions			
time compression			

FIGURE 11. STRESS PATHWAY

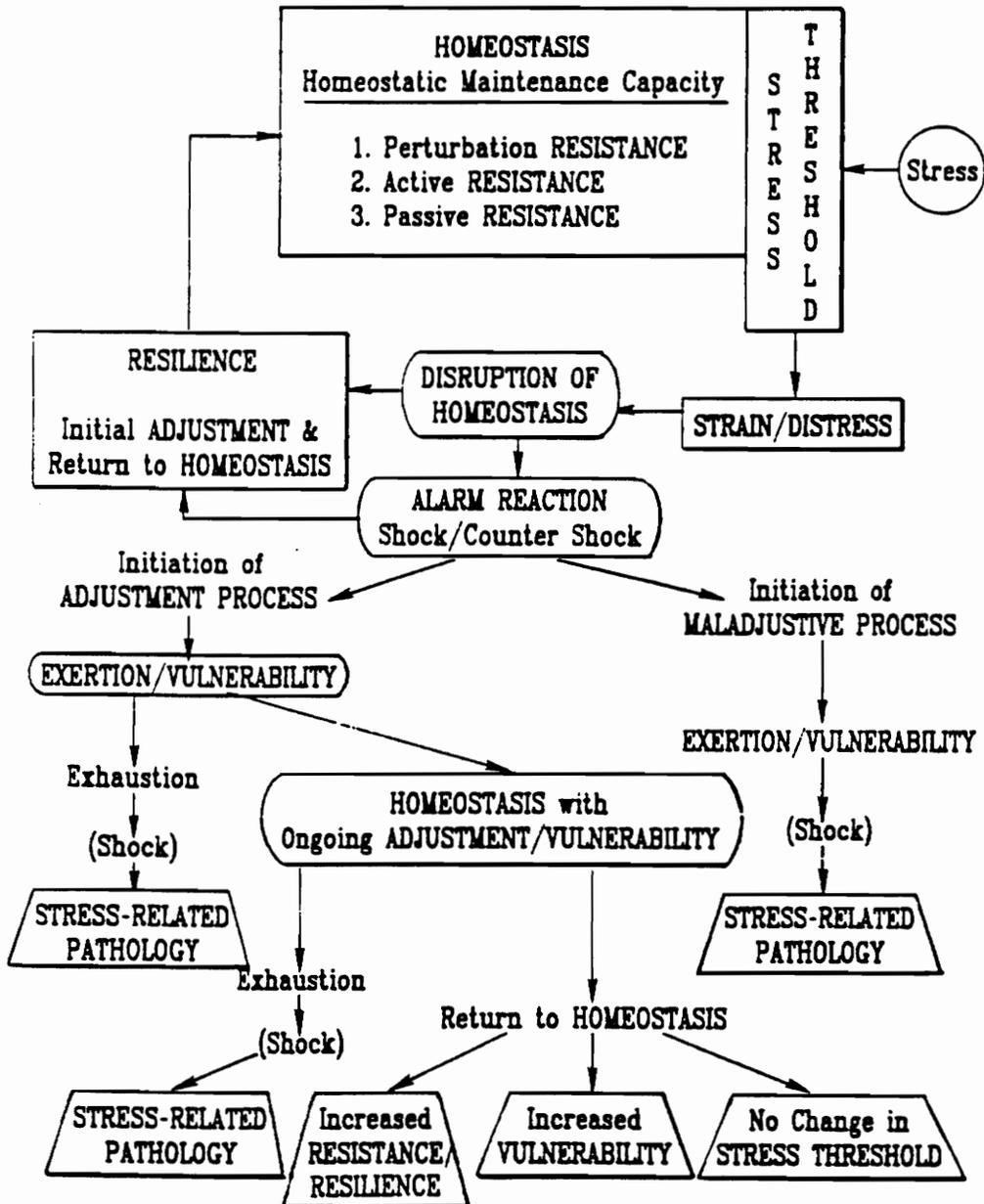


Figure 11. Depicts the sequence of events which may occur when a system undergoes stress. The circle is the initiating step. Boxes indicate key steps in the stress pathways, ovals indicate branching points, and trapezoids indicate terminal points. The arrows indicate the chronological order of occurrence.

goals, and preferences of various kinds. Information input in the form of events that happen to the system which conflicts with the systems (or individual's) goals or purposes constitutes stress. As indicated in Figure 11, an important factor which mediates the effects of stress on the homeostatic balance of a system is the homeostatic maintenance capacity of the system which determines the system's stress threshold. This threshold is a function of how much perturbation from equilibrium has occurred, and the active and passive resistance capacities of the system in question (Steinberg and Ritzmann, 1990). The dynamic environment of a spacecraft or planetary outpost will have significant stressors. The important point to consider is that the system's participants must be able to deal with these stressors within a model of system stress resistance that is adaptively flexible.

## SOME PSYCHOSOCIAL ASPECTS OF ISOLATION AND CONFINEMENT

### Background

The third and final crew of American astronauts departed the Skylab space station on February 8, 1974. Since then, the United States has had no missions to outer space lasting more than two weeks. The Soviet Union, however, has occupied various orbital facilities through most of the 1980's rather continuously generating huge volumes of scientific and military data in addition to having practical psychosocial experience with the long-duration spaceflight regime. The longest U.S. space mission was Skylab III which lasted 84 days, while the Soviets have

extended missions to nearly a year with one crew (Bluth and Helppie, 1986).

Experience with psychosocial stressors has not been the only medical issue the Soviets have faced in space. On board Salyut-7, Cosmonaut Vladimir Vasyutin developed what the Soviet News Agency (TASS) described as an "inflammatory disease" which was serious enough to prevent Vasyutin from acting in his capacity as commander during the reentry and landing sequence. The attempts to treat Vasyutin with the limited pharmacy on board failed and the cosmonaut required immediate hospitalization (Rich, 1985). The U.S. program has yet to experience such a medical "pseudo-emergency," but this can be expected to occur in the future as the U.S. begins to occupy the proposed space station in the mid-to-late 1990's, and in the early part of the new millenium with the projected lunar base and mars mission. The manned programs of the United States and U.S.S.R. seem to have answered affirmatively that man as a living organism can survive the formidable challenges posed by the space environment if the proper protocols are adhered to. The question remains as to whether man as a psychological entity can cope adequately spaceflight, because while a reasonably large amount of physiological data has been acquired, the more fundamental and potentially volatile long-duration spaceflight psychological questions remain largely unanswered.

There are some considerations as to why the psychiatric and psychosocial questions have not been answered or, in the case of the U.S. program--hardly asked. These reasons are:

- (1) In the early phases of the program, the psychological questions were not considered important due to the relatively small crew size and short duration of the missions;
- (2) The importance of addressing the essential question of whether the engineering expertise itself existed to support man in the space environment;
- (3) The astronaut's comfort and privacy in the high-task environment which lead to the crew's reluctance to engage in psychologically related research; and
- (4) The majority of the space crews prior to this time had been from military pilot and flight test populations who are generally suspicious of flight surgeons and psychological personnel that have the potential to "ground" them from flight activities (Santy, 1983).

The issues involved in psychosocial, psychiatric, and behavioral problems were considered so potentially significant by some of NASA's Space Medicine Group that Berry (1973) stated, "We still know very little about the effects of the space/environmental complex on personality and psychic well-being. These aspects of the human could prove to be the factors which limit the duration of space flight." Although Berry's comment was pre-Skylab, little in that program served to alleviate the concerns of many regarding human adaptability to long-duration spaceflight from the psychological perspective.

The United States in particular is now entering a new era of research in its space program with the post-Challenger Space Transportation System (Space Shuttle) and the imminent appearance of the space station in the 1990's. Plans for the space station will allow for the considerable expansion of mission goals and the occupants will be working on a number of tasks for much longer periods of time under conditions of potential and actual

danger and close confinement. As might be surmised, interpersonal and psychological factors will become more relevant as the missions become longer and crews become more diverse resulting in greater personal and professional background differences. These differences in life perspective might be a source for potential conflict.

Such considerations impart the importance of studying the effects of psychosocial factors on space crews. Some of the more important stressors are crew member compatibility and cohesion, leadership style, and the long periods of confinement and danger. The U.S. program has not in general specifically, systematically, studied these factors (for reasons stated previously) during actual spaceflight conditions so that a review of humans exposed to space-like conditions of confinement, isolation, and monotony in various settings may provide some insight into the long-duration spaceflight regime. Reports of actual U.S. and some Soviet space experiences will also be presented. Clearly, some studies or simulations of those conditions described in earthbound settings are more closely related to spaceflight than others.

Sells (1966) reviewed the literature thought to be relevant to long-duration spaceflight in terms of the social systems present and found that submarine missions and isolated exploration parties had the highest "similarity score" as presented in Table 5.

For the review of applicable material that follows, only the research/incidents thought to be most closely related to the

TABLE 5 - A RANKING OF SOCIAL SYSTEMS  
SIMILAR TO LONG-DURATION SPACE MISSIONS  
(MODIFIED FROM SELLS, 1966)

System	Rank	Similarity Score
Submarines	1	79
Exploration Parties	2	68
Naval ships	3	61
Bomber crews	4	60
Remote duty stations	5	59
POW situations	6	39
Professional athletic teams	7	37
Mental hospital wards	8	23
Prison society	9	20
Industrial work groups	10	16
Shipwrecks and disasters	11	11

psychosocial components involved with long-duration spaceflight will be examined and summarized with a specific look at the Antarctic and submarine literature. First, however, the generalized stages of human reaction to isolation and confinement will be addressed.

### Generalized Stages of Reaction to Isolation

Rohrer (1961) has reviewed the Antarctic and submarine literature and found three stages of reaction to conditions of isolation. Several subsequent authors have concurred (Rasmussen and Haythorn, 1963; Pope and Rogers, 1968).

A stage of heightened anxiety appears first, which occurs during the first few days, and appears to be a function of the degree of danger that each individual perceives is present. Rohrer (citing his own work in 1958) believed that this stage predisposes persons to manifest psychotic symptoms. Rohrer noted (1958) that all the men evacuated from the antarctic regions for psychiatric reasons developed the psychotic episodes within one week of getting "on the ice." Leaders of polar research parties and submarine crews' officers often use heavy workloads to reduce the anxiety level during this time.

The second stage is the block of time that often has an associated level of depressive-like feelings. This period involves the longest segment of time as the crew settles down to routine duties. Rohrer (1961) concludes that this is caused by repression resulting from a reduction in social roles as a by-product of isolation. He states: "Under conditions of

isolation, about the only social role that an individual has is connected with his occupation. The temporary loss of such social roles as a 'husband', 'brother', 'father', 'club member', and all of the other various roles that he occupies in normal society is a keenly felt deprivation."

The final stage is the period of anticipation near the end of the mission. Rohrer (1961) detailed it as follows: "It is characterized by increased affect of expression, and differs from the other period in that much anticipatory behavior occurs. Also, it is at this time that there is a great likelihood of the occurrence of aggressive behavior. This is a function of a lessening of the repressive processes that occur during the period of depression." Other characteristics of this time include decreased work performance, and adolescent behavior.

These stages have some meaning within a systems perspective for a long-duration space mission as they help to define certain periods of potential risk in flight. Astronauts and cosmonauts seemed to have fallen into these stages of function at various points during their respective missions in the Skylab and Salyut programs, respectively (Bluth, 1981; Kanas, 1987; Oberg, 1981). It must be noted that often the most critical aspect of a long spaceflight is at the end (or in the case of a mars mission--orbital insertion after a one-year journey), when the complex procedures of orbital (re)entry and landing must be performed. The spacefarers should be at their peak performance during this time as an error could prove to be dangerous or possibly fatal. This scenario actually happened upon the return to Earth for the

Apollo-Soyuz Test Project (ASTP). All three of the returning astronauts forgot to set a series of switches resulting in toxic fumes entering the spacecraft. One of the crew passed out cold while the other two struggled to manage the crisis. Disaster was narrowly averted. Given these operational examples and psychological considerations, more research is needed to keep the crew performing at high levels during high-task or critical flight periods following periods of relative quiescence that are expected to occur on planetary-type missions (Calvin and Gazenko, 1975).

#### Antarctic Data

Most of the Antarctic studies were done in conjunction with the International Geophysical Year in the time period from 1955 to 1968, or as result of military interest in men living under polar conditions. These studies examined both civilian and military personnel working under circumstances such as danger, isolation, and monotony for periods of up to one year.

Rasmussen and Haythorn (1963) conducted a study assessing the wintering-over conduct and behavior of men at five U.S. Antarctic stations. During the study period not one man was hospitalized for psychiatric reasons, which is most likely due to the high level of psychological screening that the winter-over personnel undergo; however, several behavioral problems were noted. Table 6 presents the results (Rasmussen and Haythorn, 1963) from one small station as reported by the U.S. Navy Medical Neuropsychological Research Unit in San Diego. Note that in

**TABLE 6 - FREQUENCY OF CHANGES IN  
INDIVIDUAL'S CONDUCT AND EMOTIONS  
(RASMUSSEN AND HAYTHORN, 1963)**

Behavior	1-4 months	5-8 months	9-12 months
Disruption of sleep cycle	2	15	3
Apathetic, indifferent	1	5	1
Tense, restless	3	8	19
Complaining, whining	0	1	3
Irritable, hypertensive	6	9	13
Suspicious, mistrustful	0	7	16
Uncooperative	1	2	13

general the frequency of symptoms appears to be a function of time. Interestingly, the sleep patterns of the men in this study showed adaptation to the environment after eight months. Gunderson (1963) and Gunderson and Nelson (1963) studied groups in isolated and remote Antarctic stations over several months and analyzed subjective evaluation by the men of their symptoms. By far, the most common problem was sleep disturbance (reported by 72% of the subjects), followed by depression, headache, irritability, and other somatic complaints. Gunderson (1963) found a higher incidence of psychiatric and behavioral problems among naval personnel stationed in the Antarctic than in naval personnel elsewhere, despite a higher level of screening for Antarctic duty (3% to 1%). He also found that from 1964 to 1966, the number of cases of insomnia, depression, anxiety, and hostility increased up to 40% more during the wintering-over months for naval personnel. The increases in various emotional symptoms were generally of lower magnitude for the civilian science population (See Table 7). Gunderson (1963) speculated that the work role was responsible since the civilians viewed their jobs as more important (motivational factor) throughout the winter, whereas the naval men had relatively few important tasks to perform in the winter. Additionally, Doll and Gunderson (1970) using sociometric techniques, found that the most important positive behavioral attributes looked for in naval personnel among their peers was emotional stability, whereas social compatibility was judged to be the most important factor by the civilian scientists. Personality-oriented behaviors were

TABLE 7 - EMOTIONAL SYMPTOMS IN THE ANTARCTIC  
 (1964 to 1966)  
 CHANGE IN FREQUENCY OF EACH  
 BETWEEN BEGINNING AND END OF WINTER MONTHS

Symptom	Increase, percent	
	Navy men	Civilians*
Insomnia	28	4.4
Depression	15	2
Anxiety	28	42
Hostility	39	21

\* Civilian men showed a decrease in depression.

considered more important than task-oriented behaviors for both groups. Esteem for leaders was found to be based upon concern for the men over their well-being, frequent contact with the men, a democratic leadership style, and an impartial decision making process (Gunderson and Nelson, 1963; Nelson, 1964; Nelson, 1965). An independent Air Force study by Hartman and Flinn (1964) indicated that the personality of a mission commander might be considered when selecting crew members. It has been repeatedly demonstrated that some normal personalities do not do well when dealing with other types of normal personalities. In fact, Cooper (1987) reports that NASA shuttle commanders are now asked who they would prefer to have their crew as an additional source of input for the crew selection process. The shuttle commanders supposedly carefully consider skill-mix in view of mission objectives, and how the various personalities might work together in training and during a mission.

Quite a bit of status leveling in isolated groups has also been observed in high functioning groups and experience has shown that the formal leadership structure becomes more egalitarian as time passes (Schoonhoven, 1986). This general attribute has also been noted in the U.S. space program among the best performing crews. In times of crisis, however, the NASA astronaut team is expected to assume a more formal command structure, and in subtle ways is "trained" to do this by repeated simulations of emergencies on the ground (Cooper, 1987).

An open, democratic style of leadership also served the Soviets well once in particular when a young rookie commander

cooperated carefully and diplomatically with an older space veteran with expertise in engineering that had the specific skills needed to repair the Salyut spacecraft, despite the somewhat more formal command structure of Soviet space environment (Bluth, 1986; Oberg, 1981).

Pope and Rogers (1968) studied thirteen scientists who spent ten days walking on snowshoes in Alaska under dangerous circumstances. The men who performed best listed scientific motives, above adventure and fellowship, as being the most important aspects of the trek. The monotony of the trek caused apathy among all the men but those who concentrated on the scientific aspects of the trip suffered the least. There was no overt friction, fighting, or development of subgroups and group cohesiveness was rated as generally good. Pope and Rogers attributed this to the fact that a psychiatrist was present who "permitted the ventilation of many hostilities without their becoming apparent to other members of the group." One man, however, apparently developed psychiatric problems and required emergency psychotherapy. The benefit of concentration on the scientific aspects of an expedition has been noted to aid participants in almost every isolated environment, particularly Antarctica (Harrison, Clearwater, and McKay, 1991). The same concept of scientific purposefulness is true for long-distance space travellers as well given the limited data that is available.

Smith (1966) reported on a seven-man Antarctic expedition. He found the men on the team responded to monotony and boredom in

five ways: widespread daydreaming, a desire for change, even destructive change (e.g. breakdown of one of the trucks), sensitivity to and being critical of those on the outside (e.g. the crew of a supply plane), erroneous interpretation of familiar sounds, and a tendency to choose those physically remote as companions for a future trip. The same concerns regarding monotony and boredom should be considered for the long-duration astronaut as well. One way to combat this problem is to have some training occur after the mission is safely underway in interplanetary space for certain (future) mission events. Rehearsal of already-learned critical information will help to refresh the memory of the space travellers during the long trip to mars. This new learning and retraining should help to reduce monotony and boredom. Mission software should also be flexible enough such that innovative changes can be made by the astronauts during the journey as the situation dictates.

All of these group studies cited showed that the overall group compatibility and performance typically declined during prolonged isolation. This phenomenon has also been repeatedly observed for space missions as well (Kanas, 1988). The systems conceptual framework requires that these trends be taken in account when defining mission parameters. Additionally, any countermeasures to this problem should be developed and assessed as more experience is obtained in long-duration spaceflight. Most optimally, the resolution of a problem will involve an insightful knowledge of group dynamics and an appreciation of the context that the problem arose in.

## Sleep

One of the more interesting comparative aspects of space missions and Antarctic exploration analogs is the study of sleep. In the Antarctic, sleep initially has often been poor for many explorers, but gradually returns to normal over time (see Table 6 and Kanas, 1985). Natani et al (1970) studied four men in the Antarctic and found that REM and stage 3 sleep decreased, stage 4 sleep disappeared, and the men suffered from a virulent form of insomnia called the polar "Big Eye" at the beginning of the expedition. Fatigue and fitful sleep has also been observed in Soviet hypodynamia studies (Sorokin, Simonenko, and Karelen, 1970) and in the SAM two-man space cabin simulator (Cramer and Flinn, 1963). Sleep problems have also been reported in space, including such components as poor quality of sleep, insomnia, fatigue, and alterations in sleep cycles. Berry et al (1966) noted sleep-loss induced fatigue in the Gemini Program by crew members so NASA adjusted sleep/work cycles and attempted to lower cabin lighting and noise levels. Despite these efforts, sleep difficulties continued to occur on the longer Skylab and Salyut missions (Bluth and Helppie, 1986; Cooper, 1976; Conners et al, 1985; Pogue, 1985). Sleep has also been analyzed on Space Shuttle missions (Santy, Kopanka, Davis, and Stewart, 1988). Using a standard briefing form, 58 crewmembers of the Space Shuttle were asked about sleep quality and quantity, fatigue, and sleep medication usage. At least 50% of the dual-shift crewmembers used sleep medications at least once in flight. Many crewmembers reported having fewer than 5 h sleep on some nights

with several having 2 h or less. Fatigue was thought by crewmembers and flight surgeons to be a substantial degradative factor at certain times during various missions.

From a systems perspective, sleep loss is clearly a serious problem to overcome in a spacecraft due to increased crew fatigue, irritability, and performance decrements. While sleep patterns do seem to eventually return to normal in the Antarctic for most people, the conditions involved in spaceflight are sufficiently different such that a complete normalization of sleep patterns has not been observed. More recent research in the Antarctic on sleep has revealed that a phase delay in the circadian system with respect to sleep and clock time is thought to be due to differences in individual zeitgeber strengths found in the environment (Gander, Macdonald, Montgomery, and Paulin, 1991). The nature of these zeitgebers and their relevance to a long-duration space journey are currently being investigated. This phase delay results in more difficulty adapting to the new sleep environment, leading to a (self-reported) loss in the quality of sleep and more difficulty awakening.

As a part of their extensive analysis of work/rest cycles resulting from the space program's breadth of experience and the empirical research on sleep, relaxation, and work; Conners, Harrison, and Akins (1985) stated that:

Coincident with the study of work schedules and desynchronization, the importance of sleep must be considered. Changes in either the quality or duration of sleep can have a profound impact on performance. Questions remain as to how sleep may be affected by long-term confinement and isolation, by the restrictions of the space vehicle, and by the lack of gravity.

To summarize, it is clear that isolated Antarctic parties have several common aspects to groups participating in spaceflight where sleep research and fatigue issues are concerned. Zeitgeber strength may play a role in this process as related to phase-delayed cycles in the circadian rhythms. Care must be taken, however, not to carelessly extrapolate the Antarctic data to the space environment since there are important differences between the two systems and in the interactions among the participants.

#### Submarine Data

Weybrew (1957), in one of the first nuclear-powered Nautilus missions, reported that men showed good adaption from the sixth to eighth day, but that after this time insomnia, muscle tension, headaches, and lower motivation crept in. During the historic transpolar cruise in 1958, the Nautilus was submerged for one month. Kinsey (1959), vividly describes the reasonably good conditions aboard the craft and that the morale was kept extremely high with few difficulties experienced. The emergence of self-appointed jokers, physical horseplay, and a "scandal sheet" that provided for tension release was noted. It is thought that the historic nature of the cruise also served to keep crew morale high. The historic nature of a trip to mars is likely to aid in keeping morale high as well; however, such a motivator did not keep various historic polar parties from having group dynamics problems. Again, it seems that the context of the events in question often "drives" the nature of the group's

adaptive response(s).

During the 83-day Triton cruise in 1960, forty men filled out a daily questionnaire composed of fifty behavior statements such as "happy", "tense", "can't concentrate", etc., which they scored from 0 ("not at all like me") to 9 ("exactly like me"). These factors were covaried with six atmospheric variables (oxygen level, carbon dioxide level, freon, etc.). Some interesting results were obtained by analyzing the questionnaires (Weybrew, 1961; 1963). After ten days, personal motivation and group morale declined steadily, and homesickness increased. Tension, irritability, and sleeping difficulties increased as the mission progressed, but never became a serious problem. The 83-day Triton cruise was similar to the later 60-day cruise of the Seawolf where no formal testing was completed, but the conditions were similar. The men were kept busy and none of the men showed evidence of psychological or psychiatric illnesses. As reported in many other isolation studies, time perception gradually became less accurate. Somewhat similar patterns have been seen for long-term U.S. and Soviet space dwellers. One cosmonaut remarked that "load[ing] yourself up with work" was a good way to make the time pass quickly and to reduce the overall level of stress (Bluth, 1984).

A variation of the time compression phenomenon problem has also been observed in both the U.S. and Soviet space programs (Belew, 1977; Chaikin, 1985). The major complaint by the astronauts and cosmonauts was that ground control was not giving them enough time to complete the tasks, while the ground

controllers felt that the astronauts were not working up to their capability. This resulted in the astronauts pushing themselves harder, making more errors and ground control getting more frustrated, etc. The cycle stopped when the Skylab commander Gerald Carr, "blew off" the ground controllers and gave his team a day off to enjoy the station as negotiations with ground control went on to reduce the daily workloads (Cooper, 1976). Commander Carr later referred to this as the first "sensitivity" session in space. The result was that the astronauts were allowed more latitude in choosing when and how to do their assigned tasks.

In one study involving selected tasks on the three Skylab missions, over 50% of the tasks assigned required more time to complete in space than on Earth (Conners et al., 1985). Part of this apparent operator overload has been explained by time compression. According to one ad hoc working group, time compression probably contains elements of excessive mental workload, information overload, and cognitive processing involving interferences, judgement, and decision-making, for which data bases are insufficient (Christensen and Talbot, 1985).

Ebersole (1960) reported an interesting form of tension relief known as "pinging." In this game, one sailor (the pingor) teases the "pingee" about a tender subject. If the "pingor" can incite an angry response from the "pingee", he won the game. Ebersole also describes "Channel Fever", a mild insomnia and loss of appetite that occurred at the end of a patrol as landfall was anticipated. Ebersole (1960) states:

The general opinion of the division officers at the conclusion of the patrol was that there has been a slight negative decrement in overall alertness and reaction time, but that this would be insignificant in relation to combat performance.

The implications for performance decrements in space have briefly been touched upon earlier and span the entire human response repertoire to a variety of situations. One example of this is that in space even a "small" checklist omission could prove disastrous. Yuri Romanenko was apparently so excited during his 1979 flight that he could not wait for the planned EVA, so he began to conduct an unauthorized spacewalk. He forgot to secure his safety tether as per the flight checklist. This is an incredibly serious, almost hard-to-believe, breach of flight-crew discipline and training as all military pilots are taught to adhere strictly to checklist procedures. As Yuri pulled himself up through the hatch, his inertia would not allow him to stop moving. His fellow cosmonaut G. Grechko caught his foot just in time to prevent Yuri from becoming the first free-flying Human Satellite (Oberg, 1981; Kanas, 1987). In space, even "small" performance decrements can kill quickly.

Serxner (1968) served as the medical officer aboard two Polaris submarine cruises and reported that 5% of the men were treated for psychological or psychiatric problems. These difficulties consisted of minor anxiety reactions (insomnia, headaches, somatic concerns, anxiety attacks), depressive reactions such as depressed mood associated with weight loss and anorexia. Additionally, one crewman suffered a fully developed psychotic episode along with the "more normal" stressor of

separation from family for the rest of the crew. A strong program of activity kept the crew from boredom syndromes. Preoccupation with sexual thoughts, vulgar talk, and pinups helped to release (or create?) sexual tension. Serxner also related some of the men took it upon themselves to raise the morale of their watch sections by highly imaginative joking. There were also the usual personal conflicts that occur whenever people are confined to a small area. According to Serxner, the conflicts did not significantly endanger the success of the mission.

Weybrew (1963) has reviewed the submarine literature and makes several points. Approximately 20% of submariners describe confinement as the worst aspect of submarine life even though there are few claustrophobic reactions. The submarine environment is not one of true sensory deprivation, however, but one of altered sensory stimulation. The effects of such an environment on an individual are hard to predict although during WW II neurotic and psychotic behavior was seen during the "silent running" time of enemy depth charge attacks. The extreme danger and heat in the submarine combined with other factors was believed to cause this reaction. Thus, the nature of the stressful environment interacted with contextual factors to cause the serious psychological problems that some submariners exhibited.

Interestingly, Michael Collins (Collins, 1974), who participated in the first manned lunar mission revealed that he became significantly claustrophobic whenever his spacesuit

temperature increased beyond a certain level. The confining spacesuit and the heat resulted in this sensation. He normally responded to this feeling by turning up the rate of cooling in his spacesuit, which helped to alleviate these symptoms.

Responses to these, and other, types of stressors are extremely context dependent and highly individual. What negatively affects one individual may not concern another. These examples reveal that human beings (particularly on a long-duration mission) should not be thought of in static, laboratory terms that will respond this way or that--but rather are people that may respond in a certain way based upon their own psychological history and the contextual factors surrounding the events in question. A broad systems perspective allows for this contextual interaction of humans with their environment and should be considered during mission planning. Thinking of human beings within a systems context helps to avoid the error of reductionism, whereby the more critical "forest" of human behavior and responses are lost or neglected (Marmor, 1983).

### Other Studies

Weybrew (1959), also summarized Operation Hideout, a 60-day confinement study of twenty-two men aboard the USS Haddock. As expected, as the time-duration of confinement increased, motivation declined, alertness decreased, tension increased and the quality of sleep declined at first, then later improved.

The result of the 30-day Ben Franklin submersible study parallels some other submersible experiments. The six-man crew

showed a trend towards withdrawal and an increased need for privacy (also reported by Skylab astronauts, Cooper, 1976; Pogue, 1985) as time progressed. Halfway through the mission, disagreements arose with the surface crew over procedural matters (recall Skylab experience with G. Carr as commander) depression and evident loss of a "feeling of well-being" developed, and crew proficiency was adversely affected (Ferguson, 1970). Chaikin (1985) includes excerpts from Valentin Lebedev's diary translated into English that describe his feelings during part of his 211-day journey in space:

July 16. The hardest thing during a flight is keeping good relations going with the ground and among the crew. With growing fatigue, there is a danger of serious lapses. There are tense moments, but they cannot be allowed to explode. Otherwise a crack, once it appears, can widen. The flight becomes increasingly difficult. Looking out the window is calming.

Lebedev stated these intercrew tensions, as well as station/ground control friction existed despite the fact that the Soviets extensively trained their cosmonauts and ground-support personnel in conflict avoidance and group problem-solving (Bluth, 1981; Bluth and Helppie, 1986, Nicholas, 1989).

Reviewing the submarine and Antarctic data reveals a time-dependent decrease in performance that correlates well with space-induced problems. Flinn et al (1963) have observed that

"...closely monitored groups exposed to restrictive conditions...have demonstrated significant levels of interpersonal friction, monotony, and lowered morale and motivation. Despite these problems, performance has generally remained at high levels, and gives cause for optimism about the psychological adaptability of man under severe confinement."

Kanas and Fedderson (1971) reviewed many space cabin simulator studies, submersible studies, and the polar and submarine literature and wrote that most of the studies showed consistent trends. These situations produce interpersonal stresses and spontaneous compensatory actions which arise to relieve these stressors, such as directing hostility to outside monitors or supply planes, etc. (The spaceflight analog of this is the hostility directed toward ground controllers). Though these problems increase in severity and frequency with time, generally performance levels remain high enough to accomplish most mission tasks. This appears to be largely a function of motivation. If men are sufficiently motivated, they can put up with a variety of stressors for the goal of mission completion. The analogy to long-duration spaceflight is clear, but the answer elusive.

The motivation and morale of the crew must be kept high at such critical phases of flight as orbital insertions, reentry, rendezvous, or docking maneuvers, despite the various stressors that long-duration spaceflight can impose on the participants. This can be accomplished by allowing frequent contact with family members and time off of work for relaxation and recreation. Occasionally reminding the crew of the historic nature of their work may also help to boost morale, particularly during times of tension.

### Sensory Overstimulation and Hyperarousal

An important factor for space missions that has been largely overlooked is sensory overstimulation or "hyperarousal." The physiologic state of hyperarousal can produce such symptoms as anorexia and insomnia, both of which the astronauts have complained (Collins, 1974; Cooper, 1976; Pogue, 1985). Numerous tasks, the absence of many temporal cues (day versus night) and the normal, expected excitement of the novel space environment, all may contribute to the state of overstimulation. A prolonged state of hyperarousal can result in such effects as poor muscular coordination, depersonalization, perceptual abnormalities, and impairment of concentration. An overall decrement in performance caused by hyperarousal will occasionally occur in space environments and it has been pointed out that several U.S. missions were influenced by unusual and unexpected behavior on the part of the crew. The Skylab crew behaved so erratically at times that the ground controllers wondered aloud if something in space had affected their minds (Newsweek, 1989). Other investigators (Santy, 1983) feel that hyperarousal or overstimulation could be a factor in the depersonalization and impaired performance of past and future U.S. space crews.

In the Soviet program, at least one cosmonaut had unexpected "inefficiency" in operating his spacecraft controls and had to be returned to Earth early (Akin, 1970). Could that instance have been exacerbated by a hyperaroused state? Generally, while sensory overload appears to be a problem area for short-duration missions, it is likely that both hyperarousal and sensory

deprivation (with the associated isolation) may be serious concerns for long-duration spaceflight missions. Therefore, it appears that hyperarousal and sensory deprivation may become problems depending on the context of the situation/task at that time. The context essentially defines whether hyperarousal or sensory deprivation is bad or good, from a psychosocial systems standpoint, with the effects on crew performance being a matter of degree depending on the surrounding circumstances.

#### Interpersonal and Group Interaction Issues

According to Kanas (1978), important interpersonal issues include interpersonal tensions, problems resulting from crew heterogeneity, the need for dominance, decreased cohesiveness over time, task-neutral interactions, and anger displaced toward outside personnel. As space vehicles become larger (e.g. space station) and astronaut roles become more specialized, larger and more specifically-trained crews will be tasked to carry out the scientific investigations (Sells, 1966). The space station member will be asked to work in a closely-confined and tightly-knit manner. Because of the diversity of the investigations to be performed, the occupants will most likely come from culturally and scientifically heterogeneous backgrounds (Kanas, 1987). Due to these factors as alluded to earlier, psychological compatibility will potentially play a more and more important role. The Soviet space program attempted to apply this concept for many years compared with the U.S. program.

At the beginning of crew selection, the Soviet cosmonauts

are subjected to an enormous battery of psychological tests and the candidates are grouped initially according to compatibility (Bluth, 1981, 1984; Kanas and Feddersen, 1971). One aspect of this compatibility grouping is that once a crew is selected for a long-duration flight together, they, as an exercise, take an auto-tour of the Soviet Union as a "trial balloon" to increase the chances of solid crew serenity and teamwork while out in space. Despite the overall intense efforts by the Soviets to insure better crew relations, one cosmonaut has been quoted as remarking that (Bluth, 1984):

....joint existence cannot be serene. We had disagreements in flight.... The disagreement did not reach a scandal, inasmuch as there was no 'platform', it was simply fatigue, and frequently simple inattention which would cause the argument."

As mentioned earlier, similar episodes occurred on Skylab (Cooper, 1976). While the above cosmonaut may have been able to suppress his own disagreements with his crewmates, this has not always been the case in the mental-health conscious Soviet program as revealed by Dr. Arlene Levine. Psychologist Levine studied astronaut and cosmonaut reactions to long-duration spaceflight and found that "One guy stabbed the other one with a hypodermic...Needless to say they aborted the mission. Not only were they afraid of infection, they were afraid they might kill each other." (Roanoke Times and World News, 1985). Soviet crews also have directed internal stress toward ground controllers (as have U.S. astronauts) by completely switching off communications links to the Earth. One errant psychiatrist (Santy, 1983) stated that "...it is not as likely that serious problems will arise in

small groups of homogeneous cosmonauts who have similar military background, values, and mission goals."

The question that naturally arises now is this: If the Soviets have intensively tried to handle crew problems and still have had less than optimal results, what then is there left to do?

### Contextual Approach

The previously cited incidents and studies show that perhaps a new modality of thinking about small groups in space is needed. One approach, among many, would be to view the space station environment as an evolving psychosocial developmental system where information (events in space) is a difference that makes a difference (new crew cognitions, interaction and behavioral patterns). This concept, articulated somewhat similarly by Susan Oyama (1985) could replace the somewhat channeled and static longitudinal model of behavior usually presented in scientific literature with a more dynamic evolving one. Figure 12 from Furukama and Buchanan (1984) illustrates this concept. The figure shows a conceptual relationship of man in the space environment in a systems perspective with time passage as an important consideration. The figure's content reveals that behavior, habitability, physiology, and environment all interact as mission time progresses to produce a different overall systems context at a later point in time. The importance of the concept of context cannot be overstressed as a framework for addressing long-duration spaceflight issues. One of the key attributes of

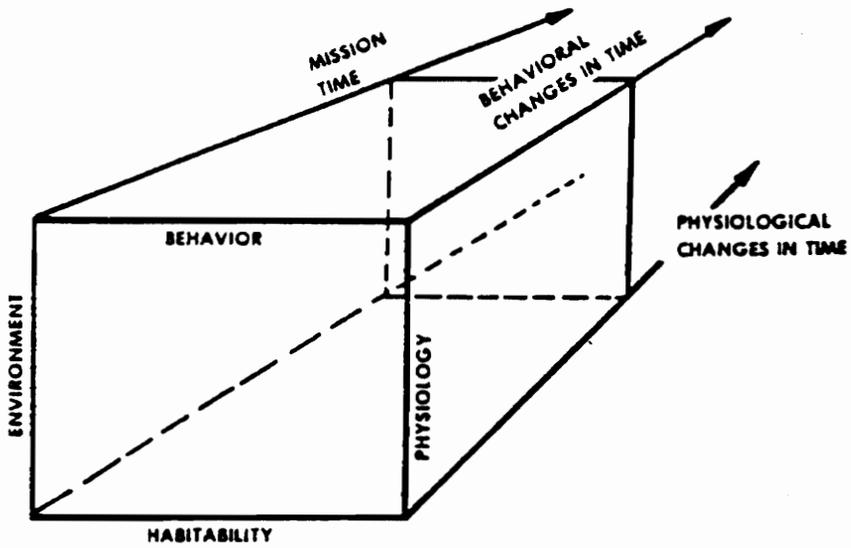


Figure 12. A Dynamic Conceptual Relationship of Man in Space and Environment

Adapted from Furukawa and Buchanan, 1984.

well-functioning groups in space will most likely be flexibility in thought and action during long spaceflights. Flexibility that involves the consideration of context as a key variable in the group's self-introspection during minor crises could help to avoid larger ones. Ground control should also be presented with the idea that the mission as a whole is an ongoing process that is heavily dependent upon contextual factors so far as the astronauts' feelings (and performance) are concerned. Marmor (1983) proposes a similar idea for systems thinking where the impact of stressful circumstances depends upon the specific context in which they are experienced. For a long-duration spaceflight, much of the context regarding psychosocial stressors is related to group behavior and processes which will be reviewed next.

### Group Behavior

Dynamic group behavior is a very complex subject area--even moreso in space--such that the "classical" lines of thinking may not accurately predict the potential problem areas of the long-duration spacefarer(s).

One possibility of handling the complexity of group interactions in space would be to train and educate astronauts in simple group dynamics (Nicholas, 1989). The Soviets (as the current long-duration leaders in space) have a formal Psychological Support Group that helps to train and monitor crews engaged in ongoing group processes and interactions to help identify and resolve potential trouble spots. The group learns

problem-solving techniques before they explode in the more dangerous space station environment itself. Practical aspects of this approach are that it gives the crew a model for resolving in-flight hostilities and interpersonal tensions that unchecked can lead to destructive group behavior and lowered crew mission performance (Cunningham, 1977; Mintz, 1951; Nicholas, 1989).

Interesting correlates have been found in other studies for the resolution of group tension. Recall the aforementioned "pinging" by some submarine crew members (Ebersole, 1960). Kanas (1987) reviewed the 30 and 60-day McDonnell Douglas space simulation studies where interpersonal conflict was observed to be minimal. This was explained by the fact that the subjects in each study received 12-24 hours of sensitivity training before beginning the isolation. The training was designed to improve "behavioral flexibility and social awareness." The participants in the McDonnell Douglas 90-day simulation study received no such training and the group tension to internal and external agents became increasingly worse, impersonal, and the language of the members toward each other was noted to become more and more task-oriented and non-interactive. The conflict was somewhat reduced when a "bull session" took place between the subjects and the study's behavioral director. Very similar incidents have occurred in Skylab and the Apollo program (Cooper, 1976; Cunningham, 1977). As Cunningham relates from Apollo 7:

Wally (Schirra) was never a detail man, and at least part of his testiness during the flight was caused by his discovery, for the first time, of some of the details of the tests we were to perform. Then there was the added stress of a bad head cold and the realization that if the mission had to be aborted, there was a high risk that his eardrums

would be damaged in the subsequent reentry. It added up to Wally being an irascible fellow most of the (11-day) trip.

...Donn had been working hard on the test and had just one more sighting to make. He finally got fed up (with Schirra) and snapped back, which for him was uncharacteristic: "Okay, if you insist, I'll wrap it up. But we've already spent the fuel to get here and I could be finished in another five minutes. I just want to put it on the tape that we're knocking off this test because you ordered it."

Wally didn't even blink. "Okay", he said. "You just do that and when you get through, I'm going to put on that same tape that you were threatening mutiny."

Cunningham continues with the description of the minor crisis and how it was eventually pseudo-resolved. The fact that an exchange such as this occurred at all among highly trained and motivated professionals during a rather short flight is somewhat revealing. Given the set of circumstances and some preflight crew-sensitivity training, would the remarks in that vein have happened? The importance of this isolated event is minor, but several incidents such as this on a long spaceflight could significantly alter the dynamic equilibrium among the crew members and seriously upset the balance within the crew that was achieved during the training months. The application of such sensitivity training in the U.S. space program has not directly occurred, but empirical arguments support such an attempt for future U.S. space crews. Sensitivity training also recognizes implicitly that the group evolves with time such that the group that arrives at mars is not psychologically the same group that left the Earth.

While the Soviet Union has had mixed success with its own Psychological Support Group for cosmonauts, it nevertheless has

proceeded actively to research the area of how to discern a cosmonaut's functional state during his professional activity. Ground-analyzed speech signal patterns for cosmonauts' communications are used as indices of emotional stress and mood. Simonov and Frolov (1973) claim that they can differentiate "adequately" the degree of emotional stress by voice analysis of cosmonaut transmissions 85% of the time. The Soviet group also uses the average physical distance between two (or more) cosmonauts as a barometer of the interpersonal tension between the men as the flight progresses. Cosmonaut "syntax" has also been analyzed and observed to be more task-oriented as tensions rise. Routine ground links with family members and celebrities of Soviet life along with "surprises" on the Progress supply ship help to bolster the lonesome cosmonaut's morale (Bluth, 1981; Kanas, 1985). The interactive nature of the communications in LEO is not going to be the norm for a Mars mission since communications will take 15-20 minutes to be received on the red planet. Because of the communications time delay and other technical factors, one-way monologues will most likely dominate much of the flight to Mars which could have a negative morale impact on the crew over time.

#### Other Interpersonal Issues

As time goes on, crew heterogeneity is expected to become a significant source of tension (Kanas and Feddersen, 1971; Kanas, 1987). As an example, how will men and women relate on long-distance flights? Cosmonaut Chief Shatalov has been heard to say

that spaceflight is too difficult for women. An amusing sidelight to the issue which reveals such covert thinking happened on the Salyut-7 spacecraft. A cosmonaut commented on his visiting female counterpart: "We waited for her to make her appearance, and just like a women, she kept primping" (Chaikin, 1985; Bluth and Helppie, 1986). Santy (1983) deals with the male/female issue of sexuality directly in her paper:

The issue of sexuality, especially on long-duration missions, such as an interplanetary one, is not trivial. No matter how well trained the crew is, there is reason to expect that such issues as sexual arousal, tension, and competition are just as likely to occur in space as they are in any other earth-bound endeavor, as they present a potential hazard to the accomplishment of mission goals. Having astronauts who are married to each other fly on the same missions is one approach to reducing the issue (currently there are two married couples who are astronaut/mission specialists), but again there is no reason to believe that the same type of tensions may not develop.

Santy concludes this aspect of her paper by stating that historically, new environments and situations have caused changes in group social structure. She cautions that too rigid cultural values and customs, particularly in the area of sexual mores, may hinder the processes of physical and psychological adaptation that are key ingredients for the exploration of the universe.

Rumors abound regarding the inflight sexual activity of Space Shuttle astronauts (Frazer, 1991). As Santy has speculated, there is reason to expect that sexual activity will occur if a mixed crew goes to mars. Pregnancy could be dangerous, however. If complications arose during pregnancy the mother and/or baby could be lost due to the limited medical facilities on board the spacecraft. It is not known if a fetus

would develop properly in space and be able later to adapt to the Earth's gravity field. Two crew members engaging in sexual activity might also upset the dynamic equilibrium among members that was established during training for the mission. Jealousy and competition could be serious factors for individuals to deal with so a group model of adaptive flexibility and professionalism would have to be adhered to by all of the crew. As Santy (1983) has pointed out, strict sexual values and customs may be counter-productive from a systems standpoint during a long space tour.

Other concerns of writers and thinkers in the psychosocial realm of long-duration spaceflight are the cultural differences among people, language barriers, diverse political backgrounds, and the added problem of distorted (zero-g induced) facial expression as compared to the Earth training environment. A Czech guest cosmonaut sarcastically joked that his hands turned red due to his reaching for switches whereby his Russian hosts shouted, "Don't touch that!" (Oberg, 1981; Kanas, 1987). A visiting French cosmonaut reported a similar state of tension between him and his Soviet hosts (Bluth, 1984).

Often, task-neutral interactions are utilized as a method for avoiding interpersonal conflict. Many of the comments involved with spacecraft piloting and data collection involve complex instructions between the crew members themselves as well as ground control. Flinn and colleagues found that a high level of information transfer was observed in the ground-based simulated space mission studies. Flinn et al (1961) using the Bales Interaction Process Analysis scored interactions among

individuals in one of twelve categories to arrive at a result which demonstrated that space simulator populations had a significantly higher proportion of information exchange and opinion than in a composite of twenty-one other studies of small groups. Flinn et al (1961) noted that there were fewer socio-emotional interactions when negative emotions were involved. The belief was that task-neutral interactions could be a vehicle whereby negative emotions/interactions were avoided. This space cabin simulator data result has been noted in actual spacecrew interactions as previously mentioned.

The potential psychiatric problems to be encountered and their treatment is far beyond the bounds of this paper. The prediction of an individual's transition from an event merely being a psychosocial stressor to a fully-developed psychiatric episode in space would be nearly impossible. However, given the stresses involved during a long mission, anything is possible. For these reasons, some thought is being given to the psychiatric components of a Health Maintenance Facility (HMF) on the space station (Santy, 1987). Santy feels that, "As part of a comprehensive HMF on Space Station, psychiatric health maintenance emphasizes the biological, psychological, and social factors which contribute to emotional disorders. Attention to these factors may make the difference between success and failure in the colonization of the 'final frontier'."

Table 8 lists the most likely problem areas seen by Santy (1987) in terms of mental health situations/DSM-III coding. While there is good reason to believe that well-adapted

**TABLE 8**  
**TREATMENT OF SITUATIONAL PROBLEMS ON SPACE STATION**

Situation/DSM-III Code	Comments	Management
Occupational Problem (V62.20)	e.g., crewmember cannot adjust to space environ- ment	Supportive therapy on Station
Life Circumstance Problem (V62.89)	Is it a normal phase of life accentuated by life in space?	Supportive therapy on Station
Family Problem (V61.10, V61.20, V61.80)	Would need to monitor the effect of such problems of job performance Confidentially may be an important issue	Supportive therapy to family on earth; crewmember may be involved
Uncomplicated Bereavement (V62.82)	This problem could be pre- pared for in advance according to individual wishes	Official leave; private com- munication downlink
Other Inter- personal Problem (V62.81)	Includes problems of crew interaction or ground/ crew interactions	Group problem-solv- ing; disciplinary action, with trans- fer to earth
Sleep-depri- vation/ fatigue	Possibly a common opera- tional problem	Rest; sedation if needed; better work/rest planning

Adapted from Santy, 1987.

individuals such as the astronauts (almost by definition) may be somewhat less susceptible to the various psychosocial and non-psychosocial stressors on a space station than the average person--even astronauts are quite capable of reacting to stress as this paper has shown. Because of the constellation of factors involved, Kanas (1988) and Santy (1987), among others, are arguing for a physician on the longer flights to have some formal Psychosocial Training because actual emergency intervention and the psychosocial research needs should be accommodated (ideally) under actual spaceflight conditions. Clearly, careful crew selection procedures can help to minimize the risks involved and NASA's record and method of selecting astronauts thus far has generally served the U.S. space effort well (Nicogossian, 1985a).

#### Summary and Recommendations

The literature reviewed thus far reveals that individuals in isolated and confined environments have unique stressors to deal with. These stressors may include the loss of normal life roles, other group members' attitudes and interpersonal issues, the group dynamics process, and the threat from the external environment. A thoughtful systems perspective regarding these issues reveals that it is an oversimplification to assume that external adversities always cause psychological distress. For example, if such adversities are experienced in a group situation and shared equally by all, they can sometimes act as a cohesive factor that lessens the impact of the negative experiences or

even transform them into positive ones. If, on the other hand, these stresses are experienced in a context of inequity or under circumstances that produce a sense of personal alienation or isolation, then the same adversities can be devastating. Each individual will respond to such a challenge based upon their own developmental history. A more theoretical perspective reveals that context contains both temporal and quantitative aspects that may be difficult to describe and nearly impossible to predict. This is why an adaptive model of flexibility is essential for ground and spaceflight crews where psychological issues and the wellness of the group as a whole are concerned.

From a systems perspective-- tensions, conflicts, or difficulties with any of the interacting elements on a long-duration spaceflight mission can induce ripple effects with many of the other system components. This holistic concept is essential for considering individual and group dynamics behaviors within a long-duration spaceflight regime. A broad psychosocial perspective will increase the chances that the morale and productivity of the crew can be maintained during an extended mission. Given the potential for psychosocial problems to develop during an extended mission for the individual or group, a model of adaptive flexibility for all participants within the system process as a whole is highly recommended. This concept applies to such diverse areas of mission integration as which astronauts are assigned to work closely together to changing mission timelines if need be to accommodate other unforeseen factors that may arise impacting human performance.

CHAPTER V  
MEDICAL ISSUES

Overview

A great deal of research has been done on the medical problems associated with spaceflight. A significant concern, however, is that none of the databases exceeds 366 days. Journeying to mars will require at least 600 days to complete if chemical propulsion is utilized, with approximately 40 days being spent on the martian surface. A trip to mars using nuclear propulsion that is currently being conceived has a different set of mission parameters that will be discussed later. The longest Soviet experiences with spaceflight are one man for 326 days and two others for 366 days (Garshnek, 1989). The Soviet medical data is generally difficult to obtain and their publications often do not contain information that many Western authorities consider important when documenting the evaluation of scientific data. Most likely, the United States will have to generate its own long-duration databases and experiments to test the various hypotheses regarding the effects of long-duration spaceflight and countermeasures that may mitigate them.

The Soviets have learned, and stated repeatedly, that the optimal crew time in orbit appears to be between 4 and 6 months. Afterwards, fatigue increases and the ability to do work efficiently declines. What is unclear is whether the astronauts can do meaningful work on the martian surface after spending approximately a year in a microgravity environment. The gravity field of mars is about one-third that of Earth. The combination

of the spacesuit, martian gravity, and workloads imposed on the astronaut's body by doing exploration tasks which are often physically intensive may over-burden the musculoskeletal and other bodily systems of the explorer. At what point a weakened bone or muscle will break or tear under loads imposed by martian surface activity is still unknown. The same concerns apply for enroute EVA activity as well. Since the astronauts will be doing dynamic work on the martian surface, static models will not completely predict the transient forces exerted on the musculoskeletal system while the astronaut is engaged in various tasks (Fung, 1981). Thus, extreme care should be taken during the re-adaption to a gravity field following a long period of microgravity to avoid overstressing the various physiological systems which are to be discussed.

The variety of physiological changes associated with weightlessness are (Garshneck, 1989):

- \* cardiovascular changes
- \* reduction in body fluid and electrolyte level
- \* decreased bone mass
- \* loss of strength and muscle atrophy
- \* decreased exercise capacity postflight
- \* decreased red blood cell mass
- \* neurovestibular disturbances
- \* immunological changes

Each of these changes may impact the mission or astronaut safety and will be discussed in turn.

### Cardiovascular Changes

The acceleration of gravity on the Earth creates a hydrostatic gradient that tends to pull the body's fluids towards the feet. One-way valves in the veins, continuous muscle contractions, and the pumping action of the heart aid in fluid circulation and prevents fluids from pooling in the lower extremities. During spaceflight, the headward rush of fluid is unopposed by gravity, resulting in a migration of fluids to the upper body causing the tissues of the head and neck to swell. Thus, the volume of blood "seen" by the heart increases dramatically. The body attempts to adjust to this volume overload by lowering the blood plasma and red cell mass (Nicogossian, Huntoon and Pool, 1989). Returning to a gravity field after weightlessness reverses the adaptive processes. The heart must beat faster to maintain cardiac output since in space at least 1.5-2.0 liters of body fluid has been lost. The size of the heart is decreased, and its electrical and mechanical pumping activities indicate depressed function due to the lower filling volumes and lack of hydrostatic pressure to work against.

Orthostatic intolerance, which is the ability to stand or function in an upright posture, is diminished dramatically immediately post-flight. This loss of orthostatic tolerance is caused by increased pooling of the blood in the lower extremities and the lower overall fluid volume level. The intolerance results in dizziness, lightheadedness, and possible fainting.

From a systems perspective, orthostatic intolerance could be a problem during a martian orbital insertion when decelerative

g-forces are likely to be high. Another area of concern regarding systems/human interfacing might be the early physical EVA activity on the martian surface as discussed to earlier. The long-tour lunar explorer could also have problems if a stay on the one-sixth gravity of the moon did not challenge the heart enough for the Earth gravity field when returning home.

Anemia (reduced red blood cell mass) may impair an astronaut's ability to do prolonged work, even if it is of low intensity. Other problem areas might be not having the energy reserve needed to respond to an emergency such as helping a disabled crewmember or doing strenuous work to accomplish some needed task in a crisis.

Consideration of these physiological factors leads to the conclusion that countermeasures must be tested in the near future and later carried out on a long-duration stay in space and should be kept in mind within the mission-design and systems perspective.

#### Cardiovascular Countermeasures

The problem of orthostatic intolerance has been especially obvious in Soviet crews returning from long spaceflights (Bluth and Helppie, 1986). Several countermeasures to prevent or reduce the cardiovascular deconditioning have involved the on-orbit, re-entry, and post-flight regimes. These included regularly scheduled exercises for 2-4 hours per day, repeated exposure to lower negative body pressure (LBNP) devices to "simulate" some gravitational force, fluid and salt replacement, and the wearing

of anti-g garments for a short time post-flight (Yegorov, Itskhovskiy, Turchaninova, Alferova, Polyakova, and Bernadskiy, 1984). Despite sometimes variable and confusing results, these approaches have appeared promising enough to demand further investigation (Levy and Talbot, 1983).

One essential concept that should be remembered is that the heart, after all, is just a muscle. Therefore, any generalized effects on other muscle groups in the body from weightlessness are also very likely occurring in the heart as well. Keeping this in mind, an examination of the microgravity effects on muscle will be addressed next.

### Muscle Effects

The microgravity environment decreases loading on the muscles and leads to significant muscle atrophy. Muscles need a substantial gravity field to maintain normal function, strength, and mass. Both U.S. and Soviet astronauts have tested with lower muscle strengths and girth post-flight. Strength testing after Skylab missions (84 days was the longest) revealed decreased arm extensor strengths in eight of nine crew members and a reduction in leg extension force of all nine crewmembers (Johnston and Dietlein, 1977). Although daily, sustained, vigorous exercise of muscle groups appears to significantly retard the deconditioning of some muscles, these time and energy-intensive exercises have not been shown to clearly arrest the atrophy that is progressive in zero-g (Herbison and Talbot, 1984).

As with cardiovascular changes, systems requirements within

a human context should evolve that do not overstress a weakened muscular system. The probability of reduced muscular performance on the surface of mars, or during EVA, after microgravity exposure has to be accounted for or injury could result. Full recovery of muscle strength on Earth after space station stays requires weeks to months, depending upon the length of stay in microgravity and the intensity of the countermeasures employed.

Exploration activities on the surface of any planetary body may have to be specially designed to accomodate the muscle systems re-acquaintance with gravity and working in a higher-load environment initially upon planetary arrival. Later, as the muscles strengthen and regain their flexibility under loading, heavier work schedules within a mission\systems context might be designed.

The muscles are connected to bones by tendons that allow for mechanical work to be accomplished, so the changes in bone tissue will be reviewed next.

### Bone Changes

Bone is a living tissue. It is constantly growing, being reabsorbed, and responding to hormonal and other biochemical changes in the human body. Exposure to microgravity results in the loss of calcium, phosphorus, and other minerals. Skylab astronauts had 60-100% increases in calcium levels in urine representing an overall bone loss rate of 0.5% per month--even when the astronauts vigorously exercised. The calcaneus (heel) bone, which is a major weight-bearing bone, loses as much as 5%

of its mass per month during spaceflight (Johnson and Dietlein, 1977). Once bones lose 20-25% of their mineral content, they become fragile and may fracture (Nicogossian and Parker, 1982). If a fracture should occur, there is serious doubt as to whether the bone would re-fuse properly without a gravity field (DeCampi, 1986). If the break is in one of the leg bones, this type of injury is known as a "non-union" fracture and requires surgical intervention for the astronaut to walk.

The Soviets have apparently reduced the rate of bone loss somewhat by heavy exercise regimens. The loss of heel bone calcium had been observed to increase roughly proportionately to mission length until the regimens were imposed. Percentage losses seen after six-month flights then decreased to roughly the level observed following three-month flights (Gazenko, Gerin, and Yegorov, 1981).

The bones that appear to be susceptible to mass losses of 7 to 11% are the leg bones, hip bones, and lower lumbar vertebrae (Gazenko, Grigorov, and Egorov, 1988). Other reviews of Soviet reports have stated (Bluth and Helppie, 1986) that the bone loss in the tibia averaged 15% for all crewmembers after 212 days in space with full countermeasures in effect. This value is approaching the 25% loss limit that in an earth gravity environment might break a bone (DeCampi, 1986).

Another systems problem relatable to bone resorption is kidney stone formation due to high levels of urine calcium. Kidney stones are quite painful and may become incapacitating. If a ureter blockage occurs, surgery is often indicated. The

potential for kidney stone development should be considered in a systems context when assessing the development of the spacecraft's Health Maintenance Facility (HMF) attributes.

### Musculoskeletal Countermeasures

Bone demineralization and muscle atrophy seemed to be intertwined by as yet unknown processes. One of the countermeasure devices that the Soviet have used is the "Penguin Suit." The Penguin Suit is a garment worn that places an axial compression on the musculoskeletal system. The wearer must constantly work against the suit's rigidity to move and perform daily tasks. The suits are considered to be uncomfortable and cumbersome. The Soviets also have their cosmonauts workout on a treadmill and bicycle ergometer with various "bungee cord"-types of pulling devices attached to them.

The cosmonauts exercise 2-4 hours per day overall and this is divided into two sessions and performed in three-day cycles with a fourth day as optional (Garshneck, 1989). Although the exercise does apparently slow the effects of deconditioning and atrophy, Soviet crews still return from space deconditioned, often barely able to walk more than a few yards with concomitant dizziness and disequilibrium.

The Skylab program incorporated the combined use of bicycle, treadmill, and pulling devices on the 84-day flight to evaluate these countermeasures versus the previous shorter flights where the treadmill was not used. The results were that the astronauts on the longer flights had significant physical improvements as

compared to the non-treadmill exercise groups on earlier flights (Nicogossian, Sulzmann, Radtke, and Bungo, 1988). The Soviets reported that longer flights do not show a stoppage of the deconditioning effects even through drastic countermeasures have been employed. It may be true that after a certain period of time exercise is only so helpful in countering the detrimental effects of microgravity. However, it may be possible to perform exercises in a 1/3-g environment such as mars and regain some lost conditioning, but at present, such statements are only conjecture. One of the key reasons to establish a lunar base before going to mars is to test some of these hypotheses and attempt countermeasures based upon what is found. A human factors\systems perspective will aid in the evaluation and design of the applicable tests and countermeasures that might be applied.

The use of artificial gravity is a key possibility to help mitigate some of these factors and will be discussed in a separate section later in the paper.

#### Hematological Changes

As mentioned earlier, the fluid shifts and decrease in fluid volume result in a "pseudo-anemia" seen on all longer U.S. and Soviet spaceflights. Red cell mass losses by U.S. astronauts have averaged 10-15%, with decreases in hemoglobin mass of 12-35%, and plasma volume reductions of 4-16% (Cogoli, 1981). The greatest reductions occurred on the Skylab flights for the U.S. program. Soviet losses on flights of up to 7 months of the same

categories of blood components yielded somewhat greater losses (Gazenko, 1982).

Human Factors/Systems concerns regarding lowered hematological values would affect planning for the on-board HMF since any injury involving blood or plasma volume loss would automatically put the spacefarer in a more compromised medical condition. Storing blood products and some drugs for the time frame of a long-duration mission has not yet been accomplished. Lowered red blood cell mass might also limit the ability of the astronaut to sustain a strenuous work pattern. There are also substantial unknowns regarding how the hematopoetic (blood-forming) system may respond during missions of longer than a year since there is no data beyond this time. Further study is going to be required to evaluate how to counteract the loss of red cell mass to insure a margin of safety so that the astronaut can perform all tasks needed, whether a normal mode or in a more stressed emergency type of capacity.

#### Immunological Changes

Analysis of the immune system of astronauts on the first 12 Space Shuttle flights showed a post-flight increase in neutrophil number with decreases in numbers of circulating T-lymphocytes. The post-flight analyses also revealed an inability of lymphocytes to respond to a challenge (Nicogossian, Huntoon, and Pool, 1989). Neutrophils are the white blood cells that seek out, ingest, and kill bacteria and are considered the body's first line of defense against bacterial infection. Lymphocytes are the

cells responsible for humoral and cellular immunity against infections, bacteria, and foreign tissue.

The increase in the number of neutrophils, along with decreases in lymphocyte and eosinophil numbers reveals that likely factors biochemically driving these changes are the increases in epinephrine and glucocorticoids that accompany excitement and stress which have also been observed (Taylor and Dardano, 1983).

Cosmonauts have also showed decreases in the numbers of T-lymphocytes after the 185-day Salyut-6 flight (Vorobyov, Gazenko, Genin, and Egorov, 1983) and decreased activity of T-killer cells after the 150-day Salyut-7 flight (Vorobyov, Gazenko, Shulzenko, Grigoriev, Barer, Yegorov, and Skiba, 1986).

A sketchy, intuitive theory may explain the changes in this way: an unchallenged and therefore unexercised immune system in a nearly antigen-free environment loses some competence after dealing successfully with his companions' microflora (Cosman and Brandt-Rauf, 1987). Realistically, the situation is obviously more complex. In Antarctic studies, increases in respiratory infections at the end of isolation is a variable phenomenon, as is the individual's freedom from disease. Common cold epidemics occur during mid-winter suggesting a surprising persistence of pathogens as well as some mechanisms of a decrease in resistance over time. Confounding the overall picture is that mid-winter airdrops are reportedly virus-laden (from civilization) and could possibly introduce certain cold-like symptoms in winter pole-dwellers (Muchmore, Parkinson, and Scott, 1983).

Systems-level implications for immunological changes are numerous. Negative changes in the immune systems and microflora of space crews could lead to increased susceptibility for a variety of infections on long missions. These infections could be from self-sources as well as from the other crewmates' microflora. Hygiene standards should be kept at a high level to keep the titers of the microorganisms low in the spacecraft environment. Lower density of infectious organisms (titer) means a significantly reduced chance for infection to occur. Maintaining high hygiene standards has implications for other parts of the system such as water usage/recycling, time for personal and spacecraft cleanliness, and how the potentially "sweaty" exercise regimen impacts the factors just listed.

Supply ships, unless heavily decontaminated before leaving Earth, could infect the crew with viruses or bacteria from Earth causing a variety of crew health problems since their immune systems would already be in a somewhat weakened state. Obviously, the problem of exposing the crew of a long-duration stay in space to immunological challenge upon return to Earth via either space station or a direct reentry path might substantially tax the ability of the immune system to respond adequately to the challenge. Answers to other questions that are still unresolved, involve how the effects of long-term, low-level interplanetary radiation may impact the elements of the immune system. Research is underway to find some of the answers to these questions.

### Neurovestibular Problems

Space motion sickness (SMS) is one of the most common physiological problems among astronauts. SMS thus far has been experienced by 40-50% of U.S. and U.S.S.R. crew members during the first days of exposure to microgravity (Nicogossian, Huntoon, and Pool, 1989). The predominant symptoms of SMS based upon data from Space Shuttle crewmembers are anorexia, lethargy, malaise, and headache. Interestingly, there have also been several instances where vomiting occurred suddenly, without the normal prodromal symptoms (Homick, Reschke, and Vanderploeg, 1984). SMS symptoms normally gradually intensify over a period of hours and are usually resolved after 30 to 48 hours. There is some evidence that repeated exposure to microgravity somewhat moderates the symptomology (Nicogossian, Huntoon, and Pool, 1986).

The working hypothesis concerning SMS is that it is caused by sensory conflict. The otoliths on Earth have a component of the gravity field stimulating them. This signal, and inputs from the semicircular canals (which transduce angular acceleration) are no longer "compared" in the neural store normally resulting in a sensory mismatch for the neural store. This "mismatch" is then thought to confuse the brain and the symptoms of motion sickness occur. Reason and Brand (1975) believe also that another component of SMS might be a visual-inertial rearrangement, in which the sensory conflict arises between the visual and vestibular system.

Some theories regarding SMS exist that include otolith

asymmetry as a causal factor. Von Baumgarten and Thumler (1979) have proposed this as an explanation for most aspects of SMS including individual susceptibility. They believe that some individuals possess slight functional imbalances between the right and left otolith receptors. On Earth, in a one-gravity field, these slight differences are compensated for by the central nervous system. This "compensation" is inappropriate in zero gravity since there is no weight difference for each otolith receptor. The result is a neural store temporary asymmetry in terms of expected signals producing vertigo, eye movements, and posture changes until the brain's central "compensating" centers adjust to the microgravity environment.

A similar imbalance may also appear upon return to a one-gravity (or partial gravity?) field leading to some post-flight vestibular disturbances. Markham and Diamond (1991) have confirmed aspects of this concept in a variety of tests with the possible conclusion that individuals with a greater degree of asymmetry in otolith morphology probably are more susceptible to SMS.

Systems and human factors implications for long-duration spaceflight abound. Because SMS may only lower crew productivity during the first days of flight, crew schedules need to be flexible. The question remains as to how the neurovestibular systems will respond to a spacecraft insertion into martian orbit (which will require decelerative "g" forces) and to the martian 1/3-g gravity field. Studies on astronauts returning for orbit have shown that pitch-and-roll head motions performed during

reentry from space or post-flight on the ground will often create a perception of self-motion in the direction of head movement. The implications of these results while performing skilled tasks in the martian realm could be dangerous illusions that impair perception of reality at critical flight times, perhaps just enough to create an adverse situation.

Post-flight deficits in postural equilibrium were noticed in one Apollo and all 9 Skylab crewmembers (Johnston and Dietlein, 1977). Returning Soviet long-duration cosmonauts have also had similar problems (Bluth and Helppie, 1986). The Soviets have reported long-lasting postural instability and vomiting after some head movements. Some Soviet investigators have concluded that the degree and duration of such symptoms is proportional to the time spent in microgravity (Nicogossian and Parker, 1982). The astronauts appeared to return to normal in approximately 10 days. Some Apollo and Skylab astronauts also reported other post-flight disturbances such as difficulty in turning corners and vertigo during rapid head movements. Therefore, experimental results support the theory that the brain adapts to the microgravity environment, and must readapt to the normal gravity field of the Earth (Kenyon and Young, 1986; Nicogossian, Huntoon and Pool, 1989).

Countermeasures have been attempted, and have as of the present time, not fully succeeded. Currently, the best way to reduce the severity of SMS is to reduce head movements during the first days in space and to take a combination of scopolamine and dexedrine (Beck, Davis, and Jennings, 1991). Scopolamine is an

effective anti-motion sickness drug, but produces sleepiness and thirst in many. Dexedrine is a stimulant that counters scopolamine's fatiguing effects and has its own low-level side effects. Scopolamine can be administered by a transdermal patch worn behind the ear.

Other interesting man-in-the-system questions arise regarding the human readaption to a martian gravity field such as:

- (1) How long will it take to (re)adapt to 1/3-g gravity field and what can be done in the mean time?
- (2) How long should be allowed before driving a roving vehicle on the martian surface and under what restrictions?
- (3) Should certain activities such as bending over that may cause disequilibrium be avoided or a period of time?

The only basis thus far for readaption to a gravity field is from some of the Soviet flights. Dr. Atkov, who participated in the Salyut 237-day mission believes that about three weeks is required before the crew was back to normal (Bluth and Helppie, 1986). More recent data from the eleven and twelve month Mir flights had about the same results (Grigoriev, Bugrov, and Egorov, 1991).

Neurovestibular defects may also have to be considered from a systems failure or emergency standpoint. If an astronaut has to take over emergency control of a descent to mars by manual override, could the necessary tasks be accomplished, and what visual/vestibular illusions might be anticipated under certain conditions. This scenario is not as unlikely as it may seem since Neil Armstrong had to choose an alternative landing site

just before landing on the moon since the assigned landing site was in a field of boulders that may have destroyed the lunar lander (Wolfe, 1981). Armstrong eventually landed with less than ten seconds of fuel remaining, calling out to mission control: "Tranquility Base here. The Eagle has landed."

### Artificial Gravity

As highlighted previously, there are serious doubts as to whether exercise countermeasures can adequately mitigate the body's physiological responses to microgravity. The critical decision of whether to provide artificial gravity through spacecraft rotation has functional hardware and physiologic consequences for almost every mission parameter. Approaches to generating an artificial gravity field range from rotating the spacecraft on its axis to providing on-board centrifugation. Artificial gravity at some level when combined with exercise would most likely help to reduce some physiological and operational problems associated with microgravity such as (Garshneck, 1989):

- \* cardiovascular deconditioning
- \* bone demineralization
- \* muscle atrophy and decreased strength
- \* body fluid loss due to shift and redistribution of body fluids in weightlessness
- \* time invested on exercise
- \* time invested on re-exposure to a gravity field for rehabilitation (at least 3, perhaps 6 weeks)

A systems perspective forces an examination of how some of

these issues impact others and to what extent. This involves a reasonably reliable definition of environmental, physiological, and operational specifications that have not yet fully evolved. The NASA report Exploring the Living Universe (1988) for the Life Sciences Strategic Planning Study Committee states clearly that

"spacecraft intended for extended space missions cannot be designed to support human crews safely if the physiological and environmental specifications have not been reliably defined. It would be inadvisable to commit to either a weightless or an artificial gravity-based vehicle design before the basic reactions of humans to space flight are fully understood."

This type of thought process on how to pursue an artificial gravity research program was echoed in the 1988 report to the Administrator from the Office of Exploration stating that zero gravity and artificial gravity research programs must be evaluated and compared in light of the other. Further systems-level recommendations advised that "relatively simple experiments in space be performed soon to find out the effects of various rotation rates and levels of artificial gravity on people so we can establish practical design parameters."

Owen Garriot, one of the first U.S. scientist-astronauts referred to artificial gravity issues with this comment: It is the Devil we know (microgravity), and the Devil we don't know (artificial gravity). What Dr. Garriot meant is that there is general agreement about what effects microgravity have on the human body. What we do not know, however, are the long-term effects of artificial gravity on the human--along with all of the associated "problems" that may come with it.

Kennedy (1991) reviewed the research and found that above

3-4 RPM (revolutions per minute) there was a definite Sopsite Syndrome in most of the participants. After 3 days, the motion sickness symptomology disappeared, but the low-level fatigue remained indefinitely. Kennedy (1991) noted that performance deficits due to fatigue do occur with the associated problems of vigilance and signal processing. Beyond the fatigue effects, there seems to be rather good adaption by test subjects to the non-inertial reference frame as long as the rotation did not exceed 5.4 RPM. After 5.4 RPM, almost any "provocative" head/body movement would cause motion sickness in at least 50% of the subjects tested. After rotation was discontinued, a certain period of time (variable for different persons) was required by the neurovestibular system to "forget" that it had been in a rotating reference frame and respond to more traditional inertial cues once again.

The systems implications of this research are significant. Assuming a decision is made to rotate the spacecraft: Can an astronaut then be expected to do an EVA without becoming ill or making an error in judgement since outside the spacecraft (s)he is then in an inertial reference frame? Concerns about a descent to the martian surface also exist when the lander will not be descending to the surface in a rotational reference frame. Also, how much of a time buffer should be required from stopping the spacecraft's participants from rotating prior to execution of a landing profile? Additionally, the concerns that Kennedy (1991) expressed about fatigue/illness limit the rotation rate to less than 3-4 RPM as fatigue effects could impact the mission

negatively with error-induced systems problems created by the astronauts. The ability to detect important signals during certain tasks has also been to be degraded while in a rotating frame of reference (Kennedy, 1991).

As of now, much basic research needs to be done preferably in the microgravity environment before a decision should be made with reference to using artificial gravity. Additionally, key operational experiments would need to be performed in space to evaluate the duration and fraction of gravity that would be required to maintain a level of fitness needed to accomplish a long-duration mission.

### Radiation

One of the key issues for long-duration manned exploration of space is the radiation hazard. There are four general sources of radiation as shown in Figure 13 from DeCampi (1986). The figure illustrates that there are both high- and low-energy particles that need to be considered. Biologists face uncertainties as to how the body behaves when absorbing high- and low-energy radiation particles. What is known is that the absorption is not uniform (Reiber, 1986). Because the body is composed of water and solids which vary throughout and are located at various depths, there are different layers of protection for various organs. In general radiation effects are more harmful toward the end of a life span, but women of childbearing age are more susceptible and at greater risk than males of equivalent age. The risk of breast cancer is

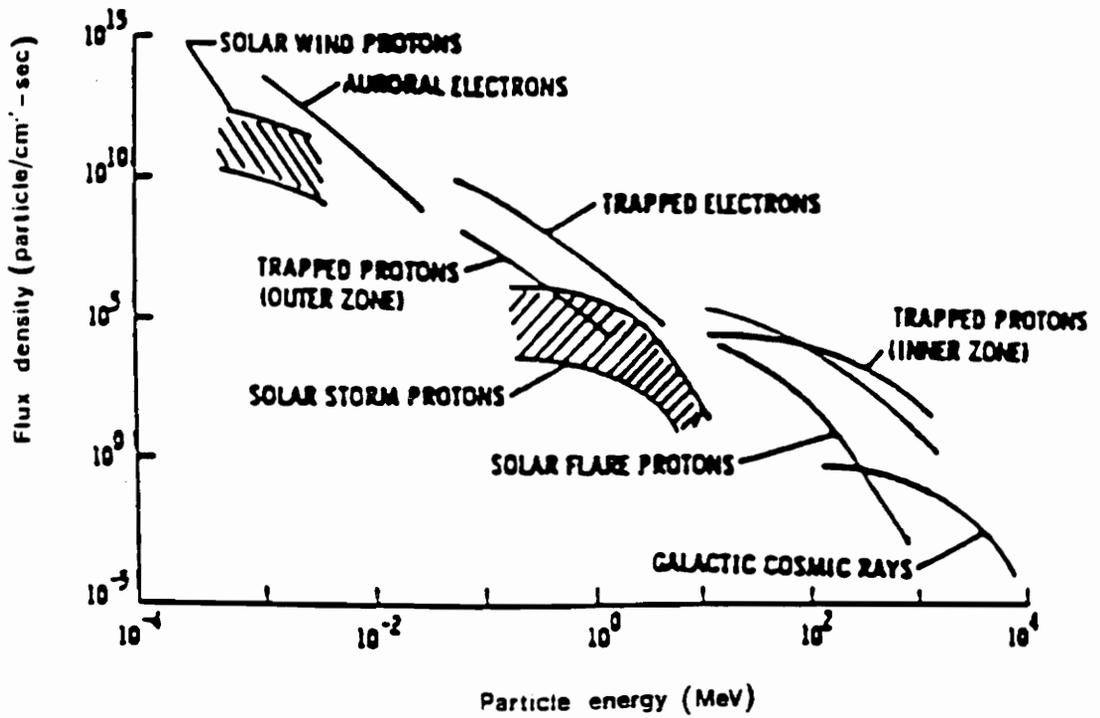


Figure 13. Spectrum of Radiation in the Space Environment  
Adapted from DeCampi (1986).

particularly increased as result of radiation exposure.

The first source of radiation that the astronauts will encounter is that of trapped particles in the magnetosphere from the sun. These particles are protons and electrons that the Earth's magnetosphere has trapped and this radiation source is strongest from 2,500 km to 20,000 km above the surface. An anomalous region of protons from this source actually dips down into LEO and is known as the South Atlantic Anomaly. Overall, there is a rapid rise in radiation above 450 km as the innermost Van Allen radiation belt begins to make its presence known. Doses to the skin and blood-forming organs in 90-day Space Station tours are shown in Table 9. Exposure limits for astronauts, presently formulated by NASA, are shown in Table 10 (from McCormack, 1986). Based upon the guidelines set by NASA, a 40-year old male astronaut would have a career limit exposure of 275 rem to the blood-forming organs. Even under Solar Min conditions, as astronaut could safely complete a 3-month tour every 2 years over a 20-year career. However, a 1-year stay during Solar Min on the Space Station would yield a dose of 65 rem, which exceeds the annual limit.

Interestingly, doubling the station wall thickness would only reduce the dose factor by 1.2 for an annual dose of about 54 rem which is barely under the annual limit (Nicogossian, Huntoon, and Pool, 1989).

EVA workloads on Space Station will be heavy initially, with routine passage through the South Atlantic Anomaly. Present spacesuits do not provide enough protection from such radiation

TABLE 9  
ACCUMULATED DOSES - SPACE STATION\*

Target Time	Dose Rate(mrem/day)		90-day Dose(rem)	
	Skin	BFO	Skin	BFO
Solar Min	390	180	35.1	16.2
Solar Max	195	110	17.6	9.9

\*Altitude is 500 km. "BFO" means blood-forming organs.  
Adapted from McCormack (1986).

TABLE 10  
NASA RADIATION EXPOSURE LIMITS

Period	BFO (5 cm)	Eye (3 cm)	Skin (.001 cm)
30 Days	25	100	150
Annual	50	200	300
Career:	200 + 7.5 (age-38) females 200 + 7.5 (age-30) males		

Adapted from McCormack (1986). All values shown are in rem.

hazards with the result that shielding on the suits will have to be increased to at least a  $1.5\text{g/cm}^2$  aluminum equivalent. The magnetosphere of the Earth largely protects astronauts from the radiation of the solar wind, solar flares, and cosmic rays. Solar wind particles consist largely of protons that are of low enough energy such that even minimal spacecraft shielding is very protective.

Solar flares and galactic cosmic radiation are of much higher energy and therefore demand much more integration into the systems process to allow for adequate protection. Solar flares cause an intense burst of proton radiation that may last for a few hours or as long as several days. Shielding from this type of radiation is essential or death could result. A good example of this is the 1972 solar flare that pushed the radiation level in geosynchronous orbit to one million times that on Earth (Nicogossian, 1986). Despite significant protection from the Earth's magnetosphere, the level of radiation encountered by a Space Shuttle crew in low Earth orbit at that time could have been dangerous. Thankfully, there is a blast of radio waves that precedes the solar flare protons by one hour, giving the astronauts some warning time to seek shelter. Any long-duration spacecraft or extraterrestrial colonies would need a storm shelter with the equivalent shielding of ten times what the shuttle provides for protection from solar flare radiation (DeCampi, 1986). This one-hour constraint on the ability of astronauts to seek a storm shelter environment means that any EVA and planetary exploration activities in general need to be

considered in light of the potential radiation threat. EVA could be a particularly troublesome area in this regard since decompression time would be required after EVA to avoid "the bends." How this is to be traded-off in a systems perspective is now being examined. If an astronaut got caught outside of a protected area during a solar flare, the effects could be quickly noticed. Diarrhea and nausea would occur within 24 hours due to the destruction of the intestinal epithelium. The subsequent dehydration might cause further problems such as hemorrhage, electrolyte imbalances, and cardiovascular instability. Soon, the radiation damage to the bone marrow would cause anemia, infections, and bleeding from three to six weeks later depending upon the initial dose received. Death might result later if a high enough dose was received, with higher rates of cancer occurring for those doses which did not kill.

The best answer to the radiation problem appears to be to design a "storm shelter" on the spacecraft for radiation protection. Water and other shielding materials might be added as part of the station architecture around the storm shelter to increase its effectiveness. Adequate solar flare warning systems and spectral dosimeters will need to be installed aboard the craft. After a planetary surface is reached, radiation exposure can be minimized by selecting protective sites in valleys and covering habitats with protective layers of surface material (Garshneck, 1989). Exposure values are thought to be approximately half as much in the martian valleys compared to the higher plateaus due partially to the effects of shielding

provided by the CO<sub>2</sub>-rich martian atmosphere and surrounding terrain.

Reiber (1986) has suggested that the daily galactic cosmic radiation dose at the martian surface ranges from 12.5 to 18 millirads. However, one or two major solar events could expose a crew up to 5,000 rads--which is a lethal dose. Therefore, the radiation from the solar flares should be predicted and a "safe haven" designed to keep the total dose below 400 rad (see Table 11). Historically, scientists had considered a solar flare episode to be (more or less) a one-time event as the 1972 eruption had behaved. In 1989, there was a series of flares that had widely different particle energies associated with them that could have been just as dangerous to astronauts as the 1972 episode (Townsend, Cucinotta, Shinn, and Wilson, 1991). This series of solar flares has forced scientists to reconsider what the impact is of the spectrum of particles reaching the crews for the first time. Additionally, the fact that a series of moderate but dangerous eruptions occurred has to be accounted for in future systems planning for long-duration spaceflight. The general expected doses of radiation from galactic (cosmic) and solar flare sources is shown for various conditions and exposure times. Solar flares occur in 11-year cycles and within the cycle there are relative periods of maximum and minimum solar flare activity. The potential statistically for a "maximum" exposure during certain time intervals must be seriously considered.

The last type of radiation hazard in the space environment beyond the magnetosphere is galactic cosmic radiation. Cosmic

TABLE 11

	Exposure
Galactic Cosmic Radiation. . . . .	25-36 mrad/day
* Mars Surface Dose. . . . .	12.5-18 mrad/day
* Total Dose (30 months) . . . . .	=20-32 rads
 Solar Flares	
* 11-Year Solar Cycle	
* 1 to 2 Major Events/Solar Cycle. . . . .	5,000 rad (lethal)
* 2 to 5 Major Events/Solar Cycle. . . . .	500-1000 rad
* 20 to 30 Major Events/Solar Cycle. . . . .	50-100 rad
"SAFE HAVEN" Shielding to Reduce Dose Below 400-rads is Necessary.	
Radiation Estimates for Mars Mission (cosmic, mars surface, solar flares)	

Adapted from Reiber (1986).

radiation is composed of proton, alpha particles, and HZEs (energetic nuclei of heavy particles). Due to the high energy, cosmic radiation is not only difficult to protect against, it is also hard to measure exposure accurately since it is the geometry of exposure--not necessarily the intensity--that determines the biological effect (Todd, 1991). DeCampi (1986) feels that HZEs operate by single-hit kinetics where each particle creates a sort of microscopic stab wound; whose severity is determined by its position on the body and the angle at which the particle strikes the cell involved. Rat experiments have shown that even a single HZE particle can cause irreparable damage to a corneal cell (Worgul, 1991). The implications of this result is that this type of radiation can kill cells, as opposed to damaging the genetic material such that the original cell hit itself is largely unharmed, leading to the loss of non-dividing cells (such as those found in the central nervous system). The effects of this type of radiation, and at what level those effects occur, is not known at this time.

McCormack (1986) suggests that a two- to three-year round trip to mars would cause a dose of 140 rem to an astronaut protected by  $2.5 \text{ g/cm}^2$  shielding. This exposure does not include major solar events and exposure to other potential spacecraft radiation sources.

From a human/systems perspective, radiation exposures must be kept as low as is reasonably possible to avoid a host of long- and short-term effects. Increased psychological stress will become a factor if the crew knows that certain tasks or

environments will expose them to higher levels of radiation. Jobs exposing the astronauts to radiation risks (EVA, extended forays into certain regions on mars) should be shared fairly to avoid potential group infighting and disunity. Interestingly, the last redesign of Space Station Freedom did not have a designated "safe haven" for protection of solar flare bursts (Boyce, 1990). At present, it could take as long as 45 days to effect a rescue by the Space Shuttle of station personnel. Also, in recent months design reviews have resulted in the deletion of an Assured Return Vehicle (ARV) from program funding so that there now is no immediate escape possibility from a crippled station or one that would soon be bombarded by particles from a major solar event.

#### Operational Medical Problems

Thus far, the following clinically significant medical risks to crewmember health have been identified:

- \* radiation
- \* "bends"(dysbarism)
- \* brittle bone tissue
- \* dehydration
- \* cardiovascular problems
- \* kidney stones
- \* infections
- \* trauma

Other medical conditions due to the environment of the spacecraft (toxicological events) could prove to be extremely

dangerous. Potential sources of toxicity include offgassing of interior materials/chemicals, combustion of materials, and the escape of chemicals from various containers (Garshneck, 1989). A systems perspective in this area reveals that some mission contexts might enhance certain physiological parameters that would result in an increased severity of response to a toxic event. These systems physiological concerns may involve exposure to other contaminants, the altered physical state of the crewmembers after a long period in space, and the concomitant exposure to radiation.

Utilization of systems/human factors considerations can aid in the optimal reduction of hazards to the crew and spacecraft. An occurrence of serious toxic event(s) can be minimized by considering the following (Duke and Keaton, 1986):

- \* Reliable alarm system for warnings
- \* Optimal material selection
- \* Ensuring heat stability of materials
- \* Proper toxic chemical containment
- \* Protective clothing for materials handling
- \* "Safe Haven" for emergencies

Adequate provisions for atmospheric purging and revitalization are also important. The HMF should be conceived with the idea that such toxic contaminants may have particular medical sequelae resulting from them. As the HMF concept evolves through experience on long-duration shuttle flights and the space station, a better understanding of the needs for a trip to mars will be gained.

Another important aspect of operational medical problem definition involves assessing the risks for certain diseases to occur. After the likelihood of certain medical issues arising requiring treatment has been evaluated, the HMF support elements needed can be more fully ascertained. DeCampi (1986) lists the "endogenous" problems normally requiring hospitalization that may arise during a 3-year mission to Mars with a crew of 7 (four men and three women). The results are listed in Table 12. Many of these problems are undetectable by current screening processes. Indeed, long-duration missions may allow enough time for nonexistant/undetected cancers or other problems to become worse that may not have been a factor at liftoff. Difficulties with the immune system, such as an autoimmune reaction that could cause kidney failure may become dangerous in three years. Other authors (Nelson, Gardner, Ostler, Schultz, and Logan, 1990) have evaluated the most likely medical problems to arise for space station astronauts using analogous military populations and specialized filtering techniques for enhancing the attributes of the space station where health impact was concerned. Their analyses revealed that cardiac events, musculoskeletal injuries, affective psychosis, and renal calculi were among the highest scoring categories in terms of probability of occurrence (see Table 13). The Nelson et al. (1990) results compare favorably to the Soviets "limited" operational experience. On two occasions, once due to cardiac arrhythmias and once due to an undisclosed illness, the Soviets had to expeditiously return cosmonauts to the Earth (Canby, 1986; Raymond, 1988). For the U.S. space program,

TABLE 12

DIAGNOSIS	PROBABILITY
Gastrointestinal	12.6
Cardiovascular	11.9
Genitourinary	11.2
Musculoskeletal	8.3
Respiratory	7.0
Cancer	6.8
Mental disorders	6.3

SURGICAL PROCEDURES	PROBABILITY
Gynecological	18.4
Gastrointestinal	15.8
Acute appendicitis	2.5
Musculoskeletal	12.6
Ophthalmological	2.3

"Endogenous" Medical Problems Normally Requiring Hospitalization  
(Assumptions: 3-Year Mission, Age Range 30-50, 3 Females, 4 Males).

Adapted from DeCampi (1986).

TABLE 13

FINAL TOP 20 CATEGORIES BY OPTIMIZED MEDICAL IMPACT SCORE  
 COMBINING ARMY AND NAVY DATA, AFTER ADJUSTMENT FOR DEMOGRAPHIC  
 AND ENVIRONMENTAL DIFFERENCES VERSUS SPACE STATION

Rank	Category Name
1	Cardiac dysrhythmias
2	Acute myocardial infarction
3	General symptoms
4	Disorders of back, other and unspecified
5	Internal derangement of knee
6	Disorders of bone and cartilage
7	Derangement of joint, other
8	Intervertebral disc disorders
9	Affective psychoses
10	Sarcoidosis
11	Erythematous conditions
12	Disorders of joint, other and unspecified
13	Viral hepatitis
14	Calculus of kidney and ureter
15	Disorders of muscle, ligament, and fascia
16	Disorders of soft tissues, other
17	Essential hypertension
18	Acute pulmonary heart disease
19	Causes of morbidity and mortality, other ill-defined and unspecified
20	Depressive disorder, not elsewhere classified

Adapted from Nelson et al (1990).

the cost of a Space Shuttle rescue from the space station is estimated to be 100-300 million dollars (Raymond, 1988). The spectre of an "unnecessary" space rescue is one of several reasons that an adequate HMF should be a part of the overall space station concept. "Front-end" skimping on HMF capability from a systems standpoint might save a few dollars initially but have very serious consequences later in an operational environment. The effects on group dynamics of having to take care of a chronically-ill or disabled crewmember on a long-duration mission is largely unknown. What is clear, however, is that the crew selection process must account for the loss of each of the team members and the skill that each individual contributes to that mission. Therefore, a mission doctor might be cross-trained as a geologist or a pilot taught crew medical officer skills.

#### Space Station Medical Support

The requirements for space station medical support are based on many factors. A systems perspective requires that the HMF on the space station have a substantial amount of ground support infrastructure. Some of the factors which impact the requirements for such support are crew size, the organizational architecture of NASA Life Sciences Division, and the overall NASA operational medical system (see Table 14). Similar support factors for a long-duration mission to mars will be conceived with the main exception being that much more self-autonomy will be required for the HMF in that system.

TABLE 14

## MEDICAL AND LOGISTICS SUPPORT REQUIREMENTS FOR SPACE STATION

## Medical Support Considerations

- |  |  |
|--|--|
| * Crew Size and Rotation                               | * Communication  |
| * Space Station Crew Jobs                              | * Launch and Landing Site Requirements   |
| * Medical Selection and Annual Certification Standards | * Organization of Life Sciences and Medical Operation System for Space Station Era |
| * Autonomy and Ground Support                          |  |
| * Psychological Support                                |  |

## Logistics Support Requirements

- |  |   |
|--|---|
| * Food   | * Biowastes and Industrial Hazardous Wastes Aboard Station, Storage, Transfer, and Disposal |
| * Potable Water  | * Animals, Plants, and Other Biological Experimental Subjects                               |
| * Eclss Gases and Liquids                                    | * Medical/Life Science Logistics System for Kennedy Space Center                            |
| * Fuel/Propellant Operation                                  |   |
| * Life Science and Medical Care Technology Experiments       |   |
| * Drugs, IV Fluid Shelf Life, Quality Control, and Inventory |   |

Adapted from Furukawa and Buchanan (1986).

Logistical issues cannot be forgotten during HMF system development. Aspects of overall station support must be considered as the superset of medical support concerns for planning purposes. For a trip to mars, the logistics of the medical support capability becomes a greater priority as the HMF evolves with more a priori autonomy. Integrative station support systems include the interfaces with the medical concerns associated with food, environmental hygiene, and sanitation. Logistics support requirements are also listed by category in Table 14.

The HMF attributes for a trip to mars will certainly be driven by a different set of requirements than that of a LEO space station. Davis (1991) and other colleagues at the Johnson Space Center have estimated that a crew of 8 (4 males, 4 females) has a 48% chance of one of the crewmembers needing major invasive surgery at some point during the journey. For this reason and others (such as accidental trauma to the body), the HMF for a mars mission must have surgical capability. The surgical function of the HMF will also need a telemedicine capability for additional consultation and intellectual augmentation (Stewart, 1991; Rayman, 1991). At present, no one fully understands what the impact on the health of an astronaut will be due to psychological stress. What is known, however, is that the immune responses are somewhat damped during long-duration missions for a variety of reasons (Cogoli, 1981; Taylor, Neal, and Dardono, 1986). With this in mind, it is important to realize that "medical" and "psychological" issues may more directly affect

each other than is generally recognized here on Earth.

### Summary and Recommendations

The effects of physiological deconditioning due to the microgravity environment are extensive. A summary of the effects to human bodily systems appears in Table 15 (Jenkins, 1992) along with potential countermeasures as defined by the Ad Hoc NASA Space Systems Advisory Committee (SSTAC) formed to evaluate technology requirements for human performance on long-duration space missions. Many of the countermeasures discussed in this review appear in this Table. However, as Furukawa and Buchanan (1984) point out, the current concepts of countermeasures should be considered the tip of an iceberg due to the overall lack of experience with the long-duration spaceflight regime (see Figure 14).

Careful consideration of the human element within a systems context should help to optimize the process of finding solutions for long-duration spaceflight problems. As Table 16 (Jenkins, 1992) illustrates, there are significant technology needs to be developed for a variety of system functions that directly impact the human factor. Because they affect and support the human being, these systems functions must be developed with human factors considerations as central tenets of the process.

One of the ways to mitigate the serious physiological performance decrements is to shorten the trip time to mars. At present the only method by which to reduce the time for the journey to mars is nuclear propulsion. Shortening the transit

TABLE 15  
EFFECTS OF PHYSIOLOGICAL DECONDITIONING  
IN EXTRATERRESTRIAL ENVIRONMENTS

PHYSIOLOGICAL SYSTEM	POSSIBLE DECONDITIONING EFFECTS	POSSIBLE COUNTERMEASURES
Cardiovascular System	<ul style="list-style-type: none"> <li>• Headward shift of body fluids</li> <li>• Puffiness of face</li> <li>• Decrease in size of heart</li> <li>• Diminished blood volume</li> <li>• Reduced blood flow</li> <li>• Decreased orthostatic tolerance after flight</li> <li>• Reduction in red blood cells (anemia)</li> </ul>	<ul style="list-style-type: none"> <li>• Induce artificial gravity with centrifuge, rotating Space Station or linear-g</li> <li>• Pressure suits (antigravity suit)</li> <li>• Exercise devices (treadmills, ergometers)</li> <li>• Pressure cuffs (Soviet)</li> <li>• "Chibis" vacuum suit (Soviet)</li> <li>• Pharmacological agents</li> </ul>
Neuromuscular System	<ul style="list-style-type: none"> <li>• Atrophy of muscles (decrease in muscle mass and loss of muscle tone)</li> <li>• Postural changes to fetal-like position at rest</li> <li>• Decline in muscle strength</li> </ul>	<ul style="list-style-type: none"> <li>• Exercise programs/devices</li> <li>• "Penguin" suit (Soviet)</li> <li>• Electrostimulation (Soviet)</li> <li>• Artificial gravity</li> </ul>
Neurovestibular System	<ul style="list-style-type: none"> <li>• Dizziness</li> <li>• Nausea, pallor, vomiting, malaise (symptoms normally subside within 48-72 hours)</li> <li>• Reduction in lateral walking stability</li> </ul>	<ul style="list-style-type: none"> <li>• Cuban Boot (Soviet)</li> <li>• Head restraints (Soviet)</li> <li>• Pharmacological agents</li> <li>• Use of treadmill</li> </ul>
Skeletal System	<ul style="list-style-type: none"> <li>• Bone demineralization (calcium loss)</li> <li>• Greater potential for fractures</li> <li>• Formation of kidney stones</li> <li>• Predisposition to osteoporosis</li> </ul>	<ul style="list-style-type: none"> <li>• Increased calcium consumption</li> <li>• Dietary supplements</li> <li>• Artificial gravity</li> <li>• Exercise programs/devices</li> <li>• Electromagnetic stimulation</li> </ul>
Immune System	<ul style="list-style-type: none"> <li>• Partial suppression of immune system</li> <li>• Potential allergic reactions</li> </ul>	<ul style="list-style-type: none"> <li>• Countermeasures unknown (Use of lactobacera derivative being explored by the Soviets)</li> </ul>
Endocrine System	<ul style="list-style-type: none"> <li>• Decrease in ACTH in plasma</li> <li>• Decrease in TTH and STH hormones</li> </ul>	<ul style="list-style-type: none"> <li>• Countermeasures unknown</li> </ul>
Vibroacoustic Exposure to All Systems	<ul style="list-style-type: none"> <li>• Reduction in tolerance to sounds and vibrations</li> <li>• Increase in irritability</li> <li>• Sleep disorders</li> </ul>	<ul style="list-style-type: none"> <li>• Control sound sources (fans, motors) through design</li> </ul>
Circadian Rhythm Changes	<ul style="list-style-type: none"> <li>• Performance decrement</li> <li>• Malaise</li> <li>• Insomnia</li> <li>• Appetite loss</li> <li>• Decrease in REM sleep</li> </ul>	<ul style="list-style-type: none"> <li>• Standardize work/rest cycles</li> <li>• Standardize light/dark cycles</li> </ul>
Radiation Exposure to All Systems	<ul style="list-style-type: none"> <li>• Symptoms of radiation sickness at 100 rem</li> <li>• Death at 300-500 rem</li> </ul>	<ul style="list-style-type: none"> <li>• Medical Protocols</li> <li>• Passive shielding (storm shelters)</li> <li>• Electrostatic and electromagnetic shielding</li> </ul>

From Jenkins (1992).

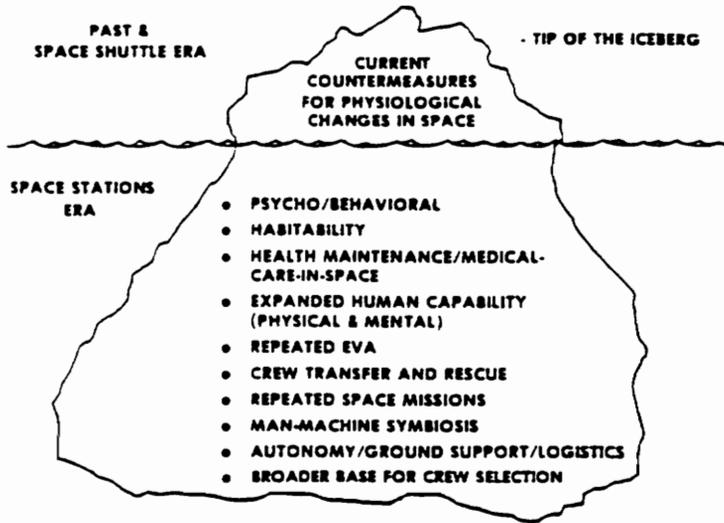


Figure 14. Current Concepts of Countermeasures are the Tip of the Iceberg in Terms of the Responses of the Various System Attributes.

Adapted from Furukawa and Buchanan (1984).

TABLE 16  
TECHNOLOGY NEEDS FOR LONG-DURATION MISSION FUNCTIONS

FUNCTION	TYPICAL TECHNOLOGY NEEDS
Control Overall Life Support	<ul style="list-style-type: none"> <li>• Order of magnitude improvement in the reliability of the hardware to be utilized in long-duration missions</li> </ul>
Temperature and Humidity Control	<ul style="list-style-type: none"> <li>• Investigate alternatives to condensing heat exchangers i.e., membrane separators</li> </ul>
Atmospheric Revitalization (CO <sub>2</sub> control/removal/reduction, O <sub>2</sub> and H <sub>2</sub> makeup, trace gas monitoring and control)	<ul style="list-style-type: none"> <li>• Minimization of the weight, volume and power demands in closing the CO<sub>2</sub> loop by electrochemical, absorption/desorption, or molecular sieve processes.</li> <li>• Development of long-duration quality monitoring, including sensors and control technology for trace contaminants, toxic compounds and pathogens</li> </ul>
Food Supply (Storage, processing/preparation, growth chambers)	<ul style="list-style-type: none"> <li>• Development of closed loop bioregenerative food production systems</li> <li>• Development of automated systems for harvesting and processing edible biomass or space crops</li> </ul>
Water Management (Waste water collection/processing, water quality monitoring, storage and distribution of recovered water)	<ul style="list-style-type: none"> <li>• Development of closed loop water recycling systems</li> <li>• Investigation of alternative ways to increase efficiency of waste processing equipment; and reduce resupply needs</li> <li>• Development of techniques for long-duration quality monitoring</li> </ul>
Waste Management	<ul style="list-style-type: none"> <li>• Development of waste management systems (physical/chemical or bioregenerative) to collect/process urine, collect/store fecal matter and recycle waste, e.g., super critical water oxidation</li> </ul>
Health Maintenance	<ul style="list-style-type: none"> <li>• Development of personal hygiene, exercise, diagnostics/therapeutics, and surgery/medical aid capabilities for utilization in reduced gravity environments</li> </ul>
Radiation Protection	<ul style="list-style-type: none"> <li>• Development of shielding techniques with minimum weight impact on total space system</li> </ul>
Total Systems Integration	<ul style="list-style-type: none"> <li>• Development of integrated regenerable life support systems (physical/chemical and bioregenerative)</li> <li>• Development of analytic tools/computer models and experimental database models for system simulation</li> <li>• Development of integrated testbeds</li> </ul>
In-Situ Resource Extraction (Water, oxygen, material, etc)	<ul style="list-style-type: none"> <li>• Development of techniques and processes to extract water, oxygen, and other useful materials from the Lunar and Martian surfaces</li> </ul>

From Jenkins (1992).

time to mars also decreases the crew's exposure to galactic cosmic radiation. One especially interesting set of mission parameters calls for 120 to 180-day travel period to mars, followed by 600 days on mars, and a 90-day return trip. The debilitating effects of zero gravity presumably would be reduced by separating the outbound and return trip with productive work on the 1/3-g martian surface (Aviation Week and Space Technology, 1991b).

One of the main reasons that NASA is currently pursuing the nuclear propulsion option is that not enough is known regarding the effects of artificial gravity on which to base a long-duration spaceflight program. Recent funding for Space Station Freedom has deleted the artificial gravity test centrifuge from the station configuration. This centrifuge deletion will not allow for a significant amount of research to be accomplished that should answer questions needed regarding a flight with artificial gravity to mars. Should the artificial gravity pathway be chosen in the future from a systems perspective, research will have to be done to ascertain the parameters needed to avoid deconditioning without inducing other problems. Nuclear propulsion offers a quick transit time to mars, however, it does not solve all of the physiological and psychological problems that may arise even on a short 180-day trip to the red planet. A year-long stay on mars would generate physiological and psychological problems that as yet cannot be completely predicted. This is why flexibility with respect to medical care for the astronauts is essential since there is a high likelihood

of injury or illness occurring during such a long time frame.

A partial solution to combat some of the debilitating effects of the microgravity environment is going to be required crew exercises. An attempt should be made to design the exercise regime such that it is not tedious and helps to promote stress reduction and well-being, much like our exercise programs do here on Earth.

## CHAPTER VI CONCLUSIONS

A systems perspective for evaluating long-duration spaceflight problems could prove to be very helpful. As has been seen by the previous comments, complex systems operate at a variety of levels. The human element is the crucial factor for the success of a long-duration space mission, aside from the basic spacecraft engineering. A faulty human in the loop could potentially imperil a manned Mars mission due to a variety of performance decrements. Human beings are emotional, highly adaptive organisms capable of doing a variety of tasks in space that machines cannot. Because the human element has emotions, great care must be taken to ensure that the psychological health of the astronaut does not suffer needlessly. Astronauts that return to Earth in a substantially damaged physical or emotional state after a long-duration space mission imply that the systems supporting those astronauts have not yet evolved enough to truly cope with extended stays away from the planet Earth.

This paper has been written by separating the astronaut's physical and psychological health-issues for discussion purposes. This does not mean to imply that the physical and psychological concerns discussed are so dicotomized, because indeed they are related to each other.

Consideration of the group dynamics process is an important factor within the psychological realm for extended space missions. Preferably, an odd number of astronauts should be sent on a mission to mars. This is because odd number groups tend to arrive at decisions more quickly, and have greater stability along the way as a general rule. The mixture of the crew probably should be roughly divided between males and females, although from a strictly medical perspective, each sex has certain strengths and weaknesses for predisposition to serious problems that might occur in flight. As the health maintenance facility is being developed for a long space mission, the likelihood of certain medical issues arising should be assessed and the facility designed to accommodate those high probability events.

The people in the scientific and operational communities supporting the astronauts on the ground should be considered as part of the total systems context. This means that they should be aware of basic group dynamics so that they will not inadvertently contribute to group stress and tension. This has been a problem in the past in both the Soviet and American space programs when long missions were attempted. Family and friends "back home" should be allowed routine access to the astronauts

during long missions to communicate what is going on in their lives so that the crew does not feel shut out from the world events as they take place. This interaction will help to reduce the isolation that the astronauts may feel on a long mission although the communication times will become extensive as the astronauts approach mars.

The most important attribute that an astronaut should be selected for in a long-duration spaceflight context is the ability to work well with others in confined environments and be willing to have a flexible attitude regarding his/her overall life situation. The group dynamics processes as a whole will be enhanced by selecting such individuals and with the appropriate sensitivity training the crew should be able to overcome any problems that may arise during the mission. Extensive psychosocial support for the astronauts should be readily available in a confidential modality if needed without fear of any repercussions to the astronauts career. Such strict confidentiality will help to improve the overall relationships of the participants involved and hopefully reduce the tension levels as they inevitably will wax and wane during the long space mission.

A systems perspective is essential for defining and operationally accomplishing a long-duration spaceflight mission. Many factors interact in a dynamic way that are dependent on context and therefore are relatively unpredictable. Because of the unpredictability of such occurrences, whether medical or psychological, it is important to have plasticity built into the

system to deal with these problems. Long-duration test flights on the space station and lunar base activities will help to allow for better definition of these problem areas. Given the current state of knowledge, a trip to mars at the present time would not be optimal without building up the database from extended Earth orbital and lunar operations regarding what is required to adequately support the "human factor."

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## VITA

Dwight A. Holland received B.S. degrees in mathematics and physics from Emory and Henry College in 1982. He enrolled in the graduate school at Virginia Tech in the fall of 1982 to pursue an M.S. degree in Geophysics. After two years of graduate work he took a year's leave-of-absence to participate in the United States Antarctic Research Program. Upon his return from Antarctica, he arrived again at Virginia Tech to complete his thesis and obtained the M.S. degree in Geophysics in 1986. He has publications in the area of earth-moon tidal gravity interactions and aerospace medicine.

After two and one-half years on and off active duty with the USAF for training as a reserve military pilot, he returned to Virginia Tech again in the fall of 1989 to obtain a M.S. degree in Systems Engineering with a human factors emphasis. He is interested in human factors and aeromedical issues and has approximately 1200 hours total flight time in a variety of aircraft.

Recently he has been employed by the General Electric Corporation as a safety and human factors engineer. At GE he developed an ergonomics program that has been implemented at Drive Systems and used as a model for several other GE facilities.

Currently he is a consultant to industry part-time and has developed four ergonomics products to aid in the reduction of injuries in the workplace. He hopes to continue his academic studies to the terminal degree level and develop several more ergonomics products as time permits.

He is a student member of the Human Factors Society, Aerospace Medical Association, and the American Astronautical Society. At present, he is serving on the Aviation Safety Committee of AsMA.

