

**The Space Station:
Human Factors and Productivity**

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(NASA-CR-179905) THE SPACE STATION: HUMAN
FACTORS AND PRODUCTIVITY (Lockheed
Engineering and Management) 9 p CSCL 05H

N87-12166

Unclas

G3/54 44880

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The objectives of the Space Station that the United States and its international allies will put into orbit during the 1990's can be expressed simply: living and working in space. Crews of 8 to 18 astronauts and technical experts (called payload specialists) will live on the Space Station where they will perform a variety of tasks, including materials processing research, life sciences experiments, astronomy, satellite repair and maintenance, and building and modifying the Space Station itself. The Space Station will be continuously occupied because, after a 90-day stay, the Space Shuttle will bring a new crew to the Space Station and take the old crew back to Earth. In addition, the Space Shuttle will carry a Logistics Module to be docked with the Space Station: The Logistics Module will contain consumable items, such as food and clothing, and equipment replacements.

The crewmembers will perform research tasks in three laboratories -- a United States laboratory module, a European Space Agency (ESA) module, and a Japanese module. Current plans call for these modules to be 13.56 m (44.5 ft) in length, 4.45 m (14.5 ft) in diameter, to be pressurized to normal Earth atmospheric pressure (14.7 psi), and to contain workstations that can be replaced or upgraded easily as technology improves during the 20-30 year life of the Space Station. In addition, work related to the Space Station operations, such as, guidance, navigation, and control, will be performed in the Habitability and Station Operations (HSO) module to be developed by the United States. The HSO will also contain the crew's living quarters. Much of the astronauts' and technical experts' work will be done for customers, including major research institutions, government agencies, foreign governments, corporations, and consortia.

A recent review in the Human Factors Society Bulletin described the role of human factors research and engineering in the design of the Space Station for the crews' quality of life, or habitability (Wise, 1986). We intend our report to be a companion piece that centers around the crews' quality of work, or productivity. NASA has recognized the importance of human factors in increasing productivity in the crew activities aboard the Space Station and, as a consequence, has undertaken studies in many areas that focus on the design of efficient workstations, tools, and procedures for the crews (for example, see Space Station Human Productivity Study, 1985). The major features of productivity in which we are interested for this report include the cognitive and physical effort

involved in work, the accuracy of a worker's output and the ability to maintain performance at a high level of accuracy, the speed and temporal efficiency with which a worker performs, crewmembers' satisfaction with their work environment, and the relation between performance and cost. The areas related to the Space Station that this report will describe will be (1) work that is totally inside the spacecraft, or intravehicular activity (IVA), (2) work that is primarily or totally outside the spacecraft, or Extravehicular Activity (EVA), and (3) work that uses an IVA crewmember to operate an EVA telerobotic device. Our report on productivity will cover primarily those studies being performed by human factors researchers and engineers at the Johnson Space Center. This work is only a small and, we hope, representative sample of the productivity-related work being done on the Space Station. Additional work is in progress at other NASA centers and at various Space Station contractors.

INTRAVEHICULAR CREW WORKSTATIONS

The design of intravehicular (IVA) crew workstations will largely determine crew productivity on-board the Space Station. Crew activities requiring the use of workstations can be divided into activities in support of the Space Station itself and activities in support of experiment operations and on-orbit equipment, e.g., satellites. Examples of activities in support of the Space Station include monitoring and control of Space Station subsystems (e.g., the guidance, navigation, and control subsystem, the propulsion subsystem, and the environmental control and life support subsystem), crew activity planning and scheduling, equipment maintenance and repair, and supply and inventory management. Several general tasks in support of equipment and experiments have been identified, including monitoring and controlling experiments, managing customer data, and performing Space Station rendezvous and docking operations.

Several human factors research projects at NASA Johnson Space Center investigate issues that influence the design of IVA workstations and associated crew interfaces. These projects fall into three broad categories: physical characteristics of workstation design, human-computer interface design, and expert systems interface design.

Physical Characteristics of Workstation Design. The micro-gravity environment of space provides a number of interesting twists to workstation design. For example, the optimum viewing angle for displays and the work surface angles are changed when a crewmember is in the neutral body

posture induced by microgravity. The neutral body posture somewhat resembles the position a person's body takes in a relaxed, face-down float in the water. In addition, the Newtonian law of action and reaction is not countered by gravity in space: An action that is trivial on Earth (such as pressing a key on a keyboard) can cause a person to move forcefully in the direction opposite to the action when on-orbit. Consequently, the design and placement of restraints and body positioning devices can greatly affect an astronaut's productivity at an IVA workstation (Lewis, 1986). Work is in progress to incorporate these considerations, as well as the more traditional spacecraft engineering constraints of volume, weight, and power in the design of testbed workstation mockups.

Human-Computer Interaction. Several human-computer interaction issues are important in the design of the Space Station workstation. Advanced computer technology now provides the capability to incorporate multifunctional controls in the Space Station instead of the thousands of discrete switches used on prior manned spacecraft. We have conducted research on Programmable Display Pushbuttons (PDPs), devices that can serve multiple display and control functions under the direction of software. Our research suggests that the use of PDPs as the sole display and control device is inadequate for complex spaceflight tasks: PDPs lack the flexibility and information carrying capacity to provide crewmembers with quick access to status information (Burns and Warren, 1985).

In other research, we have demonstrated that simple modifications of computer displays, including grouping functionally-similar information together, clearly discriminating data fields from action fields, and standardizing abbreviations, improve both expert and novice performance (Burns, Warren, and Rudisill, 1986). Human factors techniques that enhance the performance of both experts and nonexperts will become increasingly important for productivity because of the use of the Space Station by people who are technical experts in fields like materials processing or astrophysics but who are not experts in the spacecraft's operations.

Other user-computer interaction research that may affect productivity includes a series of experiments on electronically presented procedural information that will indicate ways in which computers may be used to replace the substantial number of paper checklists that astronauts currently use. Finally, we are examining the potential utility of user interface management systems (Foley, 1986) to facilitate partitioning and modification of the Space Station's human-computer

interface.

Expert Systems Interfaces. Artificial intelligence and expert systems technology promise major enhancements to crew productivity through reducing crew workload in normal Station operations and by aiding in the diagnosis of malfunctions. Malin (1986) has examined ways to ensure that crewmembers can gracefully shift among automatic, interactive, and manual expert system modes. Her research is also exploring ways to support the design of expert systems knowledge bases by Space Station subsystems designers and the revision of knowledge bases by operations personnel. In related research, Burns and Gillan (1986) suggest the use of several cognitive science methodologies (e.g., multidimensional scaling) in knowledge engineering for expert systems.

EVA WORKSTATIONS

Productivity studies related to an astronaut in an EVA environment must consider a variety of factors not found in the IVA environment: the protective suit with its inherent joint constraints and resistance to movement due to internal pressurization to 4.3 psi; the glove, with limited range of motion and insufficient tactile feedback; the communications link and information interchange with the Space Station with its limited, primarily vocal, interface modality. The environment also consists of the mechanisms by which the EVA astronaut maneuvers and returns to the Space Station -- the tether and the Manned Maneuvering Unit (MMU), a self-propelled craft capable of positioning the crewmember in any attitude desired. The MMU requires little human energy expenditure other than that used in the manipulation of hand controls. The tether requires constant attention and energy since it has mass and tends to become entangled as the crewmember is maneuvering into position for tool application. In most cases the tool itself is tethered to either the crewmember, a nearby workstation, or the EVA foot restraint.

The tasks that the EVA crewmembers must perform within the above constraints are as varied as the IVA tasks. The tasks include: assembly and construction of portions of the Space Station, checking out and deploying experimental equipment or spacecraft associated with the Station, planned maintenance and refurbishment of satellites, such as the Space Telescope, and unplanned service and repair of the Station and other spacecraft. All of these functions will be carried out using a variety of hand tools, including familiar mechanical tools (socket wrenches, hammers, drills, etc.) and electromechanical tools that must be set, calibrated, and/or programmed.

Current human factors research in EVAs includes measurement and analysis of the forces and torques required by the crewmember in conducting simple construction tasks . A December 1985 Space Shuttle flight experiment showed that a series of struts like those to be used in building the Space Station could be assembled on-orbit. However, the research showed that the effort required to manipulate the strut/node connectors was fatiguing to the hand and arm. As a consequence, comparative studies are being conducted for a variety of different glove designs and strut/node connectors.

Researchers also are investigating the restrictions of fully pressurized suits on the range of motion, force application, and astronaut metabolism. This baseline measurement data will aid in the development and testing of a new higher pressure EVA suit (at 8 psi). One advantage of the higher pressure suit is that it will reduce the amount of crew time needed to prepare for changes in pressure through breathing nitrogen-free air. However, if the higher pressure suit also reduces the EVA crewmembers' range of motion, decreases the intensity of the force that he or she can apply, or increases his or her metabolic expenditure, the new suit might decrease overall EVA productivity.

The test procedures for much of the EVA equipment for use in on-orbit tasks and research involves three test environments: the KC-135, an experimental aircraft which flies repeated parabolas that each provide 30 seconds of microgravity; the Weightless Environment Training Facility (WETF), a water tank in which suited crewmembers are weighted to the point of neutral bouyancy and which contains submerged mockups of spacecraft or on-orbit equipment; and the Anthropometric Measurement Laboratory (AML), which is a one-G environment at the Johnson Space Center used for carefully instrumenting and studying the performance of EVA suited humans. The KC-135 provides the best simulation of the microgravity environment in which astronauts will work on-orbit; however, the WETF provides the ability to study performance in extended duration tasks in an environment that somewhat resembles microgravity. Finally, the AML provides researchers with the ability to control the tasks and record a wide vareity of data. All three testing environments are used to obtain data on any single task or function in order that a complete means of comparison be available for extrapolation to on-orbit performance. Whenever possible, test data is compared to actual on-orbit performance data by mission experiment design or through subjective evaluation of flight-experienced crew members.

TELEROBOTICS

Telerobotics is another area of the Space Station that requires human factors input. A telerobotic servicer, which will have the capability of an EVA astronaut but which a crewmember will operate from the relative safety of the interior of the spacecraft, has been proposed for development. The servicer will be a manipulator unit that may be free-flying, attached to the end of the Space Shuttle robot arm (known as the Remote Manipulator System) or attached to mobile robot arms of the Space Station. The telerobotic servicer will be used for spacecraft servicing, structural assembly, and contingency events (NASA, 1985). Initial analyses proposed that the servicer have several of the following features: a stereoscopic vision system, a control system based on the operator's head position, a head-mounted vision display system, two 6 or 7 degrees-of-freedom manipulator arms with force control, the capability to grapple or dock with spacecraft, interchangeable end-effectors, and force-indicating hand controllers or exoskeletal arms for control for the operator. (Akin, Minsky, Thiel, and Kurtzman, 1983).

Human factors research on telerobotics for space applications is currently getting underway at JSC. One set of telerobotics research issues concerns the user's informational needs. Research has shown that for certain types of tasks on Earth, operators overwhelmingly prefer two perpendicular camera views of the performance area, with one view from the operator's position (Smith, 1986). Additional issues include how an operator uses multiple views of the task area together with stereoscopic vision, the use of non-stereoscopic cues to depth in the space environment, and camera placement to reduce disorientation. For example, use of information provided by sources other than cameras, such as a real-time moving graphics display, may help maintain operator orientation.

The incorporation of intelligent software into the design of telerobotic devices provides a second set of research issues. As advances in artificial intelligence enable the servicer to operate more independently of direct human control, function allocation between man and machine becomes a critical concern. One possible strategy is to provide flexibility in this allocation. For example, two levels of control seem likely for space applications. The first level is teleoperation, where the human operator is in direct control of the servicer. At the second level, intelligent software controls

the servicer or one part of the servicer (e.g., the end effector), with the human acting in a supervisory capacity with the ability to monitor the robot's activity and to intervene as necessary.

CONCLUSIONS

Human factors researchers and engineers are making inputs into the early stages of the design of the Space Station to improve both the quality of life and work on-orbit. Effective integration of the human factors information related to various IVA, EVA, and telerobotics systems during the Space Station design will result in increased productivity, increased flexibility of the Space Station systems, lower cost of operations, improved reliability, and increased safety for the crew onboard the Space Station. In As You Like It, Shakespeare contended, "O, how full of briars is this working-day world." For decades, human factors professionals have been reducing the briars of the working-day world; now, we are also trying to reduce the briars in work above the world.

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