Telescience Testbed Pilot Program
Final Report
Volume I
Executive Summary

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Barry M. Leiner

Research Institute for Advanced Computer Science
NASA Ames Research Center

RIACS Technical Report TR-89.7
February 1989

Research Institute for Advanced Computer Science
An Institute of the Universities Space Research Association

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The Universities Space Research Association (USRA), sponsored by the NASA Office of Space Science and Applications, conducted a Telescience Testbed Pilot Program. Fifteen universities, under subcontract to USRA, conducted various scientific experiments using advanced computer and communications technologies. The goals of this pilot program were to develop technical and programmatic recommendations for the use of rapid-prototyping testbeds as a means for addressing critical issues in the design of the information system of the Space Station Freedom era.

This is the final report for the Pilot Program. It consists of three volumes. Volume I provides an Executive Summary. Volume II contains the integrated results of the program. Volume III provides summaries of each of the testbed activities.

This work was supported in part by
Contract NASW-4234 from the National Aeronautics and Space Administration (NASA)
to the Universities Space Research Association.

Acknowledgement

The work described herein is the result of the close cooperation of a large number of people throughout the country. Fifteen universities representing a cross-section of space science disciplines along with several NASA centers were involved in the program and contributed considerable time and effort. This report, in particular, represents the effort of approximately 50 people. These people are listed in Appendix A.

The author (really more of an editor) would like to acknowledge and express appreciation for the dedication and hard work exhibited by all involved. It is clear that the successes of the program are due to their effort.

On behalf of USRA and all of the program participants, I would like to acknowledge the support given to the program by NASA, in particular Erwin Schmerling and James Weiss of NASA Headquarters and Daryl Rasmussen of Ames Research Center. Without their efforts, this program would not have existed and been the success that we believe it to be.

I would also like to express appreciation to Maria Gallagher and Lorraine Fisher of RIACS for their long hours and hard work throughout the program and in helping to pull together this report.

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Volume I: Executive Summary

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Section 1
Introduction

Space Station Freedom (henceforth referred to as Space Station) and its associated laboratories, coupled with the availability of new computing and communications technologies, have the potential for significantly enhancing scientific research. To assure that this potential is met, scientists and managers associated with the Space Station program must gain significant experience with the use of these technologies for scientific research, and this experience must be fed into the development process for Space Station. The SESAC Task Force on the Scientific Uses of Space Station (TFSUSS) has used the word *telescience* to refer to the concept in which interactive high-performance telecommunication links are used to link the space-based laboratories and facilities, the on-orbit crew, and geographically dispersed ground-based investigator groups. Instead of being a remote outpost, Space Station is, rather, an accessible and integral part of the research infrastructure.[1]

The Universities Space Research Association (USRA), under sponsorship from the NASA Office of Space Science and Applications, has conducted a Telescience Testbed Pilot Program (TTPP), aimed at developing the experience base to deal with issues in the design of the future information system of the Space Station era. The specific goals of this pilot program were to:

- Demonstrate that the user-oriented rapid-prototyping testbed approach is a viable means for identifying and addressing the critical issues in design and specification for the Space Station Information System (SSIS) and the Science and Applications Information System (SAIS), thereby assuring that these systems will satisfy the needs of scientists for an information system in the Space Station era,
- Develop technical and programmatic recommendations for the conduct of such a testbed, and
- Develop initial recommendations for the SSIS and SAIS to be factored into the design and specification of those systems.

To accomplish these goals, fifteen universities conducted various scientific experiments under subcontract to USRA. Each one of these experimental testbeds share the characteristic of attempting to apply new technologies and science operations concepts to ongoing scientific activities. Through this process, new understanding and experience was gained about system architectures, concepts, and technologies required to support future scientific modes of operation.

This report contains the results of the Telescience Testbed Pilot Program in three volumes. Volume I (this volume) is the Executive Summary. Volume II contains the integrated results of the overall program. Volume III contains summaries of each of the experiments conducted under the university subcontracts. Further details of these

1. Task Force for Scientific Uses of the Space Station, 1986 Summer Study.

experiments are contained in the various scientific and technical reports published by the participating organizations. A bibliography of these publications is included as Appendix C to this report.

Section 2
Program Overview

The fifteen TTPP subcontractors, listed in Table I, conducted a variety of user-oriented rapid-prototyping testbeds in order to gain knowledge and experience relative to the critical issues in the design of the information system of the Space Station era. This pilot program lasted from April 1987 through December 1988, and has laid the ground work for future testbedding activities and the further quantification of requirements for an information system responsive to user needs.

Table I
TTPP Subcontractors

Cornell University	University of California, Santa Barbara (UCSB)
Massachusetts Institute of Technology (MIT)	University of Colorado
Purdue University	University of Maryland
Rensselaer Polytechnic Institute (RPI)	University of Michigan
Smithsonian Astrophysical Observatory (SAO)	University of Rhode Island
Stanford University	University of Wisconsin
University of Arizona	Research Institute for Advanced Computer Science (RIACS)
University of California, Berkeley (UCB)	

The testbeds represented four scientific disciplines (astronomy and astrophysics, earth sciences, life sciences, and microgravity sciences) and investigated issues in payload design, operation, and data analysis. The investigations were selected to emulate scientific research in the Space Station era and were supported with communication and information system technologies to assess their impact and utility to ongoing scientific research. Through experience gained in these testbeds, users were better able to formulate and quantify their requirements for various aspects of the information system.

For each discipline, we list the universities and centers involved followed by a brief description of the areas of research explored.

2.1 Astronomy and Astrophysics

California Institute of Technology
Cornell University
Massachusetts Institute of Technology
University of Arizona
University of Colorado
University of California, Berkeley

NASA Goddard Space Flight Center
NASA Ames Research Center
Jet Propulsion Laboratory

In the space station era, astronomical research will increasingly demand distributed user teams for operations planning, resource management, data reduction and integration, and archiving. In addition, the creation, simulation, and adaptation of hardware and software is certain to benefit from the use of design tools that encourage intergroup communication and communications protocols. To further these objectives, a variety of experiments were performed that focused on the detailed planning, operation, data analysis, hardware design, and software development that support contemporary astronomical research.

Specific university activities were as follows:

MIT investigated the remote operation of a telescope at Wallace Observatory using a high bandwidth (T1) link and dissemination of data on a campus-wide Project Athena network.

University of Arizona conducted investigated teleoperation of a forerunner of the Astrometric Telescope Facility, which will be an attached payload for Space Station. They also participated in the SIRTF activity, described below.

University of California at Berkeley extended control and simulation systems developed for the Extreme Ultraviolet Explorer (EUVE) to evaluate techniques for remote instrument control over local and wide area networks. Distributed development environments in use at Berkeley are being extended to facilitate coordinated development by cooperating institutions.

University of Colorado studied distributed and interactive operation of an astronomy telescope and its instrumentation at a remote ground observatory, addressing a range of teleoperations issues.

The Space Infrared Telescope Facility (SIRTF) team, consisting of Cornell University, Smithsonian Astrophysics Observatory, CalTech, and University of Arizona, investigated several issues regarding telescience applied to a Space-based astronomical facility. They evaluated distributed versus resource-centered models for development (teledesign) and remote access. The ability to interchange analysis software and perform in conference mode for design, operations and analysis was evaluated. University of Arizona has a special interest in remote control and operations of a ground-based telescope to evaluate feasible degrees of automation, allowable time delays, necessary crew intervention, error control and feasible data compression schemes. Cornell University investigated trade-offs between on-line local processing and processing at the users' home location as well as investigating the feasibility of establishing standard formats and analysis techniques. Smithsonian Astrophysical Observatory is using remote operation of Mt. Hopkins telescope to evaluate data transmission and dissemination options.

2.2 Earth System Sciences

Purdue University
University of California, Santa Barbara
University of Colorado
University of Michigan
University of Wisconsin

NASA Goddard Space Flight Center
Jet Propulsion Laboratory

The area of Earth System Sciences encompasses the fields of Remote Sensing, Aeronomy, Solar-Terrestrial Physics and Space Plasma Physics. The science goals of the experiments included multidisciplinary investigations of the near Earth environment, support for coordinated science campaigns and cooperative data analysis. The possible telescience studies covered most of the key issues previously described, and focused on the operational requirements of a distributed user community, the use and interaction with both real-time and archived distributed data sources, the coordination of data collection in campaign mode and the evaluation of standards for data transfer, communications and commanding.

Specific university activities were as follows:

Purdue University evaluated teleanalysis concepts using the Purdue Field Spectral Database accessed by a variety of small computers. It also investigated methods for conducting campaign style experiments and computer data security issues.

University of Colorado in coordination with UC Santa Barbara, Wisconsin, Purdue and Michigan, used the interactive control opportunities and the science database from the Solar Mesosphere Explorer Mission to investigate coordinated teleoperations and teleanalysis issues.

University of California, Santa Barbara explored teleanalysis of large dynamic data sets for earth sciences. This investigation includes the test and evaluation of data interchange standards and knowledge based techniques for assisting remote access.

University of Michigan investigated teleoperations of a Fabry-Perot Spectrometer combining human with autonomous control, forward simulation techniques to support telerobotics, and the effects of varying time delays in the control loop.

University of Wisconsin developed a bridge from NSFnet to McIDAS, allowing any TTPP participant with access to NSFnet to acquire existing meteorological products from McIDAS.

2.3 Life Sciences

University of Arizona
University of Colorado
Massachusetts Institute of Technology
Stanford University

NASA Johnson Space Center
NASA Kennedy Space Center
NASA Ames Research Center

The life sciences testbeds addressed the issues involved in space life science investigations where the interactions are primarily between a ground-based PI and a remote crew member performing an experiment. The importance of interactive communications during life science experiments has been amply demonstrated on past shuttle missions. The emergence of the long-term space station flights, where the crew cannot be expected to be intensively trained in each experiment, will make this interaction even more necessary.

Specific university activities were as follows:

University of Arizona developed systems and software for remote fluid handling in support of microgravity and life sciences.

University of Colorado developed and demonstrated teleoperations capabilities for the remote operation of a life science glovebox experiment.

MIT is conducting conducted a Remote Life Sciences Operation testbed using the KSC sled with multi-media tests and evaluation of real video needs and implementation options.

2.4 Microgravity Sciences

Rensselaer Polytechnic Institute
University of Arizona

NASA Lewis Research Center
Jet Propulsion Lab

The microgravity sciences testbed will encompassed low gravity research in a variety of materials science areas including metals and alloys, electronic materials, glasses and ceramics, and electrophoretic peptide separations. Space experiments already been carried out in these areas, and those currently planned have frequently been constrained by the requirement of highly autonomous operation. Telescience offers the promise of allowing the investigator to observe the experiment progress from a terminal in his earth laboratory and to make fine adjustments in the equipment, change experimental parameters, modify protocols, and deal with unexpected developments.

Specific university activities were as follows:

Rensselaer Polytechnic Institute investigated the level of communications capability required to successfully perform remote controlled materials processing experiments of the Space Station era. Three different types of experiments were tried with the cooperation of the Microgravity Materials Science Laboratory at Lewis Research Center.

University of Arizona developed systems and software for remote fluid handling in support of microgravity and life sciences.

2.5 Telescience Technologies

University of Arizona
University of California, Santa Barbara
University of Colorado
University of Michigan
RIACS
Stanford University

Ames Research Center

The experiments described above were designed to identify the requirements for carrying out science in the space station era and the role that advanced technologies can play in that science. It can be seen from the descriptions that a number of technologies have roles to play in multiple disciplines.

In addition, there are several technology areas where it is desirable to develop and demonstrate particular capabilities applicable to a variety of disciplines and make them available to those science communities. The following is a description of the university activities to investigate these underlying technologies.

University of Arizona explored issues in robotics applied to both fluid handling and operations of astronomical observatories.

University of California, Santa Barbara, investigated techniques for users to interact with large datasets at remote sites through a browsing capability.

University of Colorado prototyped and evaluated onboard operations management concepts to verify that teleoperations can function safely without command pre-checking. They cooperated with a number of sites in evaluating the Operations and Science Instrument Support (OASIS) software package, and ported OASIS to the Sun workstation as a test of the portability of an operational real-time system written in Ada. They also investigated the use of packet telemetry, packet commands, and SFDU's in the Space Station environment.

University of Michigan has explored the role of expert systems in supporting remote coaching in both an on-line and off-line mode.

RIACS integrated various networking and local computing capabilities into a telescience workstation environment (TeleWEn), intended to provide a local computing environment for telescience. RIACS also collaborated with Ames Research Center in investigating experiment operation using computer-supported coaching. RIACS, again in collaboration with Ames, investigated the utility of networking and electronic mail in supporting a large distributed group activity (the TTPP itself).

Stanford University experimented with a model Remote Science Operations Center linked to GSFC, JSC and MSFC using real data from Spacelab 2 to test multimedia Telescience workstations and simulate remote control, monitoring and multi-media conferencing.

The next section presents highlights of the results and lessons learned through the TTPP. Details of the experiments may be found in Volumes II and III of this report as well as the various technical reports and publications listed in the bibliography (Appendix C).

Section 3
Highlights of Results

Sections 3 and 4 of Volume II contain the results of the TTPP. Here, we provide highlights of these results. Some of these observations and results were general and came from integrated TTPP experience. Others were developed in the context of a specific scientific discipline and could not be generalized, either because there was insufficient experience in the other disciplines or there were differences between the discipline requirements. In cases where results were from specific testbed activities, the universities are cited for cross-referencing to Volume III.

3.1 General Technical Results

A number of results in teledesign, teleoperations, teleanalysis and infrastructure were found to apply across the several disciplines. In the area of teledesign, the focus was on the remote development and debugging of software.

- Remote debugging of instrument software was demonstrated to be both possible and effective. On-line access to a variety of common software tools was shown to be important and feasible.
- A need was identified for trade-off studies and simulation tools to complement testbedding in the design phases.
- Ada was demonstrated to be a useful and acceptable high level language for the design and development of real-time systems.

Teleoperations covers the spectrum from making small instrument adjustments to optimize data taking through the full interactive operations required for Life and Microgravity Sciences. Safe operations in both cases were investigated using transaction management plus interlock concepts. A number of common results and conclusions were demonstrated in the area of teleoperations.

- The benefit of using a common workstation for access to multiple instruments was demonstrated. The experience with OASIS indicated that it is possible for groups from different disciplines to use a common teleoperations workstation.
- Interconnected facilities were shown to allow multiple researchers to collaborate on experiments, e.g. have an expert at one site available for troubleshooting during experiments being conducted at other sites with other researchers. (SAO)
- All of the TTPP sites chose either Sun or microVAX workstations along with either Unix or VMS operating systems as their main workstations, supplemented by PC-AT compatibles and Macs. This class of hardware and software was found to be adequate for teleoperations.

- Teleoperations was shown to lead to improved productivity by: 1) permitting the assembly of required resources with minimal travel costs and equipment shipment, 2) enlarging access to space instruments and scientific data, 3) permitting rapid access to flight data, and 4) permitting direct PI/crew interaction.

General teleanalysis results included the following:

- A number of the research groups found minimal need for analysis during operations, because they were simply too busy.
- Viewing data requires screen refresh on order of .1 to 1 minute, almost irrespective of data characteristics. The locating of remote data was supported acceptably through 9600 bps access with subsequent file transfer through the Internet.
- Image compression methods for preserving important information while reducing bandwidth are important. The information needed to preserve varies between applications, and therefore so do the appropriate algorithms. Experimentation with various algorithms indicate that such techniques have potential.
- There is an important niche for IBM-PC compatible and Mac II class workstations, coupled to larger host computers through LANs and dial-up circuits. This lower cost alternative needs further exploration.
- Although connectivity to data sources is a primary aspect of teleanalysis, the additional ability to exchange ideas, techniques, and software among research collaborators proved to be equally important.

Infrastructure results focussed on communication requirements and workstation characteristics.

- Space to ground communications bandwidth requirements for many of the experiments were dominated by the need for video feedback. Downlink video with PI-adjustable frame rate, resolution, and gray scale is required out to the PI remote site. Adjustment capability is required by the PI to obtain the "best picture" within the currently available bandwidth. Uplink video is required to support "coaching."
- Communication requirements for low-latency transmission appear to be for high peak rates but low average rates. Such a requirement is well suited to packet switching, but the current networks have proved to be inadequate.
- Participants found that workstation interface standardization was a more important concern than the exact hardware/software configuration used. This led to the conclusion that selection of commercial off-the-shelf hardware/software configurations may be feasible and desirable for many purposes.

- The timing cycle for NASA/universities/institutions was longer than the one-year TTPP program itself, thereby limiting the ability to install the required infrastructure during this limited program.
- Exchange of information is hampered by groups using different text/graphics formats.
- TAE+ was found to provide a good set of tools for prototyping the user interface for workstations.
- The need was identified for tools to support real-time group collaboration (e.g. teleconferencing). One possibility suggested was to incorporate NASA's audio/video teleconferencing system into the testbed to support interaction between groups and to evaluate its effectiveness for scientific collaboration.

3.2 Astronomy

The participating astronomy and astrophysics researchers noted that theirs is an observational science. Unlike several of the other disciplines (particularly life and microgravity sciences), the subject of the typical experiment cannot be modified by the researcher. This characteristic heavily flavors the nature of telescience for astronomy, driving towards monitoring of the observations and the ability to access data quickly and "fine tune" the observing instruments. Fine tuning can greatly enhance the quality of the data obtained.

Thus, teleoperations for astronomy involves the real-time control of observations and real-time access to data. Experiments conducted under the TTPP led to the following results and conclusions:

- Fully autonomous operation is often more costly than teleoperation due to the need for higher instrument precision.
- Scientific productivity is improved through access to real-time data from the researchers' home institutions. (SAO, MIT/KSC, University of Colorado, University of Arizona)
- The instrument design process can be improved by incorporating the network interface into instrument design from the start, allowing among other things that required software updates be done remotely. (SAO, UCB, Arizona)
- Data compression holds significant promise for permitting teleoperations of telescopes while keeping to available bandwidths. CCD images typically require minutes of integration, thereby reducing the required rate of image transmission. A possible exception is solar observation of dynamic processes. An image compression technique was demonstrated that reduced the required data rate from 8 bits/pixel to .015 bits/pixel. (Arizona)

Teleanalysis is a prime requirement for the astronomy and astrophysics community, permitting databases to be accessed remotely.

- Poor connectivity and performance of existing networks made tests of such remote access difficult. (Arizona)
- The utility of a standard data analysis environment (IRAF, AIPS, FITS) was validated through several of the testbed activities.

Support of the required teleoperations and teleanalysis environments required adequate communications. The experimenters found that:

- 9600 bps links with five second delay are adequate for normal operations (not including video/images). (Arizona) Many of the participants strongly expressed the need for occasional use of a "priority channel" for command and control with overall round trip time delay of less than one second. While somewhat longer delays can be tolerated, this requires use of special techniques which rapidly become more complicated and less effective.
- Network latencies of more than 30 seconds results in remote operators resubmitting requests. Therefore, there is a need to keep latency down and make the system tolerant of repeated requests. (Colorado)
- Current networks (e.g. SPAN and Internet) are adequate for electronic mail but inadequate for most other functions. Typical transfer rates for files across the Internet were approximately 1 kbps. (SAO, Arizona)
- The Astronomy community found a need for standards (ranging from networking, e.g. Internet, through data format standards, e.g. FITS), and demonstrated their utility.

3.3 Earth Sciences

Earth Science participants found that their awareness of telescience possibilities plus access to telescience tools had significant positive effects on the conduct of their research. In the area of teledesign, distributed software development was an area of concern. Specific results were the following:

- Duplicate software environments are required to support collaborative development. Moving software and software environments between sites was found to be more difficult than anticipated.
- A shared 56 kbps network (similar to the current SPAN and Internet) was found to be adequate for remote debugging of software.

Teleoperations for earth sciences focussed on remote monitoring and control of sensor platforms, and the conduct of campaign-style experiments involving researchers at multiple locations conducting observations using multiple sensors. It was found that:

- There was a de facto standardization on OASIS for remote operations, and OASIS functionality was found to be basically satisfactory even though OASIS was developed for a different discipline. A need for a library of software tools to support teleoperations was identified.

- Due to time and technology limitations, the campaign experiments conducted under the TTPP were designed to require only electronic mail for coordination. Future campaign experiments are expected to require more sophisticated collaboration technology.

As in astronomy, earth science research relies heavily on access to remote data sets for analysis. The experimenters found that:

- There is a need for secure database access methods, and techniques for avoiding conflicts between real-time system operations and retrospective analysis. (Wisconsin, Purdue, UCSB)

- The testbed experience supported the need for high-level catalog and directory services for earth science datasets. Standards for data description are more important than standards for data formats.

Network access was required throughout the science process, from design through operations to analysis.

- The need was identified for verification of file transfer, analogous to return receipt for mail. There is also a need for the ability (currently available in the Z-modem protocol) to recover from communications outages in the middle of file transfers, to permit transfer of large files.

- Current networks were found to be inadequate, with too many dropped sessions for file transfers. The 9600 bps data rate was not sufficient for interactive remote display of bit-mapped graphic images. The 30 second round trip delays sometimes encountered were also found to be unacceptable.

3.4 Life Sciences

Life sciences research is different from other disciplines in that the astronauts may be both subjects and experimenters. Life sciences research program often finds itself constrained by limitations in communication and control, limited available crew time, and time delays in data availability.

Teleoperations for life sciences involved both the monitoring and control of remote experiments and the interaction between ground-based PIs and the crew in the conduct of such experiments.

- Coaching techniques were found to be very effective in supporting PI/crew interaction during experiments. An crew "open mike" approach, allowing effective monitoring by the PI, was most effective. Workstations incorporating computer-supported collaboration tools were helpful. (MIT/KSC) PI/crew interaction was facilitated through use of medium resolution, wide field of view color TV. (Ames)

- PIs require real-time monitoring data. This allows for more effective use of crew time. (MIT/KSC, Arizona, Colorado)

- Data compression for video can be helpful. It can be lossy for monitoring/quick-look, but needs to be lossless for eventual analysis. Command/telemetry data for the specific experiments conducted did not need to be compressed due to their inherently low data rates (<9600 bps, average few hundred bps). (MIT/KSC, Arizona)

- Operations management technologies (including command interlocking and reaction control) were shown to work in protecting the health and safety of both experiments and space subsystems. (University of Colorado)

The life sciences experiments led to a number of results concerning requirements for communications and other infrastructure, primarily in support of teleoperations.

- Ada was an excellent choice as a standard programming language for life sciences telescience applications. A clear understanding and documentation of interfaces between distributed software components is required. (Arizona, Colorado)

- The functionality of OASIS (capabilities and ease of customizing) proved essential for teleoperations for life sciences. It needs to be enhanced for speed, communication capabilities, and use of a TAE+ type of front end. (Colorado)

- CCSDS SFDU's were found to be adequate for support of teleoperation data exchange for life sciences. The requirement for standard data structures for data interchange was identified, and CCSDS standards recommended. (Arizona, Colorado)

- For the experiments conducted, time delays for remote coaching between audio and video of 1-3 seconds were acceptable. Delays of 30 seconds were unacceptable. (MIT/KSC) Remote robotic control required delays of less than one second. This is a concern given propagation delays, and methods for coping with such delays must be developed. (Arizona)

- When observing crew activities under conditions of reduced video bit rate in the particular experiments investigated, PIs typically traded off color and temporal resolution (frame rate) in order to obtain at least 4-5 bits of grey scale and the maximum available spatial resolution. Although this suggests that slow scan video may be acceptable for many activity monitoring tasks, the PIs noted that there were times when bursts of full rate video were essential or helpful. (MIT/KSC)

- Data dropouts of less than one second were tolerable. Recovery of lost data was of little utility for real-time data monitoring. (MIT/KSC)

- SPAN and local nets were inadequate for experiments conducted jointly with JSC due to excessive delay and packet loss (caused by excessive network traffic). The conduct of experiments was found to require high-priority commitment from communication suppliers or the provision of dedicated virtual circuits. (MIT/KSC)

- Standard "user-friendly" workstation interfaces were shown to be very effective in improving productivity. The Macintosh interface was shown to be useful in prototyping. X-windows was an acceptable windowing standard for development of a PI workstation. (MIT/KSC, Ames, Colorado)

3.5 Microgravity Sciences

Researchers in the Microgravity Sciences found that the key contribution to productivity was via "rapid feedback," being able to obtain quick-look results rapidly by monitoring data during the conduct of the remote experiment.. The major results obtained regarding teleoperations were that:

- Control signals require internal error checking and correction and probably a "limit-switch" type of mechanical protection. (RPI)

- When crew assistance is required, a minimum of one dedicated direct voice channel is required during the period of crew involvement.

- Not all microgravity experiments are amenable to teleoperations.

3.6 Programmatics

One of the primary purposes of the TTPP (the "pilot program" aspect) was to validate the approach of having multiple universities collaborate through a set of user-oriented rapid-prototyping testbeds for the purpose of investigating critical issues in the design of the information system of the Space Station Freedom era. Part of this investigation was into the appropriate mechanisms and approaches for conducting such a program. A number of lessons were learned regarding these programmatic aspects:

- The Astronomy community found the use of networking, particularly electronic mail, highly productive. They used the network heavily for coordination and preparation of area reports, finding the technique highly satisfactory and effective.

- Life sciences participants found that coordination between participants required four different communication levels: project definition documents, telephone, electronic mail, and site visits.

- The TTPP contractual arrangement, using a prime contract with USRA and subcontracts with universities, worked extremely well.
- Critical issues need to be identified prior to the selection of individual testbedding activities. A separate activity involving requirements integration, architecture definition, etc., is required and should be carefully coordinated with testbedding activities, driving the selection of critical issues and approaches and integrating results.
- There is a need to develop a long-term program to reduce the impact of aspects such as funding delays, delays in installing communications, and delays in procuring equipment. It typically takes 2 - 3 years from proposal to results.
- Campaign experiments (involving multiple instruments and organizations) need to be more carefully coordinated and planned, with attention paid to finding the science content and managing expectations. It is too easy to try to tackle too large a problem for a rapid-prototyping approach.
- Similarly, incorporation of state-of-the-art technology takes different time scales for different activities. There is a need for a project structure that allows for differing time schedules of different testbeds.
- The combination of electronic mail, electronic reporting, electronic mailing lists, and regular program meetings and briefings was effective in coordinating and conducting the program. Guidelines are needed to avoid excessive mail. Appropriate facilities and staffing are needed to maintain electronic mailing lists. Summary reports by the USRA program manager with pointers to detailed reports would be helpful in reducing information overload.
- Databases need to be designed to manage electronic communications with priority schemes and extensive cross-referencing

Section 4
Conclusions

The Telescience Testbed Pilot Program proved the effectiveness of having multiple users, developers, and technologists join together in the investigation of critical information system issues. The multi-disciplinary nature of the effort had a number of benefits. Users from various disciplines were exposed to technologies developed under other disciplines, some of which was able to be directly transferred. Users were able to compare their results with those of other disciplines and come to common understandings about the roles and requirements of specific technologies. Significant scientific benefits were gained through the exposure of researchers to the most modern computing and communications technologies.

The telescience approach to scientific investigations in remote or dangerous locations has been validated. The general objectives of less crew time, more and better science, and increased scientific productivity can be attained through this approach. This achievement has been made possible by recent technology advances in communications systems, control systems, computers, remote vision and sensing, visual displays, and robotics, coupled with new understanding about new modes of scientific research to take advantage of these technologies. These technologies are sufficiently mature that telescience concepts can be included in all future missions, but additional research is required to ensure operational reliability and to fully exploit the advantages of these new techniques.

The user-oriented testbedding approach was also shown to have great value. Through the explicit insertion of advanced technologies in a coordinated and supported way, the scientific programs were able to explore both the applicability of advanced technologies and simultaneously to further their scientific research.

Thus, the need for such a program was clearly demonstrated if NASA is to move aggressively towards developing an integrated multi-disciplinary information system approach. Such a system is required in support of the future scientific missions, which themselves will involve researchers from many disciplines attacking the great challenges that face NASA in the future.

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Appendix A
Program Participants

University Subcontractors

Cornell University

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Appendix B
Glossary

AAS	American Astronomical Society
AGC	Automatic Gain Control
AIPS	Astronomical Image Processing System
ALOT	Arc Laser Optical Technology
Andrew	Multimedia mail system; basis of Carnegie-Mellon EXPRES system
ARC	Ames Research Center
ARPANET	Wide area data network supported by DARPA
AT	Astrometric Telescope
ATF	Astrometric Telescope Facility
Athena	MIT student network
AVHRR	Advanced Very High Resolution Radiometer; on the nimbus series of satellites. Operated by NOAA
B&W	Black and White Display
BARRNET	Bay Area Regional Research Network
BAUD	A unit of signaling speed; refers to the number of times the state or condition of the line changes per second
BCE	Bench Checkout Equipment
BDCF	Baseline Data Collection Facility (at KSC)
CAS	Canadian Astronomical Society
CCD	Charge Couple Device; a technology for converting images into electrical signals
CCSDS	Consultative Committee for Space Data Systems
CDP	Command, Data, and Power interface unit; part of the EUVE instrument
CLIPS	A programming language for expert systems..
CODEC	Coder/Decoder
CSDF	Commercial Space Development Facility
CUI	Common User Interface
DARPA	Defense Advanced Research Projects Agency
DEC	Digital Equipment Corporation
DMIL	Direct Manipulation Interface Language
DOC	Discipline Operations Center
DSP	Digital Signal Processing
EPS	Experiment Payload Specialist
EUV	Extreme Ultraviolet
EUVE	Extreme UltraViolet Explorer

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EXPRES	Experimental Program in Electronic Submission
FUV	Far Ultraviolet
FRICC	Federal Research Internet Coordinating Committee
GOES	Geostationary Operational Environmental Satellite
GPX	Graphics Processor Workstation for microVAX II
GSFC	Goddard Space Flight Center
HCIG	Human-Computer Interface Guide
HIPS	Human Information Processing Laboratory's Image Processing
HRPT	High Resolution Picture Transmission
HUP	Human Use Protocols
IBM	International Business Machines
ICD	Interface Control Document
IDL	Interactive Data Language
IGBP	International Geosphere Biosphere Program
IL	Intermediate Language
IMS	Instrument Management Services
Ingres	A database
IOMS	Instrument OMS
IPAC	Infrared Processing and Analysis Center at Caltech
IRAF	Image Reduction and Analysis Facility
IRAS	Infrared Astronomy Satellite
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
JVNCC	John Van Neuman Computing Center
KSC	Kennedy Space Center
Kermit	A file transfer program
Kiwi	A "flightless bird" consisting of prototype EUVE electronics
LAN	Local Area Network
LASP	Laboratory for Atmospheric and Space Physics
LCC	Local Controlling Computer
LIB$TPARSE	VAX/VMS library routine that provides a table driven parser. Used for the initial version of the CSTOL parser for OASIS
LSTB	Life Sciences Testbed
Magic/L	Interactive programming language developed by Loki Engineering, Inc
McIDAS	Man Computer Interactive Data Access System
MIT	Massachusetts Institute of Technology
MMSL	Microgravity Materials Science Laboratory
MMT	Multiple Mirror Telescope on Mt. Hopkins, AZ
MSFC	Marshall Space Flight Center

NASA	National Aeronautics and Space Administration
NASA SELECT	NASA operated TV channel which carries NASA related events
NASCOM	NASA Communications- mission critical
NFS	Network File System
NICOLAS	The inter-network gateway at Goddard Space Flight Center
NOAA	National Oceanic and Atmospheric Administration
NOAA-G	Name of the NOAA polar orbiting satellites
NRAO	National Radio Astronomy Observatory
NSE	Network Software Environment
NSF	National Science Foundation
NSFnet	Computer network supported by NSF
NSI	NASA Science Internet
NSN	NASA Science Network; TCP/IP part of NSI
NTSC	Standard video signal format
OASIS	Operations and Science Instrument Support
OMS	Space Station Operation Management System
OMS/PMS	Operations Management/Platform Management System
OMSS	Operation Management System Services
OSSA	Office of Space Science and Applications
PI	Principal Investigator
PSI	Payload Systems, Inc.
RA	Research Assistant
RCC	Remote Commanding Computer
RFH	Remote Fluid Handling
RGB	Red, Green, Blue Video Display
RIACS	Research Institute for Advanced Computer Science
ROM	Read Only Memory
RS-232	Standard for serial data transmission
SAIS	Science and Applications Information Systems
SAO	Smithsonian Astrophysical Observatory
SCS	Software Control System
SIMBAD	A cross-referenced database of 700,000 stellar and 100,000 non-stellar objects
SESAC	Space and Earth Sciences Advisory Committee
SFDU	Standard Formatted Data Unit
SME	Solar Mesosphere Explorer satellite
SOP	Science Operations Subgroup
SPAN	Space Physics Analysis Network

SPIE	Society of Photo-Instrumentation Engineers
SS	Space Station
SSE	Software Support Environment
SSIS	Space Station Information Systems
SSL	Space Sciences Laboratory at UC, Berkeley
SSP	Space Station Program
STScI	Space Telescope Science Institute
TAE	Transportable Applications Executive
TATS	Thaw Atmospheric Telescope Simulation
TCP/IP	Transmission Control Protocol/Internet Protocol
TDRSS	Tracking and Data Relay Satellite System
TeleWEn	Telescience Workstation Environment
Terracom	A company name
TFSUSS	Task Force on Scientific Uses of Space Station
TIF	Telescope Interface Unit
TIGS	Testbed at LASP
TMIS	Technical Management Information System
TTPP	Telescience Testbed Pilot Program
UC	University of California
UCB	University of California, Berkeley
UCSB	University of California, Santa Barbara
UIL	User Interface Language
Unify	A database program
UofA	University of Arizona
USE	User Support Environment
USRA	Universities Space Research Association
UW	University of Wisconsin
VISTA	another image processing system
WAN	Wide Area Network
ZOE	Zone of exclusion

Appendix C
Bibliography

Bennett, Elliot, *HOLOP: A Case Study of Advanced User-interface Design for Interactive Control of Space Experiments*, DFVLR IB 333 - 88/5, 24 pp., DFVLR, Institute for Space Simulation, Cologne, West Germany, June 1988.

This paper details advanced concepts in user-interface design implemented in the computer program HOLOP Ops. HOLOP Ops was designed to provide a simple, easy, and fast user-interface for remote, interactive control the HOLOP facility aboard the D2 Spacelab mission. Such a user-interface is achieved by implementing full graphics capabilities (including pictures, icons, graphs, and mouse/cursor control) as well as full text displays and control in a transparent, integrated environment for experiment observation and control. The advantages and capabilities of this program's user-interface are described and analyzed for their ability to enhance space based science productivity in the Space Station era.

Bienz, Richard A. and Larry C. Schooley, " A Survey of Computer Networks," Technical Report TSL-001/87, 85 pp., Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, February 1987.

A summary of existing wide-area computer networks and their attributes and evaluation of their possible use in the University of Arizona TTPP testbeds.

Bienz, Richard A., and Jerry J. Hunter, "Communication Software Design for Telescience Demonstrations," Technical Report TSL-019/88, Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, December 1988.

Cellier, Francois, *Teleoperation of the Thaw Telescope at the Allegheny Observatory: A Case Study*, Technical Report TSL-004/87, 56 pp., Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, December 1987.

Primary purpose of this document is to define the intermediary language to be used for computer-to-computer communication between the local controlling computer at Allegheny Observatory and the remote commanding computer which will be located at the University of Arizona. Overview of plans leading to teleoperation the Thaw Telescope at Allegheny Observatory is also discussed as well as control loops, sensors, safeguard error messages.

Chakrabarti, Supriya, Carl A. Dobson, and J. G. Jernigan, "Telescience at the U. C. Berkeley Space Science Laboratory," *Bulletin of the American Astronomical Society*, vol. 19, p. 744, Space Sciences Laboratory, U.C. Berkeley, June 1987.

The University of California, Berkeley is a member of a University consortium developing methodologies for remote design, development and operation of space instrumentations, collectively termed *telescience*. We will discuss our efforts in extending an existing local software control system to allow the development and sharing of software between remote sites. We are developing a methodology for the remote operation of instrumentations utilizing networks such as the ARPANET. These techniques have already been demonstrated over a local Ethernet. These two areas of investigations address the teledesign and teleoperation components of telescience.

Chakrabarti, Supriya, Carl A. Dobson, George C. Kaplan, Herman L. Marshall, Michael Lampton, Roger F. Malina, Stuart Bowyer, and Jeff Star, "Astronomical Data Analysis from Remote Sites," *Astronomy from Large Databases, Scientific Objectives and Methodological Approaches, ESA Conference and Workshop Proceedings*, vol. 28, p. 295, Space Sciences Laboratory, UC Berkeley & Remote Sensing Research Unit, UC Santa Barbara (J. Star), Berkeley, CA, January (1988c). Also available in Space Astrophysics Group Contribution Number 329.

Given the progress in the communication technology, it is expected that during the space station era the mode of instrument operation and data analysis will be dramatically different. A consortium of several universities and NASA centers are evaluating various aspects of design and operation of scientific instruments and data analysis over various computer networks from a remote site. Such a scheme has officially been termed telescience. We will report on the development of methodologies for teledesign, teleoperation and teleanalysis and the verification of these concepts using the Extreme Ultraviolet Explorer (EUVE), a satellite payload scheduled for launch in 1991. The EUVE telescopes will be operated remotely from the EUVE Science Operation Center (SOC) located at the University of California, Berkeley. Guest observers will remotely access the EUVE spectrometer data base located at the SOC. Distributed data processing is an integral part telescience. We will describe our experience with the Browse system, currently being developed at the University of California at Santa Barbara through a grant from NASA for remote sensing applications. We will discuss the suitability for its adoption for astronomy applications. Browse allows the examination of a subset of the data to determine if the data set merits further investigation. The examination can be as simple as looking for a specific data element based on its location, date of observation, quality indicator, spectral coverage etc. It also allows the viewing of data in various modes depending upon the available resources at the user's end (e.g., graphics terminal vs. dumb terminal), level of data compression applied, required display format etc. and its transmission over a network to a local graphics display station.

Chakrabarti, Supriya, William T. Marchant, George C. Kaplan, Carl A. Dobson, J. Garrett Jernigan, Michael L. Lampton, and Roger L. Malina, "Telescience at the University of California, Berkeley," Acta Astronautica, in press, (1988a). Also available in Space Astrophysics Group Contribution Number 356.

The University of California at Berkeley (UCB) is a member of a university consortium involved in telescience testbed activities under the sponsorship of NASA. Our Telescience Testbed Project consists of three experiments using flight hardware being developed for the Extreme Ultraviolet Explorer project at UCB's Space Sciences Laboratory. The first one is a teleoperation experiment investigating remote instrument control using a computer network such as the Internet. The second experiment is an effort to develop a system for operation of a network of remote workstations allowing coordinated software development, evaluation, and use by widely dispersed groups. The final experiment concerns simulation as a method to facilitate the concurrent development of instrument hardware and support software. We describe our progress in these areas.

Chakrabarti, Supriya, William T. Marchant, Carl A. Dobson, George C. Kaplan, Michael L. Lampton, and Roger L. Malina, "Remote Command and Telemetry Handling for a Spaceflight Instrument," *Proceedings of IECON'88: Control and Simulation, Singapore*, v III, pp. 325, Space Sciences Laboratory, UC Berkeley, Berkeley, CA, (1988b). Also available in Space Astrophysics Group Contribution Number 365.

The Space Sciences Laboratory at the University of California, Berkeley, is a member of a university consortium involved in telescience testbed activities under the sponsorship of NASA. As part of our activities, we have developed methodologies for remotely commanding a space-based instrument and receiving telemetered data. Two experiments were conducted to interact remotely with a flight-destined instrument. In the first experiment we sent commands using the Bay Area Regional Research network from a computer at Stanford University to an instrument connected to a workstation located at the University of California, Berkeley. In the second experiment we used the Internet to conduct the same experiment from the University of Colorado, Boulder. In addition to telemetry, low-rate video images of the instrument were transmitted over the same network to provide visual feedback. Although further testing is necessary, our limited experience indicates that it will be possible to interact with a space-based instrument from an experimenter's desk.

Chakrabarti, Supriya, D. Cotton, M. Lampton, O. Siegmund, R. Link, and G. R. Gladstone, "Remote Sensing of Atmospheric Oxygen from a Sounding Rocket," Acta Astronautica, in press, (1988d).

Davis, R., J. Faber, E. Hansen, A. Jouchoux, and G.H. Ludwig, *Telescience Testbed Program Results*, LASP Report 89-1, University of Colorado, Boulder, CO, January 1989.

Forgy, C. L., "Rete: A Fast Algorithm for the Many Pattern/Many Object Pattern Match Problem," Artificial Intelligence 19, 1982, pp. 17-37.

Gallagher, Maria L., *Telescience Testbed Kickoff Meeting Minutes*, RIACS TR 87.25, 26 pp., RIACS/USRA, Moffett Field, CA, September 1987.

The kickoff meeting for the Telescience Testbed Pilot Program was held on July 30-31, 1987 at NASA Ames Research Center. These are the minutes of that meeting.

Gallagher, Maria L., *Telescience Testbed Pilot Program Meeting II Minutes*, RIACS M88.1, RIACS/USRA, Moffett Field, CA, March 1988.

The TTPP II meeting was held on March 7-9, 1988 in Boulder, Colorado. These are the minutes of that meeting

Gallagher, Maria L. and Barry M. Leiner, *Telescience Testbed Pilot Program First Quarterly Report*, RIACS TR 87.26, 35 pp., RIACS/USRA, Moffett Field, CA, September 1987.

The Telescience Testbed Pilot Program participants are required to issue reports to NASA Headquarters on a quarterly basis. This is the first quarterly report, covering the period April 28, 1987 through August 31, 1987.

Gallagher, Maria L. and Barry M. Leiner, *Telescience Testbed Pilot Program Second Quarterly Report*, RIACS TR 87.31, 57 pp., RIACS/USRA, Moffett Field, CA, December 1987.

The Telescience Testbed Pilot Program is an innovative activity involving fifteen universities in user-oriented rapid-prototyping testbeds to develop the requirements and technologies appropriate to the information system of the Space Station era. The Telescience Testbed Pilot Program is required to issue progress reports to NASA Headquarters on a quarterly basis. This is the second quarterly report, covering the period September 1, 1987 through November 30, 1987.

Gallagher, Maria L. and Barry M. Leiner, *Telescience Testbed Pilot Program Third Quarterly Report*, RIACS TR 88.8, 77 pp., RIACS/USRA, Moffett Field, CA, March 1988.

The Telescience Testbed Pilot Program is required to issue progress reports to NASA Headquarters on a quarterly basis. This is the third quarterly report, covering the period December 1, 1987 through February 29, 1988.

Gallagher, Maria L. and Barry M. Leiner, *Telescience Testbed Pilot Program Fourth Quarterly Report*, RIACS M88.4, 69 pp., RIACS/USRA, Moffett Field, CA, June 1988.

The Telescience Testbed Pilot Program is required to issue progress reports to NASA Headquarters on a quarterly basis. This is the fourth quarterly report, covering the period March 1, 1988 through August 31, 1988.

Gallagher, Maria L. and Barry M. Leiner, *Telescience Testbed Pilot Program Fifth Quarterly Report*, RIACS M88.5, 76 pp., RIACS/USRA, Moffett Field, CA, September 1988..

The Telescience Testbed Pilot Program is required to issue progress reports to NASA Headquarters on a quarterly basis. This is the fifth quarterly report, covering the period September 1, 1988 through December 31, 1988.

Hack, B., *Man to Machine, Machine to Machine and Machine to Instrument Interfaces for Teleoperation of a Fluid Handling Laboratory*, Technical Report TSL-014/88, Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, June 1988.

The purpose of this thesis is the design and description of the software necessary for teleoperation of a remotely operated fluid handling laboratory. It does not include the implementation of this software. The laboratory for which it is designed is currently being developed at the University of Arizona, and is intended to be a small scale model of the fluid handling laboratory which will be aboard Space Station. The designed software includes a man/machine interface, a machine/machine interface, and a machine/instrument interface. The man/machine interface is graphical in nature, menu driven, and consists of high level commands which are independent of the devices in the laboratory. The machine/machine interface is also device independent. It consists if intermediary commands and maps the commands of the man/machine interface to low level, device dependent, commands and programs of the machine/instrument interface. Although the software is primarily designed for the model fluid handling laboratory, the needs and requirements of the operation of a similar laboratory aboard Space Station have been considered.

Haines, Richard F., *Human Performance Validation Procedures Applicable to Telescience Activities*, RIACS TR (in final review), January 1989.

Johnson, Vicki and John Bosley, "A Shared-World Conceptual Model for Integrating Space Station Life Sciences Telescience Operations," *Proc. 1988 Goddard Conference on Space Applications of Artificial Intelligence*, Goddard Space Flight Center, May 1988.

Jouchoux, A., *Ada Compiler Choice*, LASP Report, University of Colorado, Boulder, Co, January 1988.

Kallemeyn, P.H., B. Knapp, and G.H. Ludwig, *User's Manual - Science Data Base Access Program for the Solar Mesosphere Explorer*, LASP Report 89-3, University of Colorado, Boulder, Co, April 1989.

Kaplan, George C., "EUVE Contributions to Telescience," *EUVE Technical Bulletin*, no. 4, p. 2, Space Sciences Laboratory, UC Berkeley, Berkeley, CA, September 1987.

Brief Overview of UC Berkeley's telescience experiments for the TTPP.

Koch, David, Terry Herter, John Stauffer, and Erick Young, *Telescience Applied to the Space Infrared Telescope Facility*, 8 pp., Smithsonian Astrophysical Observatory (Koch); Department of Astronomy, Cornell University (Herter); NASA/Ames Research Center (Stauffer); Steward Observatory, University of Arizona (Young), September 1987.

In the future, the approach to the conduct of scientific space missions will be substantially different from the approach that has been used in the past. A more distributed approach will be taken with the scientists conducting operations and analysis, remotely from their home institutions, making major use of standardized software and compatible hardware. Key to this approach have been the rapid adoption of the use of local and wide area networks, the use of standardized software tools and the plethora of powerful workstations. These developments will be applied to the Space Infrared Telescope Facility project in the space station era. A number of telescience testbed activities are being undertaken to develop experience and to determine the applicability of telescience methods.

Leiner, Barry M., *Telescience Testbed Pilot Program*, RIACS TR 87.12, 42 pp., RIACS/USRA, Moffett Field, CA, May 1987.

The Telescience Testbed Pilot Program is an innovative activity to address a number of critical issues in the conduct of science in the Space Station era. Several scientific experiments using advanced information processing and communications technologies will be carried out and the results evaluated to determine the requirements and their priorities. This will provide quantitative evidence as to the relative importance of different functions in the SSIS and their required performance. Furthermore, it will allow a set of scientific users to gain experience with advanced technologies and their application to science. This report is based on the proposal from USRA to NASA for the establishment of the Telescience Testbed Pilot Program. It describes the motivation for the program, the structure of the effort, and several strawman scientific experiments that constitute the heart of the activity.

Leiner, Barry M. and James R. Weiss, *Telescience Testbedding: An Implementation Approach*, RIACS TR 88.2, 9 pp., RIACS/USRA (Leiner) & NASA/HQ (Weiss), Moffett Field, CA, February 1988.

Telescience is the term used to describe a concept being developed by NASA's Office of Space Science and Applications (OSSA) under the Science and Applications Information System (SAIS) Program. This concept focuses on the development of an ability for all OSSA users to be remotely interactive with all provided information system services for the Space Station era. This concept includes access to services provided by both flight and ground components of the system and emphasizes the accommodation of users from their home institutions. Key to the development of the Telescience capability is an implementation approach called rapid-prototype testbedding. This testbedding is used to validate the concept and test the applicability of emerging technologies and operational methodologies. Testbedding will be used to first determine the feasibility of an idea and the applicability to real science usage. Once a concept is deemed viable, it will be integrated into the operational system for real time support. It is believed that this approach will greatly decrease the expense of implementing the eventual system and will enhance the resultant capabilities of the delivered systems.

Leiner, Barry M., *Telescience Testbed Pilot Program Interim Report*, RIACS TR 88.6, 16 pp., RIACS/USRA, Moffett Field, CA, February 1988.

The Universities Space Research Association (USRA), under sponsorship from the NASA Office of Space Science and Applications, is conducting a Telescience Testbed Pilot Program. Fifteen universities, under subcontract to USRA, are conducting a variety of scientific experiments using advanced technology to determine the requirements and evaluate trade-offs for the information system of the space station era. This report represents an interim set of recommendations based on the experiences of the first six months of the pilot program.

Lew, A. K., *Astrometric Telescope Simulator for the Design and Development of Telescope Teleoperation*, Technical Report TSL-016/88, Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, September 1988.

Lichtenberg, Byron K., "Concepts for Crew Experiment Interaction-Future Space Flights: Workstation Design and Requirements," p. 3, Payload Systems, Inc., June 1988. Submitted to the International Conference on Environmental Systems to be held July 1988.

Current space lab and space shuttle workstations are inadequate for the next generation of space experimentation. The capability of the current experiment computers is severely limited, the maximum sample rate that can be acquired and processed for on board display is 10 samples per second, and the displays have a maximum of 750 woof storage associated with them. Second, the ability to modify experiment operations real time is nonexistent unless it was programmed in approximately 18 months before flight. The appearance of new generations of computers will alleviate these problems, but acceptance by the space engineering community is still limited. This paper will discuss the concepts and requirements for future workstations and capabilities that should be inherent in the next generation of space craft.

Marchant, Will, Carl A. Dobson, Supriya Chakrabarti, and Roger F. Malina, "Telescience - Concepts and Contributions to the Extreme Ultraviolet Explorer Mission," *SPIE Proceedings*, vol. 851, p. 173, Astronomy Dept. & Space Sciences Laboratory, UC Berkeley, Berkeley, CA, November 1987. Also available in Space Astrophysics Group Contribution Number 315.

A goal of the telescience concept is to allow scientists to use remotely located instruments as they would in their laboratory. Another goal is to increase reliability and scientific return of these instruments. In this paper we discuss the role of transparent software tools in development, integration, and post-launch environments to achieve hands on access to the instrument. The use of transparent tools helps us to reduce the parallel development of capability and to assure that valuable pre-launch experience is not lost in the operations phase. We also discuss the use of simulation as a rapid prototyping technique. Rapid prototyping provides a cost-effective means of using an iterative approach to instrument design. By allowing inexpensive production of testbeds, scientists can quickly tune the instrument to produce the desired scientific data. Using portions of the Extreme Ultraviolet Explorer (EUVE) system, we examine some of the results of preliminary tests in the use of simulation and transparent tools. Additionally, we discuss our efforts to upgrade our software "EUVE electronics" simulator to emulate a full instrument, and give the pros and cons of the simulation facilities we have developed.

Pan, Ya-Dung, *Teleoperation of Mechanical Manipulators Aboard the U.S. Space Station*, Technical Report TSL-002/87, 74 pp., Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, December 1987.

This study presents a new analytical controller design strategy for the teleoperation of mechanical manipulators aboard the U.S. space station. This controller design strategy emphasizes on the stability of a closed-loop control system involving time delay. Simplified dynamic equations of the Stanford arm are considered as the manipulator model. A local linearizing and decoupling control algorithm is applied to linearize and decouple the dynamic equations. Once the linear form of the manipulator is obtained, a model prediction control loop is constructed and implemented as a digital controller to provide the predictive states information, and a particular model reduction method is applied to yield a reduced-order digital controller. This reduced- order digital controller is a highly self-tuned controller which can control the closed-loop system with time delay by following a specified performance.

Pan, Ya-Dung and Alfie K. Lew, *Teleoperations Software for Remote Fluid Handling*, Technical Report TSL-020/88, Electrical and Computing Engineering Department, University of Arizona, Tucson, AZ, December 1988.

Pennisi, Liz, "Computers on Long-Distance Research," *LQP*, p. 8, December 7, 1987.

Magazine article on the use of computers on long-distant research at the University of Arizona.

Raize, Efraim, *Computer Interface for Electrophoresis Apparatus*, Technical Report TSL-011/88, 28 pp., Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, May 1988. The author is a visiting scholar at the University of Arizona.

This report summarizes the considerations required for an adequate interface, lists the electronics design and shows the drawings and procedures for operation and maintenance of an Electrophoresis machine in an automated laboratory.

Raize, Efraim, *Syringe Driver Assembly for Automatic Fluid Handling Laboratory*, Technical Report TSL-012/88, 17 pp., Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, May 1988. The author is a visiting scholar at the University of Arizona.

This report describes the design and implementation of a driver assembly for an automated fluid handling laboratory.

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Schmerling, Erwin, "The Interaction of Users with Instruments and Databases in Space," *Information Systems Newsletter*, pp. 12-18, NASA Headquarters, January 1988.

This article discusses the Telescience Testbed Pilot Program's objectives, planned contributions and defines the term Telescience.

Schmerling, Erwin, "Telescience in the Space Station Era," EASCON, pp. 1-6, NASA Headquarters, September 1988.

After over a quarter of a century of experience in space, and the rapid development of Information Systems capabilities, there is a naturally growing demand for the development of systems where, to an increasing extent, participants can access their fellow scientists and the appropriate NASA service before flight, during flight and after flight, preferably from their home institutions and through the same equipment. This concept has become known as Telescience, and sporadic examples of its implementation may be found in earlier programs.

Schooley, Larry C. and Francois Cellier, *Telescience Testbed Pilot Program Quarterly Report*, Technical Report TSL-003/87, 16 pp., Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, December 1987.

First quarterly report for the University of Arizona's Telescience Testbed Pilot Program.

Schooley, Larry C., Richard A. Bienz, and Francois Cellier, *Basic Research in Telescience Testbed Program Final Report: NASA Grant NAGW-1073*, Technical Report TSL-005/88, Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, January 1988.

Final report for NASA grant NAGW-1073.

Schooley, Larry C., Don G. Schultz, and Francois Cellier, *University of Arizona Presentation, Second Telescience Testbed Pilot Program Meeting*, Technical Report TSL-007/88, 50 pp., Electrical and Computer Engineering, University if Arizona, Tucson, AZ, March 1988.

The set of transparencies presented by the University of Arizona at the second TTPP meeting held in Boulder, CO on March 7-9, 1988.

Schooley, Larry C. and Francois Cellier, *Telescience Testbed Pilot Program Quarterly Report For Winter 1987-88*, Technical Report TSL-008/88, 15 pp., Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, March 1988.

Second quarterly report for the University of Arizona's Telescience Testbed Pilot Program.

Schooley, Larry C. and Francois Cellier, *Telescience Testbed Pilot Program Quarterly Report for Spring 1988*, Technical Report TSL-013/88, 10 pp., Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, June 1988.

This is the third quarterly report for the astrometric telescope, remote fluid handling, and technology development projects at the University of Arizona. It does not include the UA involvement in the SIRTF project.

Schooley, Larry C. and Francois Cellier, *Telescience Testbed Pilot Program Quarterly Report For Summer 1988*, Technical Report TSL-018/88, Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, September 1988.

Summer 1988 quarterly report for the University of Arizona's Telescience Testbed Pilot Program.

Schooley, Larry C. and Francois Cellier, *Telescience Testbed Pilot Program Final Report*, Technical Report TSL-021/88, Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, December 1988.

Final report for the University of Arizona's Telescience Testbed Pilot Program.

Schooley, Larry C., and Francois E. Cellier, *Teleoperation of a Simulated Astrometric Telescope*, Technical Report TSL-022/88 (videotape), Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, December 1988.

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As we embark on a new era in engineering education, we must exploit technological advances which offer opportunities for improving the educational process. One area of technology which offers opportunities for enhancing the manner in which research is conducted and ultimately affects scientific and engineering education is computer networks. As computer hardware has become less expensive, more numerous and more capable, individuals and organizations have developed a keen interest in connecting them together in order to form networks. This in turn has had an impact on the manner in which laboratory research is conducted. This paper addresses a relatively new approach to scientific research, telescience, which is the conduct of scientific operations in locations remote from the site of central experimental activity. A testbed based on the concepts of telescience is being developed to ultimately enable scientific researchers on earth to conduct experiments onboard the Space Station. This system along with background materials are discussed in this paper.

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This paper describes the structure and methodology of the rapid prototyping efforts and reports the results for the first eleven months of the 15 university telescience testbed program. In addition, the multi-media networking capabilities between the NASA Centers involved in space station design and operations and the universities are discussed in terms of overall requirements for telecommunications between space station testbed/simulation facilities and the telescience testbed effort.

Young, Larry A. and Barry M. Leiner, "Telescience," AIAA/NASA First International Symposium on Space Automation and Robotics, November 1988, (also available as RIACS TR 88.28, 9 pp., (MIT) Young, (RIACS) Leiner, October 1988).

Telescience is the approach and collection of tools that enable productive scientific activity to be carried out using remote resources. By using interactive high-performance telecommunication links between space-based laboratories and facilities, on-orbit crew, and geographically dispersed ground-based investigator groups, facilities such as Space Station become an accessible and integral part of the research environment. In this paper, we describe an innovative program of rapid prototyping testbeds aimed at evaluating and validating telescience modes of operation and the technologies to support them. Particular attention is given to three testbeds evaluating remote instrumentation monitoring and control, expert systems in support of the interaction between the principal investigator and the astronaut, and telerobotics in support of fluid handling. In all of the testbeds, the application of these new technologies have been shown to improve scientific productivity.

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