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THE HUMAN ROLE IN SPACE

Volume III
Generalizations on Human Roles in Space

DR-4

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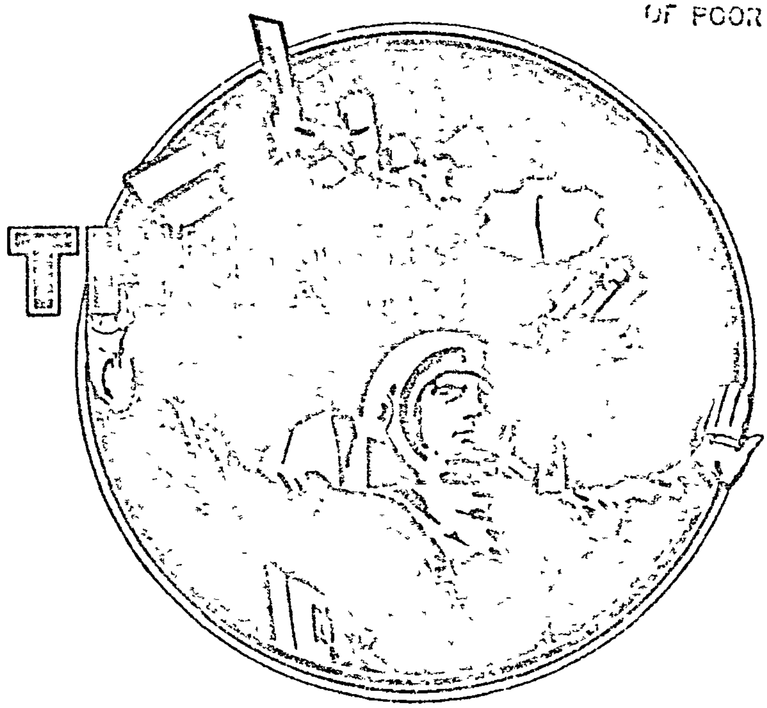

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PREFACE

The Human Role in Space (THURIS) study was a 12-month effort to (1) investigate the role and the degree of direct involvement of humans that will be required in future space missions; (2) establish valid criteria for allocating functional activities between humans and machines; and (3) provide insight into the technology requirements, economics, and benefits of the human presence in space.

The study started in October of 1983 and was completed in September of 1984.

The final report has been prepared in three separate volumes:

Volume I - Executive Summary
Volume II - Research Analysis and Technology Report
Volume III - Generalizations on Human Roles in Space

This document is Volume II in the series. It is the technical report of the work accomplished and contains the data and analyses from which the study results were derived.

The study results are intended to provide information and guidelines in a form that will enable NASA program managers and decision-makers establish, early in the design process, the most cost-effective design approach for future space programs, through the optimal application of unique human skills and capabilities in space.

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CONTENTS

Section 1
HUMAN ROLES IN FUTURE SPACE SYSTEMS

Thirty-seven generic activities have been defined in the THURIS study that can in turn be used to describe the operational sequences required in a broad spectrum of the potential space missions foreseen for the coming decades. For reference purposes, a brief description of each of the 37 generic activities is presented in Appendix A and a tabular summary of the human sensory/perceptual, intellectual, psychomotor, and motor capabilities that are required to perform each of the generic space activities is presented in Appendix B.

To illustrate the human performance potential for accomplishing these activities in future space systems, we have selected examples from the accomplishments of previous space flights. Appendix C presents a summary of these data.

From actual space flight experiences such as those illustrated in Appendix C, and from an understanding of the basic human capabilities and limitations, as summarized in Volume II of this report, the potential roles of humans in space can be defined for the benefit of the system designer. The designer can then weigh the advantages and disadvantages of direct human involvement in any specific mission operation and select the optimal man-machine mode for accomplishing his objective.

In order to gain further visibility into the specific activities that will be important in each functional element of future space systems and to thereby identify the human roles in these future systems, the THURIS study team examined the space mission descriptive data generated for the emerging Space Station Mission Model as developed by the NASA Mission Requirements Working Group (MRWG). The MRWG was a part of the 1983-1984 Space Station Task Force at NASA Headquarters assigned the responsibility for defining mission models, schedules, and operational requirements for the 1991-2000 time frame.

The 37 generic activities defined in the THURIS study were correlated with 16 space station mission parameters. These parameters included (1) the location of the work , i.e., intravehicular activities (IVA) or extravehicular activities (EVA); (2) the involvement of the crew with the mission equipment (e.g., initial setup and checkout, daily routine operations, periodic operations other than daily, maintenance of mission equipment, repair operations, and response to change and unexpected events); and (3) the places where the work is performed relative to eight space station functional elements. These space station functional elements include pressurized modules, attached payloads in unpressurized areas, command, control and communications (C^3) functions; deployment/construction/assembly functions; proximity operations; and payload staging for return to Earth. The eight functional elements defined by the MRWG are summarized in Table 1.

The results of correlating the generic activities to the space station mission parameters are presented on Figure 1. An entry in the body of the matrix indicates that for a particular generic activity and mission parameter intersection, a mission-related need is established. Inspection of the number of mission parameters associated with each of the activities shows that all the activities are required to support future missions in one context or another and 30% are required in nearly every context (11 out of the 37 activities in most demand, as indicated by a count of 15 or 16 in the total column of the matrix). Those activities that appear to be most frequently required are adjust/align elements; communicate information; confirm/verify procedures/ schedules/operations; gather/replace tools/equipment; implement procedures/schedules; inspect/observe; position module; problem solving/decision-making/data analysis; release/secure mechanical interface; transport loaded; and transport unloaded. From these data, it can be concluded that the human role in future space operations will be a very real and necessary one. Further examination of some of the specific research projects in the MRWG Mission Model provides insight into some of the specifics of this role.

Table 1

MANNED STATION ELEMENT FUNCTIONS

1. Pressurized Laboratory
A pressurized crew station module will provide power, low-gravity, and long-duration crew support for conducting laboratory work and operational support. Payload elements may be integrated directly into the module.

2. Attached Payloads
Provision will be made to accommodate payload elements exterior to the pressurized module. Limited resources plus periodic crew tending and servicing will be provided. Resources could include command, control, and data handling.

3. Command, Control, and Communications Support
Provisions will be made within the space station system to remotely command, control, monitor, throughput, and preprocess data for free-flyers and platforms.

4. Deployment, Assembly, Construction
The space station system will provide support capability for construction, assembly, and deployment. This support implies all required service devices, such as manipulators and manned maneuvering units (MMUs).

5. Proximity Operations
Payloads capable of maneuvering themselves within a reasonable distance of the station will be maintained, serviced, and checked out. Reasonable distance is defined as that limited by the capability of the extravehicular mobility unit (EMU) or a small proximity operations vehicle (POV).

6. Remote Maintenance, Servicing, Checkout, and Retrieval
Payloads remote from the space station can be maintained, serviced, and checked out via a remotely operated service vehicle. Servicing could be provided on the payload at its locations or the payload could be retrieved, serviced, and returned. The space station likewise provides for commanding, controlling, maintaining, and servicing the service vehicle.

7. Payload Integration and Launch
Payloads and satellites requiring transfer to other orbits can be brought to the space station by the Shuttle Orbiter, integrated with a transfer stage, and launched. The transfer stages could be commanded and controlled from the space station. These stages could be either expendable or reusable. Reusable transfer stages can be based at the space station, serviced, maintained, and refueled. Expendable stages could be stored and serviced.

8. Payload Staging for Return to Earth
Payloads, experimental samples, or captured samples requiring return to Earth can be demated, prepared, and stored until placed in the Orbiter for return to Earth. This function also includes the preparation of payload equipment for return at the conclusion of its mission.

GENERIC ACTIVITIES	Space Station Mission Parameters																
	Location		Crew Activities						Space Station Functional Elements								
	IVA	EVA	Initial Setup	Daily Activities	Periodic Activities	Maintenance	Repair	Respond to Change	1 Press Module	2 Attached Payload	3 C^3	4 Deploy/Constr	5 Prox/Ops	6 Remote Ops	7 Payload Integ	8 Staging/Return	Totals
1 Activate/Initiate System Operation	X	X	X		X	X	X	X	X	X	X		X	X			12
2 Adjust/Align Elements	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16
3 Allocate/Assign/Distribute	X	X	X	X	X	X	X	X	X	X	X			X		X	13
4 Apply/Remove Biomedical Sensor	X		X	X	X				X								5
5 Communicate Information	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16
6 Compensatory Tracking	X			X	X			X	X	X	X			X			8
7 Compute Data	X			X	X	X		X	X		X						7
8 Confirm/Verify Procedures/ Schedules/Operations	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16
9 Connect/Disconnect Electrical Interface	X	X	X			X	X	X	X	X	X		X	X	X	X	13
10 Connect/Disconnect Fluid Interface	X	X	X			X	X	X	X	X	X		X	X		X	12
11 Correlate Data	X			X	X	X	X		X		X						7
12 Deactivate/Terminate System Operation	X	X			X	X	X	X	X	X	X		X	X			11
13 Decode/Code Data	X			X	X				X		X						5
14 Define Procedures/Schedules/ Operations	X				X	X	X	X	X		X						7
15 Deploy/Retract Appendage		X	X		X	X	X	X	X	X	X	X		X	X	X	13
16 Detect Change in State or Condition	X	X		X	X	X	X	X	X	X	X			X	X		12
17 Display Data	X		X	X	X	X		X	X		X	X		X	X		11
18 Gather/Replace Tools/Equipment	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	15
19 Handle/Inspect/Examine Live Organisms	X		X	X	X				X								5
20 Implement Procedures/Schedules	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16
21 Information Processing	X	X		X	X			X	X	X	X		X	X		X	11
22 Inspect/Observe	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		15
23 Measure (Scale) Physical Dimensions	X	X		X	X		X	X	X	X				X			9
24 Plot Data	X			X	X	X			X		X						6
25 Position Module	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16
26 Precision Manipulation of Objects	X	X	X	X	X	X	X	X	X	X		X	X				12
27 Problem Solving/Decision Making/ Data Analysis	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	15
28 Pursuit Tracking	X	X		X	X				X	X	X			X			8
29 Release/Secure Mechanical Interface	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16
30 Remove Module	X	X		X	X	X	X	X	X	X	X		X	X	X		13
31 Remove/Replace Covering	X	X		X	X	X	X	X	X	X	X	X	X	X			13
32 Replace/Clean Surface Coating	X	X			X	X	X	X	X	X							8
33 Replenish Materials	X	X	X	X	X	X	X	X	X	X	X						11
34 Store/Record Element	X	X		X	X	X	X	X	X	X	X			X	X	X	13
35 Surgical Manipulations	X			X	X			X	X								6
36 Transport Loaded	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16
37 Transport Unloaded	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	15

Figure 1. Correlation of Generic Activities and Space Station Mission Parameters

The Advanced Solar Observatory (ASO) mission is one of the more complex of the missions described in the MRWG data set. The payload equipment includes the solar soft X-ray telescope, the pinhole occulter, and the solar optical telescope. Assigned to be accommodated by a co-orbiting platform in an inclination of 28 1/2 degrees, the payload will be periodically maintained and refurbished by a station-based remote servicer. As an option, the payload could also be accommodated as a free-flyer or as a space-station-attached payload. Other options being evaluated include final assembly and checkout at the station before placement in operational orbit.

The two station crewmembers assigned to the mission will need to be specially trained and will operate 8 hours each day. The crew will view three video displays at an IVA work station for real-time operation of the mission. In order to enable and enhance the scientific objectives of the mission, the design of the crew work station that supports this mission needs to be efficient from an operator's point of view, user friendly from a man-machine intellectual interchange point of view, and "expert" from an information sharing and data recall and exchange points of view.

The Advanced Solar Observatory illustrates a key point. As the sophistication of future payloads increases, there will be an accompanying shift in crew support skills/requirements. A transition occurs from the more physical tasks to the more intellectually oriented work activities with the progression of time. This pattern appears to be analogous to the industrial development dynamic, wherein the blue collar worker changes to a white collar worker as the transition from production of goods to provision of services takes place.

An MRWG mission even more complex than the ASO is the Solar Terrestrial Observatory (STO). As defined by the MRWG, this mission is planned for a first flight in the 1991-1992 time frame, with a mission duration of 730 days. The STO mission calls for operations of 90 days per year or about 1 week each month. The general objectives of the mission are to study space plasma atmospheric interactions using observations of natural and induced atmospheric emissions, and to exploit the natural plasma laboratory of space. The specific objectives are to investigate the influence of an electron beam, an arc jet, and a neutral gas plume on the high-altitude atmosphere, including the production of artificial aurora. In addition, radio waves are transmitted from the payload in the HF and VLF bands and received in the HF band. Atmospheric effects in the visible and UV are to be observed with a video camera. Solar monitoring instruments are also planned to be included, as well as an X-ray telescope.

In order to appreciate the complexity of the STO mission, it is appropriate to describe the elements of the payload. The objectives are met by an electron beam of energy 1 to 20 kev, with 1 to 25 kilowatts of power; a helium or argon magneto-plasma-dynamic arc jet with 2 to 10 kilograms per pulse, 250-ev particle energies; a charge current probe from the OSS-T satellite; and possibly a neutral gas plume. This collection of science instruments is called SEPAC, (Space Experiment with Particle Accelerators). The electron beam accelerator (EBA) will be designed for ultimate power levels of some hundred kilowatts, allowing for substantial growth in objectives. The power-radiating radio frequency facility is called WISP (Waves in Space Plasma) and consists of a VLF transmitter operating in the 1- to 30-kilohertz band, an HF transmitter and receiver operating from 0.1 to 30 megahertz. The dipole antenna subsystem radiates VLF and HF and receives the HF signals. Antenna elements extend 150 meters in each of two opposite directions, with tip-to-tip distance of 300 meters. The common operating research equipment assembly controls antenna retraction and extension.

The complete payload package includes the SEPAC, WISP, and AEPI (video camera) instruments together with a Solar Monitor package and the X-ray telescope. Subsatellites and instrument probes are also required. The payload is visualized as being contained on one or more pallets that include the science instruments, an antenna support structure, and a berthing adapter assembly for attachment to the Space Station. Integration hardware for providing power, thermal control, signal transfer, and electrical distribution is assembled on the pallet(s). The integration hardware includes an active thermal loop.

The baseline scenario of about 1 week per month of intensive operation of SEPAC and WISP assumes that one (SEPAC or WISP) is in a passive mode while the other is active. Coordinated (interleaved) pulses of SEPAC and WISP would be desirable. A growth option includes operation of SEPAC and WISP at the same time, if resources permit. The video camera is included primarily for observing the effects of SEPAC and WISP. It is required for all SEPAC operations and some WISP operations. The camera is normally pointed along the magnetic field toward any auroral spot formed by emission from the SEPAC and/or WISP units. The camera is to be controlled by the Space Station crew.

An operator's console within the pressurized elements of the Space Station is visualized as being used to monitor health and safety of the mission equipment, to provide quick-look data reduction, and to issue commands. Support equipment for SEPAC and WISP is to be mounted at the crew work station in addition to the control electronics for these instruments and for the SUSIM, the X-ray telescope, and the AEPI. Displays are to provide output data, including the video results from AEPI. The operator's console will also be used to control instrumented sub-satellites. Crucial to the success of the mission will be the efficiency of the functional and operational interfaces between crew and mission equipment, as embodied in the selection and implementation of the design features of the work station.

As the emphasis changes in the workplace, as illustrated by the ASO and the STO missions, the design of the crew work stations must also change to reflect the change from the physical to the intellectual. To more effectively utilize human intelligence, a better match is required with machine intelligence and with "expert" systems.

The successful implementation of the MRWG Advanced Solar Observatory and Solar Terrestrial Observatory missions will be highly dependent upon the development of work stations that (1) Communicate fluently with humans (speaking, writing, drawing, etc.), (2) assist in interactive problem solving and inference functions (deductive reasoning), and (3) provide knowledge base functions (information storage, retrieval, and "expert" systems for support).

In order to develop these work stations of the future, however, a better understanding is required of human intellectual capabilities and how they function in different operations (such as convergent production, divergent production, memory, cognition, or evaluation) and with different contents (such as pictorial or figural, symbolic, semantic, and behavioral elements) in order to obtain specific products (implications, transformations, etc.). Even when people don't speak the same language, they can communicate to some degree using gestures, facial expressions, etc., because they share common biological structure and needs, and common patterns of thought and behavior and knowledge of the world. A more "natural" language is needed for communication between man and machines using interfaces that are congenial and transparent for the average person. Voice interactive controls and displays offer considerable promise in this respect.

With regard to the issue of technological readiness to support the human role in future space operations, it would appear that the EVA-enabling technologies as currently planned are well designed to support the scheduled space station IOC in 1991. This view is further supported by the fact that the EVA equipment, for the most part, is of the "carry-on" as opposed to the "built-in" character. Carry-on equipment items are more easily accommodated than are mission and payload equipment items, which must be incorporated in the basic station design. For this reason carry-on items can be integrated into the station build-up sequence later in the life cycle than can mission and payload equipment items.

In contrast with the EVA technologies, the IVA technologies are an integral part of the basic design of the space station. At the outset, this would suggest that the IVA capabilities and work stations would need to be frozen in design several years before the start of the buildup and launch sequence for the station modules and elements. On the other hand, these work stations must be designed to be capable of meeting the needs of a continually changing set of mission requirements, some of which (for example, the ASO and the STO missions) will place an extremely complex set of operational demands on the control and display configurations of the work station. This scheduling consideration strongly suggests that a technological gap exists in the work-station-related projects and planning. It is further suggested that these IVA-related technology developments need to be focused on designs that are adaptive and transparent to emerging design improvements, allowing for both hardware and software updates to be made to the basic work station even after the work station is operational.

The human being represents a remarkably flexible and adaptable system. The human can learn to operate and function effectively in many nonoptimal work environments. It has been said that system designers often use the human component in a man-machine system as a glue to hold the rest of the system together. The real issue to be considered in the development of improved work stations is to identify ways to increase the productivity of the human in order to enhance his value to the mission.

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Section 2
FACTORS AFFECTING CREW PRODUCTIVITY

In terms of his basic capablities and limitations, man is essentially invariant. In terms of basic abilities, people will not be much different in the year 2050 than they are today. Recognizing this constancy in sensory, perceptual, intellectual, and psychomotor abilities, the real issue will be to improve productivity through (1) hardware and system improvements that can enhance human performance, or (2) procedure and operational changes that will allow more effective use of the human element in the man-machine systems of the future.

We recognize that many different factors will have an impact upon crew productivity. In this section we offer comments on a few of the specific issues that should be considered when designing advanced space systems in order to enhance the human role in space.

2.1 INTERNAL ARCHITECTURE

2.1.1 Workplace Layout

In developing recommendations for the optimal configuration and arrangement of manned modules and individual crew work stations to enhance productivity, the following considerations must be taken into account: anthropometrics; foot, hand, and/or body restraint systems; traffic flow; materials handling; social interaction; safety; lighting; hygiene; sound transmission and noise control; and adaptability and growth potential.

The objective in work station design, as with any workplace development effort involving limited space, should be to achieve optimum use of the interior space, based on priorities of spatial needs and human factors design principles.

Work stations oriented radially about the interior of the module (e.g., Skylab Multiple Docking Adapter) may be more space efficient than arrangements with a floor and ceiling, where all work stations are oriented using the floor and ceiling as consistent points of reference (e.g., Skylab Orbital Workshop and Spacelab). However, moving from work station to work station in the former configuration is considered more confusing than in the latter because of the lack of visual cues afforded by the floor and ceiling. Space volume utilization versus a standardized frame of reference for ease of orientation is an important issue to be resolved.

Another consideration in workplace design is the issue of multiple-use work stations versus dedicated work stations. Reducing the number of work stations and using multipurpose, reconfigurable work stations would save space, but it might force the crew to work in shifts, adhere to work station use schedules, and spend time reconfiguring the work station. Depending on the circumstances, this might be an inconvenience, disrupting sleeping crewmen and increasing time required for work station setup. Because of the obvious need for redundancy, especially in critical life-support systems, the resolution of this issue will require the development of an acceptable compromise between the two approaches.

2.1.2 Traffic Flow

Traffic flow through any manned module will be a major consideration in enhancing human productivity.

Certain major considerations should be taken into account in establishing a traffic flow system. First, traffic frequency should be considered a major criterion in developing a flow pattern. Once traffic needs for various crew work stations have been determined, a flow pattern must be developed that provides maximum efficiency of travel between work stations with a minimum of negative interactions occurring between those traveling through modules and work areas, sensitive areas (sleep, hygiene, etc.), and/or other traffic.

Second, the mass being transported through the work area must be considered. Flow patterns should minimize the distance large masses are transported, reduce as much as possible the congestion caused by large masses transported through tight areas, and reduce the frequency of transport.

Third, redundant paths of traffic flow should be considered. There are several reasons for this, the primary one being safety. In the event of a failure (fire, decompression, etc.) of one module, it would be necessary to avoid that module in getting to other work stations. Other reasons justifying redundant paths include the need to avoid general congestion or to avoid sensitive experimental areas, sleep areas, or hygiene areas.

2.1.3 Storage and Stowage

The storage element affects human productivity because retrieval and replacement of items necessary for work-related activities always bear a time consumption penalty. Sufficient volume must be allocated as storage space, but design of other systems may tend to drive the amount of storage space and its location. It is important that human productivity be included in any trade studies that concern storage. Specifically, optimizing the crew interface in the sense of locating, retrieving, and replacing stored items is the issue; factors to be considered should include the following:

- Optimization of storage location relative to crew use of stored items (centralized storage versus local mini-storage versus automated retrieval and replacement)
- Unique stowage methods to optimize storage volume use.
- Inventory information providing location, quantity, use rate, and shelf life
- Handling of used materials, such as trash and waste

Although past experiences in Skylab and Shuttle will provide useful data, storage system(s) in future space systems may prove to be substantially different due to the consideration of human productivity. Approaches for the storage system may include:

- Arrangement of storage to make items that are frequently used easily accessible
- Provision of a system of mini-storage near the use areas
- Use of centralized storage with automated retrieval and replacement

2.1.4 Other Architectural Factors

Some of the other specific internal architecture issues that affect human productivity are as follows:

ISSUES	DESIGN OR OPERATIONAL FACTORS AFFECTING PRODUCTIVITY
Diameter and length of modules	Noise control; space utilization; number of connecting tunnels and hatches
Number and placement of windows	Loss of wall space; crew preference or attitude; recreation source; light source
Interior partitions	Grouping; noise control; additional wall space
Reconfigurable versus fixed work stations	Scheduling conflicts; multiple shifts; reconfiguration time; contingency operation
Solid floor versus grid or open structure	Air flow; noise level
Floors and ceilings versus open area	Noise levels; visual cues; isolation and privacy; air flow
Noise control - Affecting sleep/rest - Affecting work - Affecting communications	Insulation; deflection; dampening; masking; minimize at source
Spatial requirements for work stations	Rigid construction; flexible (infrequent changes); reconfigurable (daily changes); combinations; optimum versus minimum requirements of volume
Restraint systems - Personnel - Equipment/materials	Passive; active; hybrid solutions
Anthropometrics - Work stations/devices/table(s) - Common areas - Waste management/hygiene facilities - Passageways	Design for full range of human variation; design for restricted range of variation; design with adjustable or flexible approach

2.2 CREW SUPPORT

2.2.1 Personal Hygiene

In addition to the obvious environmental support requirements such as pressure, temperature, humidity, etc., personal hygiene equipment, materials, and methods are critical for the physiological and psychological welfare of crewmembers. Key systems include:

- Body waste management - collection of urine, feces, menstrual fluids, perspiration, and vomitus
- Body cleansing - frequent bathing of hands or body parts, whole body, and hair and scalp
- Oral hygiene - daily care of the teeth and gums
- Personal grooming - body hair removal by cutting or shaving, hair combing and brushing, nail cleaning and trimming; skin care using lotions, antiperspirants, perfumes, and cosmetics

To maximize crew productivity, personal hygiene equipment must be designed to minimize crew time required for use, operation, and maintenance, and to preclude return of odors, particulates, biotic contaminants, or toxic gases to the spacecraft atmosphere. Significant engineering development effort will be needed to arrive at a washing system that is satisfactory for long-term use in the weightlessness of space. The amount of water used for washing will be as important a problem as controlling where it goes.

Some important ground rules for future manned systems are as follows:

- Facilities and provisions for collection of body, personal cleanliness, and grooming should be as near earthlike as possible.
- The system should provide for whole-body bathing every 3 days, with multiple daily hand and face washing for each crewmember.
- Waste water from bathing and other washings must be collected and stored in waste water tankage, or recycled.
- Fecal waste should be collected and stabilized by drying before storage and return to Earth in the logistics module.
- Fecal and urine collectors must be compatible with both male and female crewmembers.

• Absolute privacy during bathing and other personal hygiene activities should be available.

• Contingency fecal and urine collection systems must be provided for use in the event of failure of the nominal body-waste collection system.

• Personal grooming supplies from commercially available sources can be provided for the exclusive use of each crewmember. Personal preference selection should be accommodated when feasible.

Previous space flight programs have identified the importance of personal hygiene equipment and materials: collection, and storage of body waste (feces, urine, vomitus) is essential to life support, while the equipment and method of collection affects productivity and morale.

The most complex system in the personal hygiene area is that of collecting, storing, and disposing of feces and urine. Most of the problems result from the microgravity environment and the inherent difficulty associated wih handling liquids and semisolid materials outside of closed containers. Accidental escape of urine and/or feces into the cabin environment is esthetically revolting, biologically hazardous, and could damage or degrade performance of other equipment and components.

Whole-body bathing presented a problem for Skylab crewmembers in that the equipment required too much time to set up and tear down after use. Also, the method for water removal from the skin (hand held vacuum cleaner) was not satisfactory. However, the crews did appreciate the opportunity for whole-body bathing, in spite of the fact that they did not "feel" dirty.

An analysis of Skylab reports indicated that while sponge baths are adequate for cleaning the skin on long-duration missions, they are inadequate for cleaning the hair and scalp. Also, sponge baths lack the psychologically refreshing value of full-body showering. When the Skylab crew did actually devote the hour or so required to set up and then clean and secure the collapsible on-board shower, they felt invigorated. The inordinate time requirement, however, may have significantly eroded the positive effect on productivity.

The design and location of hand-washing equipment requires additional design and evaluation effort.

Studies must be performed to ensure that the personal hygiene system will meet crew requirements and mission constraints. The main tradeoff to be conducted will be between development costs, which must be paid early in the program, and the estimated costs of lowered crew productivity, which are both contingent and deferred. An important concern will be to minimize the amount of water used for personal hygiene. A substantial reduction in water inventory, with consequent savings in hardware and launch costs, is possible by optimizing crew washing or bathing systems.

A trade study also needs to be performed to evaluate program costs for a waste collection equipment that will perform with high reliability and will require only limited maintenance for several years in orbit compared to a system that will be designed for return to Earth for refurbishment on the logistics shuttle. Another trade study that is vital to this program element is that of urine and feces storage and disposal techniques and equipment.

2.2.2 Lighting

The type and design of the lighting system for work stations and space facilities can have a decided effect on the productivity of the crew. Excessively bright sunlight or artificial light, either direct or reflected, could be potentially damaging to the eyes of crewmembers. Poor lighting can result in mistakes and misinterpretation of written communications, instrument readings, and command and control displays. Poor lighting can also lead to eye strain and fatigue, which slow down and impair general mission performance. Glare and excessive adaptation to light changes can result in exacerbating any stress reactions, thereby further impairing long-term performance. It is also necessary to define the proper lighting environment for different work tasks and living activities, including recreation and sleep.

Different light sources have unique spectral and intensity properties that must be factored into the overall lighting design. The color and reflectance of the surrounding surfaces around the work station must be considered, as well as the location and interaction of various light sources to produce general diffuse lighting, overall work station lighting, and specific lighting for unique experimental setups and industrial processes. For example, experimentation in space may require unique color rendition or surface texture rendition for monitoring the progress of critical experiments. Such specialized perception may not have been needed in the more conventionally instrumented environments of previous missions. CRT image quality, analog and digital instrument readout quality, and visibility of flat panel and other state-of-the-art display sources must also be taken into account.

2.2.3 Health Maintenance

Exercise is a critical concern on long-duration space missions and it directly affects work load analyses and work/rest scheduling. Due to the many effects of muscle atrophy and bone decalcification characteristic of microgravity environments, special attention must be devoted to defining specific forms and amounts of exercise. Many of the required data are already available from previous space missions, in particular the Skylab series. Further work is required, however, in order to establish the most efficient forms of exercise in terms of time demands as well as to deal with the psychological aspects of exercise. That is, what appears to be required is to develop methods of exercise that make efficient use of time and are less boring and more motivating than those that have been employed or proposed for astronaut use.

Based on a review of the Skylab's archives, it has been suggested that exercise be made more recreational. The suggestion of the Skylab crews was quite simple: place the ergometer in front of the window. Clearly, this would serve to motivate some crew members. Additional measures must be developed, however, to ensure variety of experience and long-term motivation. Alternative solutions might involve bicycle ergometers, with tunable CRTs displaying recorded scenes of famous bike paths of the world, feature films, or other programming. Competition might be used as an effective motivator by maintaining station physical ability and performance records--or at least individual performance records. In this regard, zero-gravity physical games (perhaps played in jumpsuits fitted with bungee cords) may serve as appropriately motivating activities as the station matures. Also, the relative merits of group versus individual exercise must be evaluated.

2.2.4 Food and Water Systems

The most important aspect of a food system is measured in terms of its ability to meet biochemical requirements for maintaining the health of the individual in a particular environment. In broad terms, the design philosophy for any food system is to provide nutrients for adequate diets in a form or manner that ensures palatable food that is safe, easy to prepare and consume, and is time efficient in terms of quick cleanup and maintenance.

An important set of factors affecting diet selection is found in the role of food as an element of psychological well-being. Individual patterns of food intake are rarely based upon physiological need. Physical hunger for food and emotional needs for gratification are frequently intermixed. Sensory pleasure derived from eating is often substituted for other physical and emotional needs. Elimination of this source of sensory pleasure in persons confined to long-term space stations is contraindicated if positive social interaction, morale, and work initiative is to be maintained.

Also, changes in a crewmember's ability to detect some food flavors have been reported sporadically throughout the manned space flight programs of the US and the USSR. If these changes in taste perception do exist in some individuals, the problem needs to be resolved before food is selected for future space missions.

The palatability of the food and the crew's acceptance of meals over a period of a month or more requires that this area receive special consideration. High-quality food service relies upon food that can be consistently prepared and served day in and day out without detectable change in taste, appearance, aroma, or texture. This characteristic is self-defeating when a population is confined to consuming food that is so highly reproducible and consistent in organoleptic quality. All institutional food becomes monotonous at some point in time. The challenge in building food systems for long-term space flight is to delay that point at which the food becomes monotonous.

Food safety is usually expressed in terms of microbiological organisms measured in sample food lots. These measurements have been standardized in the space program and in commercial practice and do not appear to offer any unusual challenges to the assembly of food supplies that are safe for consumption over long periods of time.

2.2.5 Communications Systems

The type and quality of the communication system can have definite effects on the performance and productivity of the crew. Man's most important role in space is to take care of the unforeseen, to execute complex reasoning and judgment tasks, to troubleshoot, and to bypass possible equipment malfunctions. All these tasks require a high degree of communications both within the manned space facility and with Earth. A poor communication system can result in mistaken instructions or incorrect information ruining certain experiments or industrial processes. Awkward or cumbersome communication equipment or procedures can slow down the effectiveness of crew members and create a wasteful information float where important communications are unnecessarily delayed. Such delays can be disastrous in the case of emergency communications. A communication system that is not user friendly and well human-engineered can lead to frustration and fatigue, which can further impair the crew's overall performance on other tasks.

Thus, it is essential that a carefully engineered communication system be designed for future space missions that takes into account the unique features of a shirtsleeve laboratory environment in space. Some of the factors that must be considered are the highly reverberant and sometimes noisy environment within the modules, the unique needs for privacy and proprietary information transfer concerning industrial processes, organizational and hierarchical communication structures that will enhance the collective productivity of the entire crew, and hardware and procedures that are appropriate for a shirtsleeve environment with a variety of disciplines in a less structured crew situation than has prevailed in previous missions.

2.2.6 Housekeeping

Housekeeping for future space missions includes trash management and the cleaning of work stations and living areas. It is an element that has significant impact on human productivity inasmuch as it is a direct charge to overhead and reduces crew time available for system operations and experiments.

On Skylab and previous Shuttle missions, crews have spent considerable time performing housecleaning tasks and managing the trash (ref. "Lessons Learned on Skylab Program", NASA-JSC, March 6, 1974 and Task Order 55, "Housekeeping/Trash Management", Contract NAS9-16589). Those tasks that pose the greatest impact on crew time should receive the highest emphasis as the initial list of housekeeping issues affecting human productivity is being derived.

2.3 CREW ACTIVITIES

2.3.1 Crew Training

In the area of crew training, future missions will present challenges that have not been encountered on previous missions. Although the Skylab flights were for extended periods (up to 84 days), the overall scale of the systems was more limited than can be expected for future space stations, both in size and operational complexity. Also, where Skylab astronauts had a single set of payload-dependent tasks, the future crews could be faced with a constantly changing array of payloads, and payload-specific training may occur on orbit as well as preflight. This is especially true for crew members with longer tours of duty in space. The training concepts must, therefore, consider not only preflight ground training but also familiarization and proficiency training in space.

The training needs for future crew members can be broken up into the following areas:

A. Crew Systems Operation - This includes all of the day-to-day operations required to carry on life at the space station, such as eating, sleeping, personal hygiene, and exercise.

B. Station Operations - This includes all the nominal day-to-day operations required to maintain the space station systems, such as life support, attitude control, energy management, navigation, etc.

C. Payload Operations - This includes all the nominal operations required to deal with the various payloads, such as installation and setup, experiment data gathering, sample retrieval and handling, removal and dismantling, etc.

D. Station Anomalies - This includes all the expected and unexpected repairs of space station systems that the crew will be required to perform.

E. Payload Anomalies - This includes all expected and unexpected repairs of payload systems that the crew will be required to perform.

The impact of the type of training required by the various different types of crewmembers upon productivity of the crew as a whole must be considered. Using these training requirements, the applicable methods for each type of training can be prioritized according to the time, cost, and training value. It is envisioned that the levels and types of training for the various crewmembers will require both current, standard training methods and new, state-of-the-art training methods.

2.3.2 In-Flight Maintenance

It is anticipated that crewmembers will be required to perform both scheduled and unscheduled maintenance actions. To do so, crewmembers should be provided with lucid instructions and trained to perform efficiently all routine actions. Unscheduled maintenance actions are more difficult to anticipate. Thus, crewmembers must be trained and familiar with appropriate systems and equipment regarding the safety and missions of the space station. Appropriate troubleshooting programs must be made available and certified in the early stages of equipment selection.

As an example of the issues to be considered, selected crewmembers could be trained on specific systems and equipment as specialists, or all crewmembers could be trained on all equipment and systems, or some combination of specialists and generalists could be established. In-flight maintenance can be scheduled during working hours as a part of the working day, or scheduled outside of production hours, or some combination thereof.

2.3.3 Planning and Scheduling Activities

A scheduling procedure should be provided that will yield the highest possible crew productivity when the schedules are actually implemented during a mission.

Efficient performance by the space crews will depend largely on how activities were planned and scheduled. Much has been learned in this regard during the Skylab and Spacelab missions.

Major impairments to productivity can arise as a consequence of crew fatigue. Also, poor scheduling could lead to crowded work areas and other forms of cross-interference among crewmembers.

On the positive side, optimum duty cycle and job rotation arrangements can ensure that crewmembers will have their peak energy resources available not only for crucial activities but for project continuity when they would otherwise be distracted by fatigue.

Attitudinal benefits are likely to be achieved if crewmembers are encouraged to participate in the development of the decision rules for scheduling. Likewise, some level of crew autonomy during the mission is likely to have positive morale effects. Insofar as such attitudinal factors influence actual productivity, that value can be maximized. However, such provisions must be balanced against the likelihood that the mission might need to be extended if an activity schedule is not fulfilled. Commercial clients could also become disaffected if their undertakings are not carried out at a designated time.

Another area, also, has not been adequately explored. Specifically, there is a common assumption that duty cycles should reflect the normal ground work schedule as closely as possible -- or if not, that rest periods should be inserted at frequent, regular intervals during the mission. These assumptions may fail to reflect the prospect of changes in the work relative picture and particularly the endocrine production pattern during the mission. For example, a reasonable hypothesis might be that, early in the mission, crewmembers should easily tolerate longer work periods because of their "excited" condition. If so, the duration of the work period should be gradually shortened over the total mission -- i.e., the change-of-shift frequency would gradually increase in tune with the changes in endocrine output and related factors. The tradeoff factor in such an arrangement would be higher aggregate work output versus the complexity of a nonconstant duty cycle schedule.

The effectiveness of manual operations in space has been demonstrated for planned, contingency, and emergency operations. The effectiveness of remote operations has been demonstrated for potentially hazardous situations requiring human intelligence. The effectiveness of automated operations has been demonstrated for completely deterministic situations, where all events that could occur during an operation are entirely predictable. Data show that autonomous operations for repetitive tasks will increase productivity, compared to manual operations for such tasks, freeing crewmembers to perform more challenging tasks. However, provisions must be made for crewmembers to verify automatic and semiautomatic operations, and to override such operations if contingencies arise.

Function allocations involve tradeoffs between productivity, risk, and costs (dollars, weight, volume). At one extreme, all functions that could be performed by machines could be so allocated, with crewmembers having to perform all other functions. Excessive costs would result, as well as increased probability of unreliable mission performance. No matter how carefully the automated machine is designed, unexpected events requiring human intelligence will arise and, when they do, crewmembers must be prepared to cope with them. At the other extreme, all functions that could be performed by crewmembers could be so allocated, with machines performing all functions beyond human limitations. However, excessive qualification levels and training times for crewmembers, exposure of crewmembers to excessive risks, and requirements for life support of unnecessary crewmembers would necessarily result.

2.3.4 Organization

Both individual competence and teamwork factors will contribute to crew performance. These factors interact in the actual accomplishment of most of the work activities (and, indeed, will permeate nonwork activities, such as food consumption and recreation, as well).

The interaction between organizational arrangements and the exercise of individual competencies for productive purposes can be illustrated by the problem of role assignment. If the assigned role of a crewmember does not recognize and permit the expression of the competence, the competence is effectively lost to the crew as a whole. Specifically, a work activity could be assigned to an individual with less competence than another available crewmember and a lower level of crew productivity would result.

The teamwork factors pose a more serious threat of potential impairments to productivity. For example, many studies of team productivity have revealed otherwise hidden impairments associated with the coordination process. The gross effect is made clear and simple when it is shown that productive output per member goes down as team size is increased.

On the positive side, it is also clear from studies of group productivity that social instigation can enhance productivity when the work activity requires creativity or inventiveness. Likewise, so-called synergistic effects are achievable when the unique cognitive resources of each team member are integrated by means of a completely shared conceptual framework. In such instances, each participant (crewmember) is able to program his or her contribution to the joint activity in such a way that the contribution comes at the correct stage of the activity sequence without the need for coordination curves or overt sequence control interventions.

In summary, organizational arrangements can have a profound effect on productivity. If the organizational arrangement is "wrong," even the high level of competence produced by the individual crewmembers will be blocked off from expression. If the organizational arrangements are "right," the crew as a corporate entity can transcend any individual limitations.

While there exists a good knowledge base on small group organizational arrangements and productivity, many of the potential tradeoffs have not been characterized in quantitative terms -- particularly in the specific context of future space operations. A useful example is provided by the question of cross-training. First, it can be assumed that there is an absolute requirement for some level of cross-training to meet contingencies related to crewmember accidental disabilities. The question is not only how complete such cross-training should be, but what positions and individuals should be cross-trained for what skills. Should cross-training be determined mainly by individual aptitudes or interests, or should each position on the crew have a preassigned cluster of backup functions? Since cross-training engenders tangible costs and it is unrealistic to expect all crewmembers to have complete mastery of every skill area, more mixing and matching will be essential. The ideal apportioning algorithm would incorporate all the values in a tradeoff matrix including dollar cost, aptitudes, role compatibilities, skill area criticality, etc.

Each prospective organizational arrangement will involve a complicated set of value tradeoffs that will need to be integrated in a composite tradeoff structure that will reveal bottomline cost and productivity relationships.

2.3.5 Crew Activities, Station Autonomy

A ground support group might be composed of mission control personnel, payload operations personnel, and principal investigators whose experiments are on board the spacecraft. Typical tasks incumbent upon the ground support team are:

- The general monitoring of experiment data.
- Controlling the experiments designed to be primarily unattended by the flight crew.
- Assisting the flight crew with maintenance and repair of the flight hardware and software.
- The general monitoring of crew activity to observe their physical and mental health.

The degree to which each of these functions is performed is a function of the crew-versus-ground autonomy, philosophy of the experiment design, level of expertise on the part of the crew and the ground support team members, duration of the mission, and how nominally the spaceflight is progressing.

Examination of the day-to-day requirements for Spacecrew-Ground Support Group interactions will lead to the identification and resolution of the critical issues impacting operational procedures, emergency procedures, and simulation activities.

The critical issue on station autonomy is to arrive at the best policy (or policy-generating procedure) for balancing the space crew's level of dependency on ground control. This problem has an extensive history that developed before the space program. Specifically, in airflight navigation, two distinct policies emerged in the post-WW II era. The policy for civilian airflights was near-total autonomy for the flight crew. The role of ground station personnel was strictly advisory. This policy was derived from the older precedent covering the captains of ships at sea. The alternative policy was developed for military airflights. The military policy gives the ground controller more authority. Over the years, with the advancement of radar and computer technologies, the real differences between civilian and military air traffic control have diminished, but this gradual change does not necessarily reflect an optimum balance for air traffic control, much less space-based operations.

The relationship of station-based and ground-based activities embodies both parallel activities and interactions. The ground station will have access to all Earth-based support systems, computers, simulators, technical support staff, administration, etc., for the purpose of supporting nominal station activity or dealing with unforeseen circumstances. The station-based control will have the advantage of proximity and site communication when dealing with station operations. To the extent that crew activities are nominal, that training was appropriate, and that the hardware is functioning correctly, crew activity should be designed to be carried out independently of ground control. The extent to which ground activities are supporting station operations, such as status monitoring, computational support, and scheduled resupply, such operations will also be conducted in parallel with, and independently of, station or crew activities.

The direct line between the autonomy question and productivity lies in which group can do the must successful job on a given class of activities. For example, regardless of the level of remote systems monitoring and telecommunication from station to ground facility, there are going to be events and circumstances in the station operation that can only be intelligently interpreted by the station crew. However, the ground facility will always have access to the broadest range and depth of expertise and the greater computer support capacity. Thus, if the ground facility preempts a role or set of activities that requires that broadband perceptions be available only to the station crew, productivity will suffer. Likewise, the reverse is true.

An indirect link also exists. That is, there are psychological sensitivities associated with autonomy and what has come to be called fate control. If a command relationship is perceived to be arbitrary and coersive, those in the subordinate position can become demoralized to a degree, with possible degradation of productivity as the ultimate consequence.

Another aspect of this relationship that will effect human productivity is command authority for station activities. Even if nominally independent, station crew activities have to be reported to ground control; or if activities have to be authorized by ground control, this will have a negative effect on productivity, per se. During initial operations, it is expected that much of the activity will be serial, with much checking between ground station control and space station control. The key tradeoffs to be considered are how much control should be serial and for how long - i.e., what is the operational learning curve; what type of nominal information should be first to be relinquished to either space station or ground station; and what are the protocols for dealing with off-nominal activities? It is proposed that a classic task analysis, with task criticality as one of the measures, be undertaken for each new space system as the basis for allocating parallel crew activities to either ground or space, and as a means of deciding what crew activities should be undertaken serially and which group has the initiation lead.

Station autonomy will also be strongly influenced by the reliability, type and acceptance of station command equipment, and the roles and relationshps between the human operator and the machines. With a limit on the human resources, the degree of reliance upon machine systems might be expected to increase. This will be strictly dependent upon user acceptance, or else more control authority might be routed to the ground control systems, where there is not such a limit upon human resources.

The crucial issue in this area is between the imposition of purely rational criteria based on objective capabilities and limitations of the station as a locus of control -- on the one hand -- and the inclusion of subjective factors in the specification of the optimum balance -- on the other hand. The resolution of the tradeoff hangs on the real degree to which the subjective factors can actually depress productivity. Conceivably, it is possible that crewmembers could be disgruntled by a perceived lack of autonomy and yet perform with high efficiency.

2.3.6 Computer Modeling

During recent years, significant advances have been made in the tools available for modeling human performance, complex information management, simulation, training, etc. For example, human factors engineers now can develop computer models and conduct experiments on human operator-system design before any kind of prototype is available. In the past, the primary means for evaluating human performance was to collect empirical data. For systems or situations that did not yet exist, the only recourse available to the analyst was to look for analogous situations in order to draw inferences about how the human would perform in the new situation. The process of extrapolating to the new situation was largely based on intuition, and the result was a rather poor estimate of human performance.

Modeling enhances productivity in various dimensions. The two most frequently measured are cost and feasibility. It is frequently more expensive to collect "real world" data than to develop and use a computer model. Also, it is sometimes impossible to collect real-world data. For example, when the system under study does not exist or when you want to conduct potentially destructive tests, computer models have to be used.

Perhaps one of the most critical tools to achieve overall mission efficiency is the modeling of the flight resources and scheduling in real time. The longer the mission duration, the less applicable are the previous models used for mission planning. The concepts could be changed to vary the methods used for flight definition as a function of long-term duration, renewal of resources, using solar energy for a nonexpendable resource, and frequency of crew replacement.

Some of the criteria for selecting appropriate models might include:

- Processing versus storage and retrieval requirements. The issue is whether to assign the burden to the processing algorithms and heuristics or to massive and detailed data storage.
- Precision versus amount of data. In this case the determination hinges on whether an optimal solution is required or a "good enough" solution will do. In most loosely structured or fuzzy set variables, such as crew comfort, "good enough" solutions usually suffice.
- Complexity of the processing versus complexity of the representation. Here the problem revolves around the issue of complexity of the processing versus complexity of the representation or structure of the data.
- Fidelity of simulation. The general rule would be to maximize fidelity within the constraints of the simulation technology, time, cost, etc.
- Cost. The bottom line will be to identify the most cost-effective modeling approach.

2.4 IVA SYSTEMS

The number, type, design, and locations of IVA work stations can be derived from mission operation requirements, such as science monitoring, station maintenance, command and data management, etc., in which case development of specialized work stations could be argued. With the increasing sophistication of software-derived control and display systems, however, much stronger arguments can be made for general-purpose, reconfigurable work stations to support the broad range of station requirements from each work station. Touch control displays, interactive keyboards, high-speed high-resolution graphic displays, track balls and hand controllers, and computer-derived command menus can control and display vast amounts of variable information from any of several work stations that have been configured by the operator.

The effects the work station design will have on human productivity depend on how well general elements, such as hand controllers, key pads, CRT displays, and the like, are integrated into a single reconfigurable work station. Other aspects that will affect productivity will be display layout, density, conditioning, operator training, and similar variables inherent in any work station. The description of the Essex Reconfigurable Workstation filed in the NASA-MSFC Technology Briefs (1984) and the MSFC-PROC-711A Spacelab Display and Command Usage Guidelines (1982) are examples of work on space-based work stations and control and display technologies for advanced space applications.

Cost tradeoffs for special-purpose versus general-purpose work stations can be developed as can cost tradeoffs for integrating advanced technology into work stations versus using off-the-shelf controls and displays. Measuring operator performance times and accuracy for tasks is also a way to compare technological trades. Superior accuracy and reduced operator response times can, in some cases, justify increased costs associated with technological innovation.

Some of the specific issues related to work station design that affect human productivity are the following:

ISSUES	DESIGN OR OPERATIONAL FACTORS AFFECTING PRODUCTIVITY
General Purpose versus Specialized Work Stations	Number of subsystems or experiments; time to reconfigure work station; complexity of work station design; scheduling conflicts; potential space savings
Restraint Systems (Personal)	Foot restraints (velcro, grid, toe bar; chair; waist restraint
Restraint Systems (Materials, Tools)	Velcro, clips, elastic bands; storage locker; work station commonality
Displays and Controls	Dedicated or multipurpose; use of keyboards, VDUs, LCD, LED, incandescent, etc.; flags versus lamp indicators; energy consumption; heat production
Anthropometric Considerations	Fixed versus adjustable workstations; vertical racks versus work stations; wraparound work stations versus standard; height, widths

Science monitoring, operations and maintenance data, subsystem status monitoring, diagnotics, record keeping, and personnel communication are examples of some of the data management required. How these data are acquired, coded, organized, updated, displayed, and stored will have a very great effect upon human productivity. Within each of these elements, tradeoffs will have to be made in terms of command management, such as item entry versus special command key entry versus menu command selection; display layouts, such as block versus field versus columns versus scroll lists; and display feedback of controls and commands, such as command sent versus command characteristic sensed versus automated sequence initiation. Tradeoffs for advanced technologies will also have to be made. These would include issues in data management, such as artificial intelligence and expert systems, and voice command and feedback systems.

Work stations developed for past manned space flight programs were primarily intended for use by highly skilled crewmembers having an extensive background in the operation and control of flight vehicles. These early designs were used to furnish cockpit-type data and payload status information for crew evaluation. The burden of data reduction and analysis by the crew created serious workload penalties and engendered a requirement for extensive crew training programs. This training included thousands of hours of mission simulations providing a range of learning experiences to qualify crews to operate both simple and complex vehicle control and mission equipment, as well as handle contingency situations.

The emphasis for work areas in future space systems will be to support research and operations in a wide variety of disciplines. As such, it is impractical to provide extensive training for all potential crewmembers. Thus, the data management system must provide a highly coherent user interface (user friendly) to a wide spectrum of user expertise with a minimum of fatigue-inducing factors.

The role of data processing in space operations has increased dramatically. As more experience has been gained with the man-machine interface, areas of needed improvement have been repeatedly identified. For example, in the Shuttle, contingency responses are contained in an extensive printed Flight Data File (FDF). The crewmember must locate the procedure in the multiple volume FDF and mentally integrate data from multiple sensors before formulating the proper response. Manual searches of voluminous data and crew gathering of data from various sensors to formulate actions is clearly time comsuming and detrimental to high productivity. A significant increase in crew productivity and efficiency could be achieved by automating crew access to these files, with the Data Management System collecting and integrating necessary sensor data and prompting the crew for proper action.

Display responsiveness is considered to be a significant Spacelab problem area. On Spacelab, retrieving a display format for use by a crewmember takes 10 to 15 seconds. Studies have shown that system response times of less than a second are necessary for maximizing productivity. Mass memory hardware and software implementation and allocation of insufficient data processing power between system elements are the underlying causes of this sluggish response.

2.5 IVA/EVA INTERFACES

IVA/EVA interfaces include all those resources and equipment or capabilities that are required to support an extravehicular (EV) operation. These include such items as:

- Airlocks
- EVA equipment servicing area
- Atmospheric considerations
- Communications capabilities
- EVA equipment stowage
- Data management capabilities
- Logistics support impacts
- Pre- and post-EVA personnel hygiene requirements
- Crew training activities

Within the context of each of these supporting areas, EVA support functions will impact each of the manned station element functions described earlier (see Table 2). Based upon these interrelationships, the operational issues and the design factors that influence human productivity must be identified and evaluated. For example, the accessibility and storage of servicing and maintenance information is an issue pertaining to the data management capability for EV operations. With respect to that issue, the impact on crew productivity could be determined by the time and effort required by the crew to retrieve and prepare information for EV operations.

The design factors contributing to increased productivity might involve a computer-based retrieval system that incorporates voice recognition and activation and that displays the information on CRTs both at space station work station as well as within the space suit. Conversely, those factors detracting from the crew's productivity might involve the manual extraction of information from various documentation sources and manually constructing EVA checklists.

For each issue, the viable approaches must be identified and evaluated to determine the concept that best meets the needs of the crewman, based on enhancing total system effectiveness or productivity.

It can be anticipated that specific IVA/EVA interface factors that contribute to human productivity might include the following:

- EVA Suit Design
  - Donning and doffing
  - Prebreathe requirement
  - Maintenance and repair
  - Cleaning and drying
  - Stowage and storage
  - Anthropometry
  - Insuit food and water provisioning
  - Insuit body waste collection/containment
- Restraints and mobility aids
- Lighting (fixed and portable)
- Environmental (pressure, temperature, humidity)
- Volume and configuration (single versus multiple occupancy)
- Personal hygiene
  - Post-EVA suit and body cleaning and body waste collection during extended O_2 prebreathe
- Housekeeping

2.6 REMOTE SYSTEM MANAGEMENT

The ability to manipulate, position, move, insert, extract, and perform other dexterous tasks has been the domain of EVA crewmembers for most missions to date. The introduction of large-scale remote manipulators and smaller servicing manipulator arms will add versatility to orbital operations and increase the overall system's productivity, given appropriate designs for the management of remote systems.

IVA conduct of tasks via remote manipulation can conceivably permit increases in productivity by allowing continuous operation through shift-work. Also, shift periods can be on the order of tens-of-minutes or for several hours, depending on task difficulty and operator stress or fatigue factors. Productivity using manipulator systems will depend upon visual feedback, task lighting, hand controller designs (especially feedback of forces and torques), and work station design.

The impacts on total system productivity of single-versus-multiple manipulator arm operations; single- and dual-hand controller operations; track bar-versus-joystick operations; graphic support, such as predictive displays; and specialized-versus-general-purpose manipulator systems need to be investigated in terms of the criteria of cost, probability of success, and performance via remote-versus-EVA approaches.

2.7 RECOMMENDATIONS FOR FURTHER WORK

Based upon the foregoing comments, in order to enhance the human role in space, some of the more critical areas requiring further research are as follows:

Internal Architecture

- Research is needed to establish firm guidelines and standards regarding the degree of constancy of spatial orientation required in zero gravity workplace and work station design.
- Research is needed to develop valid criteria that can be used in establishing an optimal balance or compromise between requirements for multipurpose versus dedicated work stations.

Crew Support

- A continuing assessment of the personal hygiene and waste management systems is required in order to optimize a system design that meets crew requirements within mission and programmatic (cost and schedule) constraints.
- A continuing assessment of exercise techniques for long-duration spaceflight is needed to develop efficient yet physiologically and psychologically acceptable procedures for maintaining physical and mental health.

Crew Activities

- Research is needed to establish the optimal level of cross-training of crew skills in order to maximize crew effectiveness and overall productivity while still accommodating contingency operations such as the unplanned disability of crewmembers.
- A better understanding is required as to whether duty cycles and shift work should remain constant in long-duration missions or whether adjustments should be made to account for changing biorhythms, endocrine production patterns, etc.
- Continuing applied research is required on the dynamics of small group organizational arrangements and productivity.
- The issue of balance between ground control and space crew autonomy needs further study in order to establish the best policy for optimizing the space crew's level of dependency on ground control and to detemine when the balance of control should shift from the ground to the space facility.
- Continuing effort is needed in developing computer-based descriptive and predictive models of human performance of space activities that can in turn interact with computer models of flight resource utilization and real-time mission scheduling.

IVA Systems

- Continuing effort is required in work station design to evaluate controls and displays for special-purpose and general-purpose work stations, and to optimize the data management system interfaces to make more effective use of human intellectual capabilities.

IVA/EVA Interfaces

- IVA/EVA interface factors that enhance human productivity need to be identified and approaches for improving total system effectiveness need to be evaluated.

Remote System Management

- Further research is required in the design of controls and displays for improving the effectiveness of remote manipulators and the management of remote systems.

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Section 3
EPILOGUE

We have learned from the US and Soviet* space programs to date that (1) systems can have indefinite operational lifetimes in space if they are designed to permit the contingency of in-flight repair and maintenance; (2) structures too large to be launched intact can be constructed and assembled on orbit, using man's unique capabilities; and (3) the flexibility and creative insights provided by the crew in situ significantly enhance the probability of successfully achieving mission objectives.

Reflecting upon their experiences as crewmembers of the Spacelab 1 mission, Garriott, Parker, Lichtenberg, and Merbold** succinctly described their activities in space by describing three levels of crew participation in accomplishing the mission objectives. At one level, the space crew found itself highly involved in research activities and working together with principal investigators on the ground in the performance and real-time interpretation of research results. This was the case in areas such as space plasma physics, life sciences, and some materials-science and fluid-physics experiments. At another level, the crew found itself performing other technical tasks with very little ground interaction. This was the case in the installation of cameras on a high-quality window or scientific airlock table and in the verification of their proper performance. At a third level, the specific experiments were largely controlled from the ground with the space crew participating only when needed to verify experiment performance or to assist in malfunction analysis and correction.

*The Soviets have been reported to rely heavily on manned involvement in order to repair equipment and subsystems with serious shortcomings in reliable and trouble-free service life.

**Owen K. Garriott, Robert A. R. Parker, Bryon K. Lichtenberg, and Ulf Merbold, Payload Crewmembers View of Spacelab Operations, Science, Vol. 225, 13 July 1984, pages 165-167.

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It can be anticipated that future space missions are likely to continue to require human support at each of these levels.

The ability of the crew to manually assemble delicate instruments and components and to remove protective devices, such as covers, lens caps, etc., means that less-rugged instruments can be used as compared to those formerly required to survive the high launch-acceleration loads of unmanned launch vehicles. As a result, complex mechanisms secondary to the main purpose of the instrument will no longer need to be installed for removing peripheral protective devices or activating and calibrating instruments remotely. With the crewmembers available to load film, for example, complex film transport systems are not needed, and malfunctions such as film jams can be easily corrected manually. The time required to calibrate and align instruments directly can be as little as 1/40th of that required to do the same job by telemetry from a remote location. Even for pure manipulative tasks, experienced operators are found to take eight times longer using dexterous electronic-force-reflecting servomanipulators as compared to performing the same tasks by direct contact.

Specific experiments and operations no longer will need to be rigidly planned in advance, but can change as requirements dictate. One of the greatest contributions of crews in scientific space missions can be in reducing the quantity of data to be transmitted to Earth. One second of data gathered on SEASAT, for example, required 1 hour of ground-based computer time for processing before it could be used or examined, or a value assessment made. Before recording and transmitting data, scientist-astronauts in situ could determine in real-time whether cloud cover or other factors are within acceptable ranges.

The astronaut can abstract data from various sources and can combine multiple sensory inputs (e.g., visual, auditory, tactile) to interpret, understand, and take appropriate action, when required. In some cases the human perceptual abilities permit signals below noise levels to be detected. Man can react selectively to a large number of possible variables and can respond to dynamically changing situations. He can operate in the absence of complete information. He can perform a broad spectrum of manual movement patterns, from gross positioning actions to highly refined adjustments. In this sense, he is a variable-gain servo system.

Thus, with the advent of manned platforms in space, there are alternatives to the expensive deployment of remotely manned systems, with their operational complexity and high cost of system failure. Long-term repetitive functions, routine computations or operations, and large-scale data processing functions, however, can be expected to be performed by computers capable of being checked and serviced by crews in orbit, just as they are now serviced in ground installations. In addition, the normal functions of the terrestrial shop, laboratory, and production staff will find corollary activities in the work done by the crews manning the space platforms of the coming generation.

The human being represents a remarkably flexible and adaptable system. The real issue to consider is where, along the continuum from direct manual intervention to independent operations, the specific mission requirements of future space programs can best be met. The criteria of performance, cost, and technological readiness described in Volume II of this report remain the principal factors in this decision process, and the human role in space can be defined using these criteria for the system designer. The task then becomes one of enchancing the productivity of the human in his assigned roles. The observations summarized in this document suggest some of the system design considerations and technology developments that can significantly impact human effectiveness and productivity in future space systems.

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Appendix A

DESCRIPTIONS OF 37 GENERIC ACTIVITIES IDENTIFIED IN THURIS STUDY

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Appendix A

DESCRIPTIONS OF 37 GENERIC ACTIVITIES IDENTIFIED IN THURIS STUDY

1. Activate/Initiate System Operation

- Those events and/or command sequences involved in the activation or initialization of a space-based system or subsystem.

2. Adjust/Align Elements

- Those adjustment activities involved in such operations as alignment of optical elements, fine tuning of precision electronic equipment, antenna pointing, and remote camera focusing operations.

3. Allocate/Assign/Distribute

- Those activities involving the reallocation or redistribution of resources; e.g., the redistribution of power, coolant flow, etc., to sensitive subsystem equipment to reflect operational needs or contingency operations.

4. Apply/Remove Biomedical Sensor

- Those unique activities associated with the installation and removal and cleaning of sensors used to obtain biomedical data from a test subject.

5. Communicate Information

- Those activities involving the establishment of the communications link and the transmission of information from one source to another. It includes the verbal or visual interchange between two crewmen, as well as the electronic transference of scientific information from a space probe to a terrestrial-based user.

6. Compensatory Tracking

- Those activities involving continuous control adjustments to null an error signal against a fixed reference.

7. Compute Data

- Those activities requiring a mechanized form of data processing, such as in structural analyses, computation of positions of celestial bodies, or other forms of numerical computations.

8. Confirm/Verify Procedures/Schedules/Operations

- Those activities involving the assessment of whether or not a previous event has in fact been accomplished (such as a system verification or checkout), or a procedure satisfied, or a schedule met.

9. Connect/Disconnect Electrical Interface

- Those activities requiring the completion or termination of an electrical interface. They may involve use of blind-mated/self-aligning connectors, multiturn screw-drive interface plates, or similar devices.

10. Connect/Disconnect Fluid Interface

- Those activities requiring the completion or termination of a fluid interface. They may involve use of a simple plug-in, sleeve-lock connection, multiturn screw-drive interface plates, or similar devices.

11. Correlate Data

- Those activities involving the identification of positive or negative relationships or commonalities among data sets, such as organizational structures, characteristics, or processes.

12. Deactivate/Terminate System Operation

- Those events and/or command sequences involved in the termination or deactivation of a space-based system or subsystem.

13. Decode/Encode Data

- Those activities involving the conversion of data into either its original form or into a form compatible for transmission: e.g. converting transmitted digitized data into its original analog form or digitizing analog data for transmission to the ground station.

14. Define Procedures/Schedules/Operations

- Those activities involving logical deductions or convergent production leading to development of procedures, schedules, or operations with predictable outcomes.

15. Deploy/Retract Appendage

- Those activities associated with the extension of a hardware element to a position where its assigned function can be realized, or conversely, the stowing of that hardware element based on task completion or safety considerations.

16. Detect Change in State or Condition

- Those activities wherein the departure of a parameter from its original or reference state or condition is required to be sensed or observed.

17. Display Data

- Those activities involving the presentation of information or data by visual, auditory, or tactual means.

18. Gather/Replace Tools/Equipment

- Those activities involved in the obtaining or in the returning of tools or equipment used to perform a specific task, such as collecting or replacing maintenance tools or donning/doffing the Manned Maneuvering Unit.

19. Handle/Inspect/Examine Living Organisms

- Those activities involving the unique operations associated with working with living organisms. These activities involve the manipulation and general handling of animals, and range from stroking to inspecting or examining anatomical characteristics.

20. Implement Procedures/Schedules

- Those activities involving the instituting and carrying out of procedures or schedules (such as updating a mission model/schedule), as distinguished from activating or initiating system operations.

21. Information Processing

- Those activities involving the categorizing, extracting, interpolating, itemizing, tabulating, or translating of information.

22. Inspect/Observe

- Those activities involving the critical appraisal of events or objects. They may include the verification or the identification of particular elements, such as damage inspection of a returning OTV, the observation and identification of a celestial object, or the behavior of a living organism.

23. Measure (Scale) Physical Dimensions

- Those activities involving the estimation or appraisal of a dimension against a graduated standard or criterion.

24. Plot Data

- Those activities involving the mapping, displaying, or locating of data by means of a specified coordinate system.

25. Position Module

- Those activities involving the positioning of a component into a desired orientation; e.g., installing a new component, or tilting a payload into its launch orientation.

26. Precision Manipulation of Objects

- Those activities involving tasks which require a high degree of manual dexterity in order to be accomplished such as the assembly/disassembly of small intricate mechanisms or the installation of measurement sensors, i.e. strain gauges, thermocouples, etc.

27. Problem Solving/Decision Making/Data Analysis

- Those judgmental and sometimes creative activities involving the drawing of inferences or conclusions through the use of cognition, convergent or divergent production, memory and comparative evaluation. Functions to be performed may include analyzing, calculating, choosing, comparing, estimating, or planning.

28. Pursuit Tracking

- Those activities involving continuous control adjustment to match actual and desired signals when the desired or reference signal is continually changing.

29. Release/Secure Mechanical Interface

- Those activities involving the manipulation of a mechanical interface ranging from a simple one-handed, over-center latch application to a high torque, multi-turn threaded fastener. May involve manipulation of multiple fasteners arranged in various patterns or configurations.

30. Remove Module

- Those activities involving the physical extraction or removal of a component after the mechanical, electrical or thermal interfaces have been released or disconnected.

31. Remove/Replace Covering

- Those activities involving the removal or reinstallation of an access covering or a protective covering as required to gain access to system elements or to cover them up upon completion of the work.

32. Replace/Clean Surface Coatings

- Those unique activities involving the restoration of a degraded or contaminated surface coating such as replacing the thermal coating on a radiator or cleaning the viewing surface of an optical systems.

33. Replenish Materials

- Those activities involving the resupplying of consumables, such as refueling a spacecraft, recharging an optics cryo-based cooling system, or providing food supplies to an animal holding facility.

34. Store/Record Element

- Those activities involving the recording or storage of items for both short-term and long-term periods; e.g., recording and storage of experimental data or the temporary storage of a biomedical sample.

35. Surgical Manipulations

- Those activities, such as a surgical procedure or a dissection, including tissue sample acquisitions, that require a high degree of skill and knowledge as well as manual dexterity to accomplish.

36. Transport Loaded

- Those activities involving the conveying of a physical object by some transportation device from one location to another; e.g., the transporting of a component via a crewman or a remote manipulator system.

37. Transport Unloaded

- Those activities involving the movements of an unloaded individual or device from one location to another; e.g., the movement of a crewman to a worksite without carrying tools or equipment, or the movement of a remote manipulator system with nothing attached.

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Appendix B
HUMAN CAPABILITIES REQUIRED FOR EACH ACTIVITY

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Appendix B
HUMAN CAPABILITIES REQUIRED FOR EACH ACTIV...

HUMAN CAPABILITIES / GENERIC SPACE ACTIVITIES	SENSORY/PERCEPTUAL															
	Visual Acuity	Detection and Discrimination of Brightness	Color Discrimination	Depth Perception and Discrimination	Peripheral Visual Detection and Discrimination	Visual Accommodation	Detection and Discrimination on Tone	Discrimination of Sound Intensity	Localization of Sound	Detection of Light Touch	Tactile Recognition of Shape and Texture	Discrimination of Force Against Limb	Recognition of Limb (Movement and Location)	Detection and Discrimination of Angular Acceleration	Equilibrium	Detection and Discrimination of Vibration
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 Activate/Initiate System Operation	●		●												●	
2 Adjust/Align Elements	●			●		●										
3 Allocate/Assign/Distribute																
4 Apply/Remove Biomedical Sensor	●									●	●					
5 Communicate Information	●	●	●								●		●			
6 Compensatory Tracking	●												●			
7 Compute Data	●					●										
8 Confirm/Verify Procedures/Schedules	●															
9 Connect/Disconnect Electrical Interface	●					●				●	●					
10 Connect/Disconnect Fluid Interface	●					●				●	●					
11 Correlate Data																
12 Deactivate/Terminate System Operation	●															
13 Decode/Encode Data	●															
14 Define Procedures/Schedules/Operations																
15 Deploy/Retract Appendage	●															
16 Detect Change in State or Condition	●	●	●			●	●	●	●	●	●					●
17 Display Data	●										●		●			
18 Gather/Replace Tools/Equipment	●										●		●			
19 Handle/Inspect/Examine Living Organisms	●					●				●	●					
20 Implement Procedures/Schedules																
21 Information Processing	●	●	●				●	●	●							
22 Inspect/Observe	●	●	●	●		●					●					
23 Measure (Scale) Physical Dimensions	●			●												
24 Plot Data	●															
25 Position Module	●					●				●	●		●			
26 Precision Manipulation of Objects	●			●		●						●	●			
27 Problem Solving/Decision Making/ Data Analysis	●	●	●			●	●	●	●		●					
28 Pursuit Tracking	●															
29 Release/Secure Mechanical Interface	●					●				●	●					
30 Remove Module	●					●				●	●		●			
31 Remove/Replace Covering	●															
32 Replace/Clean Surface Coatings	●		●			●										
33 Replenish Materials	●															
34 Store/Record Element	●										●		●			
35 Surgical Manipulations	●		●	●		●					●					
36 Transport Loaded	●			●								●	●		●	
37 Transport Unloaded	●			●								●	●		●	

Appendix B
APABILITIES REQUIRED FOR EACH ACTIVITY

SENSORY/PERCEPTUAL												INTELLECTUAL				PSYCHOMOTOR				MOTOR	
7 Detection o…	8 Discrimination of Sound Intensity	9 Localization of Sound	10 Detection of Light Touch	11 Tactile Recognition of Shape and Texture	12 Discrimination of Force Against Limb	13 Recognition of Limb (Movement and Location)	14 Detection and Discrimination of Angular Acceleration	15 Equilibrium	16 Detection and Discrimination of Vibration	17 Detection of Heat and Cold	18 Detection and Discrimination of Odors	19 Cognition	20 Memory	21 Divergent and Convergent Production	22 Evaluation	23 Production and Application of Force	24 Control of Speed of Motion	25 Control of Voluntary Responses	26 Continuous Adjustment Control (Tracking)	27 Arm/Hand/Finger Manipulation	28 Body Positioning
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Appendix C
EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE

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APPENDIX C

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
1.	Activate/Initiate System Operation	Shuttle crew manually initiated 216 attitude maneuvers	STS-9/Spacelab 1 Young and Shaw got very tired not only performing the maneuvers, but having to watch the clock very carefully to timeline them properly. The orbiter was used as a pointing system for the Atmospheric Emission Photometric Imaging (AEPI) experiment. 94 maneuvers were real-time changes/additions.	The summary of STS-9/SL-1 crew debriefing
2.	Adjust/Align Elements	Soviet crew manually aligned the rotating mirror on the solar telescope	Soyuz-17/Salyut-4 The telescope's pointing system was inoperative due to mirror blinding by the sun and required the manual positioning of the rotating mirror. To properly position the rotating mirror the crew had to listen to the mirror's movements in its support structure. To do this the crew used the stethescope from the medical supplies. The calculation and precise positioning of the rotating mirror enabled the continuation of their solar research.	Aviation week and Space Technology 30 June 1975
3.	Allocate/Assign/Distribute	Crew on the Spacelab 1 mission were assigned to work 2, 12-hour shifts during the mission	STS-9/SL-1 The spacelab crew were happy with the working arrangement and recommended no changes. The shuttle crew, however, thought that the shifts were too long and could be dangerous if an unforeseen problem should arise. It was recommended that workloads/shifts be redistributed.	The summary of STS-9/SL-1 crew debriefing

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE (Cont'd)

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
4.	Apply/Remove Biomedical Sensor	Experiment M092 blood pressure measurement system cuff 11 failed to drive the experiment support system displays and was removed	Skylab 4 Crew changed to cuff 12 and operations returned to normal	Skylab Experience Bulletin #5 September 1974
5.	Communicate Information	Crew communicated precise locations of forest fires in remote areas	Soyuz 35/Salyut 6 During the dry season the crew observed and reported locations of many forest fires. The crew received messages of thanks from firefighters for their timely warnings.	Spaceflight October 1981
6.	Compensatory Tracking (usually considered to be more efficiently performed in an automated "error-nulling" mode although humans can manually perform compensatory tracking tasks if required)	Skylab crew had to manually perform a zeroing position alignment of the fine sun sensor wedge for the solar observatory	Skylab 2 mission The crew reported problems with fine sun sensor wedge position indicators. The problem was caused by a timing error in the on board computer. The problem was corrected by updating the navigation parameters in the computer, and by the crew zeroing the fine sun sensor wedge position at the start of each orbital day.	MSFC Skylab Mission Report-Saturn Workshop NASA TMX-64814 October 1974
7.	Compute Data	Cosmonauts had to make precise position calculations in order to determine when to stop the movement of the rotating mirror of the solar telescope to overcome the pointing problem they were experiencing	Soyuz 17/Salyut 4 The telescopes pointing system malfunctioned due to blinding of the mirror by the sun. Pointing of the telescope was accomplished by reorienting the station and then calculating the desired position of the rotating mirror and moving it to that position. The repairs worked satisfactorily, thus enabling the solar research to continue.	Aviation Week and Space Technology 30 June 1975

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE (Cont'd)

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
8.	Confirm/Verify Procedures/ Schedules/ Operations	The crew visually (via CCTV) observed the deployment to verify the PAM motor ignition	STS 41-D The crew used the manipulator arm camera to observe the motor ignition. The orbiter was faced away from the motor firing so as not to expose the orbiter's windows to solid rocket motor debris. When the motor ignited the distance between the spacecraft and the orbiter was approximately 10 miles.	Aviation Week and Space Technology 10 September 1984
9.	Connect/Disconnect Electrical Interface	In the Solar Max Repair mission exchange of the Main Electronics Box (MEB), the crew disconnected and reconnected 11 "D" series electrical connectors	STS 41-C During the removal of the connectors, the crew had to remove 22 small screws (2 per connector). To do this they used a powered screwdriver. While reconnecting the connectors the crew used small spring-type retention clips to secure the interface rather than reinstalling the 22 small screws.	Mission operations directorate, STS 41-C EVA checklist NASA-JSC Contr. No. JSC-17325 16 March 1984
10.	Connect/Disconnect Fluid Interface	The crew reserviced the primary coolant system on the airlock module	Skylab-4 The coolant system on the airlock module was leaking fluid and the operating pressure had dropped essentially to zero. Reservicing of this system had not been considered until it started leaking in orbit.	JSC Lessons Learned on the Skylab program 30 April 1974

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE (Cont'd)

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
11.	Correlate Data	Cosmonauts predicted grain crop yields by correlating agricultural/changes and vegetation patterns during the growing season	Soyuz 35/Salyut 6 This mission coincided with the growing season in the USSR. Crew became adept at predicting harvest yields. On one occasion they estimated the yield of grain crops at 30 quintals/hectare (552 lbs/acre) and the actual harvest resulted in 34 (625.6 lbs/acre).	Spaceflight October 1981
12.	Deactivate/Terminate System Operation	The operation of the Electrophoresis system was manually terminated	STS 41-D The EOS system began experiencing "wildly divergent pressures" and automatically shut down. It was reset, pressures again went out of tolerance and system was manually shut down The observations of the problem being experienced were transmitted to the ground for their evaluation.	Aviation Week and Space Technology 10 September 1984
13.	Decode/Encode Data	One EVA crewman received an alert warning relative to one of his suit systems, this he quickly translated to be a high sublimator pressure message	STS 41-C The cause of the problem appeared to be contamination which prevented complete valve shutoff during periods of low demand (low metabolic rate). The crewman followed the standard procedure of shutting off the supply water until comfort dictated a restart.	Flight 41-C mission report for EMU, MMU and ancillary hardware crew systems division 1 July 1984

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE (Cont'd)

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
14.	Define Procedures/ Schedules/ Operations	During operation of the electrophoresis system, problems arose which required redefinition and changes in the operational procedures in real time	STS 41-D The unit was experiencing a problem with software commanding operations. The machine was set to the full manual operation and began functioning normally. The operational speed at which the machine processed the material was manually revised to attempt to process as much of the material as possible. The flow was being vectored too far to the left up the column so the deflection vanes had to be manually changed. STS-9/Spacelab 1	Aviation Week and Space Technology 10 September 1984
15.	Deploy/Retract Appendage	Deployment and retraction of the Scientific Airlock (SAL) on Skylab I was accomplished by manual handcranking	The cranking operation was a problem with the outer hatch level operation. It was estimated to require about 50 pounds of force at the end of the 2 foot handle without restraints to accomplish this operation. This task was less stiff in the hot case than in the cold case.	Summary of the STS-9/Spacelab 1 crew debriefings 22 December 1983
16.	Detect Change in State or Condition	Crew detected presence of hydrogen in their drinking water by the peculiar taste	STS-9/Spacelab 1 By the end of the mission the crew had developed a method to manually separate the gas from the water.	Summary of the STS-9/Spacelab 1 crew debriefings 22 December 1983

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE (Cont'd)

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
17.	Display Data	"Shopping lists" were manually prepared to display potential objectives and to allow the crewmen to work independently of ground advice in selecting targets for the solar observations	Skylab III & IV The lists were originally devised to suggest to the crewmen a variety of short objectives that could be met if an extra 5 or 10 minutes of observing time should become available. The data collected in these intervals were found to be so useful that soon the ground team was requesting specific allotments of time be used entirely at the crewman's option.	Skylab Report: Man's Role in Space research, Science magazine 18 October 1974
18.	Gather/Replace Tools/Equipment	Fifteen items of equipment as well as tools were obtained and replaced during the Solar Max Mission EVAs	STS 41-C Items used during the EVAs included the T-pad for the MMU to dock with Solar Max; many tools such as the powered screwdriver, the power tool, and the scissors used to expose the MEB; the Manipulator Foot Restraint (MFR); and the 35 mm camera for photo documentation.	STS 41-C Flight crew report 24 May 1984 EVA checklist STS 41-C 16 March 1984
19.	Handle/Inspect/Examine Living Organisms	A honeycomb structure created by Italian honeybees while in a weightless environment was examined in situ	STS 41-C The experiment consisted of an enclosure which housed approximately 3300 bees. The experiment required a series of photographs, TV recordings, and two temperature measurements to be performed on three occasions. The crew found the experiment both interesting and entertaining.	STS 41-C Flight crew report 24 May 1984

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE (Cont'd)

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
20.	Implement Procedures/ Schedules	Crewman was required to implement procedures relayed from the ground to repair film jam in the metric camera	STS-9/Spacelab 1 Detailed repair procedures were developed on the ground. The crewman was not previously familiar with the insides of the camera. The procedure was carried out in the darkness of a sleeping bunk completely by hand without visually seeing the camera.	Science Magazine 13 July 1984 Payload crew members' view of view of Spacelab operations
21.	Information Processing	Use of the Shuttle Portable On-Board Computer (SPOC) allowed the crew to process information in real time and identify Earth observation targets relative to their ground trade	STS 41-C SPOC identified the crews location at a glance, provided excellent cues for acquisition of signal and loss of signal for both TDRESS and STDN sites and readily identified Earth observation targets.	STS 41-C Flight Crew Report 24 May 1984
22.	Inspect/Observe	Crewmen would observe fluctuations in Extreme Ultraviolet (EUV) intensity to predict probable locations of solar flares	Skylab missions The crewmen would observe these intensity fluctuations, knowing that a possibility of an impending solar flare exists, and would initiate the appropriate experiment operation. This prediction technique allowed for the recording of the flare activity within a few minutes of its earliest manifestation and well before it reached peak intensity.	Skylab Report: Man's Role in Space research, Science magazine 18 October 1974

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE (Cont'd)

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
23.	Measure (Scale) Physical Dimensions	The Crew Optical Alignment Sight (COAS) was used to measure the range and the line-of-sight angle to the Solar Max spacecraft during rendezvous and proximity operations	STS 41-C During rendezvous the COAS initially marked the spacecraft at approximately 600K ft. During proximity operations the COAS was used to monitor the relative positions and closure rates between the spacecraft and Shuttle.	STS 41-C Flight Crew Report 24 May 1984
24.	Plot Data	The mass measurements of the crewmembers in the Skylab missions were plotted periodically during the missions	Skylab 2, 3, and 4 Mass measured in oscillating chair called Body Mass Movement Device (BMMD). Time, BMMD temperature, and oscillating period plotted in log for each experiment. All crewmen participated in this experiment.	Proceedings of the Skylab Life Sciences symposium NASA-JSC Report JSC-09275, November 1974
25.	Position Module	Positioning the Solar Max MEB in its mounting hinge was a tight fit but was accomplished.	STS 41-C MEB had to be installed on a mounting hinge in order to allow for installation of the electrical connectors. During the positioning of the module a tight fit was experienced, however, with a slight tap of the fist it went in.	STS 41-C Flight Crew Report 24 May 1984

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE (Cont'd)

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
26.	Precision Manipulation of Objects	Emergency repair was accomplished on the Elena-F gamma ray detector	Soyuz 35/Salyut 6 When the detector malfunctioned, the crew was able to disassemble the unit, fashion a pin to replace the malfunctioned part and reassemble it. The controllers were surprised when the unit failed and the crew with no consultation embarked on its repair.	Spaceflight October 1981
27.	Problem Solving/ Decision Making/ Data Analysis	Problems arose and fluid physics experiments had to be greatly modified when air bubbles appeared in the liquid containers, antispread barriers failed to prevent liquid spreading, and electrostatic effects and other surprises were encountered	STS-9/Spacelab 1 During the fluid physics experiments the fluid behavior observed and reported to the ground investigators required a complete revision of the procedures in real time in order to solve the problems encountered and to accomplish the desired tasks. Similarly, along with developing the new procedures, the crew devised hardware modifications and substitutions in accomplishing the experiment's goals.	Science magazine 13 July 1984

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE (Cont'd)

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
28.	Pursuit Tracking	The IR spectrometer experiment was used to locate and track specific ground targets such as agricultural fields.	Skylab Missions 2, 3, and 4 Simultaneous aircraft and ground truth was being obtained concurrent with the IR spectrometer data. The field of view of the spectrometer was only 1 milliradian, which corresponds to a square on the earth of .4 kilometer per side. Careful training and considerable experience were required to locate and track the desired target. In addition several different targets were sometimes acquired only a few minutes apart in time.	Skylab Report: Man's Pole in Space research, Science magazine 18 October 1984
29.	Release/Secure Mechanical Interface	The crew manipulated the two Acme screws on the ACS module of the Solar Max spacecraft (8 revs each) with the Module Service Tool (MST)	STS 41-C The thermal blanket had to be removed to install the MST. The MST was set at a torque value of 100 ft/lbs. The crewman was restrained in the manipulator foot restraint.	STS 41-C Flight Crew Report 24 May 1984
30.	Remove Module	The crew manually removed the 500 lb ACS module from the Solar Max spacecraft	STS 41-C After releasing the mechanical interface on the ACS module the crewman removed the 500 lb unit. The crewman was restrained in the manipulator foot restraint	STS 41-C Flight Crew Report 24 May 1984

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE (Cont'd)

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
31.	Remove/Replace Covering	The crew had to remove the thermal blanket to expose the Solar Max Main Electronics Box (MEB)	STS 41-C To expose the MEB the crew had to make three, 4 foot vertical cuts and two, 2 foot horizontal cuts. The EVA scissors used to make the cuts were difficult to work with.	EVA checklist STS 41-C 16 March 1984 STS 41-C Flight Crew Report 24 May 1984
32.	Replace/Clean Surface Coatings	Cosmonauts recoated the receiving and focusing mirrors of the Orbital Solar Telescope	Salyut 4 Due to particulate matter collecting on the mirror's optical surfaces, the crew was required to apply new reflective layers on the mirrors. The procedure involved using an aluminum globule which was melted by a tungsten wire carrying an electric current.	Aviation Week and Space Technology 24 February 1975 Spaceflight October 1981
33.	Replenish Materials	The primary airlock module coolant loop was recharged by replenishing the coolant supply in order to support planned crew EVAs	Skylab 4 The crew carried a servicing kit consisting of an 18 gal. tank with 40 lbs of coolant in a locker in the command module. The coolant reserve tank was pressurized to 35 psi with nitrogen and was then hooked into the primary coolant loop by puncturing the line and charging the system. Reservicing the system allowed the crew to use liquid cooling in their suits during EVAs.	Aviation Week and Space Technology 26 November 1973

EXAMPLES OF 37 GENERIC ACTIVITIES PERFORMED IN SPACE (Cont'd)

Activity No.	Generic Space Activity	Task Accomplished	Comments	Reference
34.	Store/Record Elements	The Skylab crews were subject to several medical studies of which some required samples of blood and urine to be stored till return to Earth	Skylab Missions 2, 3 and 4 Each of the crewmembers were, on a routine basis, to obtain samples in order to determine the effects of long term space exposure. This resulted in many samples in storage throughout the particular Skylab missions.	The procedings of the Skylab Life Sciences symposium JSC-09275 November 1974
35.	Surgical Manipulations	Crewmember blood samples obtained for Life Sciences investigations	STS-9/Spacelab 1 Blood was drawn from two payload and mission specialists for purposes of the Life Sciences experiments.	Aviation Week and Space Technology 19 December 1983
36.	Transport Loaded	Crewman maneuvered 500 lb ACS module while transporting it from the work-site to the storage location	STS 41-C Crewman transported unit while in the manipulator foot restraint. Handling the unit was easy during transport as long as translation rates were kept low. Handling larger masses in this same manner would be equally feasible as long as there were adequate handholds.	STS 41-C Flight Crew Report 24 May 1984
37.	Transport Unloaded	Crewmen translated around the Shuttle cargo bay during an EVA operation	STS 6 Crewmen were tethered to the slidewire which runs the length of the cargo bay. Translation around the CCTV cameras was difficult.	STS 6 EVA Crew Debriefing 3 May 1983

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