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HUMAN FACTORS AND SPACE TECHNOLOGY:
Notes on Space Related Human Factors Research and Development, History, Faculties and Future Requirements

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FOREWORD

These notes on Human Factors Research and Space Technology are meant as a first step in documenting the history, capability and future requirements of space related human factors research and development. It is hoped that they will stimulate the progress of human factors in advanced space programs such as the space stations, large space structures, and future Spacelabs by describing the capability and advantages of integrating human factors in the conceptual stages of program definition.

These notes are not intended to be comprehensive nor complete at this time, but rather to serve as a guide for the collection of information. Comments, program descriptions, historical data, additions to the literature survey, and suggestions for the inclusion of human factors in advanced space programs should be addressed to Dr. Melvin Montemerlo, NASA Headquarters, telephone (202) 755-2494.

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ACRONYMS AND ABBREVIATIONS

ACS	Attitude Control System
AEC	Atomic Energy Commission
AFD	Aft Flight Deck
ATM	Apollo Telescope Mount
AXAF	Advanced X-Ray Astrophysics Facility
DARPA	Defense Advanced Research Projects Agency
DDU	Data Display Unit
DOF	Degree(s) of Freedom
EMU	Extravehicular Mobility Unit
EVA	Extravehicular Activity
FY	Fiscal Year
IVA	Intravehicular Activity
JSC	Johnson Space Center
MIL STD	Military Standard
MMU	Manned Maneuvering Unit
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
ORU	Orbital Replacement Unit
PCTC	Payload Crew Training Complex
POCC	Payload Operations Control Center
RMS	Remote Manipulator System
SOC	Space Operations Center
SMRM	Solar Maximum Repair Mission
SRMS	Shuttle Remote Manipulator System
ST	Space Telescope
STS	Space Transportation System
TBD	To Be Determined
TMS	Teleoperator Maneuvering System
TRS	Teleoperator Retrieval System
WETF	Weightless Environment Training Facility
Zero-G	Zero Gravity

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1.0 INTRODUCTION

The history of manned spaceflight has had a substantial impact upon the human factors disciplines, microgravity anthropometry, life support systems, zero-G simulations, extraterrestrial work environments were all quite "foreign" to conventional ergonomics and a whole new branch of human factors began to develop to accommodate to the new and exotic requirements of space travel and orbital working environments. Some may argue that entrance into the space age had a greater impact on human factors than vice versa, but without question, considerable effort was made to broaden our research base and develop new techniques for studying human/system interactions. Now that we have gained skills and knowledge through our participation in the many space programs, we can make significant contributions to, and have an important influence upon, future programs.

1.1 BACKGROUND

Much of the early human factors research in space technology was undertaken to protect the human in space and to prepare for gathering data on human performance in a new environment. In preparation for the Mercury flights, safety and protection were foremost in the programs, and human factors research reflected this. With more experience through Gemini and Apollo flights, human factors research was able to expand its attention to deal with performance, comfort and habitatiblity. This culminated in the Skylab program where humans were supported in an orbiting work environment for extended periods. Not only did Skylab provide an opportunity for extensive application of human factors research, it also served as a laboratory for the collection of human factors data and the development of an empirical data base dealing with human concerns of space missions. The capabilities of EVA were extensively demonstrated; the medical and psychological consequences of space flight were examined; work and human performance were evaluated; and the stage was set to move permanently into our space environment.

1.2 SCOPE

This report was developed as a record of the authors' knowledge of the human factors research undertaken in support of space technology, the work currently being done at research centers in NASA, and how these apply to future space programs. They are notes to be shared among human factors specialists to facilitate communication and are not necessarily meant to be a comprehensive statement about research, facilities or future programs. Comments for inclusion in future revisions will be collected, and all comments are welcome.

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2.0 STATUS OF HUMAN FACTORS RESEARCH

Very often appended to a specific program, and therefore difficult to identify, human factors research is being carried out through NASA and NASA contractor facilities. Pressure suit designs, extravehicular (EVA) workstations, EVA/remote manipulator system (RMS) symbiosis, remote systems technology, ground control stations and operations are some of the general areas of human factors concern. Specific research being conducted by NASA for advanced programs includes space station definition, large space systems (LSS) assembly, EVA servicing of spacecraft, and Spacelab payload crew training.

2.1 STATUS OF EVA RESEARCH AND DEVELOPMENT

Much of the early EVA research was performed to determine what crew restraints, mobility aids and tools the crew would need to perform simple spacecraft maintenance operations such as fastener removal and module changeout. Much of this research centered around the configuration of handrails, foot restraints and equipment restraint, tethers and the design of powered and manual hand tools. Pre-Gemini investigations into antirotation, low impact tools turned out to be unnecessary, and modifications to simple hand tools were determined to be adequate for most maintenance tasks as demonstrated many times on Skylab. Skylab also seemed to standardize handrail, foot restraint, and tether configurations.

Most of our knowledge about the capabilities of EVA crewmen has been acquired through development of specific spacecraft such as Skylab and Spacelab and payloads rather than through research. The current difficulties being experienced in the Space Telescope EVA operations as evidenced by difficult crew tasks and multiple simulations for design, development and verification do not indicate a lack of research data but a wholesale disregard of the lessons learned from Skylab and the existing EVA design standards. This body of knowledge and experience is adequate for most foreseeable EVA tasks such as instrument changeout, spacecraft maintenance, inspection, and contingency repair that may be required on Space Station and most STS EVA payloads. However, EVA will be used on some future missions in ways different from our current experience. An example of this is large space system assembly. Our knowledge of EVA assembly, large equipment handling and multiple shift EVA operations is insufficient to predict crew fatigue, suit and glove wear, and assembly timelines.

A description of EVA tasks performed to date and the status of EVA crew equipment and EVA design standards are presented below.

2.1.1 EVA Tasks

A brief history of EVA tasks performed on Gemini, Apollo, Skylab are presented in the following paragraphs. More detailed descriptions can be found in mission reports.

Gemini

During Gemini, an EVA crewman demonstrated a hand-over-hand translation technique using simple handrails, demonstrated the use of a "dutch shoe" foot restraint, and performed simple servicing simulations. The EVA lessons learned were that EVA servicing tasks can be performed if handrails are provided to the work site and if foot restraints are provided at the work site.

Apollo

During the Apollo transearth periods, an EVA crewman translated from the command module hatch to the service module and retrieved a camera. This activity verified that Skylab film changeout tasks could be easily performed.

Skylab

Skylab provided a wealth of spacecraft EVA servicing data. The Apollo Telescope Mount (ATM) film retrieval and D024 sample retrieval tasks were simulated many times in the MSFC Neutral Buoyancy Simulator and on the KC-135 zero-gravity aircraft. Tools, crew aids and servicing methods developed for the planned EVA tasks are still valid.

Only two of the contingency EVA tasks for which the crew was trained were required. The 22 unplanned, contingency EVA tasks performed by the Skylab crews kept the Skylab vehicle and its instruments alive and provided additional science capability. When planning the contingency EVA tasks before the flight, engineers and project personnel were too naive to think of all the things that could go wrong and underestimated what the EVA crews would be asked to do to correct the problems.

The planned, unscheduled and contingency tasks performed during Skylab are listed below, followed by the number of times each task was performed.

Film Retrieval - 28 Thermal Coatings Sample Retrieval - 2	Planned (7 EVA Tasks)
Solar Array Deployment - 1 Thermal Sail Erection - 1 XUV Camera Operations - 1 Particle Collection Experiment Materials Sample Installation & Retrieval - 2	Contingency or Unplanned (24 EVA Tasks, 2 Envisioned Prior to Mission)

Kohoutek Camera Operations - 2
Operations - 1
Sail Material Sample Installation
& Retrieval - 4
Camera Door Latch Removal - 3
Occulting Disc Cleaning - 2
Camera Filter Wheel Repositioning - 1
Battery Charger Repair - 1
S193 Antenna Repair - 1
Rate Gyro Cable Installation - 1
Vehicle Exterior Inspection - 1
(Electrical shorts, blown fuses, coolant leak)
ATM Door Opening - 2.

Contingency or Unplanned (24 EVA Tasks, 2 Envisioned Prior to Mission)

These lessons learned from the Skylab EVA's which were determined to have beneficial application to future spacecraft were reported in the EVA section of MSFC-STD-512. The reader is strongly encouraged to study this design standard.

Future EVA Missions

Planned and unscheduled, contingency EVA anticipated for STS, Space Telescope, AXAF and the Solar Max Repair Mission are listed below.

- STS
  - Radiator stowage
  - Payload bay door latching
  - Airlock hatch closing

- Space Telescope
  - Camera changeout
  - Unplanned ORU changeout
  - Solar array operations
  - High gain antenna operations
  - Aperture door operations

- Solar Max Repair Mission
  - ACS module changeout
  - XRP vent cap installation
  - XHIS thermal cover installation
  - C/P MEB changeout

- Advanced X-Ray Astrophysics Facility (AXAF)

  - Planned and contingency EVA operations are TBD but are expected to be similar to the EVA tasks for Space Telescope.

2.1.2 EVA Equipment

Before STS, there were no tools developed for any EVA servicing task on any spacecraft. On Apollo and Skylab, all planned and potential EVA tasks were designed to be performed without tools. However, the

Skylab contingencies necessitated the real-time development of numerous EVA tools, either developed before or between the manned missions, or developed from onboard IVA servicing tools. These tools are listed below.

- Combination wrench
- Ratchet
- Allen attachment
- Hammer
- Screwdriver
- Lens cleaning brush
- Mirror
- Flashlight
- Electrical connector pliers
- Duct tape
- Safety wire.

Currently available tools and support equipment developed to date include foot restraints, tethers, handrails, ratchet wrench, allen attachment, extensions, and 7/16-in. sockets. Additional tools under development include a RMS-mounted foot restraint and a power ratchet.

2.1.3 EVA Design Standards

Three EVA design standards are in existence and provide different types of information to spacecraft designers and project office personnel. These standards are described below.

- o JSC - 10615
  - This standard provides a good description of STS EVA provisions and what is planned for ST and SMRM
  - Very little useful information on past EVA tools and tasks, work envelopes, allowable forces and torques, and other specific data needed by the designer.
- o MSFC-STD-512
  - This standard contains specific information on workstation layout, access requirements, tools, fasteners, connectors, equipment insertion guides, touch temperatures, and edges and covers needed by the spacecraft designer and should be a contract requirement for all spacecraft developers.
  - It does not include data and experience from LSS and Space Telescope EVA simulations.
- o MSFC-STD-512A
  - This is a revised version of 512 (EVA section) but lacks most of the specific design information.

2.2 STATUS OF TELEOPERATOR RESEARCH AND DEVELOPMENT

NASA's interest in remotely manned systems has been long lived, being formalized in a joint AEC-NASA technology survey in 1967. Since 1971, MSFC has been involved in the Teleoperator Technology Development Program and is now investigating remote systems assembly technology for large space systems.

2.2.1 Teleoperator Technology and the Human Operator

Visual Systems - Vision is presumed to be the primary feedback mode for the control of teleoperators, and as a result, many investigations have been undertaken to determine the effects of various visual system parameters on operator performance. The recent summary of visual system investigations is found in Essex Corporation's Report H-82-01 and addresses findings for black and white, color, monoscopic, stereoscopic, analog, digital, slow frame rate, narrow band pass filtered TV systems in combination with environmental parameters such as signal-to-noise ratio, contrast, illumination, target shapes and angles and ranges. The point of contact for teleoperator visual systems is Daryl Craig, EC35, Marshall Space Flight Center, (205) 453-1575.

Manipulator Systems - For dexterous manipulation of the remote site, several classes of manipulator arms, end effectors, controllers and control schemes have been investigated as part of the Teleoperator Technology Development Program. General and special purpose systems, tool kit adaptors, bilateral and unilateral arms, anthropomorphic and non-anthropomorphic designs, discrete and integrated controllers, computer resolved control laws and direct drive controls are some of the parameters dealt with in manipulator system evaluations at MSFC. The point of contact for current manipulator evaluations is Keith Clark, EC25, Marshall Space Flight Center, (205) 453-3447.

Evaluations and simulations of operator performance using the Shuttle Remote Manipulator System (SRMS) have been carried out by the developer, SPAR, and the sponsoring agency, JSC. Data on large space manipulators and simulation capabilities can be obtained from Jeri Brown, Johnson Space Center Crew Systems, (713) 483-3774 and from Bryan Fuller, SPAR Aerospace, Ontario, Canada.

Mobility Systems - Remote mobility, through space, underwater or across a land mass is crucial for guiding the teleoperator to the task site. At JPL, work is on-going for planetary rovers; at MSFC, work has been going on since 1974 in the air bearing test facility on thruster propulsion for teleoperators. The point of contact at JPL is Ewald Heer, and the contact at MSFC is Ed Guerin, EC13, (205) 453-4635.

Integrated Teleoperator and Robotics Evaluation Facility - This facility is currently under construction at MSFC. It will provide a test environment for an extremely wide range of teleoperated activities. It contains a 4,000 sq. ft. air bearing epoxy flat floor, an automated orbital servicer simulator, two six degrees-of-freedom test beds for mounting mockups. There is a computer room for data analysis and test conduct, an electrical and mechanical shop for test apparatus, two remote control rooms and all the supporting equipment for communications, video, manipulation, etc. The completion data is late 1982. The point of contact for detailed information on this facility is Fred Roe, EC25, MSFC, (205) 453-3369.

2.2.2 Teleoperator Program Concepts

Several teleoperator concepts have been put forward in response to specific and general mission requirements. The Teleoperator Retrieval System (TRS), envisioned for boost/deboost of Skylab, is probably the best developed of these. Martin Marietta, under contract to MSFC, brought firm definition to the TRS, including engineering analyses, simulations, component flight items, and documentation. Another concept, pursued by Vought for MSFC, was the Teleoperator Maneuvering System (TMS) which has been designed with the delivery capability of the Shuttle in mind. The pancake shaped TMS is a departure from historical concepts, but this configuration is carried on in yet another teleoperator concept--Martin Marietta's Mark II propulsion module for the TMS. Each of these three teleoperator concepts has implications for human factors, and indeed, some limited human factors research has been conducted on these programs. The current status of teleoperator research and development is pressing toward a prototype for future flights and the point-of-contact for detailed information on teleoperator concepts is Jim Turner, PD21, MSFC, (205) 453-0367.

2.2.3 Other Remotely Manned Systems Research and Development

Programs outside NASA have particular interest in RMS research and development. Underwater research is being conducted by the Navy; nuclear energy management is being investigated at the Oak Ridge National Laboratories, and the Defense Advanced Research Projects Agency (DARPA) has research ongoing into remote system components. While not directly related to any NASA program, the research conducted at other agencies may have an impact on the research and development requirements of NASA.

2.3 STATUS OF CREW/VEHICLE INTERACTION RESEARCH AND DEVELOPMENT

Based upon experience gained in early manned missions and the extensive data gained in the Skylab missions, NASA has continued to accomplish human factors research in support of crew/vehicle interaction. Large Space Systems, Space Operations Center, Space platforms, teleoperators, satellite servicing and Spacelab are only some of the areas where this research will be applied.

2.3.1 Anthropometry for Crew/Vehicle Design

Several sources exist for crew vehicle design criteria. Many are NASA specific as is the case with MSFC-STD-512, Man/Systems Requirements for Weightless Environments, and others draw from more general anthropometric data bases such as NASA Reference Publication 1024, Anthropometric Source Book, Vols. I, II and III. Still others, like MIL

STD 1472C, have application to some NASA designs but were developed by other agencies. Current research has dealt with the new generation of space pressure suits (EMU), the flight control stations and the aft flight deck of the Shuttle, and the EVA service stations on serviceable payloads such as Space Telescope. Points of contact for anthropometric research are Allen Louviere, JSC Spacecraft Design Division, and Jack Stokes, EL15, MSFC Systems Analysis and Integration Laboratory.

2.3.2 Spacelab Experiment Control

The crew/vehicle interaction requirements for Spacelab are fairly complex and provide a good source of research data. The data requirements include EVA, DDU Display and Command Guidelines, crew procedures, crew training, and simulations.

The Spacelab Display Design and Command Usage Guidelines were developed to give standardized criteria for displaying experiment control and feedback information on an interactive video terminal. The point of contact is Ron Schlagheck, MSFC PCTC, (205) 453-1474.

2.4 STATUS OF ANALYSIS AND RESEARCH DESIGN TECHNOLOGY

A presumption that human factors research and technology is part of every complex system is usually made but is not always valid. In complex space systems, because of our short history and advanced technology, the requirement for user/system data is crucial to mission success, and this section briefly outlines current space related human factors technology development programs.

2.4.1 Research and Development Techniques and Resources

Human/Systems Simulations, Neutral Buoyancy Simulator. This facility is located at the Marshall Space Flight Center and provides a simulation environment for studying human task performance in zero gravity. The facility offers a large volume working environment in a 75 ft. wide by 40 ft. deep water tank. The facility can conduct full scale evaluations using two pressure suited subjects and preliminary concept evaluations using scuba subjects.

The facility has provided the environment for Skylab crew operations, Large Space Systems assembly and deployment, Space Telescope servicing, Shuttle RMS operations, MMU/EVA evaluations, and EVA contingency operations. It has a long history of EVA simulation activity and provides the largest earth-based environment for studying human performance in space suited operations.

The facility is currently equipped with a full size Shuttle cargo bay mockup, an operational SRMS, a MMU simulator for EVA mobility, and pallet and payload mockups for mission simulation.

For human performance simulations, the point of contact is Jack Stokes, EL15, MSFC, (205) 453-4430. He can provide information on past research, particular capabilities and requirements for human factors simulations, and information on use of the research facility.

Human/Systems Simulation, Weightless Environment Training Facility. Located at JSC, this facility also provides a zero-G simulation environment, used for astronaut training. The facility is outfitted with a cargo bay mockup and Shuttle bay pallets. The test tank is 78 ft. long, 30 ft. wide, and 25 ft. deep.

The point of contact for training studies at JSC is Carl Shelly, CG, JSC, (713) 483-2061; for the WETF, Ray Dell-osso, JSC, (713) 483-2541.

Human/Systems Simulation, KC-135 Weightless Environment. Flying from JSC, the KC-135 simulation facility allows 2-3 sec. periods of induced weightlessness through a flight profile of parabolas. Part task simulations and special applications can be conducted aboard the aircraft and by "stringing" tasks over successive parabolas, a task sequence can be studied in zero-G.

The point of contact is James W. Billodeau, CG, JSC, (713) 483-2061.

Manipulator Evaluation Criteria. A useful research technique, the evaluation criteria, employs a hierarchy of task modules with increasing degrees-of-freedom (DOF). In use at MSFC since 1973, it permits elimination of manipulator components such as end effectors, hand controllers, arm configurations, etc. from further test and evaluation if they fail to satisfy performance criteria at an elemental level (1 or 2 DOF). This procedure saves resources in that all possible combinations of manipulator components don't need to be extensively evaluated to find one or two complete systems which excel in typical task performance. The task modules typically measure tip position accuracy, orientation, stability, force/torque application, performance time and error rates.

The point of contact is Nicholas Shields, Essex Corporation, (205) 883-7471.

Teleoperation and Robotics Integrated Test Facility. Currently under construction, this test laboratory combines the capability of three existing laboratories: visual systems, manipulator systems and mobility systems. The completed facility (FY83) will provide a 4000-sq. ft. epoxy flat floor for air bearing vehicles. The vehicle stands provide 6 DOF for target motion. A remote workstation provides for evaluation of human performance during remote operations, such as satellite servicing, docking, inspection. The facility provides for a wide range of remote systems and robotics simulation in a simulated space environment.

The point of contact is Fred Roe, EC25, MSFC, (205) 453-3369.

Teleoperator Technology Development Program. This program provides a means of transferring and applying teleoperator and robotic technology to various space programs. Begun in 1971, the program is a laboratory based research program to develop design criteria for remote systems.

The conventional human factors criteria have assumed that the human operator and the controlled system occupy the same physical and temporal space, but this is not true for teleoperated systems. Consequently, performance data using remote support systems--manipulators, sensors, motion bases--had to be developed. This is an ongoing program for both basic and applied research issues.

The point of contact is Wayne Wagnon, EC31, MSFC, (205) 453-4623.

Six Degree-of-Freedom Motion Base and Crew Station and the Target Motion Simulator. These two complementary facilities provide for the simulation of rendezvous and docking in remote or local operations. The motion base provides proprioceptive/kinesthetic cues for user/system flight simulation and is equipped with a terrain table and visual system. The target motion simulator provides computer resolved vehicle approach and motion between two vehicles, one of which is controlled by the operator.

The point of contact for these facilities is Frank Vinz, EF93, MSFC, (205) 453-3991.

Analytical Techniques for Human Factors in Space Applications. Task analyses are still the most common means to derive system roles and responsibilities for humans in space, but other techniques are also in use. The SAINT program for integrated systems analysis is a more demanding analytical technique requiring substantial data for implementation but it also yields more data on performance of the system. The Man/Machine Assembly Analysis is a developmental technique for assessing appropriate modes of large space system assembly from manual, remote or automated alternatives. Conventional cost and engineering studies can generally be applied to human factors areas, but they tend not to provide human factors-specific information.

2.4.2 Control Station Design Data Base

There are ample volumes on control and display station design, but some of the unusual user/system requirements found in space applications require, and certainly the unusual environment has dictated, special designs for control stations.

Spacelab Experiment Control Station. This interactive station is designed for the command and control of experiments through a data display system consisting of a keyboard and video display unit. The requirements for command and control are derived from the hardware and software constraints, and the display protocols are presented in MSFC-PROC-711A. The display guidelines were derived from evaluations on the Experiment Computer Operating System and provide information on human performance in controlling remote software and hardware activity.

Teleoperator Control Station Design. Several models for teleoperator control stations have been investigated as the requirements for specific teleoperated systems have developed. Free flying teleoperator, teleoperator bay experiment, earth orbital teleoperator,

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teleoperator retrieval system, teleoperator maneuvering system are some of the concepts that have been put forth, and with them control stations based on differing operational philosophies have also been proposed. Aft flight deck, Spacelab, TDRSS, ground station and POCC versions have been investigated. The level of investigations has not been such that there is any firm basis as yet for deciding on a "best" control station.

The point of contact for Integrated Teleoperator Control Station design is Ed Guerin, EC13, MSFC, (205) 453-4635. Work done for the integrated Orbital Servicer crew station design is included under teleoperator related research, and the point of contact is Don Scott, EC24, MSFC, (205) 453-5758.

3.0 TOPICS FOR FUTURE HUMAN FACTORS RESEARCH

In order that human factors data be an integral part of advanced space systems, it is desirable that programs in their conceptual stage be reviewed for areas of human factors applications. The review of advanced programs will enable human factors data to be part of the design basis for advanced programs rather than an add-on or system design afterthought. The responsibility for identifying human factors applications in advanced space systems is shared between the system designer and the human factors community. Additionally, the human factors applications are both generic and system specific in nature. Consequently, the aim of future research should be to assess the adequacy of generic human factors data in meeting the requirements of advanced systems and to contribute to the human factors data base by performing system-specific research not currently a part of the generic base as in MSFC-512A, JSC 10615, MSFC PROC-711A and similar technical documents.

3.1 ADVANCED SPACE SYSTEMS, GENERIC RESEARCH TOPICS

Habitability - Systems such as the Spacelab module provide for shirtsleeve operations on-orbit. Potentially missions of long duration, 90 days, can be carried out from a Spacelab type module attached to an orbiting large space structure. Habitability requirements for long duration human occupation of a module can be derived from a review of Tektite data, Skylab data, and from specific Spacelab simulations.

Output - Long duration human habitability requirements document.

Anthropometry - As those people involved in space based activities become more representative of the general population, the anthropometric data base for space system design criteria must also be expanded. Current data bases from military sources and the NASA-REF-1024 can be used as a foundation for future expansion of a representative anthropometric data base which is appropriate to space applications.

Output - Representative anthropometry for weightless environments.

Advanced Crew Station Design - More reliance upon multi-function, computer driven displays and multifunction command and control panels is apparent in aerospace and earth-based workstations. Using current data on human computer interaction and the expanded anthropometric data base, a set of crew station design standards for advanced space programs should be developed. The design standards should reflect the anticipated future space programs and the data already generated from programs such as the Apollo Telescope Mount (ATM) and Spacelab Experiment Control.

Output - Advanced crew station design standard.

3.2 SPECIFIC RESEARCH TOPICS

3.2.1 Remote System Control/Supervision

Several distinct research efforts are coalescing and have significant implications for advanced space missions. Machine intelligence, teleoperation, space structure fabrication and assembly, large space systems, automated experiment management and long duration orbital repair and servicing are research programs which have been developing independently, but from a programmatic viewpoint have binding relationships with each other. What is needed is a research and development program which identifies the areas of human factors applications for specific remote system programs such as large space structures assembly, teleoperator servicing missions, and human interaction with intelligent machines; identifies the data which still need to be developed for human/remote systems technology; collects those data and then compiles them into remote system/human factors compendium. While this is a very large order for a specific research program, it can be broken out into component parts, as follow:

A. Human Interface with Intelligent Systems for Operations Management

1. Develop and evaluate intelligent computer programs for experiment control. Develop an intelligent system to assist in crew operations of complex science experiments. Perform evaluations on human alone experiment control, human/computer management, and computer alone management. Compare data return and accomplishment of science objectives using the three modes.

2. Evaluate the command/control feedback alternatives for operator/machine interaction and develop a set of optimal design standards for advanced experiment control, orbital activity management and other remotely managed tasks. Standards should address specific issues of AFD vs. POCC vs. specialized control/display station operations as well as command protocols, display arrangement, and uses of special visual and auditory displays.

3. Evaluate automated system control with the operator in a supervisory role and expert systems/artificial intelligence for system control for the purpose of defining the role of humans in highly automated systems, and providing adequate human control functions for contingency and off-nominal operating conditions, including emergencies.

B. Human Control of Remote System Mobility and Manipulation

1. Evaluate the effects on performance of utilizing a single controller system which serves to control both vehicle mobility and docking and post-docking manipulator control. Determine the performance differences between a single hand controller and dual hand controllers for such a system.

2. Evaluate operator performance on manipulative tasks where visual feedback is degraded but still available (< 20 dB S/N, 300 lines resolution, <.25 target background contrast). Determine performance baseline on degraded system and then employ augmentary feedback systems such as tactile displays, computer enhanced displays, computer generated displays, radar image displays to test for changes in task performance.

3. Develop concepts for specialized manipulator applications, including specialized controllers (as in a full torso exoskeletal controller for use at a ground station) and specialized end effectors (as in an inflatible end effector for use with beams, or a delicate claw for use with composite columns). Full sized controllers, while not desirable for Shuttle aft flight deck use, might be preferred for control via dedicated work stations.

C. Control Station Design

1. Current planning calls for zero-G and one-G operating environments for control of remote systems. The human factors requirements for the two environments are quite distinct as we discovered on ATM-Skylab. A research evaluation effort is required to identify what data bases and which design criteria apply specifically to one-G operator stations, to zero-G operator stations and which apply appropriately to either or both environments. Particular points of interest should be human restraint/support during mobility/manipulation activities, head movement and visual displays, multiple system operations from the same control station.

2. Simulation mockups for use in neutral buoyancy simulation and one-G simulations should be fabricated for use in operational simulations and concept verification.

3.2.2 EVA Applications During the Shuttle Era

The Shuttle will provide a broad opportunity for extravehicular activity in the next several decades. EVA servicing missions, satellite repair, experiment management, unscheduled and contingency operations are just some of the EVA tasks proposed for future space missions.

The new equipment available to the EVA crew members--EMU, MMU, SRMS--for support and maintenance of EVA tasks, and new equipment in the concept stages--power ratchet wrench, RMS-mounted cherry picker, large construction manipulator module, and mobile work stations--will greatly expand our current knowledge of the role of humans in space as well as expand our ability to use the human's unique capabilities in the space environment. In order to appreciate the full capabilities of EVA potential, human factors scientists should direct their attention to each of the following areas:

(1) Determine the effects on workstation design of the EVA mobility unit for the anthropometry represented by the 5th percentile female through the 5th percentile male.

(2) Determine the effects of MMU configuration on EVA workstation design. This should include MMU stand-off and positioning aids.

(3) Evaluate several standard module changeout designs for EVA and remote manipulator compatibility. Where are the effects of different changeout approaches on task times, task performance, EVA workload, and manipulator capabilities?

(4) Evaluate EVA performance changes using a three-axis EMU foot restraint. Current foot restraints must be egressed before reorienting them at the worksite in violation of MSFC-STD-512. What performance benefits can be gained by using a 3 DOF station which is manually adjustable while the EVA crew member remains in the foot restraint? What foot restraint design criteria must be met to assist the EVA crew in task performance?

(5) Determine potential cost savings associated with multiple crew, multiple shift EVA assembly and servicing operations for Space Station construction and maintenance tasks.

(6) Develop EVA cost data for tools, manual overrides and crew aids for comparison with conventional automated devices. Evaluate cost savings for potential Space Station servicing tasks.

(7) Evaluate system performance during spacecraft servicing tasks. This should include EVA workload, tool interface, glove wear, effects of manual vs. power tool on task performance, and generation of empirical data on which to base tool and workstation design criteria.

(8) Develop an EVA body positioning kit for use by system designers involved in EVA applicable programs. With new EMU configurations, tool packs and MMU's, our existing design data are out-of-date. The body positioning kit would be a suited subject model and would indicate the preferred and the worst case body positions for general categories of EVA tasks such as translation, assembly, module changeout, etc.

(9) Develop human factors/EVA design criteria for EVA restraint systems on advanced missions. These restraint systems would include EMU foot restraints, leg restraints, restraint systems for cargo bay servicing of payloads, RMS attached workstation restraints and assembly restraints. The requirement for further development of EVA restraint systems is derived from the anticipated expansion of the role of EVA in servicing, assembly, and mission support. These new EVA tasks will be

accomplished most effectively with equipment designed specifically to accommodate the EVA crew.

(10) Develop a standardized design specification for changeout requirements via EVA. The design specification should address workstations, restraints, EVA capability, stowage, transfer, access and safety for items such as electronics packages, fluid and power connectors, electrical and mechanical instruments, film and data packs, and similar EVA serviceable packages. The design specification should also address, as a secondary issue, design requirements for remote changeout via manipulator systems where these requirements do not interfere with EVA requirements.

(11) Design and develop an EVA power tool for on-orbit operations. The power tool should be generally applicable to common EVA activities and should include tool attachments such as grippers, cutters, screwers. The tool should be reversible in operating direction and have provisions for manual use in case of power failure. Additionally, evaluations on manual vs. power tool selection--in terms of performance times, task accuracy, support requirements--should be conducted to access the two tool modes. Space telescope servicing tests conducted in the neutral buoyancy simulator have indicated savings in time, restraints, glove wear and increased accuracy of task performance for some classes of EVA tasks.

(12) In conjunction with tool operations, a design standard for selection of fasteners and connectors should be developed for use in EVA tasks.

ESSEX

4.0 LITERATURE SURVEY

Ref. Appendix A - Data Sources

A.1 EVA

MSFC-STD-512	Man/System Design Standard for Manned Orbiting Payloads
MSFC-STD-512A	Man/System Requirements for Weightless Environments
JSC-10615	STS EVA Design Guidelines and Criteria
NASA TMX-64825	MSFC Skylab EVA Development Report
Essex H-76-7	Design Guidelines and Criteria for Shuttle Payloads to Accommodate EVA
Essex H-80-4	Structural Attachments for Large Space Structures
CONT OPS 2102	Contingency Operations Training Workbook (STS EVA)
LS-005-003-24	Photographs of Skylab Inflight Tools and Equipment
Skylab Experience Bulletin No. 1	Translation Modes SI Bump Protection
No. 5	Inflight Maintenance of a Visible Program Element
No. 13	Tools, Test Equipment and Consumables Required to Support Inflight Maintenance
No. 27	Personnel and Equipment Restraint and Mobility Aids (EVA)
JSC-18201	Satellite Services Workshop (June 22-24, 1982)

A.2 TELEOPERATOR

ESSEX H-82-01	Human Operator Performance of Remotely Controlled Tasks
NASA/MSFC T/O Task Team	Teleoperator Maneuvering System Program Definition Activities, 1979

A.2 TELEOPERATOR (Continued)

Essex H-79-01	Earth Orbital Teleoperator Systems Evaluation
H-30093B, NBS	Proximity-Vision System for Protoflight Manipulator Arm
Machine and Machine Theory	Manipulator System Performance Measurements
Proceedings of the Sixth Congress of the International Ergonomics Association	A Method and Data for Video Monitor Sizing
Essex H-75-30953	Role of Man in Flight Experiment Payloads
NASA SP-5047	Teleoperators and Human Augmentation
NASA SP-5070	Teleoperator Controls
Martin Marietta Documentation on TRS, NAS8-32821	Teleoperator Retrieval System Program Documentation

A.3 CREW/VEHICLE INTERACTION

MSFC-PROC-711A	Spacelab Display Design and Command Usage Guidelines
VanCott and Kinkade	Human Engineering Guide to Equipment Design
NASA-CR-3285	EVA Manipulation and Assembly of Space Structure Columns
NASA SP-377	Biomedical Results from Skylab

A.4 ANALYSIS/DESIGN TECHNOLOGY

Essex H-82-02	Man Machine Assembly Analysis
NASA-RP-1024	Anthropometric Source Book
Proceedings of the 23rd Annual Meeting of the Human Factors Society	Lewis, J.L. Operator Station Design System: A Computer Aided Design Approach to Workstation Layout.