LONG DURATION MANNED SPACE FLIGHT SYSTEMS CONSIDERATIONS

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(ABSTRACT)

The systems engineering process must be executed within the constraints imposed by the system environment (including the social, technical, economic, and political (STEP) factors) as well as those imposed by the personnel who will operate and maintain the system. These constraints can sometimes create interdisciplinary, systems issues which will influence the optimization of the interfaces between humans and equipment in the spacecraft system. Also, the synergistic relationships of these issues can sometimes intensify their ultimate effect on the system.

The duration of the mission, in conjunction with the isolation and confinement of the crew, indicate that the spacecraft's social environment and the capabilities and

limitations of the crew will be critical to the success of a long duration spacecraft system and must be considered in the crew selection and training criteria, as a part of the system design and development activities.

The design and development process could be improved if the diverse sociological and psychologial theories were integrated. A rudimentary Crew/System Interactions Model (CSIM) is proposed which would provide a tool for synthesizing and linking the various theories. The CSIM would serve as a focal point for experts to improve/refine the theoretical causal relationships describing the effects of crew actions and behaviors on the performance of the system.

A systems perspective must be developed throughout the system life-cycle, especially in the crew who will operate and maintain the spacecraft. This perspective can be enhanced through training to identify inaccuracies in the individual's mental model of the spacecraft system. The STEP issues and personnel factors impose constraints on the system design and development activities, encouraging the compartmentalization of the various phases of the life-cycle process, and increase resistance to change, which can make a systems perspective impossible to achieve. The proper consideration of these constraints is therefore crucial to the success of systems engineering.

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INTRODUCTION

The United States is preparing to embark on a new era of manned space exploration which will be characterized by long duration missions which will transport humans farther into our solar system than ever before. On November 2, 1989 President Bush approved the National Space Policy which called for the achievement of a manned presence on the surface of Mars by the thirtieth anniversary of the Apollo moon landing (by the year 2019). The "Report of the Advisory Committee On the Future of the U.S. Space Program" (also known as the Augustine Committee Report), published in December 1990, called for the establishment of a "Mission from Planet Earth" with the long term goal of human exploration of Mars.

A systems perspective will assist in accomplishing this goal by encouraging the most effective and efficient resources utilization. This is crucial because of the severely limited budget and facilities available for developing and utilizing spacecraft. Unnecessary duplication of effort must be avoided. The systems perspective can be implemented via a systems engineering process that coordinates and integrates the resource requirements and activities involved in the acquisition and utilization of a system (Blanchard & Fabrycky, 1990, p31). The long duration space flight vehicle and its crew can be viewed as a system composed of humans, machines, and other components that work together (interact) to achieve the goal of placing humans on the surface of Mars (Sanders & McCormick, 1987, p518).

Systems engineering provides a top-down, systematic framework for ensuring that the total engineering effort has been integrated such that the system design incorporates reliability, maintainability, human factors, supportability, safety, producibility, disposability, and other related specialties (Blanchard & Fabrycky, 1990 p21). The philosophy embraced by systems engineering promotes the concurrent consideration of the life-cycles for the system, the associated manufacturing system, and the support systems (Blanchard & Fabrycky, 1990, p19). Figure 1 illustrates the system life-cycle process that would be tailored to meet the specific requirements of a long duration space flight system. The identification of a need to place humans on Mars by the year 2019 marks the initiation of the long duration space flight system life-cycle process. The system would evolve and progress through the life-cycle process until the system is ultimately phased out or disposed of.

In manned space flight systems humans serve as an integral component of the spacecraft system, providing a critical link between system components and performing a major role in the system's feedback process by providing adjustments to the system's performance. Figure 2 describes the process typically used to define human factors

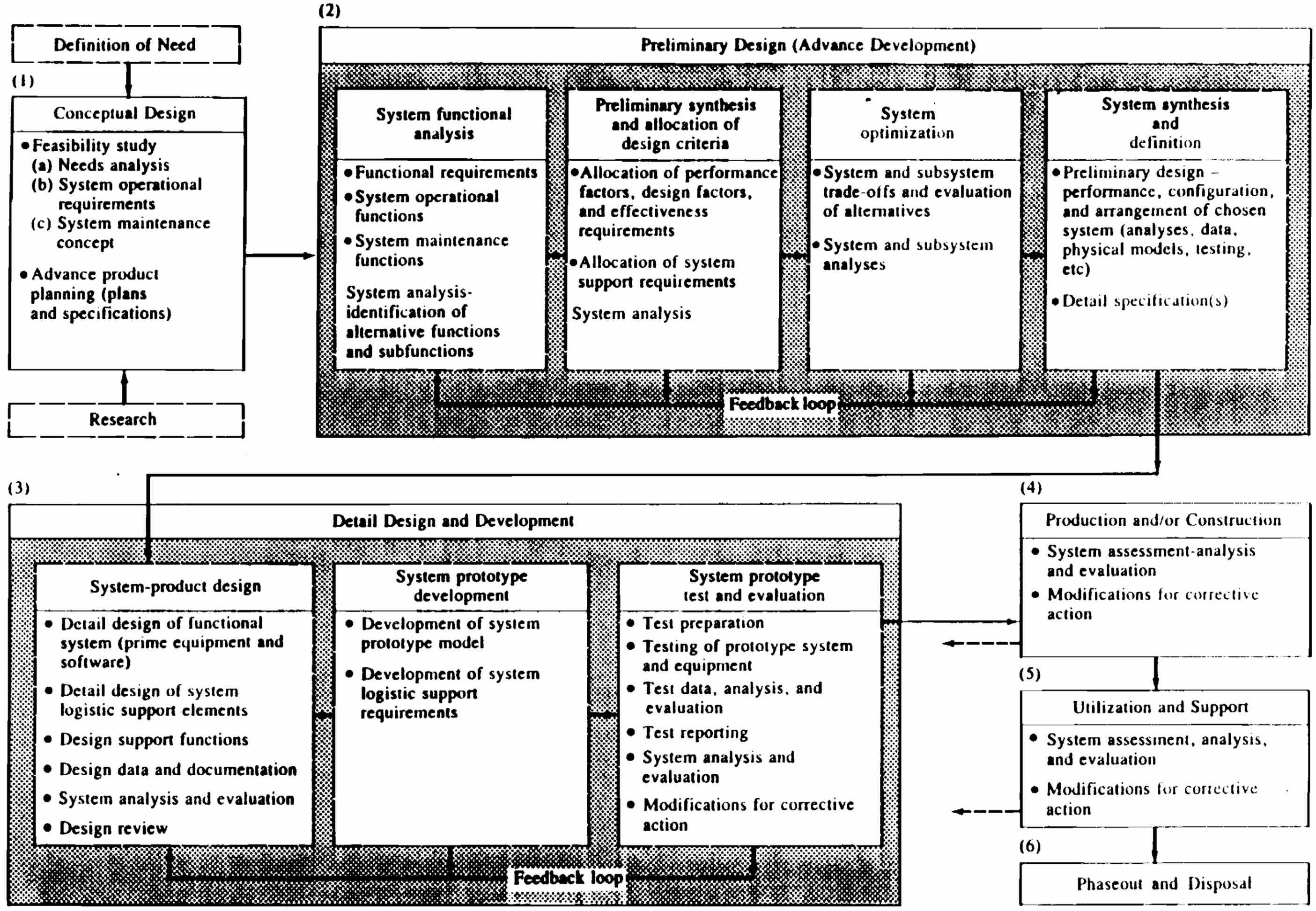


FIGURE 1: Overview of the Systems Life Cycle Process (from Blanchard and Fabrycky, 1990).

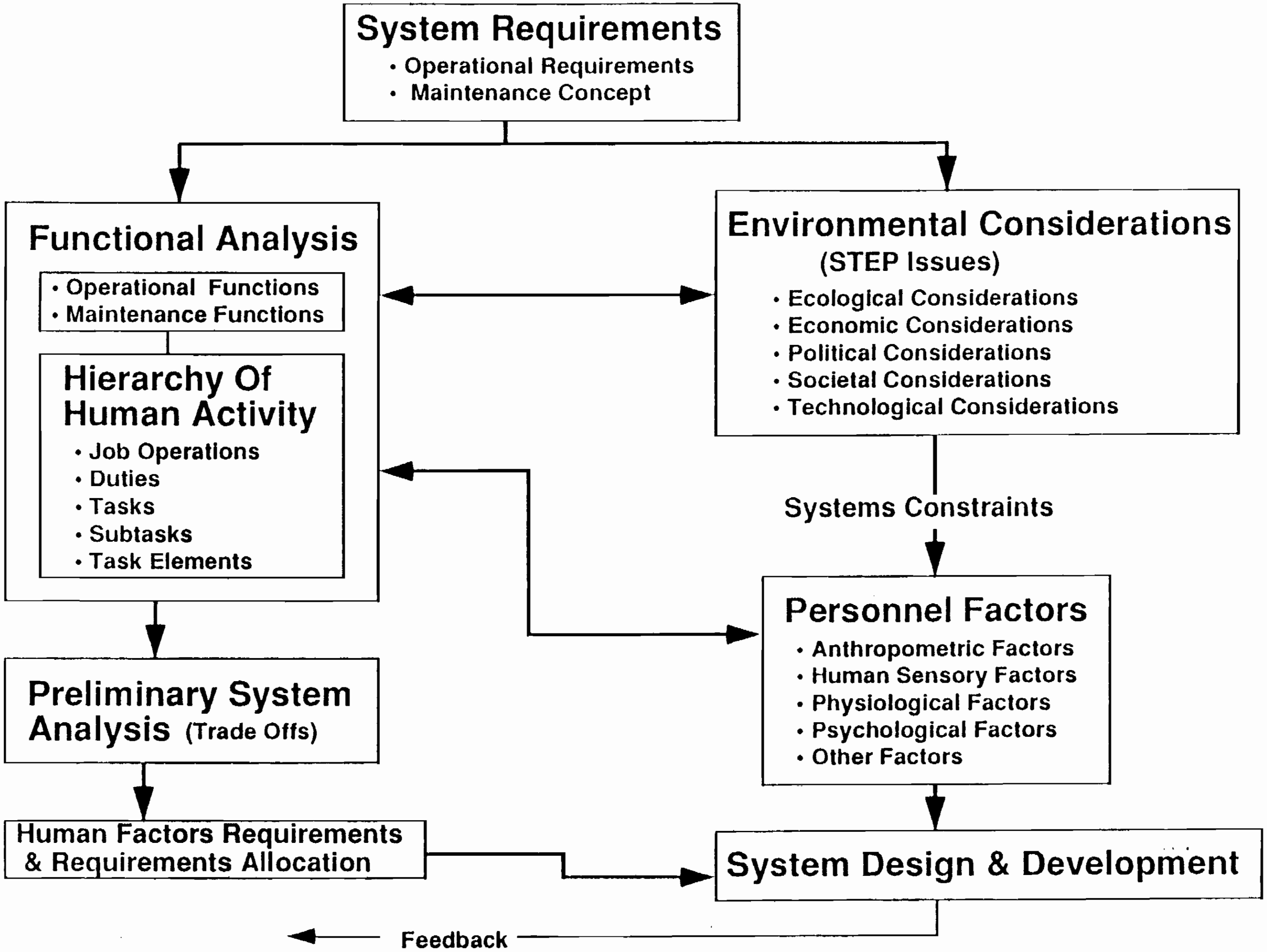
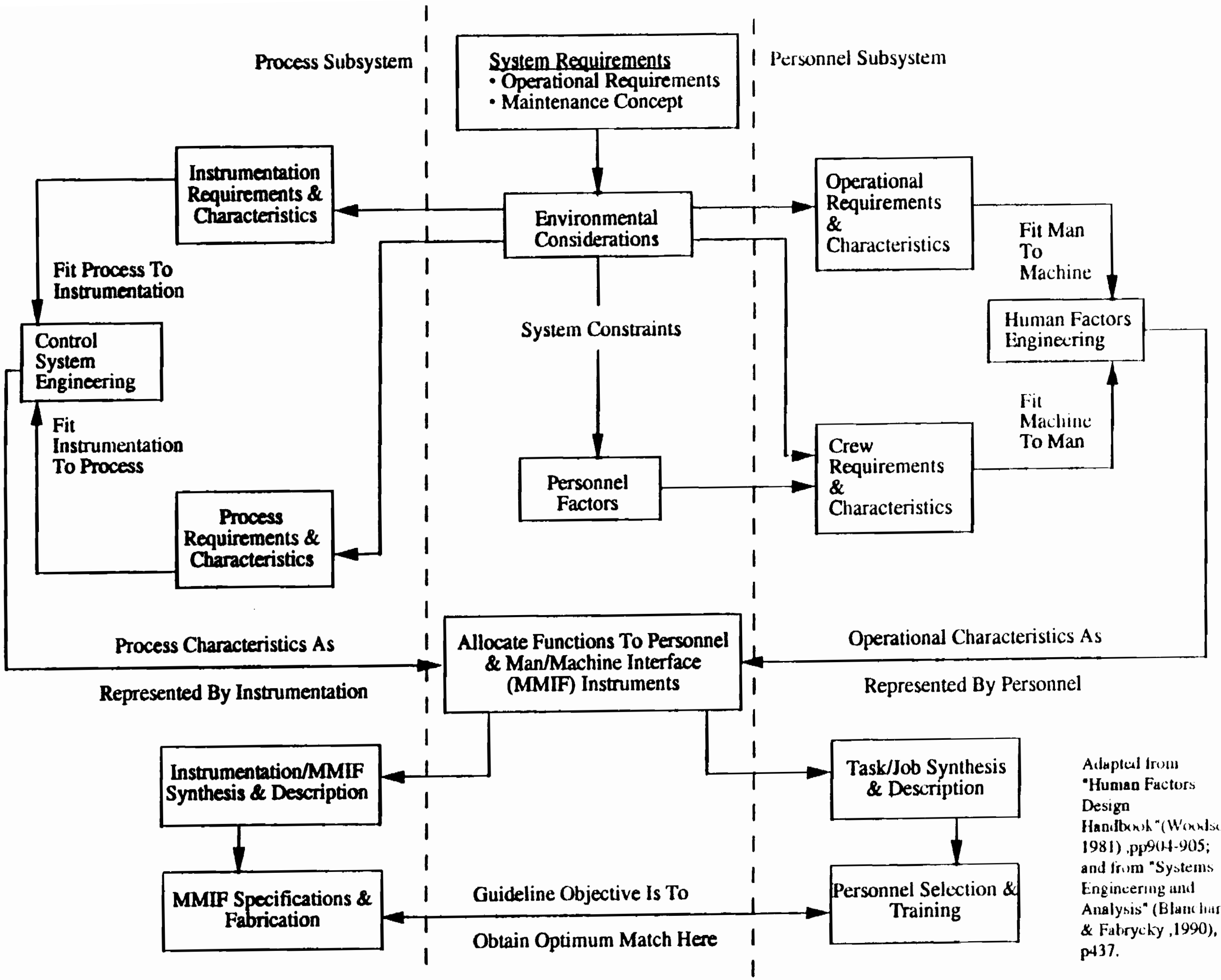


FIGURE 2: HUMAN FACTORS CONSIDERATIONS IN SYSTEM DESIGN

(Adapted from
Blanchard &
Fabrycky, 1990)

requirements and to allocate them to the level necessary to establish the proper human-machine interface. The operational requirements, maintenance concept, and the environmental and personnel factors are iteratively analyzed to develop an allocation of functions to humans and machines. The environmental considerations are the Social, Technical, Economic, and Political (STEP) issues which impose constraints on the system development process. The personnel factors relate to the capabilities and limitations of the human being operating in the system and has generally been oriented towards the individual (Blanchard & Fabrycky, 1990 p436-446) rather than the group as a whole.

As illustrated in Figure 3, the allocation process allows the development of task descriptions that specify the human-machine and human-environment interactions (DeGreene,1970 p108). From the task descriptions, task analyses are performed to systematically study the behavioral requirements of the identified tasks, "where a task is a group of activities that often occur in temporal proximity with the same displays and controls, and have a common purpose" (DeGreene,1970 p108). These descriptions and analyses are used in the performance of systems staffing studies that determine the types and quantities of crew members needed and how they can be selected and trained to operate the system effectively (DeGreene,1970 p357).



Adapted from "Human Factors Design Handbook"(Woodson, 1981) ,pp904-905; and from "Systems Engineering and Analysis" (Blanchard & Fabrycky ,1990), p437.

FIGURE 3: Human/Machine Requirements Development Process

The staffing studies provide a means for relating the system requirements to the issues of crew selection and training methods, crew-time resources, and system operations (both normal operations and emergency situations) (DeGreene, 1970 p358 & 364). Staffing studies are performed throughout the system life-cycle process and assist in system development and production by demonstrating how the design of the system hardware, software, and operational procedures can be made compatible with the kinds of personnel who will most likely be assigned to the crew (DeGreene,1970 p358). The staffing studies provide visibility into the diversity of skill requirements for a crew. The operation and maintenance of the spacecraft system requires some highly specialized personnel as well as those whose skills are more generalized. The United States spaceflight programs have emphasized the development and operation of the spacecraft hardware and software, with the interfaces between the system and the individual as the primary focus. However, it is important that the staffing studies take into account the diverse educational and cultural backgrounds and personalities that will be present in the crew of the long duration space flight system.

The United States' Space Shuttle orbiters transport crews into low earth orbit for short duration space missions that have lasted as long as 13.8 days using an "extended-mode" orbiter (Columbia, STS-50). For definition purposes, it is assumed that missions lasting for over thirty (30) days are "long duration" missions. With long duration space missions and the associated isolation and confinement of the crew, an additional dimension must be factored into the system staffing studies. It is the consideration of the crew as a collective entity. Since the transit time for a Mars mission may take as long as 300 days, one-way (Guidi,M.A. and Holland, D.A., 1992) without the ability to return directly to Earth, there are significant safety implications if the crew becomes dysfunctional. To maximize the probability of mission success, it is imperative that the crew works together in an effective, efficient, reliable, and harmonious manner.

In order to achieve a viable system, it is important that timely, useful information be available to support decision-making. The success or failure of the long duration space flight system in meeting its objectives will depend upon the quality of decisions made at the various stages in its life-cycle. Effective systems management depends upon the ability to make decisions that achieve the intended results. Decisions made and actions taken, or not taken, will have a feedback effect on what has previously been accomplished (Blanchard & Fabrycky, 1990 p 29). This requires that the significant issues associated with selecting and training an effective crew and establishing a human presence on Mars be identified and resolved early in the system life-cycle process. Feasibility studies and advanced system planning are performed during the conceptual design phase to identify the technical and informational deficiencies and alternative approaches for correcting them.

The selected approach(es) to resolve the issues and correct deficiencies may include creating and manipulating models of the system to obtain a better understanding of the interactions and operational characteristics of the system. Simulations and analogs can be used to explore the effects of variations in system characteristics on its performance without having to actually commit to the alternative(s), thus providing an economical way to optimize the system performance (Blanchard & Fabrycky, 1990, p 124-127). The Space Station can serve as a useful analog for a long duration space flight system since it has many similarities to spacecraft designed to carry crews to the moon or Mars. If properly selected and utilized, Earth based analogs and simulations can also provide pertinent information.

PURPOSE AND OBJECTIVES

While there is an identified need to place humans on Mars by the year 2019, there is inadequate information to determine performance parameters, operational requirements, or support policies. At this time it is difficult to justify defining hypothetical functional analyses, task definitions, or man/machine functional allocations. It appears to be more beneficial to concentrate on some of the issues that must be addressed early in the systems engineering process (starting in the conceptual design phase) to facilitate the decision-making process.

Therefore, the objective of this report is to identify and discuss some of the issues related to:

- Environmental considerations (i.e., STEP issues) which will constrain the long duration manned space flight system development process until they are resolved.
- Personnel factors which will likely influence system performance, including the dynamic aspects of the crew interactions.
- Crew selection and training.
- The synergistic effect of the systems issues on the system life-cycle process

Finally, areas for future research efforts are discussed, including the proposed joint National Aeronautics and Space Administration (NASA) and National Science Foundation (NSF) Long Duration Space Flight Antarctic Analog.

ENVIRONMENTAL CONSIDERATIONS (STEP ISSUES)

To ensure that the long duration space flight system will meet its operational requirements it is essential that all pertinent factors which may affect system performance be addressed during the early phases of systems development (Blanchard & Fabrycky, 1990 , p17). The pertinent STEP issues must be systematically examined to gain insights into significant causal relationships which will act upon the system. Some of the more significant considerations are discussed below:

Manned and Unmanned Space Exploration

The integration of the manned and unmanned missions to achieve a permanent base on the surface of Mars will require the cooperation of two factions that have been at odds over the direction of the United States' space program since the early 1970's. There has been a perennial conflict between the manned and unmanned space exploration proponents as to how much emphasis (and dollars) should be spent to place humans on the surface of Mars.

The budget of NASA has been very limited since the 1970's. This has meant that the various NASA programs must continually compete for a budget allocation and rarely receive full funding requests. Some program(s) invariably do not get funded and must be put on hold or cancelled. This has led to divergent opinions within the scientific community as to how NASA's budget should be allocated between manned and unmanned programs. Some feel NASA should emphasize expanding manned exploration of space while others feel unmanned exploration provides more direct benefits to the scientific community and to the United States economy.

The National Aeronautics and Space Administration (NASA) has traditionally divided its focus between manned and unmanned programs. The distinction has to do with the additional requirements that manned programs have to meet to be qualified to support humans. Any vehicle which transports humans must be designed to certain habitability requirements in order to be qualified for use. The physical and mental well-being of the humans must be assured. For unmanned vehicles, these habitability requirements do not typically apply. This frees up a significant amount of funds and facilities that would have been used to develop human systems. The unmanned programs are able to concentrate their efforts on enhancing scientific research capabilities and developing advanced automation technologies. The proponents of unmanned exploration feel that the manned programs make up too large a proportion of NASA's budget.

To place humans on Mars by the thirtieth anniversary of the Apollo moon landing, the conflicts between manned and unmanned adversaries must to be resolved so that a united effort towards a common goal is achieved.

Schedule and Budget Uncertainties

The Augustine committee recommended that an "open ended" schedule be adopted for a long duration space flight system which would be tailored to match the availability of funds (Augustine Report). In addition to affecting the funding and schedule for the prime contract for designing and developing the system, this open ended schedule would negatively affect the research and development activities that are needed to understand the long term effects of space flight. With a limited budget, it is management's responsibility to allocate the funds in ways that maximize the chances of a successful program. The available resources (e.g., dollars, facilities, time) are prioritized and allocated such that the tasks that are on the critical path receive the highest priority. If an area of science is perceived as more crucial, it will receive higher funding. This leads to conflict within the scientific community, which can exacerbate the issue of manned versus unmanned space exploration.

Logistics Support

To date, the longest United States mission has been during the Skylab program and has lasted for eighty-four (84) days. The Skylab atmosphere and water systems were not designed to be resupplied -- consumables required for the three Skylab missions were aboard the Skylab before the first launch and maintenance was not considered a routine activity.

The Russian Space Station, Mir, receives consumables and spares from an expendable launch vehicle called "Progress". The Progress is constructed from the motor section and guidance section of a Soyuz spacecraft, without the manned section attached. The canister section of the Progress is capable of automatic rendezvous and docking with the Mir Station. The waste materials are placed in the canister and are burned up in a controlled reentry of the canister in the Earth's atmosphere. There is also the capability for quick sample return via a tether system which lowers a sample into the atmosphere before it is released to prevent it from burning up on reentry. However, the experiments and samples are normally returned with the crew. (Charles C. Daniel, NASA-MSFC, personal communication, August 8, 1992)

The Freedom space station will be the first permanently manned and maintainable spacecraft for the United States. The Freedom will remain permanently manned by rotating the crews every ninety to one-hundred twenty (90-120) days and will remain operational through regular logistics resupply missions, and by means of preventive, planned, and unplanned maintenance activities. The Freedom's logistics system has been designed for transport in the cargo bay of the Space Transportation System (Shuttle). It consists of pressurized and unpressurized elements that will transport consumables, spares, and experiments to the station. The pressurized logistics element (the Logistics Module) is similar to the other habitable modules in that it is the same diameter and has the same human factors requirements imposed on it. During the mission the Logistics Module is used as a storage facility for consumables, spares, and waste materials. It is attached at a berthing port on the habitable section of the Station and is routinely changed out during Shuttle visits with another Logistics Module and returned to Earth for refurbishment.

The logistics system to support a long duration space flight system will be different from those developed for the Mir and Freedom space stations, which have relatively easy access to Earth for resupply. The entire mission must be analyzed and provided for at the beginning of the mission. This may require prepositioning consumables and spares on the surface of Mars for the return voyage. Many of the problems associated with Skylab (e.g., insufficient wet-trash bags) could occur unless the logistics system is properly designed and implemented.

Technology Development and Resource Management

Emphasis has been placed on utilization of Space Station technologies for future long duration spacecraft. The Space Station has been billed as "the Next Logical Step" for the United States Space Program. This is not an overstatement since many of the technologies being developed for the Space Station are needed for successful long-term missions. The Space Station will develop technologies to make the spacecraft self-sufficient while simultaneously satisfying the crew's emotional and physical needs and providing a long-term safe and healthy environment.

Many of the technologies required to sustain humans for extended periods are still in the developmental stage. Also, spacecraft designed for long duration missions have severely limited resources (e.g., weight, power, volume, maintenance man-hours, data management, thermal, water, etc.) which must be conserved and/or recycled efficiently and economically. This is encouraging the development of technologies that are compatible with these resource restrictions. These technologies have a significant impact on the program cost. For example, the decision to develop partially closed-loop environmental control and life support technologies to conserve and reuse consumables has significantly increased the costs of manned systems while offsetting the cost of launching the consumables.

Generally speaking, the manned system technologies under development for the Space Station program can be adapted for use in future programs. Time and effort spent on the Space Station program now will have paybacks (economic and technical) for future manned programs. It is foreseeable that the Space Station technology will reduce the cost of manned systems for a future manned spacecraft and will free some of the budget for use in scientific research (both life sciences as well as the more traditional sciences). However, one must recognize that technology development is an evolutionary process and that new requirements may require changes to existing or planned technology.

Man/Machine Interactions

The system engineering process works to achieve an optimum match between the equipment and the crew's capabilities through the man-machine interface (MMIF) and the crew selection and training process (see Figure 3). A long duration space flight system which integrates the efforts of humans, robotics, and advanced automation components will take advantage of the capabilities of each to achieve a permanent base on Mars.

The crew of the long duration space flight system will rely upon robotics and other advanced automation to perform the jobs required to accomplish the mission functions. Humans can be used to enhance the operational flexibility of robotics and automated systems. However, it is necessary for the crew to work with the robots to know their failure modes, test procedures, and monitoring requirements prior to the mission. Recognizing the mutual interdependence of the automated systems and the crew should encourage the manned and unmanned space exploration proponents to work together in a cooperative effort to accomplish a balanced MMIF.

Limitations of Earth Based Control and Monitoring

The distance between the Earth and Mars places a physical limitation on the command and control methods used for spacecraft sent to Mars. The equipment must be relatively autonomous and adaptive in order to evaluate new and changing situations to independently determine the appropriate course(s) of action. For safety reasons, the spacecraft subsystems must include provisions for interactive crew control of the automated equipment (including the robotics systems) to verify and possibly override autonomous operations.

The distance between the crew and Earth will also require the crew to operate relatively autonomously and to make decisions directly affecting the outcome of the mission without constant supervision of Earth-based mission controllers. This will likely lead to a high level of crew cohesion and to a decreased dependence upon the Earth. This has ramifications that will be discussed in the next section.

PERSONNEL FACTORS

As shown in Figure 2, during the process of establishing human factors requirements there are crew related factors that must be incorporated into the systems engineering process. Anthropometric characteristics of the individual crew members will impact the design of the system and its workspaces. Also, the capabilities and limitations of the human senses in the spacecraft environment must be considered when designing the operator and maintenance tasks to be performed by the crew. Psychological and physiological factors will also influence the performance of the crew in the long duration space flight system (Blanchard & Fabrycky, 1990, p 447). Some of the issues pertaining to the personnel factors which must be resolved during the system design and development process are identified and discussed below.

Physiological Implications of Long Duration Space Flight

It has been well established that humans are affected physiologically by space travel. Exposure to the space, Martian, and Lunar environments affects the biological processes of the human body (further information can be found in the Masters thesis by Holland (1991)). The mechanisms of how these conditions act upon the body, whether these effects can be reversed, and how these effects can be mitigated is not fully understood. It will be necessary for research to be performed on the Shuttle and the Space Station to develop an understanding of the physiological limits of humans to these stresses. Technological fixes to alleviate the induced stresses will be required before committing humans to a long term space mission. The effort to understand the effects of long duration space flight on humans will increase the costs for the human systems and will create an emphasis on Life Science research and experiments (including Space Shuttle and Space Station experiments). This increased life sciences focus will reduce the time and funding available for pure science and unmanned space exploration, which will affect the relationship between the manned versus unmanned space exploration proponents.

Psychological Implications of Long Duration Space Flight

The effectiveness of astronaut crews will be influenced by the living conditions to which they will be subjected. Beginning with the Space Station program, larger astronaut crews will live together for longer periods than previous United States or Soviet programs. The astronauts will live in a confined habitable environment inside pressurized modules for extended periods. They will have minimal privacy and will be isolated from family and friends on Earth, with only occasional private communications with loved ones. The adverse psychological conditions must be understood if the astronauts are to work with each other and the ground crew effectively. The mission length, the crew heterogeneity (both professional and personal), and conditions of isolation and confinement may promote interpersonal tensions which could affect the overall performance of the group (Nicholas, Foushee, and Ulschak, 1990). Studies have consistently found that human responses to long term isolation include symptoms of: boredom, restlessness, anxiety, sleep disturbances, somatic complaints, temporal and spatial disorientation, anger, and (most important) deficits in task performance over time (Santy, 1983). If even a few of the crew exhibit these symptoms, they could pose serious survival problems for the entire crew. Many of the psychosocial problems that accompany long-term confinement could be mitigated by training the crew as a whole in interpersonal emotional support and crew interaction skills as well as in group dynamics. What happens in a group (the way it makes decisions, the way people communicate, resolve differences, cope, etc.) partly depends on the membership of the group (skills, beliefs, styles, attitudes), and partly on features of the group as an entity (status, norms, cohesiveness, etc.) (Nicholas, Foushee, and Ulschak, 1990). Many of the operational problems and accidents that may occur could be caused by breakdowns in group functioning rather than by hardware failures or lack of individual skill. It is therefore critical that the flight crew receive thorough training in how to recognize and avert potential interpersonal and group conflicts.

Group Dynamics

A group is defined as "an aggregation of two or more people who are to some degree in dynamic interrelation with one another" (McGrath,1984, p8; as quoted in Donelson, 1990, p8), who "communicate with one another, over a span of time, and who are few enough so that each person is able to communicate with all the others, not at second hand, through other people, but face-to-face" (Homans, 1950, p1; as quoted in Donelson, 1990, p8), is also a "social unit which consists of a number of individuals who stand in (more or less) definite status and role relationships to one another and which possesses a set of values or norms of its own regulating the behavior of individual members, at least in matters of consequence to the group." (Sherif and Sherif, 1956, p144; as quoted in Donelson, 1990, p8). Using these definitions, the crew of a long duration mission can be considered as a group.

The crew of long duration space flight missions will experience forces which will affect both the individuals and the group as a whole. These forces can be imposed by internal and external sources. Internal forces are those which exist within the individual crew members (e.g., personality, past experiences, etc.). External forces include those imposed on the crew members by the rest of the system, including the other individuals in the crew (e.g., pressures to conform to group norms and standards, the area(s) provided for crew activities, etc.). External forces can also be applied by the environments that are external to the system (e.g., radiation, space vacuum, etc.). These forces can act directly on the individuals in a group (e.g., bone-loss due to micro-gravity) or indirectly (e.g., psychological stress resulting from long term confinement). The interaction of these forces acting on the individuals and the group creates dynamics which will affect the performance of the crew. As the crew lives and works together, these dynamics shift -- modifying the behavioral characteristics and performance of the crew. The dynamic development process of a crew is discussed below.

Group Developmental Stages. From the time that a crew is selected, they will rely upon each other for the attainment of the mission's goals and objectives, for emotional support, and for physical needs such as safety and survival. However, before the crew can become a unified and productive entity, it must pass through certain developmental phases, or stages, where the individuals learn to coexist and work together. These stages are listed and described in Table 1. (Forsyth, p 77).

Forming Stage. When a crew for a long duration mission is initially convened, interpersonal attraction relations and working relationships are undefined. The initial stage

Table 1. Five Stages Of Group Development

Stage	Major Processes	Characteristics
1. Orientation (Forming)	Exchange of information; increased interdependence; task exploration; identification of commonalities	Tentative interactions; polite discourse; concern over ambiguity; self discourse
2. Conflict (Storming)	Disagreement over procedures; expression of dissatisfaction; emotional responding; resistance	Criticism of ideas; poor attendance; hostility; polarization and coalition formation
3. Cohesion (Norming)	Growth of cohesiveness and unity; establishment of roles, standards, and relationships	Agreement on procedures; reduction in role ambiguity; increased "we-feeling"
4. Performance (Performing)	Goal achievement; high task orientation; emphasis on performance and production	Decision making; problem solving; mutual cooperation
5. Dissolution (Adjourning)	Termination of roles; completion of tasks; reduction of dependency	Disintegration and withdrawal; increased independence and emotionality; regret

Source: "Group Dynamics" (2nd ed.), by Donelson R. Forsyth, 1990 of group development has been called "Orientation" or "Forming" and is characterized by mild tension and guarded interchanges. The crew members are not well acquainted and there may be no specific norms regarding the regulation of interaction and goal attainment and the roles in the group may be unclear. (Forsyth, p 78). This stage will begin when the crew is initially brought together to train for the mission.

Storming Stage. As the crew trains and works together, getting to know each other, incompatibilities will arise that must be resolved before the group can develop further. After the polite orientation stage, the second stage of development is called "Conflict" or "Storming". Disagreeing is a natural consequence of joining a group and group conflict is as common as group harmony. The dynamic forces acting on the group will lead to changes, and with change comes stresses and strains that surface in the form of conflict. Although conflict can destroy a group, it can also promote group unity by providing an opportunity to resolve the tensions and by bringing the antagonists together to achieve a common understanding. (Forsyth, p81)

The effects of long duration space flight on humans is not fully understood and it is doubtful that they can be fully neutralized. Thus the system and its environments will exert forces on the crew which will create physiological and psychological effects which will likely increase perceptions of uncertainty and instability within the crew. The magnitude of the perceived instability and uncertainty will directly affect the tension level of the crew, which corresponds directly to the rate of interpersonal conflicts.

A group has a threshold for tension that represents its optimum level of conflict among members. Conflict too far below the threshold leads to group apathy, boredom, and lack of involvement. Prolonged conflict above this level can lead to heightened hostility and a decrease in group effectiveness. It has been proposed that a balance between too little tension and too much tension will lead to "clarification of goals, an increased understanding of differences and points of contention, successful discussion, stimulation of interests, and the release of hostility." (Donelson, 1990, p80).

The concept of an optimum tension level has significant implications for a long duration space flight crew who may experience long periods of inactivity during the mission to Mars. The system staffing studies may recommend a minimum level of crew heterogeneity in personalities and backgrounds to help maintain the optimum tension level.

Norming Stage. During the third stage of group development, called "Cohesion" or "Norming", the conflicts are replaced with a feeling of group cohesiveness. The increased cohesiveness level corresponds to the development of a normative system of customs, values, laws, and standards which serve to regulate and stabilize the relationships of the crew members to one another and to their activities (Sherif, M., 1966, p2).

Groups achieve a semblance of stability through the imposition of an organizational and social group structure in which norms, customs, values, and standards provide rules of conduct for the crew to follow in the pursuit of personal goals and the accomplishment of mission tasks. These agreed upon norms, customs, values, and standards are internalized by each crew member and become frames of reference (i.e., mental models) among other factors in situations to which they are related, and thus dominate or modify the person's experience and subsequent behavior (Sherif, M., 1966, p43). The development of group structure also affects the stability of the crew by organizing the interpersonal behavior of the crew and it will play a major role in its decision making processes. There are four major structural dimensions that work together to organize interpersonal behavior: roles, status, attraction, and communication (Forsyth, p138) As the crew members work together and recognize each other's capabilities and limitations, differentiation processes occur in the roles, status, and attraction dimensions. The role differentiation process creates distinct roles for each crew member and helps to achieve stable patterns of crew behavior. The status differentiation process establishes an authority hierarchy which helps to ensure that the crew's activities are coordinated and that guidance is provided in the accomplishment of tasks. The attraction (sociometric) differentiation process establishes a network of stable social relationships due to the tendency for humans to react to one another on a spontaneous, affective level (Moreno - Forsyth, p125).

Crew size will influence the complexity of interpersonal relationships, increasing the potential for interpersonal conflict (C. Ridgeway, 1983, pp 5-11). Unbalanced sociometric structures generate tensions among crew members and the crew will be motivated to correct the attraction relations imbalance and restore the equilibrium in the group structure.

The crew development process will cycle between the Storming and Norming stages as the tension levels fluctuate. Each conflict can be viewed as a opportunity for the group to become closer and to learn to work together better (Forsyth, p89).

Cohesiveness contributes to "group stability, satisfaction, effective communication, positive personal consequences for members, and increased group influence. However, as groups become more cohesive, social pressures can become so intense that individual members are overwhelmed" and the group performance quality may be degraded and interpersonal hostility and rejection may increase (Forsyth, p85).

Groupthink. A high level of group cohesion limits the amount of dissent in the group, sometimes to the point that internal disagreements disappear. If this occurs, the quality of the group's decisions may suffer since it is through these disagreements that good decisions are made. "Groupthink" was the term invented by Janis to describe a "mode of thinking that people engage in when they are deeply involved in a cohesive in-group, when members' strivings for unanimity override their motivation to realistically appraise alternative courses of actions." (Janis, I.R., Groupthink, 1982, p9).

Isolation of the group from outside sources of information is another factor that contributes to the occurrence of the groupthink phenomena. Also, if the leader implements formal controls and rigid protocols on the group, limiting the subjects that can be discussed, groupthink will be more likely to occur due to the increased conformity pressures (Forsyth, p299).

The communication patterns that develop within the crew have a strong influence on the efficiency of system performance and these patterns can be enhanced or degraded by the characteristics of the social environment. For example, when there is a clear status difference between two operators who must share and exchange information, there is a danger that the person of lower status will not correct an error committed by the higher status person or may do so in such a manner that the error is not corrected. (Wickens, 1992 p 203-204).

The very survival of the long duration space flight crew depends on the avoidance of the groupthink mode of thinking as well as the development of uncontrolled, escalating conflict. During emergencies, the crew will operate under conditions that may lead to poor decision making. They will be isolated, receiving information from Earth, but relying mostly on the spacecraft instrumentation information and on the crew members' judgements. Also, if the chain of command is deeply entrenched, the crew members may be reluctant to correct the leader's errors and the leader may ignore warnings from the rest of the crew. Finally, when significant problems occur during a mission, the crew may overlook alternative solutions and focus on only the most obvious ones which may be incorrect. To avoid groupthink crew members must be able to think independently while rationally analyzing a situation.

Therefore, it can be assumed that an optimum level of cohesiveness would exist for a crew which would stimulate teamwork and cooperation while encouraging the independent thinking of each person. Having a very low group cohesion level would indicate that the crew members are not working as a group to achieve the mission objectives and goals. A very high group cohesion level would indicate that the members may experience very high conformity pressures which could lead to gross errors of judgement. Additionally, to reduce the risk of groupthink, the crew must have regular contact with persons and sources of information that can assist in formulating group judgements on key issues and in developing appropriate courses of action.

Performing Stage. Once the crew has become a cohesive group with established roles, standards, and relationships, it would normally enter a period of high productivity where the focus is on the accomplishment of tasks and activities required to achieve the crew's goals and objectives. This is called the "Performance" or "Performing" group development stage. The productivity of a group depends on both the crew's group structure (with its associated norms) and the group's cohesion. If the group norms encourage high productivity, then the cohesiveness and productivity of the group are positively related (Forsyth, p86). It is crucial that the group norms adopted by the crew do not interfere with the accomplishment of the mission's goals and objectives. This will require the cooperation and collaboration of the crew with mission planners during the creation of group norms that may affect group performance.

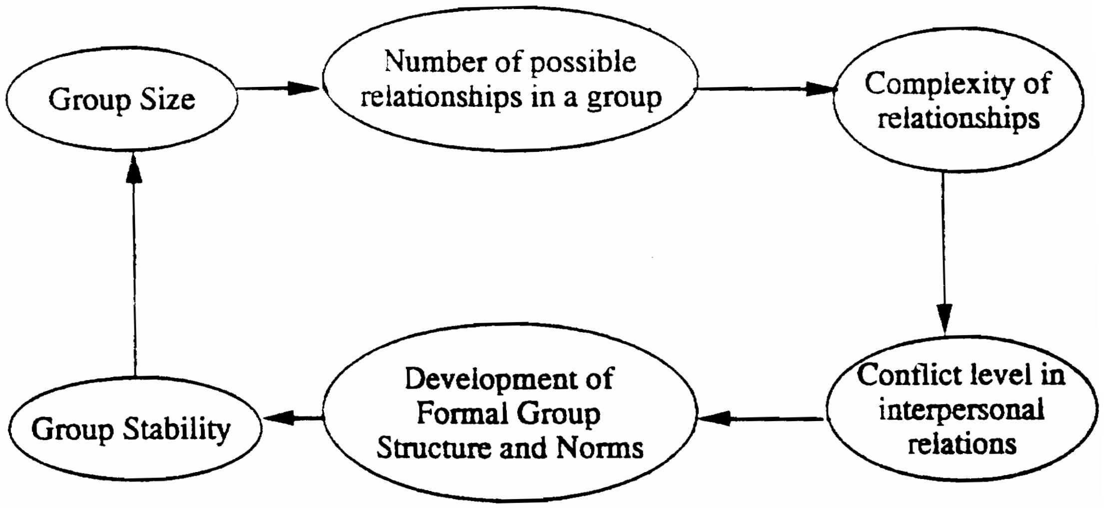
Adjourning Stage. Consistent with the systems perspective, the life-cycle of a group must include the dissolution of the crew when the mission is completed. This inevitable "Dissolution" or "Adjourning" stage can be especially stressful for the crew. Mission planning should take into consideration the probability that tension levels will increase as the mission reaches its conclusion. This increased tension level may have a negative influence on the performance of the crew during the final stages of the mission (e.g., final reentry into Earth's orbit.)

Development of a Crew/System Interactions Model (CSIM)

To understand and improve the psychological and sociological aspects of crew performance within the system requires that a model be developed which examines the dynamic effects of the interactions of the crew with the rest of the system. Unfortunately, accurately stating and predicting dynamic causal relationships for the behavior of a typical crew is very difficult, if not impossible. Social sciences posit almost as many cause and effect relationships as there are theories to explain human behavior. Also, most theories explaining human behavior in a group are based upon a static view, in which the system forces are fixed in time and place. This is done primarily because of the complexities of predicting individual human behavior. There are a large number of forces which can affect a person's behavior, some of which are internally generated. Each human is unique, with a frame of reference (i.e., mental model) which is influenced by the past experiences of that individual. Such a model would relate the various system parameters affecting the crew in such a way that the situational variability of the interactions is accounted for. As with any other simulation, one which attempts to predict crew interactions would be an idealized representation of reality which would only be able to provide inferences and insights into the characteristics and functioning of the real system.

The information feedback characteristics of dynamic systems can be analyzed using the principles of systems dynamics to examine how system structure, policies, decisions, and delays interact to influence the growth and stability of the system (Drew). A crew would have certain relatively static aspects such as its ultimate purpose. "But [the crew] also has dynamic aspects -- it is always moving, doing something, changing, becoming, interacting, and reacting" (Knowles, M. and Knowles H., 1972, p 14). The long duration space flight system and its crew constitutes a dynamic social system in which the components are integrated by the flows of materials, manpower, and information. The flows represent forces which influence system behavior and performance.

Psychologists and sociologists posit many theories to explain and predict the causation of the various characteristics and behavior of groups. The cause and effect relationships can be diagrammed using a causal diagramming technique, which provides a method to state implicit causal relationships explicitly. Figure 4 provides an illustration of the causal diagramming technique applied to the dynamic interrelationship of group size and group



Adapted from "The Dynamics of Small Groups" (C. Ridgeway, 1983), pp 5-11.

FIGURE 4: Causal Relationship Between Group Size and Group Stability

stability. The nature of the interrelationships are defined by the orientation of the arrows. The tail of the arrow is at the "cause" while the head of the arrow is at the "effect". By following the chain of arrows, the ultimate effect of an initial force (e.g., group size) through the system can be traced.

The cause and effect relationships for a long duration space flight system could be explicitly stated to describe the interactions of the crew with each other and with the system. To avoid confusion, the modeling emphasis would be limited to those feedback processes that are most influential to the system and the crew. These causal relationships would constitute a Crew/System Interactions Model (CSIM) that would provide a systematic method for making decisions regarding the roles and responsibilities of the crews and provide a simulation of the system to help fill in the gaps in knowledge and judgement during the development of the system.

In Figure 5 a causal diagram is proposed as a simplified portion of a CSIM. The assumed causal relationships should not be interpreted as scientifically validated facts. They were derived by the author through inductive logic after reviewing group dynamics and long duration space flight literature. The dynamic interactions were not easily diagrammed because of the large number of feedback processes that exist in groups and large systems.

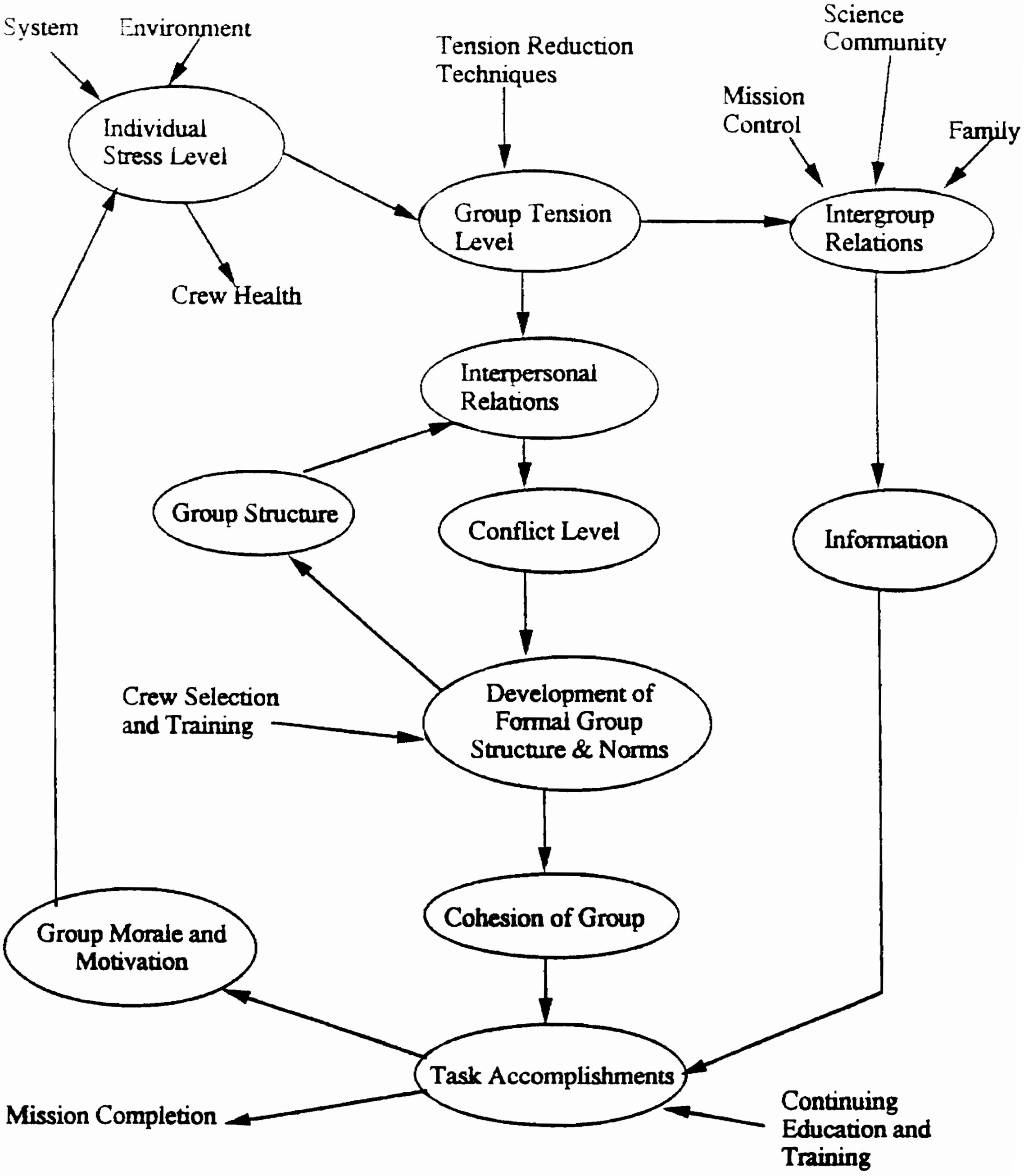


FIGURE 5: Crew/System Interactions Model (CSIM)

The causal diagram provided here should be used to stimulate discussion and to provide a systematic thought process for analyzing the interrelationships of the crew with each other and with the rest of the system. The assumed causal relationships can and should be debated. By proposing explicit relationships they can be negated, modified, or verified by experts. As better information becomes available, a CSIM would be updated to make it more accurate and it could be used to understand the potential impacts of certain group norms and standards on the crew's behavior and performance. Having a risk free method for analyzing the potential impacts of factors such as group norms, structure, and cohesion on group performance would be useful in the systems staffing studies. The CSIM could also be used as a training tool for the crew to learn about small group behavior and interpersonal relations skills.

CREW SELECTION AND TRAINING

The ultimate success of a long-duration spaceflight mission will depend on the proper functioning of the crew. The goal of the crew selection and training process is to have an effective crew which exhibits the following three dimensions: (3)

1. The crew's productive output (experiments, material products, maintenance, or other quantitative and qualitative objectives) meets the standards of the people who use, receive, review or support that output. The productive output of a space crew depends on others' (legislators, industry, and academic interest groups, etc.) assessment of their output.

2. The crew's work process enhances its ability to work together in the future. Members become highly skilled at working together, are able to anticipate others' moves and to initiate the right responses. As crew members spend more time together, they get better at being together. Mutual antagonism and mistakes diminish rather than escalate.

3. The experience of being a part of the crew contributes to the growth and personal well-being of the members. In long term confinement, the crew must largely rely upon itself to provide social fulfillment and satisfaction of personal needs.

The realization of an effective crew depends upon decisions and activities that occur throughout the life-cycle process for the system. Some of the crew selection and training issues which must be addressed during the design and development of the long duration spaceflight system are discussed below.

Systems Staffing Studies

The United States manned space program is currently oriented towards the relatively short duration Shuttle flights in which payloads such as the Spacelab are flown in the Shuttle cargo bay. The integration of the crew selection and training activities into the Space Shuttle and Spacelab design and development activities has been largely serial in nature, with the selection of a crew and the subsequent training activities initiated after a mission manifest is announced. The preliminary analysis of the mission training requirements, training tools, and an implementation plan for training personnel in experiment operation is normally initiated no sooner than three (3) years prior to the scheduled payload launch date (Lybrease Woodard, NASA-MSFC, personal communication, September 3,1992).

Also, in the current unstable budgetary environment funding cuts are common. When a program's funding is cut, the activities related to the operation of the spacecraft system are usually the first areas to be affected and are usually pushed out later in the program. This causes the operations activities to have less impact on the design and development of the system, which leads to a design that is less than optimal.

The crew selection and training process must be integrated with the design and development activities to produce a system which meets its design and performance requirements efficiently and effectively. The concurrent consideration of the design and operations requirements would enable identification of the training requirements earlier in the program and would probably reduce the procurement lead-time the training tools and simulators. Also, an integrated training program would allow common tasks and procedures to be identified, reducing the number of tasks to be learned and making crew training more efficient and effective. The systems staffing studies would provide a way to systematically interface the operational requirements and the maintenance concept with the crew selection and training process (DeGreene, 1970, p358 & 364). The objective is to achieve an optimum match between the crew selection and training activities and the MMIF specification and fabrication constraints such that a balanced system design is achieved that takes into account the capabilities and limitations of the humans who must operate and maintain the system.

Memory Limitations

The optimization of the crew training process will become more critical as the duration of the mission increases. As the length of the mission increases the total number of tasks will increase accordingly. The limitations of human memory (Sanders & McCormick, 1987, p51) makes it impractical to train the crew prior to the long duration mission to the same level of detail and complexity as for short duration missions. To maximize the effectiveness of the crew selection and training process it will be necessary to identify and focus upon those crew selection and training criteria most critical to mission success. Short duration flight crews receive intensive training in the control of the spacecraft and its systems and develop skills of basic operations to the point of automatism. Skills in handling various unforeseen factors, including emergency situations, are also developed (Link & Gurovskiy, 1975). Beginning with the Space Station, on-orbit maintenance and repair of the spacecraft systems will become a routine operation which will require additional crew training.

Exhaustive training will not be feasible for long duration missions due to the mission length and the large number of operations that must be performed (both normal and contingency). It is necessary to limit the focus of an intensive training program to develop high proficiency levels in those tasks identified as critical, such as those required to manage the day to day spacecraft operations and skills required to handle emergency situations. A well organized and systematic training program would facilitate the learning of tasks and reduce the time required to learn a task. Also, by integrating the selection process with the training program a balance could be achieved which would optimize the total training effort required with the selection of qualified personnel. Continuous education and training during the mission will be required to ensure that crew skills are maintained at the desired proficiency and that new skills are available when needed. The crew of a long duration mission will probably be better educated in lieu of the standard detailed training to maximize their adaptability and flexibility to changing situations in-flight (Kenneth Smith, NASA-MSFC, personal communication, August 31, 1992).

Spacecraft Interpersonal Communications Training

The communication patterns that develop in the crew have a strong influence on the efficiency of system performance and can be enhanced or degraded by the characteristics of the social environment. When there is a distinctive difference in status between persons who must share and exchange information, there is a risk that the person of lower status will not correct an error committed by the higher status person or may do so in such a manner that the error is not corrected. To avoid this risk, a spacecraft resource management training program could be implemented which would emphasize the importance of two-way information exchanges to spacecraft safety. The training program would emphasize the responsibility of each crew member to communicate and would demonstrate that the performance of the entire team is greater than the sum of the parts (Wickens, 1992 p 203-204).

Selection and Training Criteria For The Social Environment

A long duration manned spacecraft will utilize proven technology if at all possible. This will mean that many of the operations and maintenance functions for long duration spacecraft will be similar to those for previous short duration missions. However, the crew for a long duration mission will live and work in a confined, isolated spacecraft environment with enforced socialization which will probably lead to an increased crew tension level. The selection and training process must address the social environment that will develop during the long duration space flight mission. In addition to technical proficiency and physical capabilities, the selection of crewmembers for a long duration space flight mission must consider the psychological requirements for successful mission completion. There are no clear cut guidelines as to what psychological and personality profiles would be best for a potential members of a flight crew for such a mission. There may be incompatible personalities or individuals who can not endure the isolation and confinement of long duration spaceflight. Also, there may be long periods with minimal planned tasks for the crew. Some persons may find the long periods of inactivity intolerable.

A synergistic approach is needed to select and train a crew to operate and maintain the hardware and software while simultaneously inculcating norms and standards that are conducive to a stable social environment. The selection and training process can assist in the development of crew norms or standards that will develop common frames of references, cultivate group cohesion, and encourage high crew productivity levels. If properly designed, the selection and training process can mitigate the stresses associated with long duration space flight.

The crew must have the skills required to execute their responsibilities effectively and consistently, including task oriented technical skills as well as interpersonal and group behavior skills. Interpersonal tensions will impair the cohesiveness of the group and may degrade necessary cooperation. The ability to recognize and defuse conflicts and to resolve differences can improve the crew's performance. The crew must be trained to work together as a team so that it can develop and grow into a mature entity that will be able to handle the complex and unpredictable situations that can occur during spaceflight. Group dynamics techniques and interpersonal communication skills must be instilled within each crewmember to improve the overall system performance.

An objective of the prelaunch training program would be to have the crew work together as a group to the point where it has entered the Performing Stage in group development. This would entail the development of group norms and values that the crew can use from the beginning of the flight. NASA must work with the crew to develop norms and values that are compatible with the mission goals and objectives. It would also provide stability in the early part of the mission so that group productivity can improve without the additional problem of first developing rules of conduct. The rules and regulations deemed critical to group performance and safety, would also serve as a guideline to the crew as to what is expected of them by NASA.

Identification of Potential Risks and Rewards

The crew selection process is dependent on the existence of a pool of qualified candidates. An individual will only wish to become affiliated with the mission and the flight crew if they perceive a significant potential for personal gain that outweighs the personal hardships and risks which they must endure. NASA will have a better opportunity to select the best qualified individuals if information is available concerning the typical tasks that the crew must perform as well as a realistic description of the conditions they will see during a typical long duration space flight. For example, the volunteers should be aware that a potential for psychological stress would exist because of the enforced association of the crew during the mission.

Developing A Systems Perspective

In order for the crew to perform as an integral component of the long duration space flight system, they must view the spacecraft operations from a systems point of view, seeing the interconnections of the components of the system and how their actions could affect the functioning of the system (Wickens, 1992 p244). The crew members will receive extensive training in the operation and maintenance of the system and its elements to ensure that pertinent information is accurately stored in and retrieved from the individual's long term memory when needed. Long term memory is the portion of the human memory used to store declarative and procedural knowledge and mental models. Declarative knowledge includes facts about the system that can be easily verbalized or written down (e.g., safety rules and regulations). Procedural knowledge concerns how to do something and is often not easily verbalized (e.g., how to operate a computer). (Wickens, 1992 p231). Mental models are internal pictures of how an individual sees the world and they influence the behaviors and actions that the individual takes (Senge, 1990 p175). Mental models provide the means to implement systems thinking in the crew (Senge, 1990 p203). Accurate mental models provide useful knowledge about the system operations that can be used when other learned procedures fails (Wickens, 1992 p244) and is critical in the response to malfunctions or failures (Wickens, 1992 p506). Successful control of the long duration space flight system will be dependent on the crew possessing accurate mental models of the dynamics of the system operation (Wickens, 1992 p513).

To develop a systems perspective, a map of the mental models of the members of the group is needed that will expose underlying assumptions about important systems issues. "Two people with different mental models can observe the same event and describe it differently because they have looked at different details" (Senge, 1990 p175). The idiosyncrasies and unique life experiences that crew members carry with them will influence the formation of an accurate mental model of the long duration space flight system (Sherif, 1966 p106). "The inertia of deeply entrenched mental models can overwhelm even the best systemic insights" (Senge, 1990 p177).

To optimize a group's performance, it is necessary that the various subconscious mental models be surfaced and tested within an open and non-judgmental group forum. The goal would be to bring together the members of the crew to develop the best possible mental models for facing any situation at hand and to transform the decision making processes by encouraging the group to examine different ways of looking at the world (Senge,1990 p182). By viewing the system as a whole, without focusing on individual actions, the crew will be better able to understand the factors which influence their decisions and actions. Additionally, if the team members have compatible mental models, the complex situations which arise can be better understood and the actions taken and decisions made (or not made) which affect the performance of the system can be made more reliably.

The training process provides the means to carefully form and structure mental models such that inaccuracies in a person's mental model of the system are revealed (Wickens, 1992 p244). Training aimed at correcting mental models would emphasize the underlying causal structure and principles operating in the system and principles behind the procedures necessary to operate the system.

SYNERGISTIC EFFECTS OF SYSTEMS ISSUES

There are many factors which must be considered when planning and implementing a long duration manned spacecraft system. These factors include environmental considerations which are social, technical, economic, and political (STEP) factors that may exist prior to the inception of a new system (system independent) or occur as a result of the system coming into being (system dependent). Environmental considerations influence the definition of the operations, hardware, and software requirements as well as the crew requirements. Also, the STEP factors create system constraints on the personnel factors dealing with the crew members' physical and mental capabilities and limitations, which influence the definition of crew requirements.

Systems engineering provides a systematic framework to concurrently address the life-cycles for the spacecraft system, its manufacturing system, and associated support systems to ensure that the various constraints and requirements are understood and implemented properly (Blanchard & Fabrycky, 1990, p19). Several of the STEP and personnel constraints are interrelated and can only be fully resolved when addressed concurrently as systems issues. Systems engineering must be flexible and adaptable to work within the existing STEP and personnel constraints since they can significantly influence the selection of mission goals and objectives, the funding allocation process, the management process, the selection and development of technologies, and the crew selection and training process.

The economic constraint imposed upon NASA by the limited federal budget encourages intra-agency competition for an adequate budget allocation. This competition for funding influences the transfer of knowledge between the NASA programs by reducing the synergetic efforts of the scientific and technical disciplines. Fluctuations in the NASA budget influences the technical content of programs, the delivery schedules, the quantity and skill level of the government and contractor personnel, and the development of advanced technology required for long duration manned spacecraft systems. The safety requirements for manned space programs increases the cost to develop manned spacecraft technologies, which impacts the available budget for other NASA programs, accentuating the competition for budgetary resources.

The spacecraft resources (e.g., power, thermal, crew-time, etc) will be restricted by the availability of technologies and budget for the design and development of the spacecraft system. Design trade-offs must be performed to optimize the amount of each resource provided, within the budgetary constraints. The available resources are allocated and controlled to ensure that they are used effectively. Changes to the funding allocations, especially budget reductions, affect the spacecraft resources allocation process since reduced funding usually means reduced spacecraft capabilities and resources.

The performance of the spacecraft system depends upon the crew performing their assigned functions and tasks. The physical and mental state of the crewmembers will be influenced by the spacecraft system and its environment, creating physiological and psychological constraints which will influence their ability to carry out assigned tasks and functions. The design of the long duration spacecraft and its support systems must consider the potential physical and mental constraints that will affect the crew performance. Group dynamics will become more important as the mission duration increases and the social environment becomes more influential on total system performance.

As the distance of the spacecraft from Earth increases, the time required to communicate increases which will lead to less interaction between the spacecraft and Earth. This requires a relatively autonomous spacecraft system. The human component of the spacecraft system (the crew) must be integrated with the hardware and software components such that the system can be operated and maintained efficiently and reliably. The capabilities and limitations of human memory must be considered when defining the man/machine interfaces (MMIF) and during the design of crew training programs.

The inevitable isolation and autonomy of a long duration spacecraft system increases the risk that "groupthink" may develop which could endanger the crew and reduce the chances of mission success. To reduce the chances of groupthink, the spacecraft's social environment must be created and managed to maintain an optimum level of group cohesiveness that emphasizes productivity and teamwork while encouraging independent, rational thinking. In addition to the normal training in hardware and software operation and maintenance, training in interpersonal communications techniques can improve the ability of the crew to work together effectively, reducing the risks of a breakdown in crew communications.

A systems perspective must be developed within the crew to improve the ability of the crew to interact with the system and to improve the compatibility of the mental models of the crew members. By creating an understanding of how the spacecraft system components interact to accomplish the mission objectives, the crew will be better able to operate and maintain the spacecraft and to deal with complex situations.

The design and development of support systems such as the logistics system for a long duration manned spacecraft are also constrained by the budgetary process. The design of a logistics system depends upon the accurate and timely identification of consumable quantities, maintenance concepts, and spares requirements. Reductions in the budget for a spacecraft system usually requires redesigning the spacecraft system, which impacts the development of logistics databases and associated analyses.

FUTURE RESEARCH/EFFORTS

The issues identified in this report will influence the design, development, and operation of a long duration manned spacecraft system. The following is a discussion of activities and research that would further clarify or resolve these system-level issues.

Develop An Understanding of the NASA System

An understanding of the systems engineering process for a spacecraft system requires an understanding of the environment in which it will exist. A spacecraft developed and operated by the National Aeronautics and Space Administration (NASA) must interact with the components of the NASA system that includes government and contractor personnel and facilities as well as the scientific community and Congress.

The systems engineering process described in the Introduction is an idealized approach which does not consider the influence of the preexisting political and economic environments. The systems issues can only be resolved by analyzing the total system with its environmental and personnel constraints. The existing NASA system must be further assessed to identify areas where the systems engineering perspective could be improved. To implement changes in the existing system, schedules with significant milestones are required to provide adequate visibility of the progress towards the ultimate goal of facilitating the systems engineering process.

A barrier to systems thinking is the natural resistance to changing established and proven procedures for executing activities and tasks. When organizational hierarchies and their roles and responsibilities are impacted, resistance will be encountered. To minimize the resistance, the benefits of proposed changes must be clear. Whenever possible, the impact on the existing organization and personnel should be minimized.

Implementation of Systems Staffing Studies

The crew selection and training activities for NASA programs have evolved from earlier programs and have been handled differently for each manned spaceflight program, with the result that there is no standardized, systematic method for integrating the crew selection and training activities into the life-cycle process for the spacecraft system.

The systems staffing studies described in this report would provide a method for integrating the crew selection and training process with the hardware/software design and development activities and with the operations and maintenance task definition activities. Also, it would provide a valuable tool for optimizing the training process with the crew selection process.

Future activities include developing a plan to implement systems staffing studies into NASA's manned spaceflight programs such that the existing crew selection and training process is maintained to the maximum extent possible. Systems analyses and procedures required to carry out the staffing studies that are not currently provided should be identified.

Development of a Crew/System Interactions Model (CSIM)

The incongruities among psychological and sociological research and theories dilute their usefulness in assessing the social aspects of the design and operation of a long duration spaceflight system. These diverse theories must be synthesized if they are to have a significant impact on a long duration manned spacecraft system. A suggested approach for integrating the social aspects into the system is to develop a CSIM. This model would demonstrate how the crew interacts with the system and could be used as a tool to statistically predict system performance in the presence of certain crew behaviors and reactions.

Further research is needed to identify the key system variables that should be incorporated into a CSIM. An understanding of the interaction of the system variables with each other and with the system is needed. An understanding of the statistical nature of the variables is needed to develop a more realistic CSIM.

The dynamic relationships among the system variables would be represented mathematically using a systems dynamics model such as DYNAMO (Pugh, A.L., 1983) which would provide a method for assessing the effects of changes to the system variables. A model validation process would be required to verify that the model is an adequate simulation of reality. Recommended modifications to this model would be tested to determine their effects on the performance of the system. The ultimate objective would be to have a validated model of the spacecraft system which incorporates the social aspects of the spacecraft system.

Investigation of Group Dynamics Principles Using an Antarctic Analog

To provide the training required to develop and improve the group's interpersonal emotional support and crew interaction skills requires an understanding of the group dynamics involved in situations where a team that is isolated and confined must work together to carry out relevant tasks. To provide this information, NASA and the National Science Foundation (NSF) have proposed a collaborative effort to develop a high fidelity simulator or planetary analog of lunar and Mars outposts using the Antarctic outposts managed by the NSF. The characteristics of the Antarctic outposts which support the Antarctic analog include: physical remoteness, isolation, hostile environments, rugged terrain, logistical constraints, and limited human contact. Even the research performed in Antarctica is similar to that which would be done on Mars or the Moon. A report has been published by NSF and NASA concerning the mutual benefits of a collaborative effort in Antarctica to test and verify systems to be used in space, while similarly applying technologies developed for space exploration to Antarctic research stations. An Antarctic analog would complement the overall development strategy (especially for human dynamics and physiological accommodations) for a long duration manned spacecraft system (NASA-NSF, 1990).

The Analog would provide a structured setting where the cause and effect relationships of the parameters which influence crew interaction and group dynamics can be studied. To obtain the most value from the Antarctic experience, it is important that an agreement be reached as to the relevant parameters which would be measured. Otherwise, a great deal of time and money could be wasted.

By establishing these relationships and putting them out for general criticism, a dialogue could be initiated between the systems modeler and experts who would either accept the stated relationships or provide suggested modifications. In this way the integrity of the relationships could be improved and developed further. Eventually, when the relevant cause and effect relationships are understood, a single systems dynamics model could be created which would integrate the parameters. The model would provide a good indication of which parameters need to be measured, thus eliminating the effort involved in recording unnecessary data. This model could therefore provide valuable assistance in planning the Antarctic analog.

As the Antarctic simulation is carried out and the relationships of the parameters are better understood, the systems dynamics model would be updated and refined. The model could then serve as a tool to report the results of the analog. It could also serve as a simulator for training the crew in the dynamics of interpersonal and group behavior. In this way, the crew could reflect upon, expose, test, and improve the mental models on which they will rely when facing difficult problems (Senge,1990). It would serve to train the crew on how actions they take will affect the outcomes of the mission as well as how their actions affect the actual and perceived effectiveness of the crew as a whole.

CONCLUSIONS

The procurement process for a long duration spaceflight system by NASA can be facilitated by the adoption of a systems perspective by all persons involved in the design, development, testing, manufacture, utilization, and support of the system. Systems engineering provides an iterative approach for integrating the technical and programmatic disciplines, addressing the issues that affect program implementation, and it serves as an effective tool for implementing a systems perspective.

The long duration manned spaceflight system, which includes the spacecraft, the environment, the crew, the manufacturing system, and the various support systems, will impose constraints upon the life-cycle process that must be accounted for. In addition to the constraints imposed by the terrestrial, lunar, martian, and space environments (including contamination, vibration, radiation, microgravity, etc.), the system has social, technical, economic and political (STEP) environments which also impose constraints. Issues arise when there are difficulties in mitigating these constraints in the design and development process. The issues identified in this report will impact the implementation of a long duration manned space flight program in many ways. Some of the causal effects are readily identifiable while others may not be seen until later in the system life-cycle. The issues can have direct effects on the system parameters or indirect effects in which changes to a system parameter will affect other system parameters. These synergistic effects can intensify the effect of the issue to the system life-cycle.

The physiological and psychological capabilities and limitations of the crew will be an important factor affecting the design and development of the system. The success of the mission will depend upon the ability of the crew to perform its assigned tasks and functions. The effects of the spacecraft and space environments on the human component is not fully understood, but will likely have a significant influence on crew behavior and attitude, thereby influencing the system performance.

The availability of technologies and procedures to accommodate the personnel constraints placed on the system will be essential to the successful implementation of the spacecraft system. However, the costs associated with the development of the advanced technologies will exacerbate the long-standing dispute between the manned and the unmanned space exploration proponents concerning the allocation of the NASA budget.

The environment for a manned spacecraft includes the social environment that develops as a result of the interactions of the crewmembers. The U.S. space program has not typically considered the social environment as a significant aspect of short duration missions. However, as the mission duration increases, the social environment will become more complex and critical to mission success. The group dynamics that develops as a result of crew interaction with each other and the rest of the system must be accommodated. Groupthink is a phenomena which may develop in a highly cohesive group that is isolated from outside sources of information, such as the crew of a long duration manned spacecraft. When internal disagreements disappear and the group members do not realistically evaluate alternative courses of action when responding to a situation, groupthink is said to occur. Increasing the exchange of information between the crew and Earth can reduce the risk of groupthink developing. The design of the communication subsystem should consider the importance of timely, rich, and consistent information flow to the proper functioning of the crew. The crew training program can also reduce the risk of groupthink developing by implementing techniques for interpersonal communication that minimizes the opportunities for a breakdown in the flow of information between the group leader and the team members.

The isolation of the long duration spacecraft will require an increased reliance upon automated spacecraft subsystems. The man/machine interfaces (MMIF) must allow the human to obtain a status of the system and to intercede in the automated functions when required. The degree of automated versus manual control of the spacecraft and the

MMIFs must be defined in a manner that makes the best use of the capabilities and limitations of the humans and the equipment, within safety and budgetary constraints.

The logistic support system must also be compatible with the isolation and autonomy of the spacecraft and its crew. The operation and maintenance of the hardware and software must be accomplished with on-board spares and consumables. There is no opportunity to return hardware to Earth for maintenance or to replenish inadequate consumables. The operational procedures must be designed to match the skill levels of the crew and the training process should facilitate the learning process by accommodating the capabilities and limitations of human memory.

The spacecraft system performance could be enhanced if the similarities and differences among the psychological and sociological theories could be understood. The inconsistencies among the sociological and psychological points of view reduces the influence of the social environment on the design and development of the system. This report proposes the development of a crew/system interactions model (CSIM) which would attempt to integrate the causal relationships of the social environment into a simulation of the spacecraft system. The key system parameters could then be identified and studied, perhaps using the proposed NASA/NSF Antarctic Analog, to achieve a synthesized theory which would demonstrate the importance of crew behaviors and actions on the performance of the system. This model could be used to develop systems thinking in the crew of the long duration manned spaceflight system, which will improve the performance of the system.

Planning is the key to successful systems engineering. The advanced planning that is performed during the conceptual design phase will enhance the ability to control and integrate the engineering activities and enables a synthesis of the data and analysis requirements into a single set to facilitate effective and efficient resource utilization and decision making.

This report has assessed potential impacts of important systems issues on a long duration manned spaceflight system. To control and/or to mitigate the overall effects of these issues, it is crucial that they be addressed in the conceptual design phase of the system life-cycle process. By focusing attention on areas that need management attention and advanced planning, this report has provided a preliminary step towards resolving the systems issues. The future activities and research discussed herein also provide guidance by suggesting an approach for addressing these issues.

The systems constraints can hinder the implementation of a systems perspective by encouraging compartmentalization of the various phases of the system life-cycle process. Resistance to change will be encountered when established policies and organizations are challenged, but it must be overcome before the systems perspective is adopted. Innovative approaches to resolving the system issues will require an approach which looks beyond the established current mode of operations and considers the big picture and how the entire system can be improved.

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VITA

Kathy S. Upshaw received a B.S.E. in Mechanical Engineering from the University of Alabama in Birmingham in 1982. She began work for the National Aeronautics and Space Administration (NASA) in Huntsville, Alabama at the Marshall Space Flight Center (MSFC) in the Engineering Analysis Division in July 1982 and spent the first two years in the Professional Intern Program. Assignments included performing thermal and stress modeling and analysis. In the spring of 1984, she participated in the Space Station Skunk Works activity to prepare the Phase B Request for Proposal. In the fall of 1984, she transferred to the Space Station Division within the Systems Analysis and Integration Laboratory (SAIL) where she assisted in the development of conceptual designs and requirements documentation for Space Station systems and critical end items. She also participated in formal reviews, including the Source Evaluation Boards (SEB) for the Phase B and Phase C/D contracts.

In 1988, she transferred to the Space Systems Chief Engineer's organization to work for the Chief Engineer for Space Station in the Systems Engineering Office, where she is currently working. She performs a variety of systems engineering functions, including serving as the Space Station member on the Materials Application Evaluation Board

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Beginning in fall of 1987 through the fall of 1989 she attended evening classes at the local extension of the Florida Institute of Technology (FIT), working towards a Master of Science degree in Systems Management. In 1991, she was approved to spend a year in full-time study and beginning in the fall of 1991 attended classes at the Virginia Polytechnic Institute in Blacksburg to obtain a Masters of Science degree in Systems Engineering. In August 1992, she returned to MSFC and continues to work for the MSFC Space Station Chief Engineer.

She hopes to progress further in MSFC management to achieve more personal responsibility for the quality and performance of space systems. She also plans to pursue her academic studies to develop more proficiency in the applications of systems dynamics to space systems, particularly the effects of the social dynamics that develop during manned missions.