HUMAN FACTORS IMPLICATIONS OF PSYCHOLOGICAL STRESS
IN LONG DURATION SPACE FLIGHT

by

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(ABSTRACT)

The basis for this report was President Bush's proclamation that the U.S. should land astronauts on Mars by 2019 A.D. In such a trip, astronauts would be in a weightless environment for a considerable length of time. This report examines different conditions and environments that could cause stress during such a long duration space mission. Both psychological and physiological conditions are examined and the human factors implications of those potential problems are discussed. Finally, recommendations are made as to potential countermeasures and/or standards that should be followed.
ACKNOWLEDGEMENTS

I would like to express my appreciation to my chairman Professor Paul Kemmerling for all the time and effort that he spent assisting me with this project as well as the guidance that he provided during my time at Virginia Tech. I would also like to thank the other members of my committee Dr. Blanchard and Dr. Dryden for their inputs to this work. Finally, I would like to thank my parents for seeing me through these last two years.

I hope that this project will help bring to light some of the problems that will be faced by future long duration space crews in their exploration of what is truly the last frontier.
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INTRODUCTION

In July 1989, on the 20th anniversary of the Apollo 11 lunar landing, President Bush announced the beginning of an effort to land an American on Mars by the year 2019 A.D. (Covault, 1989). The largest obstacle anticipated by the President was congressional support and funding. While this remains a substantial obstacle, the limiting factor of such a mission could turn out to be the frailty of the astronauts that make the trip.

As mankind continues its exploration of space the time spent by astronauts in isolation aboard space craft and space stations has increased. Table 1 lists all the long duration spaceflights to date where "long duration" is defined as a spaceflight lasting 60 or more days (Stuster, 1984). The Soviets currently hold all of the long duration space flight records with the longest being 365 days set by cosmonauts Titov and Manarov (Kidger, 1989). Soviet cosmonauts regularly spend four to six months in space. In addition, cosmonauts perform space walks to maintain and repair their space station. Even major malfunctions are not beyond the Soviet's capability to repair (Covault, 1990).

With President Bush's announcement that the United States must retake the lead in space, the human factors
Table 1

Space flights of 60 or more days

<table>
<thead>
<tr>
<th>country</th>
<th>year</th>
<th>structure</th>
<th>crew</th>
<th>duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>1973-74</td>
<td>Skylab</td>
<td>3</td>
<td>84</td>
</tr>
<tr>
<td>USSR</td>
<td>1975</td>
<td>Soyuz 18B</td>
<td>2</td>
<td>63</td>
</tr>
<tr>
<td>USSR</td>
<td>1977-78</td>
<td>Salyut 6</td>
<td>2</td>
<td>96</td>
</tr>
<tr>
<td>USSR</td>
<td>1978</td>
<td>Salyut 6</td>
<td>2</td>
<td>140</td>
</tr>
<tr>
<td>USSR</td>
<td>1979</td>
<td>Salyut 6</td>
<td>2</td>
<td>175</td>
</tr>
<tr>
<td>USSR</td>
<td>1980</td>
<td>Salyut 6</td>
<td>2</td>
<td>185</td>
</tr>
<tr>
<td>USSR</td>
<td>1980</td>
<td>Salyut 6</td>
<td>2</td>
<td>75</td>
</tr>
<tr>
<td>USSR</td>
<td>1982</td>
<td>Salyut 7</td>
<td>2</td>
<td>211</td>
</tr>
<tr>
<td>USSR</td>
<td>1983</td>
<td>Salyut 7</td>
<td>2</td>
<td>149</td>
</tr>
<tr>
<td>USSR</td>
<td>1984</td>
<td>Salyut 7</td>
<td>3</td>
<td>237</td>
</tr>
<tr>
<td>USSR</td>
<td>1985</td>
<td>Salyut 7</td>
<td>2</td>
<td>112</td>
</tr>
<tr>
<td>USSR</td>
<td>1986</td>
<td>Mir/Salyut 7</td>
<td>2</td>
<td>125</td>
</tr>
<tr>
<td>USSR</td>
<td>1987-88</td>
<td>Mir</td>
<td>2</td>
<td>326/160*</td>
</tr>
<tr>
<td>USSR</td>
<td>1988-89</td>
<td>Mir</td>
<td>2</td>
<td>365</td>
</tr>
<tr>
<td>USSR</td>
<td>1989</td>
<td>Mir</td>
<td>3</td>
<td>150</td>
</tr>
<tr>
<td>USSR</td>
<td>1989-90</td>
<td>Mir</td>
<td>2</td>
<td>166</td>
</tr>
<tr>
<td>USSR</td>
<td>1990</td>
<td>Mir</td>
<td>2</td>
<td>180**</td>
</tr>
</tbody>
</table>

* One of the original cosmonauts was replaced after 166 days due to a heart condition.

** Planned
problems inherent in such an undertaking must be carefully considered. It is evident that any long duration stays in space will entail a great amount of effort to protect humans from adverse affects; for example, physiological hazards in space include radiation, musculoskeletal and cardiovascular system degradation, immune system deficiencies, as well as complications with most of the human body’s major systems (Guidi, 1990). These dangers will be examined later in terms of what happens and their psychological implications.

Scope

The systems engineering process stresses a life cycle approach to systems design (Blanchard and Fabrycky, 1990). Figure 1 outlines the system life cycle process. The President’s announcement previously mentioned constituted a statement of need for a system to take humans to Mars and return them to Earth safely by the year 2019 A.D. From Figure 1 it can be seen that this is the first step in the system life cycle process.

The next step in the process is the conceptual design phase which is characterized by feasibility studies and advanced product planning. These are the current activities being performed in support of the Manned Mars Mission. A major element of the conceptual
Figure 1: The system life-cycle process.

design phase should be an evaluation of the manability (human factors) of the proposed system.

Figure 2 outlines the human factors considerations to be examined at each stage of the system life cycle. At the conceptual stage general quantitative and qualitative human factors requirements should be addressed. Figure 3 outlines the major areas of concern for the human factors evaluation; the Personnel Factors requirement contains those elements pertinent to this report, including: anthropometric, human sensory, physiological, psychological, and other factors.

Anthropometric factors are critical to the proper design of operator stations, consoles, control panels and accesses for maintenance. The application of anthropometric data involves many considerations, including aspects of force and weight-lifting capacities in the space environment. Fortunately the critical parameters involving anthropometric factors in space flight have already been compiled by NASA (1978) and will not be covered here.

Human sensory factors include vision, audition, olfaction and the vestibular and tactile senses; due to time and space, these factors will only be addressed as they impact the physiological and psychological factors involved in long-duration spaceflight.
Figure 2: Human factors in the system life cycle

Figure 3: Human Factors Requirements

Purpose

This report will examine several stressors that could have an adverse psychological or physiological impact on the crew of a manned Mars mission. The psychological stressors have been broken down into four general areas. These areas are (1) isolation; (2) social interaction; (3) environmental; (4) occupational. Physiological considerations include (1) radiation; (2) musculoskeletal and cardiovascular system; (3) immune system; (4) zero gravity; (5) temperature and humidity; (6) noise. Each of these areas have the potential to place stress on the astronauts that could endanger the mission, and will be discussed in terms of the problems caused, the human factors implications of the problems and where possible, solutions.
PSYCHOLOGICAL STRESSORS AND THEIR
HUMAN FACTORS IMPLICATIONS

Isolation

Problems. After two six-month tours in space
aboard the Salyute 6 space station, cosmonaut Valery
Ryumin wrote that he had thought of the words written by
O'Henry "... all one needs to effect a murder is to
lock two men into a cabin, 18 feet by 20, and keep them
there for two months" (Bluth, 1984b). This is a good
indication of the feelings experienced by astronauts in
long duration space flights and the strong emotions that
can be evoked. Such behavior is not limited to space,
but occurs in other environments analogous to space,
including polar research stations, isolated mountains
and parks, offshore oil platforms, submarines and
research vessels. Each of these environments features a
small group of people living and working in relative
isolation for extended periods of time.

Mullin (1960) grouped the stressors of an isolated
environment into three major types. They were: (1)
individual problems in group adjustment; (2) the
"sameness" of the surroundings; (3) the absence of
accustomed sources of emotional gratification. Many
studies since then, e.g., Gunderson (1963) and Earls
(1969), have described similar problems in subjects exposed to long periods of isolation. These problems manifest themselves in individuals as symptoms that include boredom, insomnia, anxiety, restlessness, irritability, fatigue, reduced motivation, and somatic complaints (Smith, 1990; Santy, 1987a; Palinkas, 1985; Bluth, 1984a,b).

All of these are problems that could potentially disrupt a long duration spaceflight. One study revealed some impairment of mental efficiency in 40% of a group of individuals that wintered-over in Antarctica (Terelak, 1989). Such mental impairment was broken down into two types termed (1) intellectual inertia and, (2) memory and attention (Terelak, 1989). Decreases in memory and attention have been observed as a symptom of isolation in other studies as well (Santy, 1987a; Palinkas, 1986). Another symptom is a tendency for people to become more hypnotizable and to demonstrate an increase in imaginative involvement or day-dreaming (Harrison, Clearwater, McKay, 1989; Barabasz, 1984). Decreases in mental inertia can be seen in cases where members of Antarctic teams make plans to exceed their normal duties in order to improve themselves. Such plans include learning foreign languages or writing articles (Terelak, 1989). Despite an excess of leisure
time, most team members did not fulfill their plans. Some researchers attribute this to a lack of motivation (Terelak, 1989; Palinkas, 1986). The team members noted that they had more vivid daydreams and could block out external distractions more readily (Barabasz, 1984). A decreased awareness of the passage of time has also been demonstrated. Antarctic teams have been found to overestimate the time available for performing a task, and subsequently procrastinate; then, despite there having been ample time to complete the task, rush to finish it on time (Harrison et. al., 1989). Another example of people losing track of time while in isolation comes from studies of people who have spent time in caves. One such case that demonstrates this point occurred in 1989. An Italian woman spent 18 weeks alone in a cave. At the end of the 18 weeks when she was told that the study was over she felt that she had two months remaining (Kaiser, 1989).

Another problem is disassociation. Mullin (1960) describes an instance where an Antarctic team member remembered leaving his quarters and arriving at a different part of the base, but not how he had gotten there. Such temporary disassociation could be much more life threatening in space.

A final problem brought on by isolation is a drop
in stress resistance. Individuals in isolation were found to be more sensitive to fatigue, had difficulty concentrating, and perceived situations and the group differently than when not in isolation (Terelak, 1989).

**Human Factors Implications.** There are a number of human factors implications of the stresses caused by isolation. One such implication, caused by the inability of isolated people to accurately keep track of time on their own, is that astronauts may not finish projects on time. Furthermore, they may not even realize they are behind schedule. This problem may be reduced by constant communication with ground controllers who can alert the astronauts to any slips in the schedule. However, such problems will probably not be eliminated. Such schedule slippages could be worse if, due to imaginative involvement, astronauts thought they had completed a task when in fact they had only day-dreamed its completion.

Another problem arises out of the tendency of isolated individuals to block out external distractions. Individuals become so focused on what they are doing, e.g. reading a book, that they exhibit symptoms of being in a light hypnotic state. This could pose problems with astronauts "blocking out" important signals and not responding to them, and may require that critical
signals be well above this new threshold in order to draw the astronauts attention.

Other symptoms such as boredom, anxiety, fatigue, restlessness and irritability could also cause signal detection problems. In this case, the problems are not with detecting the signal but with interpreting the signal or responding to the signal correctly. More precautions should be taken to compensate for potentially higher error rates. Figure 4 represents a classic paradigm demonstrating how signals and noise are related in terms of signal detection. Originally applied to electrical theory this paradigm, called the Theory of Signal Detection (TSD) model, is an elegant way of showing the response biases of individuals when required to detect signals in a noisy environment (in this case noise can be internally generated, e.g., miscellaneous neural activity, or externally generated from such sources as computers, waste management systems, solar generators, etc., commonly found in space vehicles). Figure 4a shows two curves; the one on the left represents an assumed normal distribution curve for noise, and the one on the right represents the assumed distribution for the signal. As can be seen in figure 4b, when the two curves overlap significantly, discerning the signal is more difficult; however, the
Figure 4: Hypothetical distributions underlying signal detection theory

line representing the decision point for detecting the signal \((X_c)\) is of more importance here. This line represents the response bias of the operator. Moving the line to the left results in a more "conservative" reporting scheme - to the right indicates a more "liberal" inclination. The four possible outcomes of the decision-making process are shown in Figure 5. The combined effects of such space-specific problems as poor time estimation, boredom, fatigue, etc., will undoubtedly impact the astronaut’s decision-making processes, and may require innovative methods of increasing the likelihood of detecting signals.

Some of these symptoms can be addressed separately, for example, anxiety. One solution might be to reduce the periods of monitoring. In this way the astronauts will not feel that their every move is being watched. Another way to reduce anxiety might be to increase group communication and support. Through continual reassurance and feedback group members will be less likely to worry about their job performance. Also, frequent, private communications with family members and friends should help to reduce feelings of anxiety.

Problems with boredom can be relieved by keeping the astronauts reasonably busy with interesting work. However, care must be taken so that the astronauts are
Figure 5: Four outcomes of signal detection theory

not always busy. One possibility might be to allow astronauts time to perform their own experiments or research.

Some of the other problems such as insomnia, fatigue, somatic complaints, reduced memory and mental inertia, disassociation, and irritability seem to be related. More research is needed to determine the causes of these problems and find solutions. However, one human factors implication of these problems will probably be to further increase signal detection thresholds and error rates.

Recommendations. Although no one has ever died in space from the symptoms caused by isolation the issue is an important one. There has been at least one reported murder at an isolated Arctic station (Bluth, 1984a). A brief moment of inattention can have serious implications in space. An example, although not directly related to isolation, demonstrates this clearly. In 1978 cosmonaut Yuri Romanenko was so excited about being in space that he forgot to fasten his safety line before leaving the Salyut 6 space station (Oberg, 1981). The other cosmonaut that was performing a space walk at the time saved Romanenko by grabbing his safety line and pulling him back into the space station (Oberg, 1981).
The longer the period of isolation the more likely inattention could become a problem. Two methods are currently employed by the Soviets and NASA to enhance the safety of astronauts on long duration space missions. These methods include careful screening of applicants and specific training (Halliwell, 1989; Conners, Harrison and Akins, 1985). The Soviets also maintain an elaborate psychosocial support group on Earth to help cosmonauts through any problems that arise during flight (Bluth, 1981; Oberg, 1981).

A newer approach to augment these other two methods and help maintain the psychological well-being of long duration space travelers is to enhance the habitability of the space ship or station. This work is being performed in the United States, primarily at NASA's Ames Research Center. The work centers around efforts to make the confined and isolated environment more livable (Clearwater, 1987; Clearwater, 1985). Soviet and American space crews have complained about the lack of color and the drabness of their surroundings (Gelman, 1989). One idea already applied by the Soviets was to make their current space station, Mir, more colorful inside by adding decorations (Gelman, 1989).

It has been found that pictures with a large depth of field are preferred by astronauts (USA Today, 1988).
Another possibility might be to use holograms or three dimensional television images. Images projected on such devices could be accompanied by taped sound giving the viewer a feeling of truly "being there". An example would be an image of a beach with the simple motion of waves incorporated into the image. Such a picture combined with taped sounds of a beach may help space travelers relax. New holographic images could be transmitted to the astronauts in flight. The ability to transmit holograms has already been proven by the Soviets (Joint Publications Research Service, 1981).

Another possibility would be to transmit television shows to the astronauts.

Soviet cosmonauts reportedly enjoy visitors to their space station periodically (Oberg, 1981). This is a fine idea for long-term stays on Earth orbiting space stations but would be impossible on a trip to Mars.

Privacy is another major concern for individuals in an isolated environment. The Soviets discovered this early in their space program using Salyute space stations. Cosmonauts did not have their own private areas nor was the toilet partitioned off (Gelman, 1989; Oberg, 1981). A lack of privacy was also a complaint of U.S. Skylab crews (Conners et. al., 1985). Lack of privacy can lead to estrangement between members of
space crews or between space crews and ground controllers. Hostility between members of an isolated group is rare. This is probably because of the need for continued social acceptance after the event is over (Conners et. al., 1985). Nonetheless, the potential for hostility cannot be ignored and animosity has, in fact, occurred several times during the space age. A notable example arose during the last Skylab mission when the astronauts went on a 24 hour "strike" and refused to talk to NASA's ground controllers (Schoonhoven, 1986; Conners et. al., 1985). The Soviets have also experienced angry exchanges between cosmonauts and ground controllers. Generally disagreements arose from the cosmonauts belief that they were being monitored too closely. A number of Soviet cosmonauts stated that the introduction of a two-way television communications system greatly helped to relieve tensions between the crew and the ground controllers (Conners et. al., 1985). This was because each group could see the other and ground controller's monitoring activities could be observed.

Social interaction

Another area that is not only a source of stress but also susceptible to the effects of stress is that of intercrew relations and spacecrew-ground relations.
Some of the results of these social tensions have already been discussed, but a closer examination of the problems and their human factors implications is warranted.

**Intercrew Stress.** There is a plethora of considerations that must be taken into account to keep stress between crew members to a minimum. Three of the major ones are the size of the crew, methods of leadership, and crew composition.

The first potential problem involves group dynamics in relation to the size of the crew. It is interesting to note that all of the long duration space missions to date carried out by both the U.S. and Soviet Union have had permanent crews consisting of no more than three people. For the space station Freedom and the proposed Mars mission, crews of six or more are being suggested. Because of the larger group size more studies need to be performed to ascertain how such groups respond and perform under conditions of total isolation over long periods of time.

Before any manned long duration space missions the crew should probably be given behavioral training. This entails helping the astronauts better understand themselves, each other, and to improve their interpersonal skills and awareness. Such interpersonal
skills and awareness include understanding human
behavior, effective communication, and how to respect
and understand the feelings and values of others
(Nicholas, 1989). Another aspect of behavioral training
includes training in group skills including awareness of
group norms, social structures, and how to manage these
(Nicholas, 1989).

Cosmonaut Valeriy Ryumin wrote in his diary that
when one first enters the space station one must get
oriented to the space craft and to living alone with
others (Oberg, 1981). This latter adjustment was
difficult, Ryumin wrote, "although we trained for the
mission, the training was done in the presence of other
people" (Bluth, 1981). This should be noted for future
training of larger, long duration space crews. One must
also realize however that not all aspects of a groups
behavior can be anticipated and trained for pre-flight.
This comes about because the group is a dynamic entity
and will change over time as the mission progresses and
as experiences shape it, making it virtually impossible
to anticipate before launch how the group will react to
all possible situations (Nicholas and Ulschak, 1989;
Bluth, 1987).

Other potential problem areas are group
communications, group organization, and the method of
leadership employed. Valeriy Ryumin, in another diary entry, noted that because of the redistribution of his body's fluids, caused by the zero-g environment, his face had swollen to the point that he could not recognize himself in a mirror (Oberg, 1981). Such physiological changes can cause problems with communications (Bluth, 1980). Such problems arise when a verbal message is given with an inappropriate non-verbal facial message (Bluth, 1980). Although the sender of the non-verbal message may be totally unaware of the problem the real intent of the verbal message could be lost or confusing to the receiver (Bluth, 1980). The potential problems with erroneous non-verbal messages can have a direct impact on the effectiveness of the leader and on how well the group organization holds up. An example of a potential problem would be a leader giving a verbal message of encouragement with a scowl on his face (Bluth, 1980). This could lead to mistrust of the leader by his or her subordinates because the subordinates do not believe that the leader's praise is truthful.

The leadership method chosen will also have a direct impact on how well the group functions. The type of leadership method chosen for a long duration space mission is critical and should be carefully considered.
One consideration should be the size of the group. Different leadership styles have been shown to work better in different group sizes. For example, in groups of five or less a more democratic style of leadership seems to work best; while groups with more than five members seem to develop lines of communication centered around a leader (Bluth, 1984b). It has also been reported that groups with an even number of people tend to disagree more than groups with an odd number of people (Bluth, 1984b). Subgroups seem to begin to form in groups with more than five members, therefore there is a danger of cliques forming (Bluth, 1984b). Additional problems can arise because people tend to evaluate their position in a group based on their perceived importance of themselves or their job (Nicholas, Foushee, and Ulschak, 1988). Severe incidences have been recorded where in extreme cases in exotic environments, individuals have refused to help someone else in an emergency because "it was not their job" (Nicholas et al, 1988). To avoid such problems, perceived status discrepancies should be low, and menial jobs should be apportioned equally (Nicholas et al., 1988). This technique has been used successfully by the Soviets where everyone participates in such mundane tasks as house cleaning and waste disposal (Oberg,
The leadership style that seems to be most effective in space analogous environments is one in which the group leader seeks the advice of the group members and then makes an informed decision (Nicholas et. al., 1988). Leaders however must be both task oriented and aware of the current social and emotional status of the crew (Nicholas et. al., 1988; Conners et. al., 1985) Being an expert in both fields is difficult and rarely can one person be found that is qualified for both types of leadership role (Conners et. al., 1985).

When planning a long duration space mission leaders with the appropriate qualities need to be carefully selected. One such method is the least preferred co-worker (LPC) method (Conners et. al., 1985). The details will not be covered here, but a complete description of the method can be found in Goldstein (1986) or Fiedler (1967, 1971). The LPC method yields low and high scorers. Low scorers tend to possess a task oriented leadership style and high scorers tend to possess an interpersonal leadership style (Goldstein, 1986). Planners of future space missions might want to consider having a task oriented leader supported by an interpersonal type leader. This would allow for the accomplishment of mission goals while hopefully
minimizing any interpersonal conflict. The key to the success of this form of leadership is that everyone in the group must understand and accept that, although their opinions and feelings are important, there is only one leader.

The third major potential problem area in intergroup relations is the composition of the crew. As spaceflight becomes more of an international affair space crews will not only have to deal with interpersonal differences but interethnic ones as well. If there are to be persons from more than one ethnic background on any long duration missions there should be at least two people from each ethnic background (Santy, 1987b). If only one member of an ethnic race (a "token") is sent on the mission he or she may withdraw, feeling socially and culturally isolated (Schoonhoven, 1986). Evidence of ethnic based disagreements have already been seen in the Soviet space stations when foreign cosmonauts visit (Oberg, 1981).

Sexuality. Another major issue involving crew composition is that of gender. Studies in analogous environments have shown that conditions that spark conflict in an all male group did not spark conflict in an all female group (Harrison and Conners, 1984). However, when a female was introduced into an all male
group, tensions were higher than when another male was introduced (Harrison and Conners, 1984).

The two major problems with mixed gender space crews are the chauvinistic feelings which may be exhibited by some members of the crew and the potential for intimate relationships. First, the feeling that space is no place for a woman still permeates the space community (Conners et. al., 1985; Oberg, 1981). The fact that few U.S. females have flown in space lends credence to this belief. A similar feeling is shown in the Soviet Union by both the lack of female cosmonauts that have flown in space and overt disparaging comments made by male cosmonauts (Oberg, 1981). The second aspect, that of intimate relationships arising while on long duration space missions, must also be considered. One very serious problem could be a pregnancy occurring. This could be dangerous for both the mother and the child if it occurred on a spaceship half way to Mars. Extremely little is known about giving birth in weightlessness. The Soviets conducted an experiment on their Mir space station where they tried to hatch quail eggs in space (Kidger, 1990). In March some of the eggs hatched but the chicks were frail and unable to feed themselves and it was decided to put the chicks to sleep (Kidger, 1990). Based on this experiment the Soviets
claimed that they had established that "embryo
development proceeds normally [in space]. . . but the
rest deserves serious scientific analysis" (Kidger,
1990). Another problem is that if an intimate
relationship ends, neither party can simply "get in the
car and drive home." Both parties must be able to
continue to live and work together for the remainder of
the mission. Such a failed relationship could result in
anger and/or jealousy which could impair an individual’s
sense of judgement and potentially put both the mission
and the rest of the crew at risk.

Although there have not been any problems during
the short duration shuttle missions there is no reason
to assume that intimacy will not occur in a mixed crew
on a long duration mission (Santy, 1987a, 1983;
Helmreich, 1983). It has been suggested that an equal
number of astronauts of each gender be sent on long
duration missions (Santy, 1987a). However, this would
sacrifice the ability to have an odd number of group
members for leadership purposes as previously discussed.
Another idea put forward is to send married couples on
long duration space missions (Santy, 1987b, 1983). Even
with married couples however, there are no assurances
that one member or the other will not stray and finding
enough married couples that are qualified and willing to
embark on such a journey could also prove difficult (Halliwell, 1989). This could cause further complications if one member or the other decided to end the relationship.

Decisions must be made regarding intimacy in space. Clearwater (1985) reported being told by a military commander of an underground military complex that if a two-year "lock-down" took place sex simply would not occur. He based his reasoning on the fact that his people were professionals. Whether the commander was correct or not, such assumptions can not be made for space travel due to the seriousness of the problems that could arise, and the likely heterogeneity of the crew.

All of these aspects of sexuality, no matter how taboo, must be considered when planning crew composition for long duration space missions. There are really only two alternatives. The first would be to ban intimacy and design the mission and space vehicle around preventing its occurrence. The second would be to allow intimacy and plan for it by providing privacy and by taking appropriate precautions to avoid a pregnancy.

Stress between space crews and Earth. The last area of interpersonal stress is primarily caused by communications between space crews and the Earth. A Salyut Seven cosmonaut once commented that "the hardest
thing during a flight is keeping good relations with the ground" (Nicholas and Ulschak, 1989). If good space crew-Earth relations are not maintained problems can arise as demonstrated by the Skylab Four "strike" and harsh exchanges between Soviet cosmonauts and the ground. Some believe that the ground controller responsible for communications with the space crew is the most important person in the communications chain (Akins, 1979). Sensitivity of space crews to new ground controllers has been shown by Soviet cosmonauts who have become upset by someone unexpected being on the radio (Bluth, 1980). Ground controllers who are not sensitive to crew emotions can sometimes cause even more stress between crew members (Bluth, 1980).

A final problem with space/terrestrial communications stems from the lack of interface between family members and friends. This could be a real problem on a trip to Mars where distances could reduce two way communications to monologues (Harrison et. al., 1989). However, cosmonauts report that the most enjoyable communications are with their families (Bluth and Helppie, 1986). Because of this, some satisfactory method of communication must be worked out for long distance space missions.

Recommendations. Planning for and adequately
training the crew for every possible social problem that may arise would be an impossible task. This is especially true considering that as the voyage progresses the group will change as will their reactions to situations. Two methods could be employed to alleviate any unforeseen problems. First would be to give ground controllers the same, if not more, behavioral training than that which is given to the astronauts. Ground controllers must be aware of the current emotional state of each crew member at all times.

The second method would be to train the crew for a period of time away from other people. One example of such a procedure would be to have the entire crew live in isolated conditions, such as on a mountain, for a period of months; their task would be to survive. This would allow them to test their leadership roles, life and death decision making and social interaction in an environment similar to space.

Finally, because both Soviet and American space travelers base such a considerable amount of importance on communications with home, methods for such communications must be devised. Due to the distances involved in a Mars voyage, communications with the Earth will be conducted in monologues, as previously
mentioned, for most of the trip. This should not pose too much of a problem if families could communicate with each other via video mail. Taped messages could be sent every few days to and from the space ship.

Environmental

Psychological stress can also originate from environmental factors. Three major factors are noise, temperature and humidity. All these factors are generally classified under the heading of habitability.

Acoustic problems. One of the major complaints of the U.S. Skylab crews was the amount of noise and vibration continually present in the space station (Willshire, 1984). Despite being well within safety limits, continuous noise emitted from air circulating equipment and power generators created the most frequently cited problem by the Skylab crews (Willshire, 1984). It has been shown that noise can have an impact on performance and can increase stress (Conners et. al., 1985). Continuous noise has also been reported to have adverse affects on many of the human body’s systems including the cardiovascular, autonomic nervous and vestibular systems (Conners et. al., 1985).

Soviet cosmonauts have also complained about excessive, continual noise on their space stations. Both U.S. and Soviet space travelers have experienced
symptoms of irritability, sleep disorders and headaches caused by continual background noise (Bluth and Helppie, 1986). The Soviets even reported that they would subconsciously listen to the noise while they slept to determine if everything was working properly (Bluth and Helppie, 1986). This could lead to fatigue over time because the astronauts may not sleep deeply enough to become fully rested.

**Human factors implications.** Noise for the purposes of this paper is considered to be any unwanted sound. Generally, on a spaceship noise will primarily take the form of continuously emitted sound from different parts of the ship such as the power plants and air circulating equipment. Such continuous noise has the effect of narrowing ones attention (Jones and Broadbent, 1987; Conners et. al., 1985). This facilitates the performance of simple tasks, but degrades the performance of complex tasks such as those involving vigilance, time estimation and two-handed coordination (Conners et. al., 1985; Nicogossian, Buchanan and Furukawa, 1984). Performance can also be affected indirectly by noise. The other effects of noise such as annoyance, headaches and fatigue from disturbed sleep also degrade performance (Conners et. al., 1985).

Another problem with noise is that it can block out
other signals. A characteristic of acoustic phenomena is that a tone of a given frequency will have a masking effect on other signals at that and higher frequencies. However, the effect on signals at lower frequencies is minimal. Figure 6 shows this tendency for noise to propagate forward in frequency. The implication this has on space structures is that alarms and other important signals should utilize tones at frequencies not masked by ambient noise. Speech should not significantly be affected unless ambient noise levels exceed 70-75 dB (Webster, 1979).

The most problematic type of noises are those that are intermittent or unpredictable and are not under the control of astronauts (Conners et. al., 1985). Individuals have been found to have difficulty adapting to or blocking out such noises (Conners et. al., 1985). Noise has also been linked to aggressive behavior, i.e., the louder the ambient noise the more aggressive one is inclined to act (Conners et. al., 1985).

Recommendations. There have been a number of standards concerning noise that have been developed from Soviet and U.S. long duration space missions. Noise levels in rest areas are recommended to be less than 40 dB. Noise levels in sleep areas should be 35-40 dB during the day and 25-30 dB at night (Bluth and Helppie,
Figure 6: Masking curves for a narrow band of noise centered at 1200 Hz.

1986). Constant background noise should not exceed 65 dB for a 60 day exposure and the amplitude and frequency of the noise should vary (Bluth and Helppie, 1986).

A variety of noise abatement techniques are available to space ship designers. Some of these include insulation, vibration isolators, or encasement of the noise source. Care must be taken however not to use an abatement technique that would hinder equipment maintenance if such action becomes necessary.

Another type of noise abatement technique that may work well in space structures is called active protection. Active protection works by generating acoustic waves at the same frequency and intensity as the noise that is to be abated, but at 180 degrees out of phase of the source noise. An active protection system was employed by Dick Rutan and Jeana Yeager when they made their non-stop flight around the world in the Voyager airplane (Gauger and Sapiejewski, 1987). The system prevented the pilots from suffering any permanent hearing loss that would have occurred due to the continuous noise emitted by the engines (Gauger and Sapiejewski, 1987). Figure 7 shows graphically how the system works. This results in a cancellation effect and can reduce the overall noise level by as much as 25 dB (Gauger and Sapiejewski, 1987). Such active noise
Typical signal waveforms of the Bose ANR headset system.

Figure 7: Typical signal waveforms of the Bose ANR headset system.

protection works best on noise which is below 1000 Hz (Gauger and Sapiejewski, 1987). The frequency of noise emitted by air circulating equipment, in particular, varies with the size and design of the fans, the size of the ducts and the material with which the ducts are made (Kingsbury, 1979). Despite this variance, the decibel levels of fans decrease as the frequency increases, with the highest decibel levels being at 1000 Hz or lower (Graham, 1979). This means that an active protection system should work well on such noise in a space structure.

Temperature and humidity. Individually or in combination both of these factors can have adverse affects on space travelers performance and psychological well being. The threat of both excessively high and low temperatures must be dealt with and protected against. Excessively low temperatures can result inside a space structure if the heating system fails or has to be shut down. A prime example of this occurred on the Apollo 13 mission where the astronauts had to survive freezing temperatures during the four day emergency return to Earth. Humidity was also a concern in the Apollo 13 mishap because as the temperature decreased, condensation began to form in and on the electronics equipment. It was feared that when the astronauts
reached Earth equipment failures might result, although they subsequently did not.

The opposite problem occurred on Skylab 2 when due to a defective heat shield, the temperature inside the space station became unbearable. Although the problem was corrected the crew was subjected to rather high temperatures for the first day of their 28 day stay.

**Human factors implications.** There are a number of considerations that must be accounted for when people must function in adverse temperatures. First, high humidity exacerbates the effects of high temperatures. Additionally, studies have shown a reduction in both cognitive and psychomotor performance in temperatures of 30°C (86°F) (Sanders and McCormick, 1987; Conners et. al., 1985). In the study reported by Conners, degradation in performance continued as temperatures rose (Conners et. al., 1985). There is some evidence that women are less able to withstand the effects of high heat and humidity, due to their possessing more body fat then men (Sanders and McCormick, 1987; Conners et. al., 1985). It has also been shown that the more complex and/or cognitive a task, the more susceptible it is to the effects of heat (Sanders and McCormick, 1987). Finally, excessive temperatures have been associated with emotional outbursts and reduced tolerance for
others (Conners et. al., 1985).

Similarly, there are problems associated with cold temperatures. As temperatures decrease manual performance is adversely affected, especially with tasks that involve fine, detailed work (Sanders and McCormick, 1987). The point at which dexterity begins to be affected is uncertain but impairment seems to begin between 13-18°C (Sanders and McCormick, 1987). Similarly, mental activities and tracking performance begin to decrease around the same level (Sanders and McCormick, 1987).

Another potential problem that has been noted is a reduction in the body's adaptive reactions after prolonged stays in a stable thermal environment (Joint Publications Research Service, 1981). This could result in degradations in astronaut performance occurring with less of a change in the thermal environment. Such a problem could arise if after working properly for several months or a year the heating system failed and astronauts were forced to work under cold conditions to repair the system.

**Recommendations.** A finding with considerable implications was reported in 1967. After a 32 day space simulator study it was found that no one set of thermal conditions satisfied all six participants (Conners et.
al., 1985). The implications of this and the previously mentioned problem are two fold. First, astronauts should be able to control the environment in their own sleep areas, thus permitting everyone a place to go and be comfortable. Second, having temperature and humidity vary periodically might help maintain the astronaut's adaptive reactions to severe thermal changes in the event of an emergency. People begin to feel uncomfortable in temperatures below 19°C and when relative humidity exceeds 60% (Bluth and Helppie, 1986). The Soviets find that temperatures in the range of 22-24°C are the most comfortable for cosmonauts (Bluth and Helppie, 1986).

A final observation on temperature is that although protective clothing can be issued in the event of a drop in temperature, such clothing will generally decrease mobility and dexterity. This must be considered when planning for emergency situations.

**Occupational Problems.** Thus far, this discussion has focused on psychological stressors pertaining to either the astronauts surroundings or from interactions with each other. However, another cause of psychological stress is occupational or work related stress. Such stress can result from a number of different causes such as over or
under work, boredom, monotonity and the criticality of the job. Two additional factors include environmental and individual sources of stress (Smith, 1987). Each of the factors will be discussed in turn.

The first factors mentioned were the problems associated with over and under work. There are two areas of thought on how these two problems manifest themselves. The first concept is that both overwork and underwork result in fatigue (Conners et. al., 1985). In this case, fatigue is considered to be a lowering of physical or mental sensitivity or capacity (Conners et. al., 1985). However, others feel that the problems associated with work overload are a result of fatigue but that the problems associated with underload are different. These individuals consider underloading to result in monotonity which manifests itself in lethargic performance, missed signals and inattentiveness (Conners et. al., 1985). Whether one considers the problem associated with underwork and overwork the same or different they remain as problems that must be addressed.

The next two problems mentioned were boredom and monotonity. These are related to each other as well as to other work related factors, such as underload. Boredom and monotonity tend to be caused by a lack of work or
unchanging work (Conners et. al., 1985). Both of these need to be taken into account when preparing work schedules, especially when planning for the cruise phases of a long interplanetary flight.

The criticality of a job can also influence one's performance. If a job is mission critical, life threatening or in some other way inherently stressful, performance can degrade and the probability of error increased anywhere from two to 10 times (Miller and Swain, 1987). Performance degradation varies depending upon the amount of stress involved and the skill level of the individual performing the task. This finding in conjunction with the degradation in one's ability to deal with stressful situations in an isolated environment, could lead to normally unstressful jobs becoming stressful. They could also lead to a "vicious cycle" where because individuals are less able to cope with stress due to environmental changes, they feel a job is more stressful than it normally would be. This further decreases the person's ability to deal with any other stressful situations that may arise.

The space environment itself can be a source of occupational stress. The major stress causing factor is the lack of gravity. Because of this lack of gravity a third dimension is added to human motion. Although
there does not seem to be a problem with astronauts adjusting to this third dimension of motion it does manifest itself in slowing the performance of tasks (Kanas, 1987; Sanders and McCormick, 1987). Both Soviet and American space travelers have complained about not being given enough time by ground controllers to complete tasks (Kanas, 1987). This problem was a major contributor to the Skylab 4 "strike". The astronauts believed that they were being worked too hard while the ground controllers felt that the astronauts were not performing up to their capability (Kanas, 1987).

It has in fact been reported by many space farers that fine motor movements are impaired in the zero-g environment of space (Conners et. al., 1985). Such impairment is most severe during the first few days in space and abates as astronauts adapt to the environment (Conners et. al., 1985). Additionally, from time and motion studies performed on the three Skylab missions, it was found that tasks took longer to perform in space than they did on Earth 54-68% of the time (Kubis, McLaughlin, Jackson, Rusuak, McBride and Saxon, 1977).

**Human factors implications and recommendations.** There are human factors considerations that arise from all of the outlined problems. Problems caused by overwork or underwork include, as indicated: fatigue,
confusion, lack of attention and generally degraded performance and productivity. Major implications of this are missed signals and/or erroneous actions due to confusion. Monotony and its effect on signal detection has been studied for years. The general term applied to this is vigilance. Some argue that any task that requires continuous monitoring leads to fatigue (Wickens, 1984). If vigilance comprises a majority of a task there should be a limit of about 30 minutes before a rest period is given (Conners et. al., 1985). Working longer will result in high error rates in the form of missed signals (Conners et. al., 1985). There are a number of ways that vigilance can be improved. One such method is through the presence of background sound (Jones and Broadbent, 1987). Such sound has also been found to counteract some of the affects of sleep loss (Jones and Boradbent, 1987). Another method of improving vigilance is to artificially insert false signals (Wickens, 1984). Such signals would be tagged so that if the astronauts missed the signal, the signal would be known to be false (Wickens, 1984).

The problems associated with boredom are similar to those of monotony and involve reduced vigilance and signal detection. Ways of reducing boredom include varying the daily routine and exchanging tasks with
other astronauts. Another suggestion has been to perform in-flight training (Conners et. al., 1985; Oberg, 1982). Astronauts could be given the training needed for the in-flight routine and emergency procedures, but other aspects of the mission, such as orbital insertion and landing, could be trained in-flight (Oberg, 1982). This implies however that all the spacecraft controls and computers must be able to function in either training or real-life modes (Oberg, 1982). Such in-flight training would be an asset because it would not only break the daily routine for the astronauts but it would maintain their proficiency on the tasks being trained.

High stress tasks markedly degraded performance (Miller and Swain, 1987). To counter this, unless an emergency arises, such tasks should be rotated and adequate breaks given to help reduce the stress.

Finally, while planning tasks to be performed in space, adequate time must be allocated by ground controllers. This is especially true for new tasks or tasks that require fine dexterity. Additionally, when planning for emergencies, ample time should be allocated to complete tasks. Degraded performance caused by the stress of the situation, the weightless environment and the uniqueness of the task to be performed must all be
taken into account when planning time schedules.
PHYSIOLOGICAL STRESSORS AND THEIR HUMAN FACTORS IMPLICATIONS

As mentioned at the beginning of the paper spending long periods of time in weightlessness causes problems for most of the human body’s systems (Guidi, 1990). Some of the systems affected include the: (1) musculoskeletal system; (2) cardiovascular system; (3) immune system; (4) vestibular system. In addition to these four systems, hazards and stresses associated with radiation will also be examined.

Radiation

One of the most discussed hazards of long duration spaceflight is radiation. Radiation can be life threatening, unpredictable, and the natural protection provided by the Earth and its magnetic fields decreased as one travels farther out into space.

NASA has set a combined radiation exposure limit of 400 rem that should not be exceeded during an astronaut’s career. (A standard X-ray taken in a doctors office exposes a patient to 0.01 rem of radiation. In Denver, Colorado, due to the altitude, residents are exposed to approximately 0.2 rem of radiation per year (DeCampli, 1986).)

A single exposure to 100 rem of radiation causes
acute radiation sickness (Decampli, 1986). A single
exposure to 300 rem of radiation, can be lethal (Oberg,
1982); and a person receiving a single dosage of 500 rem
of radiation has only a 10% chance of surviving after 60
days (Duke and Keaton, 1985).

Space travelers must be protected against four
primary sources of radiation. These sources are (1) the
Earth's magnetosphere, (2) solar wind, (3) solar flares,
and (4) cosmic. The first radiation source, the Earth's
magnetosphere, is strongest between 2,500 and 20,000 km
above the ground. This is the best understood of the
four radiation sources and astronauts can be
sufficiently protected from any danger with current
spacecraft shielding.

Protecting astronauts from the second radiation
source, solar wind, is more difficult than protecting
them from Earth's magnetosphere. Solar wind is composed
of high energy particles that would require spaceships
to be equipped with extra radiation shielding. Current
technology is capable of adequately protecting
spaceships from this hazard as was demonstrated with the
Apollo lunar missions.

Solar flares and cosmic radiation are much more
serious threats and guarding against them is more
difficult. The frequency of solar flare activity occurs
in 11 year cycles, corresponding to sun spot activity. During any given 11 year cycle it can be expected that there will be 20-30 solar flares that expose an astronaut to 50-100 rem of radiation, two to five flares in the 500-1000 rem range, and one or two flares in the 5000 rem range or more (Nicogossian, 1986). A person exposed to a dose of solar radiation resulting from a solar event in either of the last two categories would not survive. (An example of the danger this problem represents, even to spacecraft and space stations in Low Earth Orbit (LEO), was brought to light in 1972, when a solar flare pushed the level of radiation in the geosynchronous zone to one million times that of normal (Nicogossian, 1986).)

Another problem with solar flares is that they are difficult to predict. The particles that precede a solar flare do so by approximately an hour. This does not give space crews much time to react. Fortunately, the radiation storms caused by solar flares, no matter what their size, generally last less than 24 hours (Nicogossian, 1986).

It is extremely difficult to protect astronauts against the last type of radiation, cosmic, because of its high energy particle content. During a trip to Mars, astronauts will be exposed to relatively small
doses of cosmic radiation; however, it does not take much cosmic radiation to cause severe damage to the human body. The damage a single cosmic ray causes is based more upon the location and the angle at which it strikes the body, than on its intensity (DeCampli, 1986). For example, one high energy particle, can cause irreparable damage to a corneal cell (DeCampli, 1986). Also, most radiation tends to damage a cell’s genetic material, thus affecting the next generation of cells. Cosmic radiation, however, not only damages a cell’s genetic material, but destroys the cell it strikes also. This could lead to the onset of symptoms similar to Alzheimer’s Disease if enough cosmic radiation hits non-reproducing brain cells (DeCampli, 1986). The rate of onset of symptoms is not known.

**Human factors implications.** A major human factors problem associated with radiation is psychological in nature. It is possible that as time passes, fear of encountering a life threatening solar storm or burst of cosmic radiation could cause an increase in psychological stress.

Another stressor caused by radiation would be the confinement of the crew in a radiation shelter while awaiting the end of the storm. All efforts should be made to make the shelter as livable as possible.
Recommendations. Due to the seriousness of the radiation hazard, methods of protection must obviously be developed and employed. One solution is to increase the radiation shielding in future manned spacecraft. One might equip all manned interplanetary ships with a radiation shelter which provides increased radiation shielding compared to that present in the rest of the ship. The shelter must be able to sustain and accommodate the entire crew for at least 24 hours, since even the most intense burst of solar radiation usually does not last more than a day (Nicogossian, 1986). A problem with the incorporation of radiation shelters on board spacecraft is the added cost and launch weight. This problem should not be considered a limiting factor, however, because the safety of the crew should be the paramount consideration.

As mentioned, there is generally only about one hour of lead time before a radiation storm hits. This fact means that signs for such a storm must be automatically monitored at all times and everyone must be able to get to a shelter in the time available.

Musculoskeletal system

Zero gravity causes problems for the body’s muscles that range from the loss of muscle mass to atrophy. Atrophy, if untreated, results in a condition similar to
that found in paraplegics whose muscles are reabsorbed from lack of use.

The loss of muscle conditioning can cause significant problems. For instance after a 211 day mission, Soviet cosmonauts could not maintain a standing position for more than a few minutes at a time (DeCampli, 1986). Such a condition would cause severe problems for astronauts who had just landed on Mars.

Aside from the effects of radiation on bone marrow, there are a number of other disturbing problems that exposure to long periods of weightlessness cause in the human bones. The most notable is the demineralization that begins when humans enter a weightless environment.

The problem was first noticed in the Skylab crews when increased amounts of calcium and other bone minerals were detected in the astronauts' urine. As the Soviets increased the duration of time spent in weightlessness, they too began to encounter problems with this demineralization of the bones. It was found that astronauts lost calcium through both urine and fecal excretions. The urinary loss leveled off after about 30 days, however, the fecal loss continued to increase linearly (DeCampli, 1986).

The demineralization process begins upon exposure to the zero gravity environment of space and continues
for the duration of the exposure. In some cases, the Soviet's found that the process did not immediately stop upon the astronaut's return to Earth's gravity, but diminished slowly over a period of days, sometimes weeks.

There have been documented cases of Soviet cosmonauts losing 7 to 11% of the mass of certain bones. The bones that are the most susceptible are the leg bones, the hip bones, and the lower lumbar vertebrae (Gazenko, Grigorev and Egorov, 1988). This increases the concern over the demineralization problem because these are the bones that support most of the human body's weight when in a gravity environment.

One of the effects of the demineralization process is to increase calcium flow through the kidneys enhancing the chance of formation of kidney stones. Another problem is the increased possibility of a fracture. This is of great concern because in weightlessness, where there is no stress on the bone, the break might not heal. Surgically re-fusing the two bone ends could be the only viable solution.

The data gathered from both U.S. and Soviet space missions shows that without the use of countermeasures, a life threatening situation could arise from the loss of minerals in the bones after being in space for a
little over one year. It is also not known if all the
lost minerals are ever completely recovered, once the
astronaut returns to Earth.

**Human factors implications.** The human factors
problems raised by the degradation of the body’s
musculoskeletal system are primarily concerned with
regulating the activity of the astronauts when they
reenter a gravity environment. The gravity environment
could be Earth or Mars and astronauts should not be
given heavy work to do for a while after landing. The
length of time required to rebuild musculoskeletal
integrity is not known.

**Recommendations.** A number of countermeasures have
been attempted in order to reduce the effects of
weightlessness on the musculoskeletal system. So far
nothing has been able to arrest completely the
demineralization of the bones; however, the process has
been slowed by increased exercise. Increased calcium
consumption has been tried, but failed, because the
bones simply do not absorb that mineral while in a zero
gravity environment. The Soviets have been partially
successful in stemming the loss of muscle mass by
employing the so called "Penguin Suit". The suit
creates a constriction on the astronaut’s muscles which
the astronauts must work against in order to move
around. Wearing this suit for at least eight hours a day, combined with a daily regimen of two to three hours of exercise, has been found to greatly reduce the loss of muscle mass, and to some extent, the amount of mineral loss in the bones. This was demonstrated by Soviet cosmonauts who, having spent 365 days in orbit, were able to walk several yards without assistance upon landing.

**Cardiovascular system**

Another major problem that occurs in space is a redistribution of body fluids. The body's circulatory system is designed to operate in a one-g environment. For example, there are valves in the veins that prevent blood from pooling, especially in the feet and legs, and force it towards the heart. In space, where the effects of gravity do not exist, the body's anti-pooling mechanism still operates although it is not needed. This results in an accumulation of blood in the head and chest areas, and a reduction of fluid volume in the legs.

Fluid redistribution has significant ramifications. First, due to the increased volume of fluid in the upper body, the heart senses that there is too much blood in the body and compensates by reducing the blood flow. This aids the upper body, but worsens the problem in the
lower body where the fluid level is already low. Reductions in leg fluid volume can range from 8 to 20% as recorded after a 237-day space flight (Gazenko, Grigorev and Egorov, 1988). A second side effect of the increased blood volume in the upper body is an increase in head and neck vein pressure. There is also an effect on the astronaut’s thirst which is diminished due to the high level of fluid in the upper body. The decrease in leg fluid volume adds to the demineralization of the bones in the lower extremities and increases the retention of sodium. There is also an increase in the loss of potassium which contributes to the onset of muscle atrophy through a decrease in muscle cell mass. Finally, because the brain thinks there is an excess of blood, it reduces the production rate of new red blood cells. This causes anemia in the astronauts, but only after periods of more than 100 days in zero-g.

The changes in fluid distribution also have a negative effect on the heart. The increased volume of fluid in the upper body, increases the pressure in the head and neck veins. Sensing the increase in pressure, the heart actually reduces its output by lowering the heart rate and shortening the length of the diastolic contractions. After spaceflights of many months, an actual decrease in the size of the heart muscle was
noted (DeCampli, 1986).

Eventually, a new circulatory pattern is established. This does not have any ill effects on the cardiovascular system while the astronauts stay in space; however, upon returning to Earth astronauts have experienced frequent episodes of dizziness and even fainting. This comes about because while in space, the heart reduces its rate and the total volume of blood in the body. Upon return to Earth, the body’s anti-pooling circulatory mechanisms are once again needed and the body’s blood supply is redistributed to pre-flight levels. This process involves the moving of blood from the upper to the lower body. Due to the reduced overall blood volume in the body, the brain lacks the necessary supply of blood to prevent bouts of dizziness and fainting. It appears that upon sensing the now low volume of blood, the body begins to manufacture more red blood cells. This cures the astronaut of the problem within about one week after his return to Earth. During this week of recovery, astronauts are quite sensitive to rapid changes in altitude such as standing-up rapidly.

**Human factors implications.** One human factors implication, previously mentioned, is misinterpreted non-verbal facial messages caused by the redistribution of the body’s fluids. Such misinterpreted messages
could lead to mistrust between group members.

Another problem is the time it take to reestablish an appropriate volume of blood and a "normal" circulatory pattern in a gravity environment. The time to reestablish these must be determined and taken into account when planning astronaut schedules on the surface of Mars. Severe injury could occur if while performing strenuous work an astronaut fainted.

**Recommendations.** Only a few methods are currently available to counter the redistribution of body fluids. One such method is to induce artificial gravity. Another method involves the use of pressure suits which have been successful in aiding blood flow to the legs. Exercise and different drugs have also been found to help. All of the problems seem to diminish upon reentering Earth’s gravity, but for a two-year trip to Mars, effective countermeasures must be developed.

There have been attempts to limit the reduction of heart size and rate. Anti-gravity suits and exercise show the most promising results. However, the exercise regimen must be strictly followed to be effective.

**Immune system**

One of the most recently discovered problems with long duration spaceflight is the suppression of the body’s immune system. Soviet cosmonauts have returned
to Earth after 200 or more days in space and displayed severe allergic reactions which they had not displayed before traveling into space. It was found that there was a decrease in the number and activity of the T-lymphocytes and T-helper cells. (These are the primary cells involved in the human immune response.) There was also an increase in the indigenous microflora on the cosmonauts. Reasons for the suppression of the immune system are not understood (Gazenko, Shulzhenko, Grigorev and Egorev, 1984).

**Human factors implications.** A human factors problem that might affect the crew is an increased anxiety about contracting a disease due to a weakened immune system. However, because so little is known about the immune systems adaptions to weightlessness more research is needed to determine how people in isolation act, or react, to the potential of a weakened immune system.

**Recommendations.** Not much is known about why suppression of the immune system occurs or how the process could be counteracted. More studies are needed, because until this problem is understood, sending people to Mars could be fatal. Even if there was nothing on the surface of Mars that would harm humans, upon return to Earth after two or more years away the astronauts
could well be susceptible to many diseases.

The immune system seems to return to normal in one to two months. The extensive exercise programs employed by the Soviets did demonstrate some lessening of the immunological problems in cosmonauts after a 365-day flight, but more research is still needed to fully understand the problem.

**Vestibular system**

A problem that manifests itself only during the first few days of a space flight are disturbances in the vestibular system and especially in the otolith. In normal gravity, the otolith is stimulated by the lymphatic fluid in which it is contained and it helps people orientate themselves.

In zero gravity, the otolith can be stimulated in any direction at any time. This causes disorientation and nausea in astronauts for a few days while they adjust to the meaning of the new signals. After a time, which varies by individual, the body adapts. The problem causes discomfort and can have a profound impact on early mission performance, however it is not life threatening. The same symptoms reoccur when the astronauts reenter a gravity environment and the body must readjust to its original functioning. This could cause some discomfort for the first few days on Mars and
activities would have to be planned accordingly.

**Recommendations.** The only known countermeasure is training the astronaut how to handle disorientation.

**Artificial Gravity**

A trip to Mars presents many challenges to the well-being of the astronauts. Radiation is a major concern to the astronauts, both on Mars and in transit, thus a radiation shelter is mandatory. On Mars, depending upon the length of the stay, a radiation shelter could be incorporated into the landing craft or constructed by the astronauts upon their arrival. Such a shelter could be carried to Mars by a cargo ship.

Physiologically, a trip to Mars is extremely difficult and dangerous. The shortest trip to Mars that includes a landing involves astronauts being in a zero gravity environment for about 500 days. This number can soar to over 1,000 days, depending upon the method of propulsion used and the trajectory taken (Snoddy, 1986). These lengthy exposures to zero-g will cause considerable problems for astronauts in all the areas discussed in this paper. In order to counteract these harmful effects, one of two methods may be employed. First, effective countermeasures could be developed to reduce or eliminate the ill effects of weightlessness. Some such countermeasures exist such as the Penguin Suit
and physical exercise; however, most of the conditions, such as the suppression of the immune system and the bone demineralization problems, have yet to be controlled sufficiently.

The second method that could be used to counter the effects of zero-g on the body is to introduce artificial gravity. What is not known is the level of artificial gravity needed to reduce the human body's adaption problems to weightlessness to a safe level. Finally, although artificial gravity would solve most, if not all, the physiological problems, there are some technological hurdles that must be overcome before artificial gravity is feasible.

There are two ways to create artificial gravity conditions on a spaceship. The first is to rotate the ship at a constant angular speed. This solution, however, creates complex Coriolis forces which cause astronauts to experience nausea and other motion sickness symptoms. As far as can be determined, the symptoms remain until the astronaut leaves the spinning ship. This method is unsatisfactory for astronauts who continue to suffer from motion sickness.

The second method of generating artificial gravity is through constant linear acceleration. This method does not create the problem with Coriolis forces, but
unfortunately it is not feasible with current technology. The principle is relatively simple: the spacecraft is accelerated at a constant rate until it reaches the half way point in its journey when it turns around 180° and accelerates in the opposite direction. This results in the spacecraft decelerating to its destination. The technical problem is that in order to maintain a constant gravity of one half g for a 200 metric ton spacecraft, engines would have to be developed that produce about 35 million Newtons (N) of thrust continuously for 70 hours. (Note: the weight of the spacecraft was taken from Nicogossian (1986).)

A practical and technologically feasible solution is to employ a version of linear acceleration in a trip to Mars in which, instead of using engines strong enough to create a state of artificial gravity, one would employ engines with a thrust of only 5,000 to 50,000 N, maintained over months. These engines shorten the travel time to and from Mars, consequently limiting the astronauts’ exposure to zero gravity conditions. Based upon data by Snoddy (1986), an engine, or group of engines, producing 5,000 N of thrust continuously could transport a 200 metric ton spaceship to Mars in 165 days. Increasing the continual thrust to 25,000 N could reduce the on-way travel time to 78 days.
Once the astronauts reach Mars exercise programs similar to those for the lunar colonists should be established. These programs would serve to recondition the astronauts for the journey back to Earth. The programs could be developed here on Earth and then performed on Mars taking into account the Martian gravity, which is one third that of Earth's. The planned stay on Mars should be long enough to allow the astronauts to become reasonably reconditioned for the trip home. The amount of time that is "reasonable" to accomplish this will have to be determined. However, the shorter the flight to Mars, the less time astronauts will need to become reconditioned.
CONCLUSION

As humans continue the exploration of space and venture farther from Earth the problems caused by psychological stress will continue to be present. Many people believe that the continued expansion of mankind into space is a necessity. It has even been reported that some feel that through international cooperation a new planetary consciousness may arise (Cordel, 1990).

This may be true, but the frailty of the human organism must be much better understood before any manned interplanetary missions take place. After millions of years of evolution in Earth’s environment and tens of thousands of years of cultural development, thrusting people into the very unique environment of space is extremely stressful. This paper has examined many of the causes and effects of psychological stress. Much more research is needed in all of the areas mentioned before we can be certain that a space crew will survive (both psychologically and physically) a trip to Mars or beyond.
RECOMMENDATIONS FOR FUTURE RESEARCH

Perusal of this report suggests several areas for future research. Given the very preliminary nature of the study, a great deal of work remains to be accomplished before a projected journey to a planet such as Mars can be seriously contemplated. Given this tenuous beginning, the systems approach mandates further research in the following areas:

1) Differential effects of temperature and humidity on individual and group behavior in a closed environment; in particular, the effects of unvarying vs. constant environmental factors should be explored.

2) Psychosocial aspects of long duration spaceflight. Current efforts in this area, e.g., "Biosphere II" do not look at group interaction from a "systems" standpoint. A focus on this research should center around assessment strategies for determining crew composition.

3) Subsystems tradeoff analyses. This is a major area of concern, as many of the recommendations included in this report have a considerable impact on overall systems weight,
space and costs. Tradeoffs involving personal quarters, special and/or enhanced communications needs, housekeeping and toileting facilities, as well as general esthetic improvements; e.g., large depth of field pictures and cosmetic enhancements to the capsule, need to be considered.

4) Cooperative efforts involving the Soviets should be seriously considered. Data gathered from the long duration spaceflights aboard the Salyut and Mir space stations can be invaluable to the U.S. spaceflight program, particularly in the psychosocial areas of isolation, boredom, etc., and in the physiological ramifications of exposing the human body to long periods of weightlessness.
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VITA

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