TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

MANNED SYSTEMS
TECHNOLOGY DISCIPLINE

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REMUS BRETOI, CHAIRMAN
AMES RESEARCH CENTER

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TECHNOLOGY DISCIPLINE SUMMARY FOR MANNED SYSTEMS

As Space Station Freedom evolves toward its full capability to support scientific and human exploration missions with relatively large crews and long tours of duty (sixty days or more), economy, performance and safety become increasingly important. This implies that: (a) relatively little of the crew's time should be devoted to performing routine tasks and monitoring on-board systems (i.e., their skills should be directed primarily toward performing their missions); (b) crew members must be able to maintain their skills under both normal and emergency conditions; (c) they must be able to maintain and support the on-board systems as necessary to ensure their availability and safety; (d) they must be provided with an environment in which they can remain motivated and reliable; and (e) systems designers and mission planners need improved capabilities to evaluate and synthesize alternative designs and procedures consistent with future program and mission objectives. These are some of the factors which influenced the Manned-Systems Workshop Session in developing their recommendations. The technology areas which evolved quite naturally as a result of considering these factors are as follows:

Crew-Systems Interfaces and Interactions
Training
Maintenance and Support
Habitability and Environment
Computational Human Factors / Analysis Tools

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

BACKGROUND

SCOPE - Effective crew-systems integration applies the systems approach during system development to enhance functional effectiveness, while maintaining or enhancing human well-being and system performance. In this approach, the human operator is considered a component or subsystem of the total, integrated Man-Machine System. Thus, limitations, capabilities, and expectations of the operator must be taken into account to form efficient and productive crew-system interfaces and interactions. The human operator interacts with the system through the Man-Machine Interface (MMI). Through this interface, the operator must sense or perceive the state of the system and environment, then process that information, make a decision, and select a response before putting that response into the system. It is the MMI, in its broadest sense, that is the scope of the technical area. This includes not only the hardware input and output devices, but the human-computer interface and artificial intelligence/expert systems.

OBJECTIVES - The objectives in this technology area are to design and develop innovative approaches, techniques, hardware, and software that will enhance system performance by improving the crew-systems interfaces and interactions. By enhancing the operator performance and well-being, the overall system performance benefits. Thus, the goal is a more symbiotic, synergistic Man-Machine System.

RATIONALE - Greater demands will be placed on Space Station Freedom as it evolves. There will be larger and more complex systems, more payloads (in both quantity and variety), and more required EVA (generally assembly and servicing operations, such as attached payloads, free flyer servicing, and transportation node operations). This in turn will place greater demands on the crew in both the number and complexity of tasks to be accomplished. In many cases, the crew will have to sense and comprehend the system status, make decisions, and respond more quickly and efficiently. In other cases, there will be a need to off-load many of the tasks the crew would normally do, perhaps through automation, while still providing the crew the capability for insight into the systems' configuration, operation, and status. In essence, in order to meet the demands of the evolving space station, crew productivity must be enhanced. To attain this goal, sufficient resources must be focused on improving the crew-systems interfaces and interactions.

PROGRAM PLAN

APPROACH -

1. Human-Computer Interfaces and interactions: Develop improved Man-Machine Interfaces (MMI) and Human-Computer Interfaces (HCI) that enhance the operator's perception of, and interaction with, systems' operations. MMI improvements should exploit alternate sensory modalities and permit more "natural" response selections. Audition might be employed via 3-D auditory displays and speech production. Speech recognition and direct manipulation could permit more natural methods for system input. The HCI might be improved through display format standardization, advanced methods for multi-tasking management, and more rapid input and access. Improvements in both the MMI and HCI should be guided with the eventual goal of a virtual workstation in mind.

2. Teleoperations Interfaces and Interactions: Develop improved MMI's that enhance operator performance in teleoperations, including EVA (both large and dexterous manipulators), proximity operations (free flyers), telescience, and telerobotics. An improved MMI should provide a more "natural" interface to the user. Anthropomorphic input devices and force-reflective feedback are necessary advancements in this area. Three-Dimensional situation awareness must also be enhanced. This might be accomplished using improved 3-D visual and auditory displays.

3. Artificial Intelligence/Expert Systems Interfaces and Interactions: In the drive towards increased automation, attention must be paid to the limitations, capabilities, and expectations of the operator. The degree of system complexity must take into account operator intervention and take-over, and enhance crew autonomy. Efforts should focus on Artificial Intelligence/Expert Systems that provide robust Decision Support Systems (DSS), including information processing and aids to understanding consequences; troubleshooting and diagnostics support, including Failure Mode Effects Analyses; and dynamic task allocation between the operator and the system, taking into account the user's expertise, need to know, workload, etc., and the system's health and status.

PROGRAM PLAN
(CONTINUED)

APPROACH (CONTINUED) -

4. In-Situ Maintenance Interfaces and Interactions: Develop and integrate portable input and output devices that allow the user "hands-free" access to text and graphics databases (e.g., procedures, checklists, schematics, etc.). These devices are to be designed for operations performed in physically constrained work envelopes (e.g., in-situ maintenance) where the user is away from a "fixed" workstation. In addition, locations and volumes for attaching a "portable" (e.g., laptop) workstation are limited or non-existent, and the user requires frequent access to the database. The design should be modular, capable of operating both stand-alone and through a wireless interface to the Data Management System, and "wearable" by the user. Color and video capabilities should be available on the monitor.

5. Analytical Tools and Methods: This technology element is fully addressed in the "Computational Human Factors" section below.

DELIVERABLES:

1. (a) 3-D auditory displays (speech and non-speech), (b) Reliable, flexible speech recognition and production systems, (c) Direct manipulation input devices (e.g., touch screens, 3-D display manipulation, 0-G cursor control devices), (d) Virtual workstation.

2 (a) Anthropomorphic input devices with force-reflective feedback, (b) 3-D auditory displays (for auditory tracking and positioning), (c) Compact 3-D visual displays (not requiring special glasses).

3 (a) AI/Expert Systems providing automation transparency, easy operator intervention, robust DSS and dynamic task allocation capabilities.

4. (a) Modular, portable, "wearable" input and output devices, (b) "Wearable" monitors with color and video capabilities.

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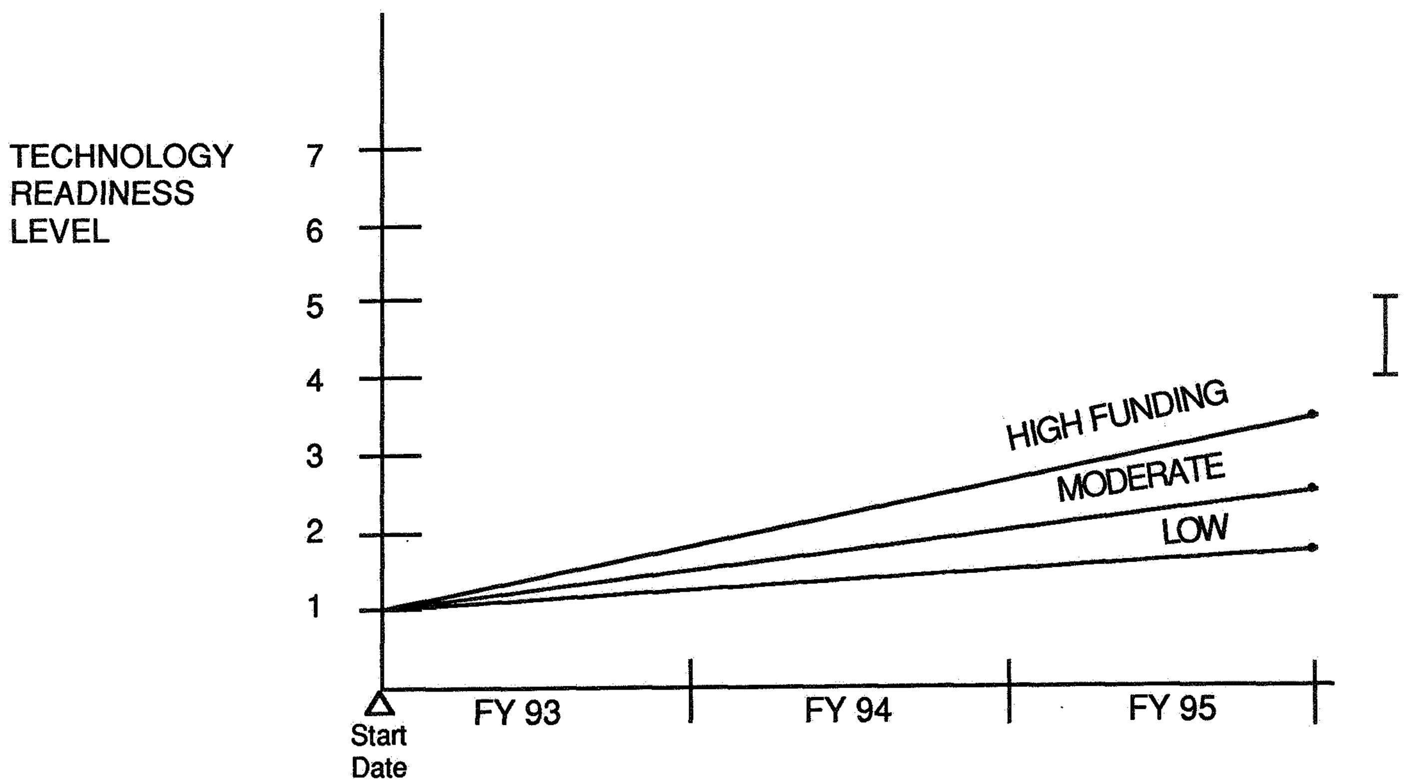
MANNED SYSTEMS *CREW-SYSTEMS INTERFACES AND INTERACTIONS*

<u>TECHNOLOGY ASSESSMENT</u>



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

BACKGROUND

SCOPE - Skill retention, human performance, embedded training, crew operation of back-up systems, and back-up system design guidelines.

OBJECTIVES - To develop techniques, concepts and design guidelines for (a) advanced systems and payloads embodying embedded training capabilities, and (b) design of automated systems with operator-backup in mind.

RATIONALE - Space Station Freedom crews will function in space for sixty days or more on a routine basis. The Space Station will probably also be used for research on the ability of crews to function for longer periods of time to support future human lunar and martian human exploration missions. The issues which must be addressed here are (a) skill retention and maintenance of performance during relatively long tours of duty, and (b) crew operation of back-up systems in the event of system failure. This must be done in order to satisfy safety requirements, and to maintain human reliability and performance.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *CREW TRAINING*

PROGRAM PLAN

APPROACH -

1. Embedded Training: Conduct studies and simulations involving the kinds of systems and payloads which will be used in future space missions. Develop training techniques and concepts for use of operational systems and payloads in space to maintain crew skills, performance and reliability; develop guidelines for design of future systems and payloads so that they may provide an in-space capability for crew skill maintenance and training; and identify hooks and scars to systems being developed so they may accommodate evolving embedded training concepts.

2. Back-up System Design: Conduct studies and simulations of critical on-board functions such as environmental control. These will include one or more crew members operating in a back-up mode to a highly-automated system. Define and evaluate back-up systems concepts and develop systems design guidelines for future systems.

DELIVERABLES -

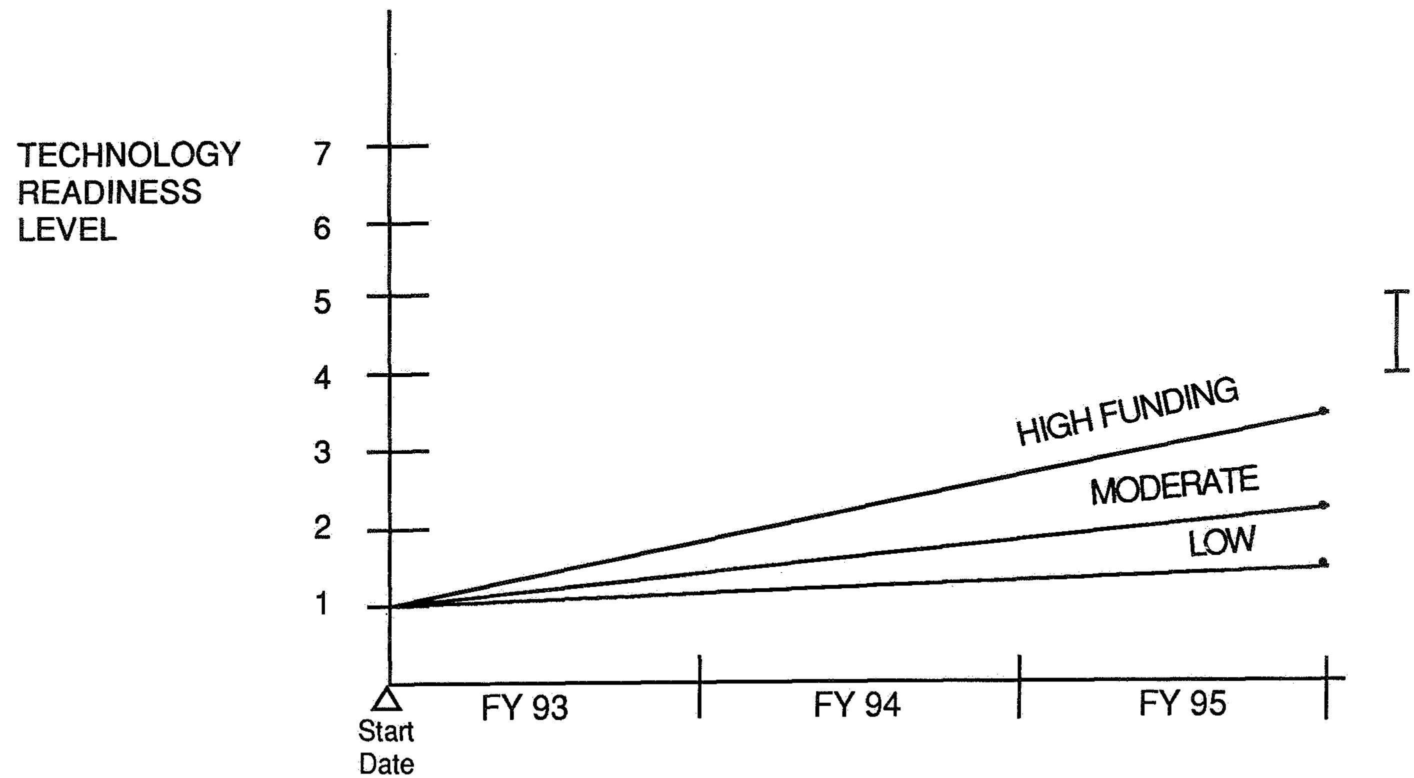
(1) Embedded training techniques, concepts and design guidelines for systems and payloads.

(2) Back-up systems concepts, operational procedures and design guidelines.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *CREW TRAINING*

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *MAINTENANCE AND SUPPORT*

BACKGROUND

SCOPE - Techniques and guidelines for improved maintainability and supportability of on-board systems, including: fault detection identification and resolution; design concepts for maintainability; inventory management techniques; loose item tracking and location; and modeling and simulation.

OBJECTIVES - To develop techniques, concepts and design guidelines for on-board systems in order to minimize crew time devoted to performing maintenance and support tasks.

RATIONALE - The large number of complex systems on board the space station, their criticality for safety and mission performance, the limited crew time available for performing mission and maintenance tasks, the cost of maintaining an in-space inventory, the relatively long times between re-supply, etc., require application of advanced techniques for performance of maintenance and support tasks. Further, design guidelines are needed to aid the systems designer in developing systems which are easily diagnosed, maintained and supported.

PROGRAM PLAN

APPROACH -

1. Diagnostics: Develop improved techniques for fault detection, identification and resolution. These techniques will be based on application of Artificial Intelligence (AI), Expert Systems, and computer graphics. Computer and laboratory simulations of representative on-board systems will be used to (a) evaluate alternative technical approaches, (b) establish guidelines for role and task allocation between automated diagnostics systems and the human, (c) evaluate alternative methods for interaction between the human and the diagnostic system, including computer and display interfaces, and (d) establish guidelines for design of on-board systems to ensure that they can be easily diagnosed.

2. Design Concepts: Develop design concepts for improving the ability of the in-space crew member to maintain in-space systems. These include ORU concepts; interfaces that accommodate humans, robots and tools; and improved EVA/IVA tools.

3. Inventory Management Techniques: Develop inventory management techniques based on computer simulations which will anticipate failure of system components or ORU's, and provide that information to flight and ground personnel. This information will be used to decide when to replace specific items, when to transport them to orbit, when to place them in the pipeline, etc.

4. Loose Item Tracking: Develop and evaluate concepts for keeping track of tools and other items which may be loose or lost in the space station modules.

PROGRAM PLAN
(CONTINUED)

DELIVERABLES:

1. (a) Advanced diagnostic systems concepts and technical approaches, (b) guidelines for role and task allocation between automated diagnostic systems and the human operator, (c) techniques and procedures for interaction between the human and the diagnostic system, and (d) design guidelines for design of on-board systems design to ensure that they can be easily diagnosed.

2. Demonstrations of ORU concepts; systems interfaces accommodating humans, robots and tools; and tools for improving the ability of the in-space crew member to maintain in-space systems.

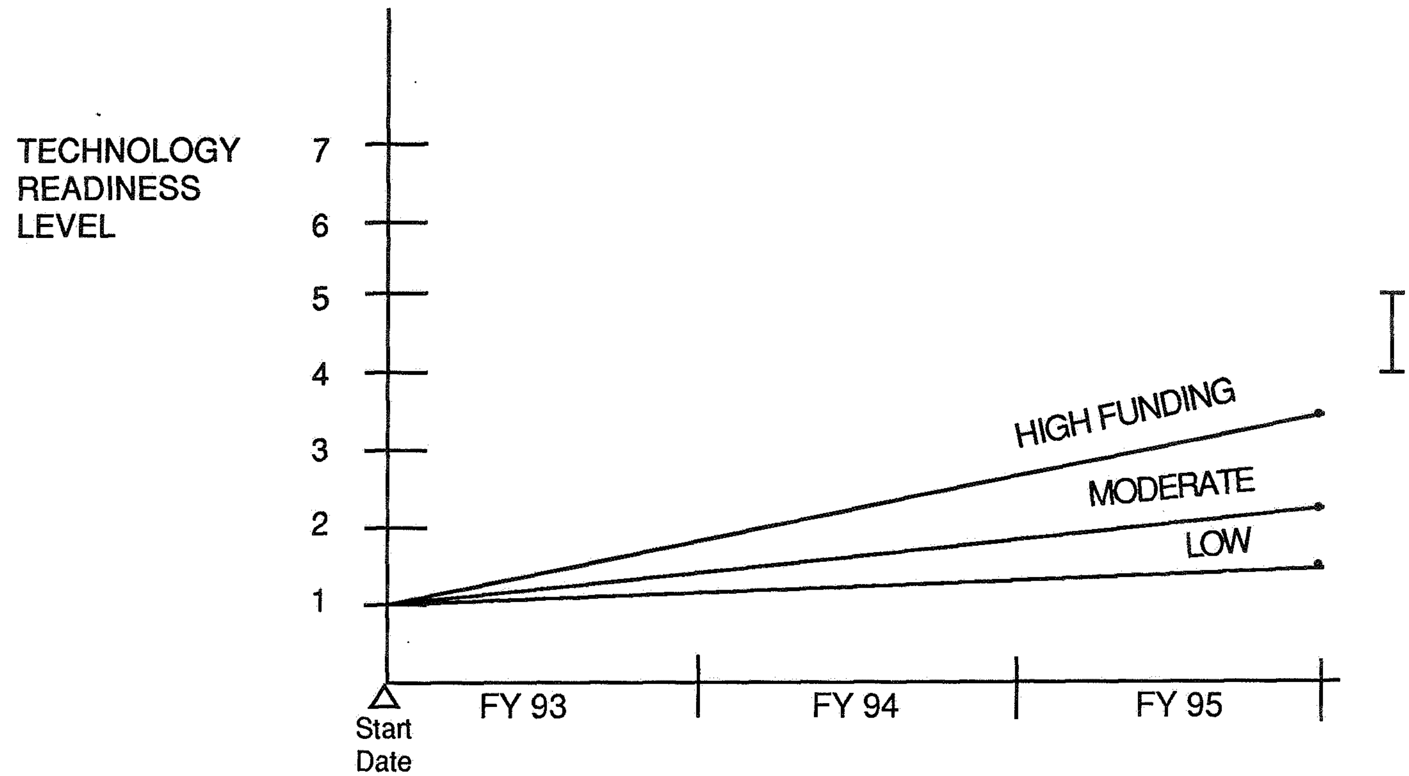
3. Computer simulations of an inventory management system, focusing on a representative on-board system such as portable life support. Identification of data requirements (e.g., reliability, re-supply schedule, test requirements, etc.) required to develop and use the inventory management system.

4. A sensing and tracking system for items which may be loose or lost in the space station.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *MAINTENANCE AND SUPPORT*

TECHNOLOGY ASSESSMENT



BACKGROUND

SCOPE - Interior design and architecture, stress reduction, motivation, human reliability, crew scheduling and work-rest cycles, mobility aids, restraints and trash disposal.

OBJECTIVES - To (a) develop an understanding of human behavior on long-duration space missions, and (b) develop crew organizational and architectural concepts which will provide crews an environment which will relieve stress, and improve performance and safety.

RATIONALE - Space crews on missions lasting several weeks or more tend to exhibit adverse behavior for a number of reasons: high work loads, the stress of operating in a hostile environment; confinement to small work and living spaces; lack of privacy, etc. Furthermore, tasks which may seem routine and simple on earth are much more difficult to perform in a micro-gravity environment. The combination of these factors tends to cause in-space crews to manifest symptoms of stress, including hostility. This can result in adverse effects on performance, motivation, judgment, performance, and inter-personal relationships. These problems can be even more severe on evolving space station missions which may be of relatively long duration, perhaps several months, and which may involve relatively large crews, perhaps 15 or more crew members. In this case the problem of trash disposal also can become compounded because of the quantity involved and because, if it gets out of hand, it can adversely affects physical and mental well-being (i.e., visual pollution).

The factors affecting crew behavior and performance need to be better understood, and countermeasures to the adverse effects of long-duration operations in a space environment need to be developed.

PROGRAM PLAN

APPROACH -

1. Conduct analytical and simulation efforts using reconfigurable simulators or test-beds with crew sizes representative of those for the evolving space station and consistent with the particular issue to be investigated.

2. Conduct experiments to evaluate the effects of alternative volume, furniture, texture and color configurations.

3. Conduct experiments to evaluate the effects on interpersonal relationships of alternative organizational structures, tasks, work loads, and work-rest cycles.

4. Conduct experiments to evaluate concepts for stress reduction, including rest, relaxation, entertainment, communication with family, photographic projections, external views, color schemes, etc.

5. Develop and evaluate concepts for body restraints and mobility aids in the neutral-buoyancy test facility and, when feasible, in space.

6. Develop and evaluate techniques for handling and disposing trash.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *HABITABILITY AND ENVIRONMENT*

PROGRAM PLAN
(CONTINUED)

DELIVERABLES:

1. Design guidelines and concepts for providing attractive and practical work and living spaces.

2. Guidelines for interpersonal working relationships and organization, work-rest cycles, and crew selection criteria.

3. Concepts and guidelines for stress reduction, including rest, relaxation, entertainment, communication with family, photographic projections, external views, color schemes, etc.

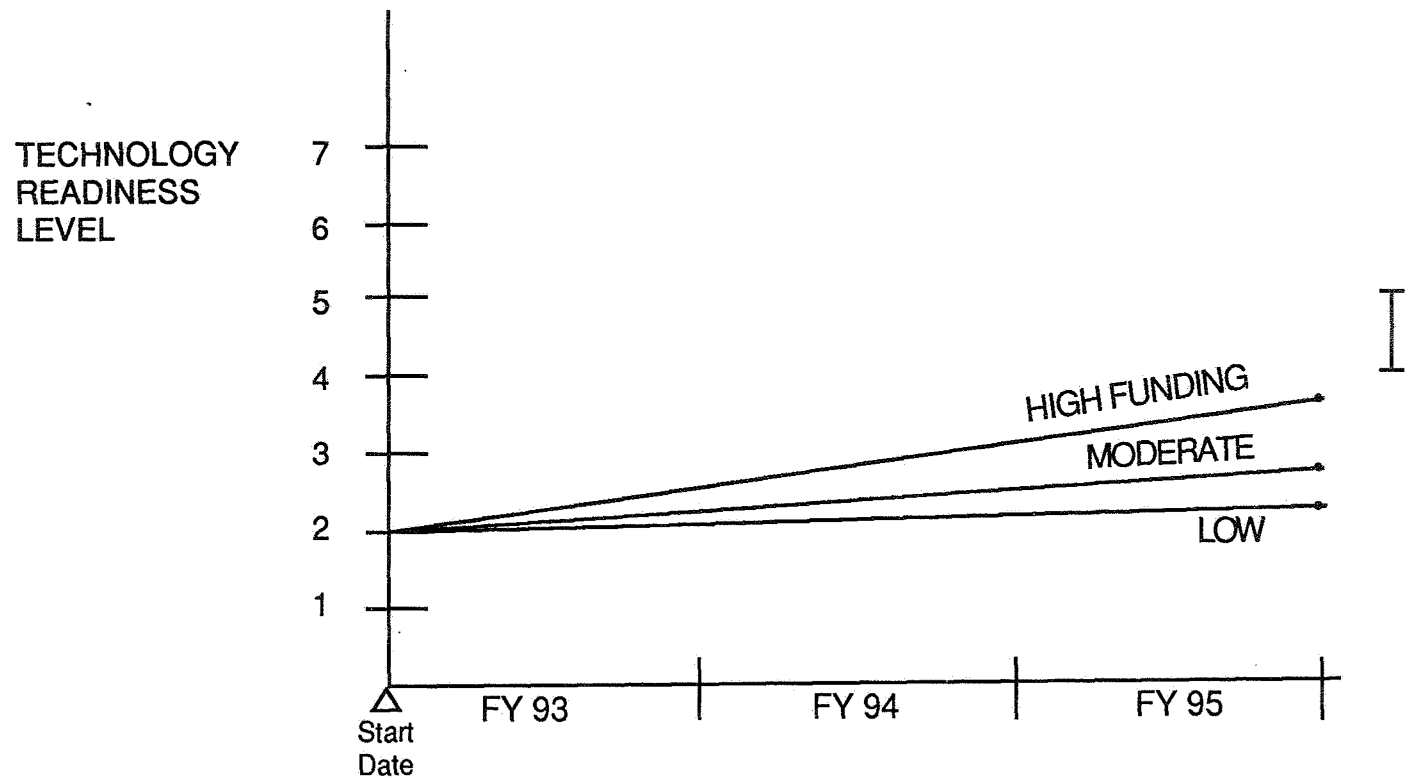
4. Concepts, recommendations and design guidelines for body restraints and mobility aids.

5. Techniques and design guidelines for handling and disposing trash.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *CREW TRAINING*

TECHNOLOGY ASSESSMENT



BACKGROUND

SCOPE - (1) Computer-aided design tools for use in: (a) anthropometry/size and fit; (b) interfaces developemtnt for visibility, placement, and information presentation; (c) procedures, considering workload aand sequence; and (d) training. (2) Digital video using perceptual components architecture.

OBJECTIVES - (1) To develop computer-aided design tools for use in interfacing the human with on-board systems and developing operational procedures, thereby reducing design costs, improving efficiency and timeliness, optimizing system performance and safety, and providing a means for effective comparative evaluation of alternative concepts before committing to hardware. This woiuld result in better designs, lower costs, less reworking, and anticipation of training needs. (2) To develop video display techniques which satisy human information requirements within the limits of available band widths aor channel coapacities.

RATIONALE - *Computer Aided Design*, Manned simulation time, design and fabrication of comples systems, and in-space experimentation are very expensive. There is a need to develop techniques for modeling the human operator interacting with complex space systems. These systems often may be highly automated, perhaps employing artificial intelligence or expert systems technologies.

Computational modeling has revolutionized most physical engineering disciplines. For example, finite element analysis has changed the design process in structures, airframe design, and electronic circuit layout. These Computer Aided Design (CAD) tools permit the engineer to ask "what if" questions about the performance of potential designs before they are built or physically prototyped. This has greatly reduced the cost of producing new systems. Computational models are also used to predict performance in new or novel situations for existing systems or to predict the impact of modifications to existing systems on their future performance characteristics.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

BACKGROUND (CONTINUED)

RATIONALE (CONTINUED) - CAD tools for human factors are now in their infancy. However, both JSC's PLAID system and ARC's Army/NASA Aircrew-Aircraft Integration system (A31) are capable of predictive modeling in the human factors engineering domain. Anthropomorphic issus such as size, fit, reach envelope, etc., can now be computed prior to system construction. Other attributes such as display visibility, workload, and trainability are computable.

This emerging technology has many applications in the aerospace industry. This technology needs to be developed further and applied to the evolving Space Station Freedom and Human Exploration Initiative programs.

Digital Video using Perceptual Components Architecture. Many on-orbit tasks in space require digital communications, e.g., telerobotics, ground/space collaboration on experimental procedures, etc. There is not a single requirement for spatial and temporal resolution for image size, or for its color rendering properties. Further, in many situations there will be a need for multiple images. The band width or channel capacity of the communication linkage is limited and, therefore, current video technology will not satisy the operational needs.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *COMPUTATIONAL HUMAN FACTORS*

PROGRAM PLAN

APPROACH -

1. *Computer-Aided Design:* Efforts will focus on developing tools for modeling the human operator interfacing with on-board systems, using JSC's PLAID and ARC's Army/NASA Aircrew-Aircraft Integration Program (A31) as points of departure. This includes simulation tools to estimate training needs, task difficulty/work load, and timeliness.

2. *Digital Video using Perceptual Components Architecture:* Digital video using something like a packet network could satisfy the operational needs of the evolution space station. A system with the ability to re-size the image, vary the spatial, temporal and chromatic resolution is technically feasible now. A full digital system using a perceptual components architecture (PCA) would have the following features: (1) images could be sized for any display, (2) the viable resolution could reduce to a minimum the communication band width requirement, and (3) by using PCA coding the system could "hide" quantization noise in the noise of the human visual system and segregate the image "energy" -- perceptually "vital" energy could be transmitted with multiple redundancy and less vital image energy could be transmitted with less redundancy (less error correction) without perceptual loss to the human. Finally, smoothing algorithms can be developed to temporally, spatially, and chromatically smooth sub-sampled digital image sequences. These smoothing algorithms would reduce the "perceptual" impact of sub-sampling the image sequence. Ideally, in theory, nearly static and/or low entropy scenes could be transmitted "without loss" over a low band width communication link. A digital video system based upon PCA coding can achieve this ideal.

PROGRAM PLAN
(CONTINUED)

DELIVERABLES -

1. A *Computational Human Factors-Based Computer Aided Design capability* which can be used by an interdisciplinary team of human factors specialists and systems designers as a part of the systems and systems interface design process. This CAD system will be applicable for (a) analysis and evaluation of existing and conceptual systems designs, and (b) comparative evaluation and optimization of alternative concepts and operational procedures, and (c) resolution of issues relating to economics, performance, reliability and safety.

2. A demonstration Digital Video System using Perceptual Components Architecture (PCA) based on the specific needs of the human operator. This system will have (a) the ability to re-size the image and vary the spatial, temporal and chromatic resolution and (b) smoothing algorithms and chromatically smooth, sub-sampled digital image sequences to reduce the "perceptual" impact of sub-sampling the image sequence. Nearly static and/or low entropy scenes will be able to be transmitted "without loss" over a low-band-width communication link.

TECHNOLOGY FOR SPACE STATION EVOLUTION
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MANNED SYSTEMS *COMPUTATIONAL HUMAN FACTORS*

TECHNOLOGY ASSESSMENT