Technology Advancements to Improve Crew Productivity in Space

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TECHNOLOGY ADVANCEMENTS
TO IMPROVE CREW PRODUCTIVITY IN SPACE

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ABSTRACT
Crew productivity will be a key factor in establishing a cost-effective Space Station design, and considerable effort has been directed over the last several years to make advancements in those technologies that will improve crew productivity and enhance crew comfort. These new technologies include the development of computer tools to allow system designers to optimize the crew work places in the Space Station (e.g., solid modeling and interior layout evaluation programs) as well as technology advancements in Space Station equipment to minimize or eliminate tedious and/or time-intensive tasks. These latter advancements include: automated inventory management and equipment controls; galley oven, dishwasher, and refrigerator Freezer technologies; housekeeping clothes washer/dryer and trash compactor technologies; and personal hygiene improvements in the waste management system and full body shower. A third area of technology advancement is in the development of job aids and procedural improvements for the everyday operation and maintenance of Space Station equipment and experiments. Advancements in this area include the design of internal station architecture for easy equipment access for maintenance, extra vehicular activity (EVA) space suit and glove design, and procedural aids such as the Operations and Maintenance Information System (OMIS). (OMIS is a technical documentation system designed to provide astronauts with the procedures required to operate and maintain the Space Station.) These technology advancements will be discussed in the following sections.

INTRODUCTION
The objective of the Space Station is to provide a permanent manned capability in space. To use this capability to its fullest for research and laboratory experiments, a major Space Station design driver has been to increase crew productivity. Many technology advancements have been made recently that will improve work environments, reduce tedious or repetitive tasks, and raise overall productivity. The technology developments can be characterized into three types: (1) the tools used to optimally design the Space Station interior for efficient work place layout, (2) the equipment designed to minimize or eliminate tedious and mundane tasks, and (3) the procedures and equipment for minimizing the effort to operate and maintain the Space Station. The tools used in designing the Space Station include solid modeling and interior layout evaluation computer programs. Technology advancements in galley, housekeeping, and personal hygiene equipment help to minimize or eliminate tedious tasks for the crew. Advancements in the operation and maintenance of Space Station equipment and experiments include the design of the internal station architecture to facilitate equipment accessibility, EVA space suit and glove design, and procedural aids such as the Operations and Maintenance Information System (OMIS). (OMIS is a technical documentation system designed to provide astronauts with the procedures required to operate and maintain the Space Station.) These technology advancements will be discussed in the following sections.

DESIGN TOOLS
Several computer modeling techniques such as three-dimensional solid modeling and internal configuration evaluation programs have been developed and utilized to define and optimize the human interface in the Space Station internal layout and equipment configurations. These programs allow the designer to model several different layouts of equipment in a rack or racks in a module and to evaluate them within a short period of time. The computer models enable rapid assessment of alternative configurations before building the hard mock-ups for final analyses.

Three-dimensional solid modeling. Over the last several years, computer programs have been developed
that enable a three-dimensional solid to be modeled on a computer. This capability enables a designer to "mock-up" a single workstation or an entire module on the computer for evaluation. These computerized models can be easily modified, and several configuration variations can be accurately evaluated in a timely and efficient manner. The evaluations performed on the computer include human-hardware interface analyses to optimize productivity. Evaluations consist of reach, fit/interference, packaging, and view (both external and internal). Examples include analyzing workstations for visual obscurations (can all displays be seen?), crew compartments for fit/interference (will the crew member bump into hardware while showering?), and the galley area for reach (can the crew member reach food packages in the back of the oven?).

Through computer modeling, several configurations can be analyzed expeditiously to determine an optimum design for hard mock-up evaluation. The combination of computer-generated models and hard mock-ups enhances the capability to design hardware configurations that maximize crew productivity.

**Internal configuration evaluation.** Another computer tool developed by McDonnel Douglas Astronautics Company (MDAC) and used to design the interior of the Space Station is a program for the Apple Macintosh computer for manipulating and evaluating interior layouts. The program uses the Macintosh user interface features (e.g., pull-down menus) for easy use. The program has two primary functions. The first function evaluates any interior layout against five crew interface criteria. The five criteria are crew movement, noise interference, similarity of privacy requirements, sequential dependencies, and shared support equipment. These criteria were identified and defined in an analysis of relationships among crew functions (see Reference 1). The program evaluates an internal layout against the five criteria by computing a correlation coefficient for each of the five criteria. The average correlation coefficient then enables a comparison of the relative validity of various layouts against a hypothetically ideal configuration.

The second function of the program simulates crew activities. This function requires external timeline files and simulates the activity timelines of up to eight crewmembers on two shifts. Figure 1 shows a sample screen from the program. This screen shows movements paths for four simulated crew members after one hour of simulation in a sample Space Station configuration. The results of this simulation include a tabulation of crew movement distances, usage rates for all compartments, and queuing (amount of time spent waiting for a particular piece of equipment). This information can be used to determine the optimum number of hardware items needed (e.g., showers) and where best to locate equipment (e.g., workstations).

The program aids in designing an interior configuration by evaluating noise, privacy, steps taken, and amount of equipment needed. As with three-dimensional solid modeling, this program improves the capability to design a Space Station configuration for maximum productivity.

**EQUIPMENT ADVANCES**

The unique problems associated with long-term living in space have created a need to examine all aspects of everyday life. To maintain morale and crew comfort, many of the everyday tasks are designed to be as much like home as possible in the zero-gravity environment. These areas have been the subject of advanced development efforts by the Space Station contractors and by NASA. Technology advancements have been developed in galley, housekeeping, and personal hygiene equipment that help to minimize or eliminate tedious and repetitive tasks, improve morale, and increase productive time available. These efforts will be discussed in the following sections as they relate to crew efficiency and comfort.

**Galley.** Recent developments in galley technology include a microwave-convection oven, a dishwasher, a frost-control system in the refrigerator/freezer, and a bar-code-based inventory management to track the amount and location of food items. Automated food preparation is possible by using the bar code to transfer preparation instructions directly to the oven. The optimum cooking cycle for multiple meals can be automatically programed into the oven using a microprocessor and a weighted averaging analysis. The dishwasher will sanitize the meal tray, beverage cup, and utensils, and will eliminate the need for manual cleaning by crewmembers. Refrigerators and freezers will be included on the Space Station to provide a higher quality and more home-like food selection. The frost-control system on the refrigerator/freezer will maintain those units in a frost-free state, aid in locating food items (labels will not frost over), and minimize the maintenance required. The inventory management system utilizes a bar-code reader and information strips to track the quantity and location of available food and will allow the crew to change daily menus on-orbit from the inventory available. It is extremely important to design this system for ease of use since its effectiveness depends on the system actually being used by the crew.

The overall galley layout has been designed by MDAC for optimum meal preparation and cleanup. Ambient, refrigerated, and frozen food storage are located in close proximity. Preparation functions such as the
oven and beverage dispenser are located together in the upper portion of the rack to facilitate meal preparation activities. The dishwasher, trash compactor, and other cleanup functions are also closely located to minimize cleanup effort. Several design iterations and mock-up evaluations have been performed on various galley configurations. Figure 2 shows one of the final MDAC galley layouts.

**Housekeeping.** To maximize crew productivity, the Space Station should be designed to minimize the time the crew will have to spend on the mundane tasks associated with housekeeping. The equipment currently being developed for housekeeping tasks includes a clotheswasher/dryer and a trash compactor. The clotheswasher/dryer combines the washing and drying functions in one unit, which eliminates one handling step in the clothes-cleaning process. The unit is designed to clean and dry clothes with minimal wrinkling and with a good appearance and feel when removed. The trash compactor is designed to minimize the trash stowage volume and decrease human handling of trash (e.g., trips to logistics module). The trash compactor unit features an airflow through the trash inlet to contain trash particles and odors. The overall Space Station interior will be designed to minimize cracks and crevices in order to decrease the time spent by the crew on surface-cleaning chores.

**Personal Hygiene.** Technology improvements for personal hygiene equipment have been developed for the handwasher, full body shower, and waste management system. The airflow capacity and flow pattern through the handwasher have been improved to contain and direct water droplets to an advanced air-water separator that eliminates potential flow blockage problems. The shower development utilizes upgraded Skylab technology that includes a heated airflow to provide crew comfort and to direct water droplets. The shower compartment has rigid walls and an efficient wet-dry vacuum with a squeegee nozzle for easier post-shower cleanup. Major improvements have also been made in the waste management system. The system currently under development uses an automatic bag-handling device and one bag per use eliminates exposure to subsequent users. An internal waste compactor will compact the waste into a cylinder, and an odor/bacteria filter will cap the cylinder when it is removed and put in long-term storage.

**MAINTENANCE AND OPERATIONS**

The effort to operate and maintain Space Station equipment and experiments can be minimized by: (1) properly designing the internal station architecture, (2) improving EVA space suit and glove design, and (3) developing job aids such as the Operations and Maintenance Information System (OMIS). The developments in these areas are discussed in the following paragraphs.

**Interior Architecture.** The interior architecture of the Space Station must be designed to maximize accessibility to all equipment items and to the pressure shell, thereby minimizing the amount of crew time spent on maintenance. The main structure of the Space Station modules is the pressure shell. The pressure shell is the "can" that holds the atmosphere and provides the space within which to put all equipment and living facilities. The requirements governing the design of the internal architecture included immediate and near total access to the pressure shell. It was also required that the pressure shell be free of all utilities (e.g., air ducts, data/communication lines, electrical cables), and that the equipment be packaged to permit cabinet interchangeability, commonality, and modularity. This equipment includes galley, workstation, laboratory, waste management, and all equipment on the Space Station.

The initial analyses performed on the internal architecture pointed to common double 19-in. equipment racks capable of sliding or pivoting to permit access to the pressure shell. Refinement of this concept led to dividing the module into four equal segments. With further analyses utilizing full-size mock-ups, the design converged to the current four-standoff McDonnell Douglas Astronautics Company-Huntington Beach (MDAC-HB) configuration adopted by NASA (see Figure 3). The stand-offs are structural supports for the racks and are located 45 deg off the horizontal and vertical. The standoffs cover the full length of all the pressurized modules. The utilities (air, water, power, etc.) are run through the four stand off structures. The utility runs will be scarred to allow for additional ports (hook-up points) that can accommodate the potential for moving racks within the station and for growth options on-orbit.

The present internal architecture of the four-standoff, tilt-out rack configuration was designed specifically for ease in accessing rack equipment and the pressure shell on-orbit.

**Extravehicular Activity (EVA).** Development is continuing on the design of the EVA suit and glove to increase the suit pressure and improve the glove dexterity. The present Shuttle space suit is designed to operate at 4.3 psia and requires the EVA crewmember to spend several hours prebreathing pure oxygen, which removes nitrogen from blood and tissues to prevent the bends when leaving a 10.2 or 14.7 psia atmosphere. An increase in suit pressure will decrease the time the EVA crewmember must spend prebreathing oxygen and will increase the productive time available for EVA tasks. EVA space suit design has
been improved to an 8.3 psia hard suit. According to the accepted prebreathe charts, this will minimize the oxygen prebreath requirement to less than 30 minutes.

The high-pressure glove technology is critical to maintaining dexterity and minimizing hand and wrist fatigue. Several organizations are currently working on designing a high-pressure glove that will equal the dexterity of the Shuttle suit glove. A key factor in EVA comfort and productivity is glove fit. Test subjects in the MDAC-HB Underwater Test Facility frequently commented about poor glove fit leading to bothersome pressure points that made the gloves uncomfortable. Pressure points and hand and wrist fatigue will significantly reduce crew productivity during long EVA shifts and multiple EVA situations, and ongoing developments are therefore geared toward the improvement of high-pressure glove design.

Another critical area in EVA systems currently under development is the automated checkout, service, and maintenance (COSM) system for the space suit and primary life support system (PLSS). Present technology requires days of checkout and maintenance on the ground to support EVA on-orbit. The scheduled amount of EVA required to build and operate the Space Station is approximately two crewmembers for 6 hours at least twice per week, which makes ground maintenance improbable and the use of present technology in the space environment impractical. Therefore, it is necessary to develop an automated checkout and maintenance system for the Space Station. The COSM, currently in the conceptual development stage, will be designed to fully reservice the space suit and PLSS within 12 hours with minimal human intervention. The system will repressurize the oxygen and nitrogen supplies, recharge the battery, and regenerate the thermal control system. The system will also automatically perform most checkout procedures to minimize crew time spent on pre-EVA tasks. The Space Station PLSS will be completely regenerable and nonvent, and the COSM system will have a nonstandard one-hour reservicing option for back-to-back EVA capability.

Operations and Maintenance Information System. The Operations and Maintenance Information System (OMIS) is an interactive technical documentation system developed by MDAC-HB (See Figure 4). OMIS capabilities include hands-free, voice-activated operation with high-speed random access to digitally-stored data, audio, and video information. OMIS utilizes a computer-driven, laser-video disc (LVD) system that will enable crewmen on the Space Station, during both intravehicular activity (IVA) and EVA, to access information using either workstation monitors or heads-up displays (HUDs). The system will have training, operations, maintenance, repair, and procedures information stored in on-board and ground-based LVDs. The information will be transmitted from the LVD/LVD-player to a host data management computer where it will undergo any necessary text editing or updating. The information will then be transmitted either via hardwire to IVA monitors or via RF to IVA and/or EVA HUD headsets.

Primary control of the system will be accomplished using a voice recognition system for verbal command and control. A back-up manual system is available. Both primary and back-up control commands are fed through the host computer.

The OMIS configuration and design requirements are driven by the need for rapid information access as well as Space Station weight and volume design restrictions. Also, since the Space Station will be autonomously operated (i.e., with minimal ground support), there is a strong requirement to have all operations, maintenance, and repair procedures and information easily available to the crew members at any time. Providing such a system for rapid access of information will improve crew efficiency in performing repair and maintenance tasks.

LVD storage is the most viable method for information presentation currently available that will meet the Space Station volume and weight restrictions, rapid access requirement, and necessary flexibility. LVD storage can provide simultaneous storage and retrieval of still-frame, audio, and motion-video data. Access to both audio and video instructions concurrently will enhance task performance. The OMIS system with voice recognition control, heads-up display, and LVD information storage will help to minimize time spent on the maintenance and operation of the Space Station.

SUMMARY

The purpose of the Space Station is to provide a place for people to work and to live in space. It is important that crew time is spent on experiments and operations rather than on the mundane tasks that can be automated. To maximize crew productivity, the Space Station design must account for crew interface in all aspects from workstation layouts to complete interior module configurations. This paper has illustrated some of the more critical areas where technology has been or is currently being advanced to make living and working in space a comfortable and productive experience.
ACRONYMS
COSM ........ checkout, service, and maintenance
EVA ................... extravehicular activity
HUD ..................... heads-up-display
IVA ....................... intravehicular activity
LVD ....................... laser video disc
MDAC-HB ........ McDonnell Douglas Astronautics Company - Huntington Beach
NASA ............ National Aeronautics and Space Administration
OMIS .... Operations and Maintenance Information System
PLSS ................. primary life support system
RF ....................... radio frequency

REFERENCES

Figure 1. Sample Screen From Interior Configuration Evaluation Computer Program

Figure 2. Galley Configuration
Figure 3. Four-Standoff Architecture Geometry

Figure 4. Operations and Maintenance Information System (OMIS) Functional Diagram