Telescience Testbed Pilot Program
Final Report
Volume II
Program Results

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Barry M. Leiner

Research Institute for Advanced Computer Science
NASA Ames Research Center

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

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The Universities Space Research Association (USRA), under sponsorship from 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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Section 1
Introduction and Summary

1.1 Introduction and Document Overview

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.

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

This report contains the results of the Telescience Testbed Pilot Program. The report is in three volumes. Volume I is the Executive Summary. Volume II (this volume) contains the integrated results. Section 1 is an introduction and summary, providing background on the program and highlights of the program results (duplicating much of the Executive Summary.). Section 2 describes the program, summarizing the various testbed experiments and the programmatic approach. Section 3 summarizes the results on a discipline by discipline basis, highlighting the lessons learned for each discipline. Section 4 integrates these results across disciplines, summarizing the lessons learned overall. Volume III contains summaries of each of the experiments conducted under the university subcontracts. Further details of these experiments are contained in the various scientific and technical reports published by the researchers.

1.2 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.

1.2.1. 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.

1.2.2. 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.

1.2.3. 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.

1.2.4. 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)

1.2.5. 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.

1.2.6. 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

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Section 2
Program Description

There are a large number of issues that need to be resolved through the use of multidisciplinary teams of university scientists and technologists working together in a rapid-prototyping user-oriented testbed environment. Examples of such issues are the following.:

- What is the impact of the distribution of users on how the system architecture should be designed?
- How can access to the variety of required resources be provided in a coordinated manner?
- What is the required user interface to allow scientists to gain access to the resources in a consistent way?
- What is the impact of reduced or intermittent communications?
- What is the interaction of remote control and autonomous operation of an experiment?
- How should the planning and scheduling of multiple activities using common and shared resources be implemented?
- What are the requirements for authentication, access control, and security, and how can they be best accommodated?
- What are the required characteristics of the underlying communications networks and what are the supporting networking technologies to be used?

The TTPP began the process of resolving these questions, both investigating technical issues and exploring the feasibility and approach to such a testbed. The goal of the testbedding program is to allow scientists to interact with potential space station technologies in a manner that will allow resolution of design and specification questions without having to wait until space station hardware is available.

In the TTPP, experiments were carried out in the context of the four generally defined space science disciplines of primary interest for the Space Station: Astronomy and Astrophysics, Earth Systems Sciences, Life Sciences, Microgravity Sciences, and Space Physics. For each of the testbeds, telecommunications infrastructures were established based on technologies representative of those available for use in the SSIS. Scientific research and experiments was then conducted using these telescience-relevant technologies.

An important methodology employed in the program was that of rapid-prototyping. As deficiencies, required enhancements, or new and relevant technologies surfaced, they were inserted into one or more of the testbeds for evaluation. The effectiveness of the various telescience technologies were then evaluated on an ongoing basis, and the infrastructure adjusted accordingly.

We now give a summary description of the various testbedding activities. Complete descriptions may be found in Volume III of this report (containing short descriptions of each experiment conducted under the program) as well as the numerous technical papers and reports written by the program participants and listed in the TTPP Bibliography (Appendix B). We then describe the programmatic approach used to manage and coordinate the large number of activities involved.

2.1 Summary of Testbed Activities

Fifteen universities together with eight NASA centers worked together in the four space science disciplines. In each case, a variety of specific experiments (described in Volume III) were performed. In addition, several testbeds were selected that span a number of disciplines and represent technologies that have potential of significant application to telescience. In all cases, the experiments were selected because they represented emulations of one or more aspects of conducting space science and allowed experimental exploration of the critical issues involved in the information systems for such research.

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

2.1.1. 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.

2.1.2. 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.

2.1.3. 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.

2.1.4. 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.

2.1.5. 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.

2.2 Programmatic Activities

As discussed in Section 1, one of the major reasons for conducting the TTPP was to validate the user-oriented rapid-prototyping testbed approach to involving the scientific users in the development process for large facilities such as Space Station. Because the TTPP was a pilot program, careful attention was paid to the programmatic approach to assure that the lessons learned could be applied to any follow-on program. We now describe the sequence of activities that took place.

Proposal Submission

Based on the recommendations of the Task Force for Scientific Uses of the Space Station (TFSUSS),[1] the recommendations of an expert panel convened to review the mechanisms for users to interact with the Space Station development process,[2] and recommendations from a number of advisory panels, NASA issued a Request for Proposals on February 10, 1987.[3] Appendix C provides the Statement of Work from that RFP.

Prior to the issuance of the RFP, a number of scientists from around the country had been discussing a collaboration to address a number of issues through a rapid-prototyping testbed environment. USRA was requested by this group to assist in organizing and submitting a proposal to NASA. Thus, when the RFP was issued, this community was well prepared to be responsive to the NASA requirement. The proposal (the text of which is available as a technical report[4]) outlines a program involving roughly 8-10 universities conducting a number of testbeds with USRA acting as technical manager and subcontracting to the universities. The proposal also outlines a management plan calling for proposals to be submitted by universities and selected by USRA with the approval of NASA, using a Proposal Review Group, again selected by USRA with the approval of NASA. This proposal, submitted on March 12, 1987, was selected by NASA with a contract award made on April 28,1987.

Subcontractor Selection

The first required step in the process of awarding the subcontracts was to develop a subcontract acquisition plan and have it approved by NASA. This was done rapidly to expedite subcontract award. This plan is included as Appendix D. The plan called for an Announcement of Opportunity (AO) to be published by USRA, included as Attachement 1 to Appendix D.

The selection criteria were included in the AO, and were focussed on the philosophy of conducting a number of experimental testbeds that would achieve a number of objectives simultaneously:

1. Emulate some aspect of the conduct of science as anticipated for the Space Station era, thereby investigating critical issues in the design of the Space Station Information System as they affect scientific research.

2. Allow exploration of the application technologies that represent the level of functionality expected in the Space Station era.

3. Be scientifically sound research in their own right.

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

2. Leiner, B.M., *Strategy for User Involvement in SSIS Design*, RIACS TR 86.19, October 1988.

3. NASA Solicitation No. RFP 10-39111/HWC.

4. Leiner, B.M., *Telescience Testbed Pilot Program*, RIACS TR 87.12, May 1987.

The AO was mailed in May 1987 and the Proposal Review Group convened on June 2 - 3, 1987 to review the proposals and recommend selection of universities for subcontract. Based on their recommendations, USRA selected and submitted for NASA approval 15 university proposals. Over the period June through November, the various subcontracts were approved by NASA and put in place.

Coordination Mechanisms

Once the participants were selected, a number of mechanisms were put in place for coordination and management of the program. These included electronic mailing lists, monthly informal electronic reports, quarterly reports, and regular meetings.

Electronic mailing lists were maintained for the program participants (ttpp-pi), distribution of news, results, and monthly reports (ttpp-news), and the individual discipline groups (ttpp-es, ttpp-ls, ttpp-astron, and ttpp-micro). In each case, parallel lists were maintained for users on the Internet and NASAmail. These mailing lists became quite extensive over the life of the program, with ttpp-news numbering over 400. Hence, a database of all participating and interested parties was maintained.

Monthly informal reports were prepared and distributed electronically. These reports were for the purpose of providing timely informal exchange of information between the various testbed participants and other interested parties, particularly NASA personnel. Quarterly reports were prepared as the formal documentation of the ongoing program. While the intent was for both the monthly and quarterly reports to be brief status reports, the compilation of the reports from the large number of participating organizations (15) resulted in fairly lengthy reports, typically averaging approximately 60 pages for the quarterly reports. Nevertheless, feedback from the recipients of the reports, particularly those who were not participating directly in the program, was quite positive, expressing appreciation of the resulting ability for them to track progress.

Finally, a number of meetings took place over the life of the program. In addition to informal coordination and review meetings with the various participants, two major meetings were held to exchange information and coordinate the overall program. The first meeting, held in October of 1987, focussed on initial coordination and refinement of program plans. The second meeting, held in March of 1988, was for the purpose of exchanging interim results and status. Each of these meetings was attended by roughly 100 people including both program participants and interested NASA personnel. A final meeting, held in November 1988, was held amongst a smaller group of program participants for the purpose of drafting this final report.

Summary

The TTPP represented an innovative approach to the involvement of university researchers in answering critical questions concerning the design of the future information system. Through the combination of ongoing scientific research emulating future operational science and advanced computer and communication technologies, much needed experience was garnered. By conducting the program as a multidisciplinary activity, considerable profitable exchange of information between scientists in different disciplines occurred. Thus, in the opinions of the authors, the participants, and the other involved parties, the TTPP has proven to be a worthwhile investment by NASA.

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Section 3
Discipline Summaries

In this section, the results and lessons learned from the various experiments are summarized with respect to their application to the scientific disciplines represented in the program. For each discipline, the participating parties discussed the results in a large number of technical and procedural areas. In Section 4, the results and lessons are integrated across the disciplines.

3.1 Astronomy and Astrophysics Summary

Many lessons have been learned in the astronomy and astrophysics discipline as a result of the TTPP and these lessons have helped in identifying requirements for Telescience in the Space Station era. Contributions to this discipline came from Cornell University, Massachusetts Institute of Technology, Smithsonian Astrophysics Observatory and the Universities of Arizona (College of Engineering and Steward Observatory), California-Berkeley, Colorado and Maryland.

The astronomy and astrophysics discipline differs markedly from the life sciences and material sciences areas. Specifically, astronomers are not able to alter their subject material in order to determine how it performs. When one has a new model of a supernova, one can not arrange to have a supernova against which to test one's theory. Astronomers can only observe and this limits their interactions to instrument operations, data gathering techniques and realtime and quick look data analysis to support the observing program. The result is to establish a database to support ones research and that of the community. Thus in what follows, there must be a greater emphasis on remote observing and teleanalysis with the need for live video and voice communication between the scientist and the remote location limited to instrument and observing needs (eg. trouble shooting, or possible quick response).

There are some aspects where results were anticipated, such as network performance, and other areas where there were unexpected results, such as the impact of using network capabilities for the administrative logistics of running a project. The aspects of telescience will be described in detail as they relate to the following topics:

1. Teleoperation Of Instruments And Experiments
2. Teleanalysis
3. Use Of Networks To Enhance Programmatics
4. Standards And Commonality
5. Network Requirements

3.1.1. Teleoperation of Instruments and Experiments

Nearly all of the astronomy TTPP had some component of instrument or experiment remote teleoperations associated with it. The extent of teleoperations varies from providing remote command and control to fully autonomous remote operation. All of the above aspects are what one can anticipate for teleoperations in the Space Station era; that is, remote operation of an instrument or facility with realtime or near realtime command and control to fully autonomous operations. The latter situation is what scientists have in many cases had to live with in the past, the former and a synthesis of automated and remotely controlled operations is what is hoped can be achieved for interactive experiment operations in the Space Station era. Fully autonomous operation does not come without a price tag. That is, in order to automatically point an instrument to its target accurately enough to perform a fully automated observation, a higher instrument precision is required than if it is foreseen that manual fine adjustments can be made during the observation after the coarse positioning (slewing) of the instrument has been completed. Also, manual intervention provides for an enhanced flexibility to modify the details of the observations to be performed. Some of the topics that have been studied in the TTPP with regard to teleoperations are:

- Scientific productivity.
- Astronomy education.
- Instruments as network nodes
- Common workstation for operations
- Interconnection of multiple facilities
- Robust design and safety
- Data compression

Scientific Productivity

Most of the astronomy testbeds identified ''enhanced productivity'' as one of the end products of incorporating telescience methods and connectivity into the observation environment. SAO, MIT, University of Colorado and University of Arizona astronomy testbeds found that, through networking, not only was remote instrument control possible, but this connectivity provided access to near-realtime-data. Analysis of these data might result in needed changes in observation parameters and sometimes changes in the controlling program, as with the SAO Mt. Hopkins experiment. These changes were implemented remotely. Having immediate access to the observed data can result in enhanced science productivity, since the scientist can analyze the data immediately rather than having to wait until later when the data may be stale or the scientist gets distracted by other concerns. Teleoperation allows the astronomer to operate the telescope from his or her laboratory (or office) where all materials are available, and where every moment of waiting time may be utilized. Traveling times are reduced and, in some cases, the duration and quality of an observation can be enhanced.

Astronomy Education

The University of Colorado team (LASP) studied this issue in a testbed in which a telescope located on campus could be operated from a remote location, such as a class room. This allowed the introduction of practical observations at a much earlier stage in the curriculum of ongoing astronomers than was previously feasible. This clearly enhanced both the motivation and the productivity of the students in pursuing their education.

The MIT group has an ongoing integrated teaching and research program started concurrently with and based on its telescience program. By using the networking and computers (approximately 600) of which a major share (supplied by Project Athena) is solely for student use, the students have been placed in a combined research and teaching environment. They have full access (e.g. from living groups or dorms and campus clusters) to the data analysis programs. This is possible due to both remote login capability as well as the across the board use of UNIX, ''C'', and ''X'' in most of the machines on campus and all of the machines in the Project Athena. Greatly broadening the base of participation in Space research is an important outcome of this type of operation.

Instruments As Network Nodes

Several recent instruments have been designed with the point of view that the instrument is a node on a network. The networks involved range from Local Area Networks (LANs) such as Ethernet to wide area networks such as the Internet. In the case of the EUVE project, the prototype instrument interfaces to one of the workstations in the LAN at the Space Science Lab. The software used to operate the instrument may be run from any of the other workstations or from any site with adequate connectivity. As the hardware and software development proceed, the network interface is maintained. In the case of SAO an IR array is operated and the data collected by a workstation which is a node on the Internet. In this way, support people can upload new software and debug and test new applications from Cambridge and support observing done with the array on a mountain in Arizona. The unique MIT highspeed CCD occultation camera is also in the process of becoming a fully functional network node (it has had a limited capability since inception). Additionally, the observer can transfer the data over the network (while the observations are taking place) to the data analysis facility and evaluate the results in near realtime to assist in the observation plan while still at the telescope. The important point is that network connectivity is part of the instrument design from the start.

Common Workstation for Operations

If the instrument interfaces could be standardized, the same workstation could be used to connect to any of a series of different instruments to which the scientist needs access. This means a common software environment, user interfaces, and hardware interfaces, not necessarily common hardware. Such commonality also increases the scientific productivity since less time is spent on studying operator manuals of unfamiliar instruments.

Interconnection of Multiple Facilities

Researchers collaborating on a scientific research effort are no longer necessarily located at the same physical site. It is extremely beneficial if several users can have access to the different instruments simultaneously and perform a coordinated observation. It may be desirable that, while one observer operates the instrument, another observer can receive a slave image of the observer's screen (both status and scientific data). From the experience at SAO, it can be extremely useful to allow an expert, knowledgeable with the instrument, to login remotely from a home institution while an observation is ongoing to help troubleshoot a malfunctioning instrument. Otherwise, by the time the expert arrives on-site, the night and the scheduled observation time may both be long gone, and the observer may not get another chance to observe for several months to come, or the opportunity may be lost.

Robust Design and Safety

This issue was studied by several of the research teams involved in the TTPP effort. If an instrument is operated under remote control, the experimental setup must be equipped with additional safeguards which compensate for the lack of physical presence. Even when instruments are designed for remote operations from the start, careful attention must be paid to the operational safety issues. The facility must have sufficient reactive control and interlocks to ensure the safety of the facility and on-site personnel. Safeguards are needed to monitor an ongoing experiment, and initiate automatic saving and recovery procedures if something goes wrong. Motion commands, for example, should be fully contained and to execute completely or not at all in case of a communications failure. A separate ''start'' and ''stop'' command would be vulnerable to communications failure before the ''stop'' command is received correctly. A preferred mode is to use fine adjustments to a pre-programmed and planned system.

The trade-offs involved in automation must be carefully considered. Complete automation may be too expensive compared to having some on-site personnel. Satellite experiments don't have this option, but Space Station experiments might. Fortunately, most operations in astronomy are not time critical and it is therefore possible to build instruments that satisfy the above stated demands. There must be sufficient command and telemetry at the remote site to give the remote user sufficient information of the current status so that adjustments can be made to maximize the science. The data links must be sufficiently reliable to allow for critical modes of operation. Data rates of 9600 baud with delays of up to 5 seconds will handle normal operations of a telescope without any video. This kind of throughput and latency is typically available on the present networks, but not assured. For critical or highly interactive operations, occasional use of a priority channel is needed with less than 1 second round trip delays. To handle longer delays requires use of special techniques which rapidly become more complicated and less effective.

Data Compression

The most serious problems with teleoperation of equipment are the demands on video feedback, since video data very quickly consume the entire bandwidth available for data communication. Fortunately, astronomers usually do not require high bandwidth video images of their telescope and its environment. Sometimes it may be useful to receive limited video of the instrument to check for proper shutter, aperture, and filter motions, to verify that everything is okay, or to check why something went wrong. However, the astronomer can easily wait for 30 seconds to receive the bitmap. Video monitoring of the observation itself is another matter. Single CCD images typically require from fractions of a second to many minutes for integration. Solar instruments where dynamic processes on the sun are being studied along with planetary occultation studies (MIT) require shorter integration times. The University of Arizona Engineering Department studied methods of data reduction for starfields. They developed a technique which allows them to reduce the data stream from 8 bits per pixel to 0.015 bits per pixel for the purpose of automated instrument positioning and tracking control, and for quicklook. However, other cases require much more information in order to determine detector noise performance, field variability (e.g. a solar glint dependent on spacecraft orientation) or overall instrument performance. Data reduction for the purpose of archival storage of scientific information is another issue and the gains achievable in compression may be offset by the computation needed to first compress the data and later to decompress the information.

3.1.2. Teleanalysis

Telescience principles are applicable to data analysis in two areas; teleanalysis by the community at large of established databases, and teleanalysis within a project group of a new or developing database. The various science disciplines within NASA have already addressed the community requirements and defined their architectures with the Planetary Data System (PDS), the Earth Science and Applications Data System (ESADS), and the Astrophysics Data Systems (ADS). Some of the general requirements that have come out of these architectures are:

1. Very capable networks with connectivity to all scientists.
2. The widespread use of workstations such as Suns and microVAXes with imaging and graphics capabilities.
3. The need for a browse system to help find information in a number of distributed databases.
4. Recovery of the data over the network or via shipment on media.
5. Data standards to permit universal exchange of data.
6. Remote access to unique resources such as image processors or supercomputers for performing the analysis.
7. High bandwidth requirements for remote image processing.
8. Uniform ways of displaying and scientifically manipulating images.
9. Standard software tools for analysis that can either be used remotely or ported to the investigators' home institutions.
10. Need for software documentation and "yellow pages".

The investigators in the TTPP have addressed various of these issues from their own project view point. Their experiences are relevant to the community at large and for telescience in the Space Station era. The group of investigators within the TTPP (University of Arizona Astronomy, Cornell University, NASA/Ames and SAO) who also represent each of the SIRTF instrument teams and project management, represent a good testbed within TTPP for these specific discipline wide architecture issues. One of the University of Arizona astronomy testbed experiments was to report on the network performance for remote access of a large astronomical database at the Infrared Analysis and Processing Center (IPAC). However, this experiment was not very successful, mainly due to poor network connectivity. The SIRTF team is beginning to look at the level of commonality required for hardware and software, so that once the SIRTF development has been completed by the separate teams, the hardware and software delivered to NASA for the science operations center (SOC) is coherent and functional. Therefore, items 2, 5, 9 and 10 in the above list have to have been worked through. In addition, for the rest of the astrophysics community to be able to have access to the data, items 1, 3, 4, and 5 need to be addressed. Within the astronomical community, items 5 and 9 have already been defined, that is, IRAF and AIPS have been developed and are in wide spread use as an environment for data analysis, and FITS has been adopted as the format for data transfer.

With the establishment of the IUE, IRAS and Einstein databases on-line at the institutions of origin, the issues of capable networks to permit teleanalysis becomes very relevant. Various of the TTPP investigators are trying out teleanalysis to learn what is practical and where the pitfalls might be. This approach to doing scientific research is not unlike what is anticipated in the Space Station era when access to many widely distributed databases will be necessary for performing an investigation.

The MIT groups connection to Project Athena has enabled them to deal with interactions between a private environment and a public multimachine net over a high bandwidth link. The issues of security and ease of use were two of the areas investigated.

3.1.3. Use of Networks to Enhance Programmatics

Although it was not part of our investigation plan, we have found that the network connections between the various participants in the TTPP has greatly enhanced our overall productivity for the program. This is not something that can be easily quantified. However, from our daily experiences with using the network we know that it provides a significant improvement in the day-to-day activities performed separate from activities such as teleoperations or teleanalysis. Specifically, the program office at RIACS from the very beginning has used the networks almost exclusively for communicating with the investigators. This has worked very well. The investigators in like manner have also been communicating with each other as well as with RIACS via networks. We have found this to be a very effective means of running a program and many of us have adopted the technique for our own general form of communications and have in many cases made it our first and primary choice. Electronic mail (e-mail) is probably the most familiar usage of networks to the casual user; however, the networks have been used for many other purposes as part of the TTPP program. We have found telemanagement to serve a vital function in the following areas:

- On-line documentation
- Submission of reports
- Proposal preparation and evaluation
- Electronic mail (correspondence/historical record)
- Electronic mail (information distribution)

On-line Documentation

Since nearly everyone is now using word processing in the office, it should no longer be necessary to distribute hard copies of every document to everybody. Rather, once the document has been approved, it should become available on-line to all users. Being on-line has many advantages, including everyone having the same and most up-to-date version to work with. Specifications, requirements, etc. tend to be poorly indexed if at all, so that standard electronic (text- or content- based) search routines must be used to locate all references to a particular item. This can also assure more accurate revisions when changes are made.

Submission of Reports

All reports of TTPP have been electronically generated and maintained. This has drastically reduced the reporting time between the PI's within the individual research teams and with the TTPP project office. Additionally, reports could be edited readily from the electronically stored information.

An excellent example of how this was used was in preparation of the area quarterly reports. In this case, each PI wrote his or her own quarterly. In addition to submitting them to the project office, a copy was sent to the area coordinator who could then use the information contained in the individual PI reports to create an area summary report. As part of the summary, the area coordinator performed a survey of the PIs asking for information on hardware, operating systems, software, network usage, etc. This poll was conducted over the network, results received as e-mail which could then be easily and rapidly be collated to produce the area summary report each quarter. Depending on verbal responses or delivery of ''US snail'' would have made the task much more difficult and time consuming.

Proposal Preparation and Evaluation

For the TTPP, the original proposals were submitted and reviewed electronically. Proposals for observing with spaceflight instruments in the Space Station era will be considerably more complex, particularly when timeline planning, instrument capabilities and resource allocations are included. Many of the constraints are quite technical, such as, thermal, power, guide stars, momentum management, orbit ascending node, etc. Experience has shown that these constraints interact in complex ways which make it very difficult to determine the feasibility and possible alternatives to proposed observations prior to formal submission of an observing plan. Remote use of artificial intelligence could be of great benefit for formulating proposals. Once the users have worked out the observation plan to their satisfaction, the planned activities would then be generated by an expert system in a standardized format for submission as a formal proposal.

Electronic Mail (Correspondence/Historical Record)

E-mail is one of the most useful aspects for making timely contact with other people. E-mail provides the details and self-documentation that has been lost with phone conversations. (Prior to the use of phones, history and documentation was preserved via letter mail records.) Also, unlike a telephone where either a person gets interrupted by the phone or may not be present to answer the phone, e-mail provides a recorded message which can either be acted upon immediately or deferred and is delivered whether or not the person is present.

Another major aspect of e-mail is the speed which provides nearly instant delivery and thereby speeds up the completion of activities. Many times in dealing with an issue several messages can be transmitted back and forth with an hour, avoiding playing ''telephone tag'', providing written explicit information and a complete record of the ''discussion''. Additionally, with e-mail one has electronic copies of the information which can be further distributed, edited or combined with other data, rather than having to re-type the information. E-mail does not present a heavy network load and the network throughputs are satisfactory in both bandwidth and latency for e-mail.

Electronic Mail (Information Distribution):

E-mail has been particularly helpful in providing for information distribution. There are several distinctly different categories of information being distributed for a number of differing reasons:

- Meeting agendas, notices, announcements and other forms of general and time critical data which are broadcast with no response expected.
- Documents that are being distributed for review and comment. These could be for document preparation purposes or could be for formal review such as that of proposals. Responses are generally expected or required.
- General distribution of completed documents. This is an area where caution is needed, that is, both from the standpoint of load on the network and filling of disk space at the recipients end. In general, we would recommend only distributing of final documents upon the specific request of the end users rather than the broadcasting approach.

There is a need for a central repository of e-mail addresses ('white pages') for astronomy (or planetary or other disciplines. Currently, sometimes the only way to get an e-mail address of someone is to call them on the phone. Even then, frequently it takes several tries to figure out the correct syntax of the address. It would greatly improve the capabilities of the e-mail system if there was a directory service, either through a printed phone book or through an on-line directory.

In the astronomical community, work is in progress to provide this service. STScI is coordinating the development of the "ASTIS" login, which will provide a remote login directory service. The American Astronomical Society is planning on providing a printed directory by simply adding e-mail addresses to their current directory.

3.1.4. Standards and Commonality

An area which can make or break the success of a project is standards and commonality. What increased American productivity was the use of standard parts in an assembly line. The same is true with the tools of science through use of a standard hardware and software environment. This is particularly true for the cases where teleoperations and teleanalysis are incorporated and many users from various institutions are trying to make use of the same equipment or data. In the TTPP we did not make any attempt to select, decide upon or even study standards. However, from surveying the various participants it was found that there may already exist a level of de facto standardization. In particular, nearly everyone is using either a microVAX or Sun workstation. Nearly all institutions are connected via Internet and are using either Unix or VMS as their operating system.

For the future it would be beneficial to adhere to vendor independent and commonly used software such as:

1. X window manager
2. NFS network file system
3. an operating system such as Unix
4. TCP/IP protocol
5. an image display interface standard
6. data formats such as FITS
7. graphics packages such as GKS

In addition there are a whole host of utilities that are used such as text formatters, editors, mailers, compilers and database managers. Astronomers have gone a step further and developed analysis environments such as AIPS and IRAF which have become widely used within their community.

Standards would also prove helpful for word processing. One of the benefits of networks is the ability for geographically diverse groups to collaborate on science projects. An immediate consequence of such collaborations is the need for geographically separated authors to collaborate in the writing of research papers. Within the astronomy and astrophysics community (and this is clearly not unique), this has been hampered by a "Tower of Babel." Different word processing software (TeX, LaTeX, nroff, troff, runoff, Word Perfect, etc.) are used. Consequently, when papers are passed between participants, either the users must convert everything to unformatted text, read unfriendly text-formatting commands interspersed with text, or rely partially on US mail to exchange printed copies using e-mail for comments. This situation would be greatly improved by a) standardizing on one system (unlikely to occur), b) translators to map between different systems, or c) standardizing on the interface, e.g. by using PostScript for exchange of documents. Similar problems with similar potential solutions exist for exchange of graphics and other media.

3.1.5. Network Requirements

A very critical component of Telescience is the communications capability. For the Space Station era, this is not just the link between the Space Station and the ground or any other orbiting facility and the science operations centers such as from HST to the STScI, but equally important is the network connection between the scientists at their home institution and the science operations center. The emphasis of network requirements for teleoperation is different from that for teleanalysis. Specifically, as part of the TTPP, performance and requirements in the following areas have been studied:

- Network latency for realtime closed loop command and control.
- Network reliability for realtime closed loop command and control.
- Network bandwidth for data transfer.

The first and second points are very important for teleoperations and have been addressed in the teleoperations section. Long latencies may make it difficult or impossible to control instrument functions which are changing and require realtime feedback for control. In addition, one would want the network connection (and accessibility) sufficiently reliable to be able to accomplish a task without great delays or without having to attempt it many times due to loss of connectivity before completion. Clearly, any teleoperations activity must be designed so that with any large latency or loss of connection, the instrument or personnel will remain safe and the experiment objectives not ruined. It has been shown by the University of Colorado team that latencies of more than 30 sec. will usually result in an attempt of the remote operator to resubmit the request. It is therefore important to make the interface insensitive to repeated requests in addition to limiting latencies to a decent value. Most people consider latencies of more than 5 sec unacceptable when operating an instrument. As a result of the TTPP, the following points can be stated with regard to the use of networks for astronomy and astrophysics:

- For highly iterative command and control, occasional use of a ''priority channel'' is needed with an overall round trip time delay less than one second. While somewhat longer delays can be tolerated, this requires use of special techniques which rapidly become more complicated and less efficient.
- The systems need to be ''hacker'' proof.
- There is little requirement for broadband video or voice.
- Cross network access needs to be made easier.
- The user should have some control over routing to direct connections over known high bandwidth connections.
- More rapid installation of new nodes and lines is needed.
- A central information office is needed to help novices get started or to handle issues.

Some of the reliability and throughput problems appear to be due to the inability of some sites to take advantage of nearby high-speed data connections. Many of these channels have access restrictions (understandably so), but there are TTPP participants who are entitled to use these links but are connected to the Internet through a University network that is not so entitled. This effectively cuts off the TTPP participant from access to the high-speed link. Improved routing software and hardware may be part of the answer, but where this proves inadequate, there should be support for installing connections from qualified organizations to the high speed lines. Specific projects may still require dedicated point-to-point links.

The question of the required performance is very dependent on the usage. The following table is a qualitative summary of the network performance experienced by the astronomy TTPP participants.

Table 1: NATIONAL NETWORK PERFORMANCE:

	E-mail	File transfer	Remote login	Instrument control
Internet	Good:	Inadequate: rate too low for large files	Marginal: drop connect	Inadequate: unreliable latency too long
SPAN (DECnet only)	Good:	Marginal: rate too low for large files	Good:	Marginal: unreliable latency too long
Bitnet	Good:	Inadequate: rate too low for large files	Not possible	Not possible

Note: NSN not installed widely enough to have any performance results. Typical transfer rates are about 1 kbytes on national networks. Regional or campus networks are not included, since in general they have T1 bandwidth and are good or adequate for nearly all purposes.

The bottom line from the experience of the astronomy PIs is that for e-mail the networks are adequate, but for most other functions they are woefully inadequate. Specifically, the measured transfer rate for files is typically on the order of a kilobyte per second. Commonly available modems have about the same performance. Unfortunately, it will probably always be true that the users will fill the available network capacity, whatever it is. The situation is somewhat better for performing remote logins. On SPAN it seems to be fairly good. Not only is it possible to have good connectivity in the U.S., but also to computers that are on SPAN in Europe. However, on the other national networks the reliability is poor, both in terms of getting access and in having a sufficiently long connect time without getting dropped, that is for a fraction of an hour to several hours. Hopefully, for TTPP users this will improve with NSN providing TCP/IP for non-DEC machines.

All in all the biggest difficulty is that the network bandwidth is too low and unreliable to perform most of the science functions envisioned. Recall that one of the major objectives of the overall TTPP was to determine the network communications requirements for performing Telescience in the Space Station era. A big plus for all of the PIs is that they have all become used to using the networks for e-mail and exchanging of information with each over the network. This has definitely improved the individual's productivity. Furthermore, higher performance networks (both bandwidth and latency) with wider connectivity can be anticipated in light of new national initiatives in this area.

3.2 Earth Sciences Summary

Overall, the Earth Sciences discipline group found that an awareness of telescience, broadly defined, plus access to the required tools and infrastructure, can positively effect the conduct of earth science. The following details some of the key issues and opportunities which came from our work in the past year.

3.2.1. Teleanalysis

Security issues were raised during the Earth Sciences TTPP activities. Secure access methods had to be implemented in the database systems at several of the universities; in some cases these were installed after users corrupted the systems. Similarly, priority-based mechanisms were required to avoid conflicts between realtime system operations and retrospective analysis users (based on the University of Wisconsin's experience with McIDAS).

Many of the activities in our area revolved around database issues. We see a need to investigate common user interface standards, as well as standards for database description and format. We feel a strong need for a high level catalog and directory for earth science datasets, to help guide us through our search for relevant information. We believe it is important that standards in the area be enabling, rather than constraining. Standards for data description are more important than detailed standards for data formats themselves. A centralized facility for guidance in creating and maintaining earth science database descriptions/catalogs and, when sensible, the actual datasets themselves, perhaps through NSSDC, would be valuable to several of the team members. We recognize the value of such efforts as the Catalog Interoperability initiative, and strongly encourage them.

In the operations environment, there has been some de facto standardization on the OASIS system. Particularly for realtime and quick-look type requirements, we suggest that future programs examine options to satisfy these requirements for teleanalysis. A library of tools for such realtime functions (including data stream decomposition, rapid graphic display of standard kinds of numeric data, bit packing and decompression, a small set of signal processing tools, etc.) could be very valuable.

A function, which we never addressed in our experiments, involves the remote use of colleagues' analytic systems. While we were interested in making use of remote software and computer systems, a number of specific issues made it impossible during the TTPP program. In order to exercise such capabilities as a program-wide systematic function, it would be necessary to provide:

- high-level directory of capabilities
- documentation
- accounts
- guidance
- multiple terminals watching the same process (in the general idea of remote coaching and multimedia mail)
- network with sufficient throughput to provide graphics/image displays within an acceptable time.

These may make it possible to collaborate with others more effectively, while minimizing the travel costs and time, and without having to move large software environments between institutions.

We applaud the effort towards a standard software environment for the telescience community. We hope that this effort can be expanded and be able to support the other popular workstation platforms in the community, in particular, Macintosh, IBM, and VAXstation. The issues here involve addressing a portable workstation for work in the field, in addition to including a larger fraction of the earth science community with their existing hardware platforms.

3.2.2. Teledesign

In software design for teleoperations, it was important to duplicate the development environments at each of the collaborating sites, particularly during debugging phases. Debugging across the network was extremely difficult without this kind of duplication. The shared 56kb network connections were found to be adequate to the debug task. Moving software and software environments between sites was found to be much more difficult than anticipated.

Project scheduling overall was found to be much more difficult than anticipated. The field campaigns, for example, required coordination and logistic planning between several university groups, NASA laboratories, other public agencies, and the private sector. These were relatively complex, and a major problem during the past year which affected the quantity and quality of the science.

The design of experiments in which geographically distributed scientists were to participate was limited to e-mail communications. While this is a significant improvement over conventional mail and telephone tag, we foresee the need for significant improvements in this area as we begin to plan more sophisticated collaborative research.

3.2.3. Network Infrastructure

Several different levels of network services were required across the Earth Sciences activities. Access to data directories and inventories were sometimes provided by existing mechanisms (i.e., SPAN, the Internet, and dial-up modems), depending on time of day and consideration of number of hops. Interactive remote graphic sessions were often unsuccessful over the Internet; frequently sessions were dropped, even when file transfers between the same points at the same time were generally reliable. Dial-up modems, although often not sufficiently fast, were usually reliable in these instances. In some circumstances (such as quick-look data views), a modest amount of noise on the line is acceptable, particularly when the error rates are known.

A number of experiments involved interactive remote display of bit- mapped graphic images (either interactive or based on file transfer followed by local display). It was the group's experience that 9600 bps throughput was not sufficient, in some cases by factors of 2 to 20; we note that the recent 30 second round-trip delay for cursor movement over the Internet between California and Purdue is of course unacceptable. The goal overall of 10 to 60 seconds for reasonable workstation displays is required for such things as browse of remote image repositories, including compression/decompression as required. For other purposes, rates as low as 1200 bps are acceptable even when the display time is still the same as above, since the data density is lower for vector and statistical graphics. One possible solution might involve providing different levels of service (in terms of throughput and latency) for different kinds of needs; this is different from the capabilities we now use under SPAN and the Internet.

We recognize that new capabilities do indeed spawn new requirements; we anticipate that improved network throughput and reliability will move us to use these services more extensively.

An important lesson involved the institutional overhead required to establish network connectivity. The temporal planning cycle at many institutions is substantially longer than the TTPP program as a whole, thus limiting our abilities during the program.

Several cases of using one university to interface others were found during the program. For example, one of the DEC systems at UCSB runs both DECNET and the Internet protocols. Purdue did not have direct connectivity with Colorado: Purdue remotely logged onto UCSB via 'telnet', and then logged into Colorado via VMS 'set host'. This was useful to bridge between systems until such time when universal connectivity is possible between all the team members.

A mechanism for verifying the result of a file transfer, analogous to a return receipt mechanism in an e-mail package, was identified as a useful service by several in the group. There were several instances where a file transfer task did not run to completion, and the investigators were not alerted to any problem. Further, when a transfer is interrupted, typically the entire transfer must be repeated; the Internet does not seem to support a mechanism to save the portion of the file that has been sent, and then continue the transfer from that point. This is particularly important when attempting to transfer relatively large datafiles. We note that some existing file transfer protocols (e.g. Z-modem) already includes this capability.

Dial-up lines, while generally reliable, displayed some inconsistencies in our experiments. At times, it was even impossible to reliably detect the carrier. These examples make us uncomfortable relying on dial-up lines for mission-critical applications. It is probably still fair to say that dial-up access is suitable for many other kinds of uses. We are concerned that there are still several incompatible protocols for 9600 bps dial-up modems that are in common use. We also note that we have had little success with one of the 9600 bps modems over a satellite dial-up link.

3.2.4. Operations

Within the operations scenarios worked by the group, person-to-person communications mechanisms were very important. The UNIX 'talk' or VMS 'phone' mechanisms were essential in demonstrations where direct telephone or voice communications were not possible.

Scheduling access to satellite observations was difficult. An understanding of the time requiredto scale up for a set of operations is one of the clear lessons learned from the TTPP. The reactivation time for SME was up to a month due to the need to schedule TDRSS support four weeks in advance of our operations, where the planning horizon for the rest of the campaign observations was approximately 10 days.

The time it takes to implement a testbed in the operations area is strongly dependent on the background of the investigators. Scientists without either ongoing hardware development or long experience in the operations area have a much more difficult time. Establishing a remote data acquisition site was very painful. Better mechanisms for near-realtime data dissemination of science data will benefit a number of the science programs in this area.

3.3 Life Sciences Summary

Life sciences requirements are summarized under two broad areas. Section 3.3.1 presents an overview of how life sciences differ from other disciplines. This section points out some of the special needs and characteristics of life science experiments, and relates them to work in Telescience at three NASA Centers, and at MIT, University of Arizona, University of Colorado and Stanford through the Telescience Testbed Pilot Program (TTPP). Section 3.3.2 summarizes the life sciences testbed experience and derives requirements and advocacy for 23 functional areas supporting telescience.

3.3.1. How Life Sciences Differs From Other Disciplines

The nature of most space life science experiments that can be envisioned for the next two decades must, of necessity, draw upon our experience from such experiments during past missions. The missions most relevant to the Space Station are the Skylab and Spacelab experiences. In both cases, significant advances in biomedical science resulted from investigations which made intensive use of the crew as both subjects and experimenters, increasingly involved the ground investigators in the experiment, and permitted some experiment modification on the basis of the observations. The process has been stifled, to a certain extent, by the limitations in communication and control from the ground, the limited crew time and resources for flexible experiment replanning, and the time delays in data availability and initial analysis. In the forthcoming Space Station era, many of these technological bottlenecks can be removed or reduced, providing they are identified early and corrected on the basis of scientific return and efficiency.

Principal Investigator (PI) Interaction

During the course of a typical life science space experiment the PI can be heavily involved in several aspects of the conduct and management of the study. These activities include monitoring, observation, manipulation and management.

Monitoring

While an experiment is running, whether or not an astronaut is in active control, the PI is involved in monitoring the status of the instruments, resources and the condition of the specimen. An experiment may have to be altered or terminated if any of the monitored variables indicate a deteriorating situation. In order to use all of his or her expertise in determining these judgements, the PI must have timely and sufficient data. In many cases, the nature of the data may not have been foreseen, and might involve a new probe or an additional video scene to be set up by the astronaut. In the Space Station scenario, with 90-180 day tours of duty and many experiments, it is not reasonable to expect the astronauts to be trained to the same level of expertise on each experiment as might have been the case for a shorter mission. On board "coaching" becomes necessary. To enable the PI to monitor an experiment, the inclusion of commands for new measurements may be necessary, as well as the inclusion of an Expert System to provide the astronaut with consulting advice and troubleshooting diagnostics.

Observation

During the conduct of an experiment, the life sciences PI is actively involved in experiment observation - to adapt to scientifically interesting data and leads, as opposed to monitoring the status of the experiment. Unlike many physical science experiments, where the nature of the phenomenon is well known and the data are largely a numerical value, the life scientist is usually exploring the very nature of the phenomenon - and often just fishing in a very promising area. The PI will need both instrumentation and especially a wide choice of imagery, including video views from various angles of a plant or animal specimen, the human subject, or a microscope slide. Only with sufficient and flexible downlink and uplink can the proper data be called for and evaluated to put the PI "in the picture" for the conduct of the experiment.

Specimen Manipulation

Not only is observation required but manipulation of the experiment is also essential if the PI is to participate actively in the data gathering phase. It may not be sufficient to tell the astronaut what view is required, or how to shift an instrument or how to adjust a pressure setting. Rather, the experimenter may need to have a "hands on" involvement that has not thus far been available for space investigations. If the apparatus is to include a controllable robot, or a "third hand," it may be under the joint control of the astronaut and of the PI.

Management

During the conduct of an experiment, the PI is frequently involved in the tracking of critical resources, such as crew time remaining versus progress in the experiment. The astronaut typically has neither the time nor the "big picture" of the experiment's scientific progress to suggest that certain steps be omitted, repeated or re-ordered. If the PI is to make these judgements, however, sufficient data regarding the progress of the experiment and the status of data, power and crew time resources must be made available promptly.

Sharing of Specimens and Data

The Space Station-era life sciences program involves the design of space-based laboratory facilities to meet the requirements of a diverse group of science disciplines. After the necessary equipment is designed, tested, installed on orbit and made operational, several experiments are likely to be carried out simultaneously. In many cases, particularly while on-orbit research capacity is still limited, these investigators will share a common pool of animal and plant specimens. These multiple lines of research must obviously be coordinated, and yet each investigator should have some ability to influence his or her own research. Finally, the data from space-based experiments must be made accessible to the appropriate members of the science community in a format, and with a small enough delay, to permit planning and implementation of follow-on research, based on results and findings, in an uninterrupted flow.

Access to Databases

It is essential in life sciences that principal investigators and space vehicle crew have access to both onboard and onground databases. The crew will want to look at onboard data as part of routine monitoring, and out of scientific curiosity linked with their roles as team participants in the research. Ground-based investigators will naturally turn to the data in active ground-based databases, as well as to more archival data as they undertake their planned analyses. The crew will also want to get information from the ground, however, and the scientists on Earth will often want to access data that is still stored in space. Principal investigators will often wish to examine very recently collected data while it is still stored on the spacecraft, e.g., to evaluate its "reasonableness" in general, or to check on specimen reactions to some experimental intervention. The crew may request, or the investigators may transmit on their own initiative, a variety of data (perhaps after some processing), such as, text, graphics, and video information for such purposes as facilitating scientific discussions between ground and orbit, demonstrating new or difficult procedures, or helping the crew troubleshoot and repair equipment. A number of these information transmission activities may involve expert systems technology to help select and use relevant portions of databases more quickly and effectively.

Networks for Experiment Science Team Simulation/Training

Life science experiments are generically crew time intensive, and frequently involve realtime air/ground interaction over voice and video channels with PI teams on the ground. Training via high fidelity simulations has historically played a critical role in achieving and maintaining team proficiency. The design of the overall Space Station Information System (SSIS) must include the capability for conducting high fidelity crew and PI training sessions in interactive mode, with the crew relocated in a mock-up on the ground or aboard the station in orbit, and the PIs located at their workstations at their home institutions or in nearby Discipline Operations Centers (DOCs).

Experiment durations in Space Station will be measured in months rather than by days. Time may not be available for detailed experiment training sessions prior to launch, as they were in the Spacelab era. These factors indicate the need for an on-board, interactive mode of experiment training, preparation, and performance between the crew and the PI.

3.3.2. Functional Areas Supporting Telescience

The experience of participating Universities and NASA centers in the TTPP is summarized in 23 functional areas supporting telescience. This section describes life sciences requirements and advocacy in each of these areas.

Planning and Scheduling

To decrease scheduling conflicts during operations, commitments from communication links suppliers for high priority should be obtained or dedicated virtual circuits should be used. By implementing either of these suggestions, last minute conflicts should not interfere with experiment operations.

For experiment resource allocation before and during experiment operations, scheduling software tools should be developed. Using this software, crew time, experiment hardware, and SS communication networks can be allocated dynamically as experiment operations are conducted.

Remote Coaching

Both the conduct of nominal operations and malfunction analyses and resolution were enhanced by the direct PI/crew interaction during operations. This enhancement was most effective during unrestricted communications access and degraded as the restrictions on communications increased. It is impossible for the crew to have as much in-depth knowledge of a particular experiment as the PIs have. Therefore, ''coaching'' is very effective. The requirements for successful ''coaching'' include: 1) realtime downlink and occasional uplink, 2) unrestricted audio, and 3) a prior common knowledge base (training, common language, experience with common systems).

One of the three life sciences scenarios which is being carried out within the Space Station mock-up at Ames involves remote coaching of the flight crewperson by an expert who was located remotely. Full frame color video and high fidelity audio are also provided to the flight crew within the glovebox enclosure as is a graphic illustration on a Macintosh of the specimen to be dealt with. We found that as long as the integrity of all three two-way voice communication channels and an uplink channel are maintained, and all supplies are available, the flight crewperson can perform the required operations remotely. Coaching takes the form of coordinated verbal and visual cues from the expert as to color patterns on a leaf that have to be precisely cut and snap-frozen within the glovebox. Also, distributed workstations proved very helpful in providing the distributed collaborators cognizance while the crew performed complex experiment procedures.

Monitoring and Maintenance

Monitoring of experiment set-up is as important as surveillance of actual experiment execution. Realtime audio, video and data communications are required for the ground to effectively monitor and track experiment progress. This includes tracking resource use versus allocation, monitoring the status and results of the experiment and providing immediate help for maintenance of off-nominal conditions. With the capability for realtime video, the MIT experiment saved time when the ''crew'' could skip specific steps in the procedures as directed by the ground. Without telescience, they would have had to perform these steps as a matter of course. Similarly, realtime digital data allowed the PI to judge the quality of eye motion data and instruct the crew to check amplifier drifts, electrode placement or proper experiment set-up.

Arizona's testbed included a failure mode simulation. This demonstrated that with 9600 b/s status telemetry, anomalous conditions can be detected and the remote operator alerted to take recovery actions or perform necessary maintenance.

Colorado determined that several essential ingredients were necessary for a distributed environment: (1) The user/scientist needs enough status, configuration, and health information to understand the experiment. If this information is not available, the scientist will have to work locally at the experiment location, where the adequate information is available. That is, science is not dependent on location relative to the experiment, but is dependent on the amount of information available; (2) The user scientist requires feedback for each control direction. The allowable delay for this feedback is dependent on the operation; (3) The user needs to be informed of any activities that are automatically performed by the instrument or onboard subsystem.

Data Compression (non-video)

A number of data compression techniques were investigated. Results of on-going studies are not yet complete. A lossless methodology of data compression may be required for data storage and archival. Data transmitted for monitoring or ''quick-look'' analyses may be lossy or lossless. Lossless compression (no loss of information) must be used (if required by network bandwidth constraints) to maintain original data integrity; stored data and data for rigorous analysis must be complete or available in a lossless compressed form. Since full (no loss) information is not essential for monitoring or ''quick-look'' analysis, lossy compressed data may be acceptable. At present, life sciences do not have any requirements for data compression.

The technology experiment conducted by Arizona showed that the command/telemetry stream, using an appropriate intermediate language, does not require data compression due to the low information rates (never more than 9600 b/s, average a few hundred b/s), and will be more robust without such compression.

Communication Parameters

In the MIT/KSC experiment, the crew worked with open mikes in order to evaluate the impact of a dedicated, open mike voice link capability between the Space Station crew and the PIs. Both PIs commented that when compared to their own previous experience in Spacelab air/ground operations, the ability to listen continuously to open mike conversations between the crew made a major positive difference in their ability to keep track of the progress of the experiment (both with and without simultaneous video), and were surprised by the difference this one factor made. When PIs could speak to the crew without having to ask for permission, and without the 30 second "voice enabling delay" imposed in some of the sessions, the PIs were much more effective in assisting the crew in troubleshooting, or in following up on unexpected findings.

Video/Audio/Data Latency and Relative Phasing:

The MIT/KSC experiments imposed approximately 1-2 seconds delay between data and video/voice. Video and voice had approximately identical phasing, and less than one second delay. However, PIs frequently operated with video frame rates of 1/sec., and occasionally lower. Although technical limitations prevented the MIT/KSC testbed from fully exploring latency and phasing parameter space for video, audio, and data, certain requirements in this area can be stated with certainty:

Time delays between data and audio/video of 1 second or less were clearly acceptable. Latencies of 1-3 seconds (due to satellite communications delays) are routinely accommodated in Spacelab operations. Time delays of 30 seconds between video/voice and audio (encountered by the same PIs in Spacelab operations) are unacceptable for remote coaching. Time delays between video and simultaneous audio ("the Bruce Lee movie effect") - though subjectively noticeable - are probably acceptable up to about 3 seconds in most remote coaching situations. It should be kept in mind that voice monitoring greatly assists the PI in interpreting video information and vice versa, so acceptable criteria for phasing probably depends on video bit rate. In each of two quite different scientific experiments, Arizona was just able to transmit teleoperations traffic, (commands, status telemetry, and limited amounts of scientific data) at 9600 bits/second. This implies that each teleoperations connection should provide a minimum transmission speed of 19.2 Kb/s. A more reasonable requirement is probably 32 Kb/s or 64 Kb/s (ISDN B channel).

A key parameter is round trip delay time (latency). Arizona's studies showed that man-in-the-loop control of a robot was not possible with delays larger than 1 second. For near real time teleoperations using open loop (remote commands directing local autonomy) delay of less than 5 seconds is extremely desirable.

Colorado required a mix of audio, digital and video data for distributed laboratory science operations. Bandwidth limitations in any of these data types can be compensated for (at least temporarily) by varying the operations style. That is with limited bandwidth, the user directions must become more goal oriented (e.g., ''go to brightest location'') rather than activity oriented (e.g., ''turn left... go forward... stop'').

The user must be able to compensate and respond to both scheduled and unscheduled data outages. This requires a certain level of automation to continue experiment operations, during these communication interrupts, the ability to respond automatically to unscheduled operations with safing procedures, and ideally the ability to reschedule these interrupted operations through onboard, automated services.

Software

In the Spacelab era, PIs have been asked to specify their POCC or life sciences SMA displays and data analysis systems many months prior to a mission. Typically, when PIs begin to participate in interactive mission simulations, and their understanding of their remote coaching and data monitoring function matures, PI display requirements change. The ''optimal'' display format typically is found to depend on which functional objective is being accomplished, and on the experience and workload of the PI. Existing software technologies from Spacelab do not make it easy for the PI to rapidly reconfigure PI display terminals.

MIT/KSC developed a prototype PI Telescience workstation utilizing a networked DEC microVAX II running BSD Unix and a special version of X Windows developed at MIT which supported realtime video windows. Most of the programming was accomplished in C. Unix/X-Windows/C provided a powerful, flexible development environment for our experienced programmers. A number of generic data display window functions were defined which successfully supported both experiments. The PIs could quickly change the number, format, and placement of both graphics and video windows. However, due to the time constraints and the lack of a graphical block diagram compiler which would support virtual instrument and display prototyping and reconfiguration on the microVAX (comparable to LabVIEW for the Macintosh), only a very few of the possibilities were explored. Also, the data processing requirements placed on the system would have been better satisfied by using more than a single workstation in a networked configuration.

MIT believes that X-Windows represents a reasonable standard for the graphics substrate of a PI workstation, but that an additional set of graphics standards and virtual instrument/display toolkit would greatly facilitate display development and reconfiguration, both in the context of testbedding, and also before and during actual Space Station operations. PI workstation team training costs can be significant, therefore, telescience workstations should adopt user interface standards (e.g., Macintosh) for those functions which PIs use frequently (e.g., window management and text processing) which are very familiar to science team members in other contexts.

The ability of PIs to simultaneously monitor experiment operations, evaluate incoming data, and maintain an adequate running logbook is critically dependent on the division of labor and experience of the PIs involved, and on the technology which supports them. Logkeeping is a critically important PI function. The MIT/KSC experiments demonstrated, however, that logkeeping - even using a word processor - could be a very distracting task during high workload periods. Improved techniques should be developed to assist the PI in automated logkeeping. PI workstations should feature automatic timeline monitoring and display of ''minutes ahead/behind.'' Such systems could also trigger display of appropriate checklists for PI use in monitoring each experiment step, and context dependent troubleshooting checklists/diagnostic trees. Workstations should support ''nominal data'' displays for comparison with that obtained in session, and automatic reconfiguration of displays when a PI must ''tune out'' to work some side problem.

Arizona utilized generic modular software for general teleoperations scenarios. Separating the human/computer interface, the computer/computer interface (intermediate language) and the computer/instrument interface, permits application to different experiments and new experiments with minimal software development.

Ada is an excellent choice as the standard programming language for telescience applications. This is primarily due to the exception handling, privacy, and multi-tasking capabilities, which are not available in other high level languages. Also important is the structured programming basis, which greatly simplifies team software development, debugging and documentation, and re-use by third parties.

The University of Colorado has developed a prototype software package, called OASIS, for use in controlling and monitoring space operations activities. This OASIS prototype has been successfully used as part of a number of lab science testbeds with the following results:

1. The capabilities provided by OASIS (user interface, experiment control, monitoring and communications) are essential to teleoperations.

2. The ability to easily tailor the OASIS for new experiments and user interface has provided some TTPP user groups with a common tool for telescience that could be used early in their testbeds and can be enhanced throughout.

Crew Interaction

It is required that the PI and crew train in their operating environment. Almost every life science experiment requires extensive crew interaction as operators and, many times as subjects. Recognizing that the crew will not be as knowledgeable as the PI, it is crucial that they at least share a common pool of knowledge. Crews need to train together to form a rapport and a style of working together. Surveillance video and full duplex lines, with crew hot mikes and dedicated loops are required for efficient crew-PI interaction.

The Ames Life Science Testbed involves one flight crewperson, one ground controller, who also serves as cap com, and one expert plant biologist. Crew interactions are facilitated by the medium resolution, color TV systems available which provide wide field of view coverage. In addition, having adequate light level makes it possible to see facial expressions in a natural manner without unnatural shadows, the audio system which allows all parties to be recognized by their voice qualities rather than have to identify themselves each time they speak, and by their capability to call upon one another for information as soon as it was needed.

Remote Operations

It is in the best interest of the science community to design experiments which are as autonomous as possible, so that valuable crew time is well spent on those experiments and procedures which absolutely require crew support. The use of robotics and the telescience concept is one solution to this potential shortage of crew time.

Experiment preparation (i.e., equipment warm-up, pre-experiment calibrations, etc.), shutdown (calibrations, turning off equipment), and periodic housekeeping (cage cleaning, equipment or environmental monitoring, maintenance), among other activities, can be accomplished using autonomous "robots" controlled by the PI from a NASA facility or home institution using SSIS data/video/voice network links. Many experiments may need only occasional intervention from the crew; some can only be done by the crew (human physiological studies, for instance). But in all cases, crew time must be considered as a limited resource, as well as power, volume, and other resources. The use of robotics and PI direct command and control of experiment hardware to minimize the need for human intervention onboard Space Station should be advanced as a telescience and SSIS option.

Remote operations can be made safe, effective, and robust by including proper sensors, safeguards and controls. This must be carefully considered early in the experiment design process.

Scientists will eventually require multiple access to multiple experiments. Arizona has demonstrated the feasibility of this mode of teleoperation, but it is necessary to incorporate this in the hardware/software architecture from the beginning.

Video

It is anticipated that the video bit rate available to individual experimenters on Space Station may be severely restricted due to limitations of TDRSS and ground data networks. Hence the ability of the PI to perform a remote coaching function with decimated video images was made a focus of the MIT/KSC Telescience experiment. The PIs were given independent control of frame rate, resolution, and grey scale ("FRG parameters") subject to an overall video bit rate restriction, which was systematically varied in different sessions from 12 Mb/sec to 50 Kb/sec. When monitoring the progress of crew activities, PIs invariably were willing to sacrifice frame rate in order to obtain at least 4-5 bits of grey scale and the maximum available resolution. The PIs found that they could "get along" at video bit rates lower than they subjectively "liked." However, the true value of having full bandwidth video occasionally available to the PI for monitoring dynamic events was exemplified when it was retrospectively discovered that a sled stripe display had been consistently moving at the wrong speed through all the sessions thereby invalidating one of the experiments. The PIs felt that if they had been given occasional bursts of full bit rate video on demand, the display problem likely would have been discovered and corrected. The PIs can accomplish most surveillance monitoring functions using black/white, relatively slow scan video. Bursts of high frame rate, high resolution video are extremely useful as are video cameras which can be remotely aimed and focused.

The Ames testbed employed four medium resolution (400+ line) color TV cameras within the Ames Life Science Testbed. A fifth high resolution color CCD miniature camera was located on the arm of the robot inside the glovebox. All required life sciences procedures were completed successfully using these five cameras. Two orthogonal cameras are needed within the glovebox since the arms and hands of the flight crewperson often occluded one camera's view. Specimen illumination had to be diffuse and bright enough to provide sufficient camera depth of field.

The video is considered absolutely necessary to the successful conduct of the Life Sciences since they permit the ground flight controller and ground expert to continuously monitor space actions and to identify moments of opportunity when new and unplanned activities are inserted in the protocol. A roving camera in space is felt to be important as well as a set of rigidly located cameras.

Arizona demonstrated that color video feedback is absolutely required for a robot controlled fluid handling laboratory. Since these are high volume passive channels, they cannot be routed through the operations management system. Delays of less than 2.5 seconds were required, as were multiple cameras with remote camera control. Commercially available data compression technology for teleconferencing should be applied. Required data rates range from 80 to 400 Kb/s per channel, depending on image quality and rates of motion.

One of the major areas of concern which has been identified is the distribution of video information via the SSIS. SSIS requirements documents call for distribution of real time video information, and duplex video teleconferencing capability with Space Station. Real time video and teleconferencing capability are believed to be particularly important for crew-time-intensive experiments in the life sciences area. However, several significant obstacles to a full implementation of these capabilities are imposed by bandwidth and distribution limitations.

Payload Design

Throughout the hardware development stages of certification, verification, testing and integration, the PI should be able to monitor progress of the hardware remotely from a User Operations Facility (UOF) or from a home institution using SAIS/SSIS video/voice/data network links. This includes teleconferencing for design reviews and teleoperation during ground hardware tests.

Data Transfer Reliability

The reliability of data transfer is very important in telescience operations. MIT/KSC testbed results indicate that a data dropout (on the order of a second) is tolerable and recapture of lost data in realtime operations is of little utility. Realtime operations are most concerned with realtime data. However, data recapture is very important in off-line data review. An archival facility is required to provide a complete data set for off-line data recapture, review and analysis during the mission.

The JSC testbed performed network analysis on DECnet (running on VAX 750, VAX 785 and microVAX computers) to test non-transparent task-to-task communication. Six network configurations were tested to evaluate performance with respect to data transfer rates and CPU consumption. Effects of buffer size on overall throughput and the effect of multiple logical links on data transfer rates were also examined.

Existing SPAN and local networks can support low data rates (up to 9.6k or 56k) without dropouts only if network overhead and traffic is not excessive. SPAN and local networks were found inadequate for the JSC experiments due to excessive delay and packet loss caused by excessive network traffic.

Distributed Software Development

An essential requirement for distributed software development at MIT was the establishment of interface control documents (ICDs). ICDs baseline the system interface requirements and facilitate the integration of dissimilar distributed systems. It is essential that the interfaces specified must not be hardware or software dependent to enable specific systems to be tailored to individual needs. Standards for user interfaces are required to facilitate commonality (and hence user friendliness within the telescience user community). The resources for the KSC-to-MIT data communications system required linking an IBM PC 386/MSDOS system using custom ASYST software with a DEC microVAX/Unix system running a custom C program. Establishment of an interface control document enabled successful distributed software development and integration of these dissimilar systems.

Successful completion of the Arizona experiments would have been impossible without distributed software development by many members of a team and by teams at several institutions. The Ada software environment was important to the success of the Arizona experiments due to its portability across computer hardware and its programming support tools for standard documentation and structure checking. Network communications, with capabilities determined and driven by experiment function, are essential to experiment success.

Colorado learned that it is important to have a clear understanding and documentation of the interfaces between distributed software components, standard (preferably Space Station standards) formats and protocols for exchanging information over these interfaces, and making sure that information passed over these interfaces is adequate.

Expert Systems/AI

The application of expert systems for telescience has progressed slowly over the past year due to the total lack of experience with the use of such tools. The telescience testbed activities have indicated several areas where AI/expert system tools could benefit from telescience operations.

An target application was enabling of astronauts as science collaborators during the conducting of a space experiment. AI techniques are applicable to planning, operation and analysis. MIT's "PI in a Box" program determined that the areas in which an on board expert system is useful are:

- remote coaching
- signal quality monitoring
- quick look signal analysis
- interesting-case detection
- experiment replanning

An initial prototype based on the Space Sled showed the feasibility of the diagnosis/trouble shooting and the difficulty of classification of interesting data on-line.

The first application is related to the teleoperations phase where scientists have expert system support tools to plan, replan and make realtime decisions during the operation of a space experiment. The MIT "PI in a Box" concept is such a knowledge-based support tool.

The second application deals with the creation of expert system tools to assist scientists in the capture, storage, retrieval, and analysis of geographically distributed information residing on heterogeneous hardware and software systems. It required the development of knowledge bases containing information on network interfaces and protocols, database architectures and formats, and display formats and analysis/decision support choices. The complexities of such systems should be made to be completely transparent to the scientist, thus, insuring that the support tools will be efficient and productive parts of the operational system.

Data Interchange

The proposed networking methodology for telescience is currently based on the NASA Science Internet (NSI) plan. This implies standard protocols (currently TCP/IP migrating toward OSI) and either NASA provided long-haul links or other existing network connections (NSFnet, ARPAnet, etc.) to connect Local Area Networks (LANs.) Concerns, both technical and political, about communication link security need to be identified and subsequently addressed. This investigation includes the evaluation of encrypted existing networks versus dedicated NASCOM links to provide secure PI access to the flight laboratory.

Life Sciences advocates adoption of the Consultative Committee for Space Data Systems (CCSDS) recommendation for the implementation of a standard data structure for the purpose of interchanging data in a uniform and automated fashion within the science community. The CCSDS recommendation defines the Standard Formatted Data Unit (SFDU) structure and construction rules that can be used to build the aggregate structure. However, additional structures and rules must be defined to address data interchange, archiving, and acquisition problems specific to the life sciences.

The JSC testbed used serial simulated and previous (recorded) unformatted experiment data, converted to Standard Formatted Data Units (SFDUs) of up to 64k bytes. At the next level of processing, a SFDU is encapsulated in a data packet according to telemetry packet standards promulgated by the CCSDS, standards which are being adopted by the Space Station Freedom Program.

CCSDS data packets were transmitted to a remote node over several existing networks (notably the Life Sciences Data Distribution System), received in sequence, and stripped of their SFDUs for data processing. Software requirements are minimal, however, processing times may impact realtime data requirements.

Arizona demonstrated that the Standard Functional Data Unit (SFDU) and CCSDS packet formats were sufficient for the data exchanges necessary for two teleoperation scenarios. They recommend that these international standards be required for all applications.

The Colorado experiment came to the following conclusions:

- The CCSDS telemetry/telecommand packets worked successfully. They can substantially increase the flexibility and capability of instruments.
- Use of Standard Formatted Data Units (SFDUs) for telemetry data increased an instrument's flexibility by providing self-identification of packet contents.
- Using SFDUs to encapsulate and identify uplink data are useful and will likely help simplify complex command and control environments like Space Station.
- Test of SFDUs for transfer of data from archives will be hampered by the lack of SFDU handling software and support systems. These tools need to be developed and evaluated.

Distributed Program Management

The MIT/KSC testbed found that to coordinate work between participants in distributed locations required four different communication levels.

- Project Definition Document - Document to provide participants with the objectives, methodology, and actual implementation of the testbed experiment. Document was used as a reference to insure that the testbed was proceeding as required.
- Telecons - Status of the testbed at each location was exchanged. A weekly telecon which included a review of an action item list provided all parties with information on the testbed status.
- E-mail - Persons working on a specific action item maintained status between telecons using e-mail or the telephone. The important issue was to provide everyone with the current state of testbed activities.

- Site Visits - To provide participants with a view of the complete picture of the testbed, reciprocal visits to each site were in order. The MIT/KSC testbed found these visits necessary to understanding the logistics problems involved and the location's capabilities. These visits were also useful in assuring that the Project Definition Document was being adhered to.

Operations Management

Colorado found that the enabling technology for distributed operations is transactions management. Key capabilities include command interlocking and reactive control. These capabilities have been implemented in a Colorado testbed and shown to work in protecting the health and safety of experiments and space subsystems.

Another operations management capability includes control and management of user access of experiments, systems and tools. In initial tests the CCSDS protocols for access control seem adequate.

The Colorado tesbed demonstrated that the onboard operations management capabilities should be distributed to the various distributed onboard instruments and subsystems.

Training and Documentation

The MIT/KSC testbed provided substantial crew (EPS) training on sled operations and experiment procedures. The PIs were not trained on the sled operation procedures. To increase the monitor/maintenance capability of the PI, for testbeds as well as space experiments, training for experiment hardware operations should include both crew and PI. The crew and PI training should be focused on the experiment hardware operation/maintenance/safety with the PI training also including work with the PI workstation.

Experiment procedures were maintained throughout the testbed which provided a script for each experiment session. A well maintained set of procedures will facilitate good PI/crew coordination during experiment operations.

Workstation Hardware

The MIT/KSC testbed PI workstation was implemented using a networked DEC microVAX II with a Parallax video board. The DEC microVAX II supplied the data processing and display while the parallax board processed the video signal for display on the microVAX display monitor. The Parallax board function was found to be sensitive to video signal content.

The testbed found that one microVAX II was not capable of handling the entire processing load, and reduction of the data set was necessary for the one microVAX II. To improve data handling capabilities required distributed processing to other computers.

Among the workstation displays which were considered particularly effective during the Ames Life Science testbed is a large format (26") high resolution color (composite) monitor which presents imagery from four TV cameras simultaneously via a "quad splitter" to the ground crew. Ground crews find their eye scans to be shorter and faster than if four separated monitors are used. A one second accuracy digital time (and date) is also displayed. A video switch makes it possible to view the output from other cameras as well (e.g., from the ground expert location). Each participant wears a wireless headset and boom microphone at all times which frees up their motions.

A Macintosh computer is installed inside the glovebox. It is used to present various experimental procedural information both visually and orally (using a voice synthesis). Directly above the computer screen is a high resolution, color monitor which is driven by the TV camera located at the ground expert's site. Both items are used in coaching of unplanned test procedures; both are found to work well.

The Ames testbed incorporates Macintosh II's, an Everex 386, an IBM PC and a microVAX GPX. The Mac II/HyperCard provides the most flexible, visual and powerful prototyping environment.

Arizona found out that microVAX II GPX or equivalent was useful for various teleoperations applications. Local controlling computers can be smaller and do not require color graphics displays.

The Colorado group has successfully implemented the OASIS teleoperations package on both the microVAX and Sun workstations.

Software Packages

MIT/KSC utilized the X Windows graphics standard for software development, including a special MIT project, Athena driver, supporting realtime windowed video. KSC employed the ASYST data acquisition/communications software package with their PC 386 system to support data acquisition/communications between KSC and MIT. Use of ASYST facilitated rapid development of a flexible data acquisition/communications system. Although the data analysis capabilities of ASYST were not employed in the phase 1 testbed effort, this capability could be used to explore flight workstation requirements. The advantages of using off-the-shelf hardware wherever applicable is demonstrated by experience.

The Ames testbed used the following packages: OASIS, adaptations of public domain communication packages for the Macintosh II, a public domain speech synthesis package for the Mac, and Scorbase, a robot programming language. The Meridian Ada compiler is used on the PC's and Macs. All of the above proved satisfactory.

OASIS proved to be very useful as the human/computer interface. The modularity of OASIS should be extended in future releases to allow it to be useful for a larger range of teleoperations applications.

Telescience Science Productivity

Seven of eight experiments performed by the MIT/KSC experiment were judged by the PIs to have been greatly improved by the telescience concepts. Noticeable were a reduction of wasted time, increased crew/PI coordination and rapid problem detection/resolution as compared to a ''negative reporting'' environment such as used in operational shuttle/spacelab missions. This increase in science productivity resulted from increased audio, video and digital data delivery to the PI.

Effective automation and remote operation saved crew time and training in the Arizona testbed. In this experiment, much of the work involved tedious and repetitive fluid handling.

The Colorado telescience approach increased scientific productivity by:

- Enabling science experiments to be performed that were previously impossible or impractical.
- Allowing more scientists and students to participate in space experiments.
- Better utilizing (through interactive operations) the most precious resource - spacecraft observing time.

Knowledge Capture

The Life Sciences discipline telescience experiments at Stanford have produced significant results which will directly influence the design of the space station and the design, operation, and analysis of life science experiments in the space station era. The telescience activities have indicated a need for a quantitative assessment of lessons learned. This quantitative assessment will enable a system-wide implementation process to occur which responds to each of the lessons learned. If support tools are available to assist in this assessment, they should be made available to all of the telescience discipline areas.

User Interface

The most important requirement is to have a consistent set of user interfaces. The MIT testbed required that PI workstations (NASA or user supplied) adopt standardization of interfaces to experiment information.

Different levels of interaction are required. A casual user would use mostly high level (graphics, icons, batch commands) interactions and not need to know, for example, programming language syntax. However, the programmer developing such an application should have access to all levels of interaction.

Ames concluded that the Macintosh user interface proves quite useful for prototyping since the users are working with familiar metaphors. Interactions are further enriched by the Macintosh bitmapped screen, animation capabilities under HyperCard, voice synthesis, etc. Color and multiple windows provide significant advantages.

Colorado's observations on user interface are as follows:

- The Macintosh-style of user interface provides a good basis for a useful interface. This interface style has been used and successfully demonstrated in the OASIS.
- Users are happiest with an interface that they have been able to mold or tailor to their own specific needs. This ability to easily tailor an interface by an individual user is a needed feature, within the constraints of the relevant standards.
- Users would like to be able to directly manipulate an icon as a control directive rather than use indirect control techniques such as typing instructions on the keyboard or going through menus.
- User interfaces should be set up to give the users the feeling that they are manipulating the process (or experiment) itself and not just manipulating the screen.

Pre/Post Flight Data Collection

The PI will monitor baseline data collection from the BCDF via SAIS/SSIS video/voice/data network links to both the BCDF and the DOC; this is for both pre- and post-flight baseline data collection. (DOC personnel will also monitor progress at the BCDF via the same links). Prior to and just after flight, the PI at the UOF (and personnel at the DOC) will monitor experiment status as hardware and specimens go through the Life Sciences Support Facilities. In-flight operations (manned base and shuttle) will be monitored by the PI at the UOF, as well as at the DOC, POIC, SSSC, and the ESC. Through the DOC, the PI will have the ability to request experiment timelines and resource allocations. Data and experiment status will be provided according to the grade of service requested (i.e., realtime, no bit drop-outs, once a day, etc.)

3.4. Microgravity Sciences Summary

The following paragraphs summarize the data and recommendations resulting from the efforts of the teams at the University of Arizona and Rensselaer Polytechnic Institute. These efforts were directed toward the study of the telescience (teleoperations) concept in the area of microgravity science. At Arizona the thrust was toward remote fluid handling and at RPI it was toward microgravity materials science. A commonality of requirements developed from these experiments and these are discussed in the following material.

Scientific Productivity of Telescience

The key contribution to scientific productivity through telescience is characterized by the words "rapid feedback." The results of an experiment will be known to a principal investigator on earth as the experiment proceeds. Thus the experimenter is able to act much as in his/her own laboratory and react to unexpected results or make modifications to the experiment or redo the experiment as the data demands.

Experiment Equipment Design

Payload design is affected significantly by the desire and capability of the earth bound investigator to perform as extensive and rewarding an experiment as possible while in the microgravity environment. With live data available and the ability through fixed automation or robotics, the PI can physically reconfigure the experiment. Clearly the payload itself and associated instrument packages must be compatible with the degree of automation provided. In liquid handling, for instance, the need for parameter adjustment based on measured results demands fluid transfer in a closed container to avoid liquid-air interfaces. Both the experiment and the associated instrument package must be designed to be compatible with the indicated demands of microgravity and the handling equipment, in this case a robot.

Information Transfer Reliability

Information is transferred to the platform from the ground in terms of control signals. These control signals may be of vital concern to the outcome of the experiment, and require conventional error checking and probably limit switch type of mechanical protection in case the wrong signal was sent and incorrectly checked.

Return data requires no more reliability than is presently demanded, and perhaps less, as the PI may review the data as received.

Planning and Scheduling/Operations Management

Since the general concept of telescience includes the concept of distributed experiment control it requires a well defined operations plan. However, this plan must be responsive to hour by hour changes. A central operations planning center is required and voice and E-mail circuits must be available to all remote control sites. In addition all commands issued by the remote sites must funnel thru this center for validation and relay. This center must be responsive to science requirements (i.e.. windows of opportunity) as well as flight requirements (i.e.. crew availability) to maximize the scientific productivity.

Video/Imagery Requirements

For a remote experimenter to control his experiment it is required that some form of visual information be available to him. For the purposes of this study only the requirements for control (not data) were considered. A review of potential Space Station microgravity experiments indicates a wide range of requirements. From a minimum of black & white, low resolution (128 x 128), and low frame rate (1 frame per minute) to a maximum of full color, media standard, systems may be required depending on the specific experiment.

Voice and Data Transmission Requirements

For those experiments requiring crew assistance at least one dedicated, direct, voice channel is a definite requirement during the periods of crew involvement. Uplink and downlink data/command channels are also required. Bit rates from 16 to 64 KB/sec are required depending on the experiment. Anticipated data transmission problems, i.e.. Z.O.E., dropouts, and moderate latency will not preclude the telescience concept.

User Interface with Computer Control Console

In this concept it is planned that the control of the experiment may be by a scientist who is not completely comfortable with a computer console. For this reason the interface must be ''user friendly''. Operation must be simple, goof proof, direct and clear. The lessons learned in developing programs such as ''OASIS'' can be utilized in the creation of software for this purpose.

Other Ancillary Requirements

In addition to those discussed above there are other requirements which are less important but nonetheless needed. These include:

- Remote coaching, monitoring and maintenance
- Remote databases
- Training and documentation

Summary

Although further experimental work is needed to determine realistic numbers for specific requirements, a large gain in science productivity can be achieved with capabilities as given. It is apparent that, although not all microgravity experiments are amenable to the telescience (teleoperations) concept, a large proportion appear to be and the required effort can be justified there on.

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Section 4
Results and Conclusions

In this section, the results of the testbed are integrated across the various disciplines. They are described in terms of the three aspects of telescience; design, operations, and analysis. In addition, lessons learned regarding infrastructure and programmatics are described. Because of the similar requirements of design and analysis, they are described together.

4.1 Design and Analysis

The design and analysis phase of research often involves many participants working together with remote databases, design aids, and testbeds. Often equipment must be located remotely from the scientist or developer. Debugging software remotely is extremely valuable from several points of view. Observatories are remote, and it is not possible to have all the team together at the site. During the TTPP, a programmer was able to remotely debug software. This saved significant travel funds; current network capabilities worked in this instance.

In terms of hardware design for Space Station and related systems, engineering studies are now in progress at a number of universities and contractors. Tying all these diverse groups together is a very hard problem. One of the key problems is the lack of knowledge of the design documentation trail. A bulletin board mechanism plus appropriate database and document retrieval components is going to be vital. However, documents are not in standard formats (Macintosh vs. VAX vs. ...), and graphics interchange standards are not in place in the community. Further, exchange of the underlying design database is sometimes needed (i.e., interface specifications documents). Overall, it is difficult to get all the groups working to the same set of specifications.

In the MIT/KSC life sciences exeriments, approximately half the anticipated number of experimental sessions were possible. Program-level problems included funding delays, getting communications lines bought and installed, and frequent revisions to the early system definition document. FAX was found to be very helpful. Further, the lack of networking literacy was a problem at the beginning of the program. Within the experiments themselves, it was not possible to look at the 'zero latency' condition during the testbed condition. NASAselect was used for video, but the low priority assigned to use of the system for the testbed program hurt both scheduling and science.

We don't generally have adequate methodologies for examining results of teledesign in the testbed, particularly when people are at both ends (human factors). Multimedia mail/conferencing have just scratched the surface. There is no tool for rapid prototyping of virtual instruments. Given the multi-year distance between engineering questions and real experience in science use of the resulting systems, the design process must provide tools for PI's to be able to modify things. A Mac running LabView worked well for some kinds of science. Other cases exhausted higher-end workstations. The lesson we draw from this is that the PI workstation is a generic idea with a wide range of possible capabilities.

Portability was found to be extremely important at multiple levels: workstation software level, as well as design documents (both text and graphics).

Information overload was clearly identified for the PI's in real time operations. A hard copy log book was vital to the experiments. Based on these experiences, more effort must be expended to automate the logging process. Statistics such as ahead/behind schedule, checklists, and a database of normative data would all help.

In some of the experiments there was minimal need for teleanalysis during operations, because the science team was just too busy.

We underestimated the time the PI team took to learn the tools created for them. Thus there is a big premium on user friendliness (i.e. choosing text editor for log function familiar to the scientists).

Ada was viewed favorably by the system developers who are using it. Problems with real-time capabilities have been identified.

A toolkit for the design of the user interface should be available to the PI - intensive interaction with high fidelity to the environment is very useful to design the user interface to the systems. Rapid prototyping tools are essential so that the contractors and system implementors converge towards a useful system, rather than the traditional specification => implement in isolation => hand off system to users. TAE+ was found to provide a good set of tools according to one experience in the program.

The experience of the group suggested a strong need for trade-off studies and simulation tools (such as robot setup vs. software simulation) in the design phases. Contrasting the time available for experiments (whether on shuttle or on station) vs. astronaut time vs. teleoperations capabilities vs. autonomous operations was not possible, although very important. In a specific example - is a robot in the glovebox useful, when the glove box is the point where the astronaut works with the equipment and samples? That is the baseline design and the PI's aren't sure it's the best way to go. Is the scientist's lab on earth a good model of the spaceborne laboratory; is it a reasonable parallel? Can a prototyping lab for materials & life sciences be developed to get more experience for the science projects? Such a lab would be a place where a PI can come in with a surrogate crew and his/her specific equipment, and optimize the experiment itself as well as the bandwidth use, etc. The proposed science and technology centers are an excellent concept, particularly if they can be used not only in verification of the instrumentation but also in design of the experiments themselves.

An observation many of us made is that we have limited experience with video teleconference, and thus cannot compare it with the multi-media mail/conference systems. Voice teleconference and fax were useful during several of the experiments during both design and analysis phases. We suggest that NASA's teleconference services be made available to the team as a near-term facilitation of the program, as well as to evaluate utility of the teleconferencing mode for operations. From another point of view, how do we find out about some of the private and public sector efforts in these areas, for example, where networked workstations were used in design experiments, the application of relatively older technology like slow scan TV for teleconferences (for block level design meetings, and for coaching), etc.

The group is concerned about standards issues in both design and analysis. We recognize that standards are both a blessing and a bother- the standards must facilitate the work rather than hinder the developments. Standards areas such as windowing environments (i.e. X-windows), communications (TCP, ISDN), and operating environments (POSIX) are useful; we have less of a coherent idea about standards for the user interface, standards for dataset formats themselves, and so forth.

Several groups observed that there are different levels of service required to support interaction with remote archives. Simply locating interesting data (perhaps by query of a database system) is accomplished reasonably well with 9.6 kb dial access, and the Internet is not bad for subsequent background data file transfer.

When the goal is to view data, on the other hand, the acceptable time scale for a graphic screen display for this kind of retrospective analysis is on the order of 0.1 to 1 minute, almost irrespective of the characteristics of the data (raster vs. vector, color vs. monochrome). This provides a mechanism to compute required throughput for some classes of operations. We also recognize that there are all kinds of trade-offs between pre-processing certain predefined products vs. on-the-fly computation based on real-time demands, as well as the use of data compression.

There were some group analysis workshops during the program, which typically meant getting the team together at a single site. There is great interest in geographically distributed work group analysis proceeding relatively in parallel, rather than sequentially, but we have no experience in this specific mode. The remote coaching type system seems a natural support mechanism for multiple scientists accessing processing systems simultaneously for collaborative analysis, but we were unable to exercise such a system. Remote access to processing capabilities requires support functions in terms of documenting the available systems and software, guidance in use of the systems and so forth, this is the same as the supercomputer center experience in many ways. There was relatively little teleanalysis in this mode, since the documentation, accepted data and interface standards, and support were unavailable.

There are several important standards areas we have recognized (principally from an image data viewpoint, but we believe these are general): Descriptive standards (the syntactic and semantic contents of catalog/inventory/directory), vs. Data format standards. We are in agreement that standards for description of the format - in effect, an envelope around the dataset - are more useful to the community rather than specifying the physical format a priority.

These become even more important as we begin to develop the level 3 and level 4 derived products from future systems. These also are important within programs for local datasets and archives, to not lose the value of the data through time (self described datasets may still be useful after the person who collected them leaves the center).

4.2 Integrated Results on Teleoperations

This section integrates the results of TTPP across the science disciplines with respect to teleoperations.

The Teleoperations Paradigm

In order to discuss teleoperations results, it is useful to first define a teleoperations paradigm. Teleoperations is the concept of operating a laboratory remotely by providing the capability to interact with remote instrumentation as if those instruments were contained in a local laboratory. In addition, teleoperations enables the conduct of interactive science where the immediate results of an experiment can be evaluated by an investigator and can be refined iteratively, or new experiments can be conducted in response to the measurements. Teleoperations optimizes science return by enabling users to make efficient use of time and resources. Central to the concept of teleoperations is the realtime delivery and analysis of both telemetry and science data to the scientists conducting the experiment, in order to evaluate the status of remote instruments, and to assess the performance of the science experiments. Of equal importance is the ability of the scientist to control remote instruments interactively.

In the ideal case, teleoperations would permit a scientist at his or her home institution to conduct an experiment remotely using realtime displays of the science and telemetry data and interactive control of the instruments within limits imposed by resource constraints, security, and safety.

Our teleoperations concerns can be summarized as follows:

- To what extent should instrumentation be controlled from a centralized NASA operations center, and what capabilities can be distributed to the science users?
- What level of interaction by a science user is needed for effective science operations? What functions should be reserved for a central NASA control facility?
- What is an appropriate mix between automated and manual operation of experiments?
- What command interlocks are necessary for hazardous operations?
- How should resources be allocated, and can the concept of resource envelopes be used successfully to manage shared resources?
- How will communications, data and control interfaces and protocols be standardized? What are appropriate standards for common user interfaces for workstations?
- How can instrumentation be shared by different experiments and by different scientific disciplines.

- How are changes in procedures handled with regard to safety? What latitudes should scientists have in modifying their experiments?

We have learned some valuable lessons in teleoperations from our TTPP experiments. These lessons are listed here and described in the following paragraphs.

- Workstation Standards
- Communication Needs
- Video Requirements
- Operations Management
- Teleoperations Through the Project Lifecycle
- Increasing Science Productivity

Workstation Standards

The human/computer interface for teleoperations should allow for:

- Ease of use
- Consistency
- Reliability
- Adequate computational power (minimum latency)
- Coherent interfaces regardless of the location of the human operator (IVA workstation, EVA workstation, ground-based)
- Flexibility of input and output devices
- Sufficient monitoring information for control
- Flexible (user adjustable) screen display

A compromise must be found between standardization and flexibility of the user interface to the needs of the particular application. Some details of the user interface may be application dependent, but the meta-interface (''touch and feel'') should be common between applications.

Among all the possible hardware/software configurations, all TTPP participants chose either Sun workstations or microVAXes, and either UNIX or VMS. While this decision was certainly dictated by the current market situation, and may change between now and the launch of Space Station, it was commonly agreed that the chosen hardware/software systems were adequate for the TTPP tasks investigated. While a number of TTPP participants complained about the realtime performance (execution speed) of their chosen workstation environments, nobody complained about the adequacy of the way in which they were forced to interact with their experiments through their workstations. From this, it can be concluded that the selection of ONE human/computer interface environment for teleoperations (for the purpose of standardization) is more important than the detailed specifications of how exactly this interface looks like, as long as the interface provides for an appropriate balance between standardization and flexibility. This indicates that selection of a commercial off the shelf hardware/software configuration may be justified.

Several TTPP participants had a chance to acquaint themselves with OASIS. It was generally found that the OASIS "touch and feel" characteristics provide for a satisfactory balance between standardization and flexibility. The workstation latency of OASIS in its current implementation is still a little too long for use in high data rate Space Station era experiments, but faster workstations will be available by then. Users have also recommended that OASIS be enhanced with respect to its communication capabilities (communication between multiple remote experimenters, and communication with the experiment itself). OASIS proved to be adequate for the uplink of telecommands and handling of moderate data rates, but is still somewhat too slow for handling large amounts of incoming telemetry data. Finally, the development of new OASIS application databases could be made more user friendly by a TAE+ like front end for the purpose of interactive screen design.

Communication Needs

The following communication parameters are of importance to teleoperations:

- Bandwidth
- Connectivity
- Latency
- Phasing

Results from TTPP indicate that the tolerable maximum values for these four communication parameters are discipline- and application-specific. However, some common lessons were learned.

- Bandwidth: The overall required space-to-ground bandwidth will be larger than the overall required ground-to-space bandwidth. The realtime space-to-ground bandwidth requirements are more stringent in life sciences and microgravity sciences than in astrophysics and earth sciences. This is due to the fact that realtime data delivery is an absolute requirement for life sciences and microgravity sciences, but for astrophysics and earth sciences longer delays can be tolerated. Space-to-ground bandwidth requirements are largely dictated by the needs for video-feedback. Such needs were reported from all science disciplines. Full ground-to-space bandwidth is desirable, i.e., NASA should provide for capabilities of video transmission from the experimenter's ground laboratory to Space Station for remote coaching.

- Connectivity: Universal connectivity is desired. Connectivity actually covers a variety of different aspects:

  - Connectivity between several geographically separated experimenters -- there are needs for fast on-line communication between several ground-based centers.

  - Connectivity between the scientist on the ground and the astronaut -- there are needs for both video and audio communication during the conduct of an experiment.

  - Connectivity throughout the experiment -- reliable connections are mandatory for most remotely controlled experiments.

  - Connectivity for longer periods of time -- the 10 minutes zone of exclusion when Space Station is hidden from both TDRSS satellites poses a problem to researchers from most disciplines.

- Latency: Latency is a crucial parameter to teleoperations. A precise value for maximum tolerated latency is application specific. Microgravity and life sciences seem to place the most stringent requirements on latency. Some applications can live with a maximum guaranteed latency of 5 seconds, but some applications require a more immediate turn-around. Microgravity sciences expressed the requirement for 2 seconds latency.

- Phasing: Phasing is important for combined video/audio feedback. It is anticipated that the audio link and the video link might use separate paths between Space Station and the remote experimenter. In this process, a phase difference between the two signals may be introduced. Although this parameter was not studied extensively by any of the TTPP sites, preliminary investigations from RIACS seem to indicate that any phase difference of more than 2 seconds between audio and video signals leads to confusion.

Video Requirements

Recommendations from the TTPP investigations for video requirements include downlink and uplink video capabilities as well as certain video hardware placement.

- Downlink Video: Downlink video should be provided to the investigator's remote site. The downlink video will provide the investigator with the information necessary to monitor experiment progress and crew interaction which will increase the scientific productivity and efficiency. Full bandwidth capability should be available at the remote site when needed. Investigator selected frame rate, resolution, and gray scale enabling the PI to establish the "best" picture for his or her needs according to the current bandwidth allocation appears to be desirable but needs further investigation. This selectability is important because the PI's "best" picture may change during different experiment phases. The latency and phasing requirements for video need further investigation to determine the acceptable levels.

- Uplink Video: Uplink capabilities are needed from the remote investigator site to the instrument site. This capability provides the opportunity for remote instruction for problem-solving, crew training, and remote coaching. Since certain experiments will require interaction with crew members, and since certain experiment results may dictate a change in procedures, uplink video may be critical in re-training. The bandwidth, latency, and phasing requirements for uplink video have not been determined and should be investigated.

- Hardware: The video cameras/optical lenses needed to monitor an on-going experiment will be largely experiment specific. However, cameras will also be needed for crew interaction, for monitoring the experiment setup, and for monitoring laboratory animals. It is recommended that movable cameras be provided.

Operations Management

A common lesson learned is the fact that teleoperations is concerned with much more than getting a command across from one remote experimenter to one onboard instrument, and getting telemetry data back to the remote experimenter.

These additional complications have to do with the fact that in reality a multitude of remote experimenters will wish to simultaneously gain access to a variety of different instruments using common communication channels and common resources.

In the first phase of TTPP, not enough time was available to investigate all key aspects of teleoperations, aspects which require more and expanded testbeds before a final assessment can be made. Some of these aspects are listed below.

- Distributed Planning and Scheduling: The remote control (teleoperation) of equipment and experiments onboard a Space Station era mission must be properly planned and scheduled in concert with other on-going activities. Several experimenters may need access to shared instruments, one experimenter may need simultaneous access to several instruments, and several experiments may share a common resource such as electric power.

- Rescheduling: Resources may have to be quickly rescheduled in response to unexpected problems or opportunities.

- Operations Management: Future operations systems must include techniques for command interlock to prevent potentially dangerous operations from being executed, and reactive control to react to situations where an instrument or experiment is interfering with other operations by using more than its allocated share of resources.

- Access control: A technique should be demonstrated that grants authorized users access to their experiment resources while preventing unauthorized users from having such access.

Teleoperations Through the Project Lifecycle

Design for teleoperations should include not only provisions for remote control of instruments during experiment execution, but also for calibration and maintenance of instrumentation throughout its lifecycle of development, test, integration into the Space Station, and operations. These provisions need to be fully explored and demonstrated in future testbeds.

- Calibration: Remotely controlled experiments should in general also be checked out and calibrated using the teleoperations approach.
- Automatic Shutdown: If connectivity is lost during a test or during the execution of an experiment, each teleoperated experiment should provide a means for a safe and automatic transition to either a waiting state or a fully automated continuation. The implications of this need to be further testbedded. E.g., it may be necessary to request that this transition be handled in a decentralized mode by each instrument computer independently. If the connectivity through the TDRSS satellite is lost, all teleoperated experiments will have to go simultaneously and quickly through this operational phase, and the Space Station OMS may be unable to handle all these requests in a centralized manner.
- Remote Recovery: After connectivity has been reestablished, it should be possible to reactivate the experiment through teleoperation.

Increasing Science Productivity

One of the many positive lessons learned during the testbed was that teleoperations increased science productivity at all levels. In this section, we shall summarize how science productivity can and has already been improved through teleoperations. The specific parameters which contributed to increased productivity are discussed below.

- Distributed Resources and Resource Sharing: Teleoperations allows the PI to assemble the needed manpower and other resources without having to pay for travel and equipment shipment. Resources include everything from super computer time for data analysis to a telescope technician for remote troubleshooting. In some instances, gaining immediate access to a highly trained remote technician may be imperative to the success of the experiment as a whole.
- Enhanced Instrument and Data Accessibility: By means of teleoperations, both space instruments and scientific data can be made available to a larger body of scientists and science students. E.g., teleoperations has enabled the University of Colorado to redirect realtime data from astronomical observations into the classroom, and to design experiments interactively and on-line with student participation.
- Rapid Access to Flight Data: Near realtime data retrieval permitted by teleoperations has numerous advantages which lead to increased science productivity. With rapid access to data at the PI's laboratory, the investigator

can perform near realtime data analysis using the hardware and software to which he/she is accustomed, and which have been customized for that type of experiment. Not only does teleoperations with realtime data increase the PI's knowledge of the progress of the experiment, but allows more realistic experimentation. For instance, on-line data analysis might show a particularly interesting event which needs further investigation. The PI can see the event occurring, and can request a modification in the experiment procedure to take advantage of the unexpected event. Off-line experimentation allows verification of hypotheses. On-line experimentation allows exploration of the unknown.

- Direct PI/Crew Interaction: The duplex voice channel and simplex video channel between the PI and the crew contribute significantly to the increase in science productivity. Audio communication promotes joint discussions of experiment progress, coaching of the crew during troubleshooting, and experiment procedure redesign during the experiment execution. This capability is most important in effectively using the time allotted for each experiment, and in redefining the schedule when unexpected events occur. "Open-mike" monitoring of crew conversations, as discussed earlier, hellp support effective PI/crew interaction.

Our work in TTPP showed an increase in science productivity as a result of improved communication links which allow video, audio, and data to be transmitted freely between participating nodes to provide the most efficient use of the allotted experiment time and resources.

4.3 Integrated Results on Network Infrastructure

Integrated results and recommendations regarding network infrastructure were addressed in three distinct operational contexts, as shown below. For the first of these, only the terrestrial network is involved. For the second, the uplink, relays, and onboard SSIS are also involved. The third may involve only the terrestrial network or the entire system, depending on the application.

Telemanagement

Telemanagement includes planning, scheduling, design, distributed program management, and operations management.

It was unanimously agreed that this class of activity has been made much more productive by availability of network service. The results showed that such service would be significantly enhanced by ''return receipts'' to indicate delivery to the addressed host (not intermediate nodes) and by more timely advice of undeliverable status. Better information exchange between NSI/NSF/DOD network managers and users (introductions, primers, users guides, etc.) was also recommended.

While electronic mail and file transfer services were mainly satisfactory, multimedia network capabilities were found to be inadequate. For the most productive planning, scheduling, design, and teleconferencing, an integrated service which provides voice, graphics, video, and text is required.

Most participants experienced some degree of information overload. It was suggested that display of detailed routing information be made a user option, and that formal network usage guidelines be issued to help avoid junk mail and careless use of address exploders (automatic distribution lists).

Teleoperations

For those functions which involve time critical monitoring and control, the results indicated that the required services included audio, command/ control/telemetry, and video. The audio channels each require data rates of 64 Kilobits per second (Kb/s) for nominal pulse code modulation of a 4 KHz analog channel. For speech channels, this can be reduced to 16 Kb/s by using a linear predictive coding compression algorithm. It was demonstrated that 32-64 Kb/s was sufficient for the command/control/telemetry channels. Data compression is not recommended here for the sake of robustness. Arizona found that their video information for control of lifescience experiments could be transmitted at 50-400 Kb/s (depending on required quality and rates of motion) by using commercially available compression techniques developed for video teleconferencing. If video comprises scientific data, much higher rates may be required. RPI used 512x512x8 bits per frame at 30 frames per second (7.8 Mb/s) for their microgravity experiment. Future use of high-definition television (HDTV) would require even higher rates. It should be emphasized that these rates are per channel. The experiments in the pilot program each used 1 or 2 audio channels, 1 command/control/telemetry channel, and 1 to 5 video channels.

Several requirements for maximum time delay (latency) were identified. All of these are round trip delay times which include the terrestrial network, uplink, relays, SSIS, and all onboard processing delays (for example those incurred in the operations management system). The astronomy, life science, and microgravity science experiments all showed the need for less than 1 second (or best available) time delay for over-ride control, and 5 seconds maximum for normal operations (priority commands and status telemetry plus video feedback and starfield images of [64x64x16] bits).

These critical services must be extremely reliable, and the maximum time delays must be guaranteed at all times except for scheduled outages such as zone of exclusion transitions. Current public access networks cannot provide these features.

For noncritical monitoring and control functions the same kinds of channels and bit rates are required (perhaps fewer per experiment), but there are less stringent time delay and reliability requirements. An example of this would be a quick look at astronomy data of 1024x1024x8 bits within 30 to 60 seconds of request.

Teleanalysis

Much of the scientific data consists of images. In these experiments the image sizes ranged from 512x512x8 bits to 1024x1024x16 bits, and the generation rates ranged from 1 to 10**5 frames/day. All other kinds of scientific data from the testbed experiments fell within these bounds. In the near future data from astronomy experiments is likely to be as large as 4096x4096x24 bits (the same as color HDTV). This data must be transmitted to earth, distributed, and stored. The allowable time delays for return of scientific data were extremely experiment dependent and ranged from near real-time to days. The integrated range of data volume, generation rates, and allowable time delays is very broad. The equivalent performance and reliability requirements vary from public network grade of service to PIOC-SS grade.

Open Issues

Several issues remain unresolved.

- Which of the above needs require computer networks as they now exist, which require computer networks with priority scheduling (virtual circuits), and which require dedicated circuits?
- The time delay requirements are quite stringent. How will overall system performance be verified prior to deployment?
- What combination of on board storage, earth station storage, and verification is required for reliable return of scientific data?
- Terrestrial distribution of large databases, long term analysis, and teledesign will ultimately require high capacity world-wide multimedia services not currently available. Required data rates will range from near 0 to more than 10**9 bits per second. How will this be accomplished?

4.4 Programmatic Lessons, Results, and Recommendations

One of the major motivations for conducting the TTPP was to validate the rapid-prototyping testbed approach and learn how to conduct such a program. The TTPP and any subsequent rapid-prototyping testbed activity involves a large number of participating and interested organizations, ranging from technologists and users collaborating in the actual testbeds to the developers of the target system (e.g. Space Station and its associated information systems) and the NASA monitors, managers, and sponsors.

The TTPP intentionally involved all such parties so that experience could be gained in how to manage and conduct such a program. This section contains a summary of the results and lessons of this aspect of the program.

Contract Arrangement

The TTPP contractual arrangement was to have a prime contract with the USRA who in turn subcontracted with the various University participants. USRA provided technical and administrative management functions, coordinating and integrating the various activities. In addition, related activities at several NASA centers were funded directly through normal NASA funding channels.

In general, this arrangement worked well. There was some delay at the beginning in establishing both the main contract and the individual subcontracts. Much of this delay could be attributed to the learning process and approval process on the part of both USRA and NASA procurement personnel. However, there were significant benefits to having the funding flow through a single non-government organization. It allowed for more coordination of the activities than would have been likely had the funding been dispersed in a more distributed fashion. Furthermore, USRA was able to act as an agent on the part of the universities to obtain the many NASA approvals for items like equipment procurement. It was the consensus of most of the participants in the TTPP that a centralized contractual arrangement such as that used in the TTPP would be desirable for any continuation of rapid-prototyping testbedding activity.

Deliverables vs. Guidelines

The TTPP has resulted in many reports, ranging from technical reports from the various university activities through to the monthly, quarterly, interim and final reports from the program as a whole. However, such reports are only part of the needed deliverables from such a program. There needs to be provision for technology and knowledge transfer from the testbedding activities into the target system development. Much of this happened, but as an ad-hoc process rather than through a programmatic approach. In addition, the issues pursued in this initial phase of the program were not selected in advance, but rather were a consequence of the proposed activities.

Thus, any follow-on program would be significantly enhanced through the identification of the critical issues prior to selection of the individual testbedding activities. The results of the TTPP documented elsewhere in this report can be used as input to that selection process. By selecting the issues to be attacked at the beginning and basing that selection in part on the needs and issues of the target system, the knowledge and technology transfer process can be incorporated into the program as an integrated element.

Use of the results of the program would also be enhanced by having a separate activity actively working on the integration of requirements, definition of architecture, and coordination with the system developers. While there have been many results developed as part of the TTPP, it was not clear what the programmatic and institutional process was to transfer those results into requirements and system development. A systems engineering activity coordinating the testbedding activity with systems development, requirements definition, and related activities would have been most helpful as the program proceeded. This would have allowed the necessary multi-disciplinary and multi-organizational activities to be pulled together into a team attacking these critical questions.

Lessons Learned vs. Recommendations

The TTPP, as any set of testbedding activities, only attacked a subset of the issues and questions. It was targeted at those issues best addressed via a testbedding approach. Other activities, such as the systems engineering activity above along with a variety of analytical and simulation studies, are also required to pull together a set of reasonable and coherent recommendations and requirements for the information system of the Space Station era.

Thus, a rapid-prototyping testbed activity should only be asked and expected to document what it did and what lessons were learned in that process. It should not be expected to pull together a set of requirements nor an overall system architecture. The integration of the testbed results together with the other aspects would logically be done through a systems engineering activity working in close cooperation with a multi-disciplinary working group representing the testbedding activities, simulation and studies, and systems development. The testbed activity can be expected to validate and explore aspects of such an architecture. The identification of the critical issues to be investigated via testbedding is again an important aspect of any overall information systems activity.

Scheduling vs. Funding Availability

There was a much larger delay in putting in place the overall TTPP contract and the various subcontracts than was expected. It took approximately one year from the time that USRA submitted the proposal to the time that the last of the university subcontracts were approved. This in fact is not a particularly large delay for government procurements but was larger than anticipated.

The major impact of this delay was to create uncertainty and changes in the scheduling of the various testbed activities. All of the university testbeds were based on ongoing scientific research, and it was expected that the TTPP activity would mesh with those activities according to a schedule beginning roughly January 1987. In fact, many of the universities did not receive funds until the fall of 1987, resulting in significant changes to the schedule of activity. Had this schedule been known at the beginning of the program, it could have easily been accommodated.

Thus, the lesson learned is that, even though a rapid-prototyping testbed activity needs to maintain flexibility, the need to build on existing and ongoing activities demands a schedule that is known in advance.

Equipment Procurement

One of the major difficulties encountered during the program was the rationalization of the nature of rapid-prototyping against the NASA equipment procurement procedures. This resulted in a compounding of the delays already encountered in dealing with several equipment manufacturers. This problem was especially noticeable in the area of workstation procurements.

Rapid-prototyping requires the ability to rapidly test out new technologies and approaches, and often requires obtaining new equipment quickly. The current NASA equipment procurement procedures require considerable specificity in the equipment descriptions needing approval. This, coupled with the rapid changes in technology, often meant that by the time the equipment procurement was approved, there was a new (or sometimes two new) generation of technology. In addition, because the universities often could not risk placing orders prior to receiving approval, the delays became additive. A procurement mechanism more suitable to a rapid-prototyping approach is needed to allow rapid identification and acquisition of new technologies for evaluation purposes.

Facilities Installed

In addition to equipment required to support the testbedding activities, many of the testbeds needed other facilities. For example, many of the universities carried out experiments requiring use of a shared packet switched network (i.e. the NASA Science Internet). Others needed access to video links and planned to use NASA provided circuits. The scheduling and installation of such facilities turned out to cause major delays in a number of the testbeds. Again, like in the case of equipment, there is a need for a procedure for scheduling installation and use of facilities in a manner compatible with a rapid-prototyping testbed. This means being able to identify the need for such facilities and arrange for its installation and/or scheduling with minimal delay, in contrast to the typical multi-year cycle of requirements definition and planning that typifies major facilities, such as PSCN, NASCOM, and aircraft.

Agency Commitment and Support

Part of the solution to both the equipment and facilities issues raised above lies in an agency commitment and support of telescience and a rapid- prototyping testbed approach. With such a commitment at the highest levels, it would be possible to work with both procurement and facilities organizations to arrange (on a high priority flexible basis) for the rapid procurement of equipment and the flexible scheduling of facilities.

One possible approach to this issue would be to have a multi-organizational review of the engineering plan for each testbed activity at proposal time. Such a review would involve all organizations expected to provide facilities in support of the proposed experiment. If the experiment were approved by the review body, it would carry with it the approval of and commitment of support to the testbed by each of the participating organizations.

Aspirations for Field Campaigns

A number of the testbeds, particularly those in the earth sciences area, applied advanced technologies and methods to campaign experiments involving multiple organizations and sensors. Such activities require considerable coordination, planning, and scheduling. The delays in funding along with delays in installation of needed facilities resulted in the campaign experiments not being carried out totally successfully.

Management of any future campaign-style testbed experiments needs to pay close attention to the management of expectations. Funding needs to be put in place before the field campaigns are planned, and careful planning needs to be carried out of exactly who is involved, their specific activities, and the coordinated schedule. Attention must be paid to the fact that the larger the activity and number of participating organizations involved, the more difficult such planning and scheduling will become. Therefore, there is a trade-off between the desire to carry out campaign experiments representative of the large scale activities anticipated in the space station era and the need to have small, manageable experiments for a rapid- prototyping approach.

Flexibility in Context of Project Structure

A rapid-prototyping testbed inherently requires flexibility. As the testbed learns the positives and negatives of particular technical and procedural approaches, it needs to be able to modify its approach, equipment, and procedures. Nevertheless, the overall testbedding program needs to identify the critical issues to be addressed, each testbed needs to be specific about what it will be contributing to the project goals, and each testbed has to work with the particular science activity to assure that the science goals are achieved. This means that a balance must be maintained at all times between the needed flexibility, the overall project structure, and the objectives of the cooperating science activities.

Prototyping Time Scale

All of the university testbeds in the TTPP were based on the principle of augmentation of existing scientific research activities. In some cases, this meant that the small modifications to incorporate new technologies and approaches yielded large gains in understanding and productivity. These often yielded payoff in rapid time.

However, in some cases, the incorporation of advanced technologies required more lead time, as new facilities (e.g. PSCN circuits) or new equipment (e.g. workstations) were installed or procured. In these cases, while there was tremendous productivity increases made possible through the use of the new technology, and the scientific program would not have been able to explore the new approaches without the TTPP activity, delays were incurred as the new facilities were installed or procured.

The lesson learned from this is that it takes time to install the needed machinery to carry out a rapid-prototyping activity. ''Rapid'' requires being able to leverage off of existing facilities and equipment. Thus, one of the major contributions of the TTPP has been one of investment; installing the required facilities and equipment to allow rapid-prototyping of new techniques to take place more rapidly in the future. Any future activity must pay close attention to maintaining an infrastructure to carry out rapid- prototyping. This includes people and coordination mechanisms as well as equipment and facilities.

University Staff Commitment

The TTPP activity was a one year program. Normal university practices in hiring, funding, and research demands that research programs be long-term activities (a minimum of three years). Such a commitment is required to permit the training, use, and commitment of graduate students and staff as well as faculty researchers. In fact, the understanding of the participants in the TTPP was that the TTPP was to be the initial phase of a multi-year program with the initial year focussed on validation of the approach and subsequent funding dependent only on the success of the first year. Without that understanding, it is not clear whether the universities would have been able to participate.

Coordination, Integration, and Information Flow

The TTPP involved a large number of organizations and people, including universities, NASA Centers, NASA HQ, and various industrial contractors and cutting across scientific research, technology, space station, and other activities including networking and communications. Validating and exploring the approaches for conducting such a program was one of the major objectives of the TTPP.

A number of lessons were learned concerning the coordination and information flow in such a dispersed and flexible program. These are best described by noting that there was a need to promote information flow between:

- the universities themselves,
- the universities and USRA/RIACS,
- the TTPP and NASA HQ, and
- the TTPP and other interested parties (e.g. space station contractors).

A variety of mechanisms were used to support this information flow, including:

- electronic mail,
- working groups with associated electronic mailing lists,
- monthly and quarterly reports with electronic distribution,
- program meetings, and
- briefings.

Electronic mail was used extensively throughout the program starting with the development of the proposal and continuing to the preparation of this final report and beyond. It was used for a multitude of purposes, including:

- bilateral communications (e.g. specific exchanges between universities, between universities and others such as program management, and to answer queries from interested parties)
- group activities (e.g. preparation of group reports and coordination of campaign experiments), and
- dissemination of information (e.g. distribution of monthly reports and requests for programmatic inputs from RIACS to the universities)

Electronic mail was absolutely essential to the conduct of the program. It would have been virtually impossible to have carried out the program as a coordinated and integrated activity without it. Even so, there were several problems encountered. One complaint voiced by a number of participants was the length of mail "header" information. Upon investigation, this turned out to be more due to the forwarding of mail between different mail systems (mostly between NASAmail and Internet mail). Because of the nature of the typical NASAmail interface, this was particularly onerous on the NASAmail users. Internet mail users typically read their mail on an advanced workstation and therefore have more flexibility and power to deal with long messages.

One issue that surfaced was the large amount of electronic mail and the need to establish guidelines on its use. This was noticed in two ways. First, many messages were sent to larger groups than necessary. For example, a reply to a query sent to a group might be sent to the whole group when it was only necessary to send it to the original source of the query. Second, a need was identified for handling the large amounts of mail, sorting it, prioritizing it, and associating it with other messages of similar subject matter.

The large amount of mail also taxed the local mail systems at times. Towards the end of the program, an attempt was made to use bulletin board and public file transfer capabilities more. Long reports and messages were put on the bulletin board or publicly accessible file system, and only a notice of the availability of the report was sent via electronic mail. This appears to have some promise. However, an investigation will be needed as to whether affiliated people for whom the reports were peripheral to their major activities would be less likely to read the reports if they had to take the additional step of retrieving it rather than having it as a part of their main electronic mail stream.

Another problem encountered was related to the maintenance of the many electronic mailing lists. Lists were maintained for each of the participating scientific disciplines as well as general programmatic purposes. For example, a list was maintained (called TTPP-NEWS) for the purpose of dissemination of program information (such as the monthly reports) to all interested parties. By the conclusion of the program, this list had about 400 people on it. Maintaining this list with accurate addresses was a non-trivial issue and required a fair amount of time by the administrative support personnel at RIACS. Nevertheless, feedback from those receiving the reports (particularly those not involved in TTPP per se such as Space Station government personnel) was positive and attested to the value of keeping them informed as to the progress and results in the program on an ongoing basis. Any future activity should make sure that appropriate facilities are provided to maintain such mailing lists. (RIACS used a relatively standard database program to accomplish this and it was satisfactory.)

In order to assure that the program would generate useful results, it was organized according to scientific discipline, with groups associated with earth systems sciences, astronomy and astrophysics, life sciences, and microgravity sciences. Each group had a leader that was responsible for working with the participants in that discipline to coordinate and integrate their activities and results. This approach worked relatively well. It allowed for focus on specific issues of concern to each discipline in a flexible manner. It is critical that these working groups be well coordinated with the NASA management structure inside OSSA.

To make sure the results of the TTPP were well documented and disseminated, monthly and quarterly reports were generated in addition to the normal technical reports of the individual activities. The monthly reports were intended to be informal brief reports to keep everyone informed of each others activities, thereby helping to coordinate the program. Unfortunately, the well known phenomenon that it is easier to write a long report than a short one took hold. The monthly reports became fairly detailed and lengthy, despite the original guidance of requesting that the inputs be just a few paragraphs for each university, focussing on just highlights. A similar difficulty occurred with the quarterly reports, which were intended to simply be status reports.

This had a beneficial side, though. While the TTPP subcontractors felt that the number and length of reports was excessive, the other participants and recipients of the reports indicated that they found both the monthly and quarterly reports quite helpful in tracking the progress of the program and staying abreast of developments.

On the whole, it was the consensus of the group that NASA's purposes would have been better served through shorter reports, but the monthly reports were helpful and useful. The USRA Program Manager, in retrospect, should have emphasized summaries in the monthly and quarterly reports with appropriate pointers to the detailed reports. The summaries could have been generated by the USRA Program Manager or he/she could have provided stronger guidance and direction to the preparation of the report sections by the subcontractors (or both).

Finally, several meetings were held throughout the life of the program, beginning with the initial proposal formulation and continuing through the writing of the final report. These meetings were all deemed as extremely useful and productive, whether they were working meetings or presentation and demonstration oriented. The latter were particularly useful in supporting information transfer to those outside the immediate TTPP participants. Attended by personnel from NASA HQ, space station at all levels, and a number of space station contractors, the larger meetings (attended by approximately 100 people) provided an opportunity to share information and exchange views on a variety of subjects. It is critical that such meetings continue to provide a forum for exchange between the various science, research, and development communities.

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Appendix A
Program Participants

University Subcontractors

Cornell University

Terry Herter (PI)

Justin Schoenwald

Massachusetts Institute of Technology (MIT)

Charles M. Oman (PI)
Laurence R. Young (PI)
Byron K. Lichtenberg (PI - Payload Systems, Inc.)
James Elliott (PI)
Hale Bradt (PI)

Anthony P. Arrott (Payload Systems, Inc.)
Paul Boutin
Ben Davis
Feroza A. Deen
Mathew George
Barbara J. Glas
Matt E. Hodges
Braden J. McGrath
Sherwood A. Modestino
Vinit Nijhawan (Payload Systems, Inc.)
Robert L. Renshaw
Ilya Shubentsov
Jacqueline A. Stewart

Purdue University

Richard H. Collier (PI)

Gary M. Bass
Larry L. Biehl
David W. Brown
Rick S. Gifford
Chris J. Johannsen
David A. Landgrebe
Victor M. Mendoza-Grado
Lorraine K. Van Meter
Mahesh Veerina
Phil J. Wyss

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Rensselaer Polytechnic Institute (RPI)

Richard C. Hahn (PI)

R. H. Doremus
Martin E. Glicksman
Bruce Herbach
Heribert Wiedemeier

Smithsonian Astrophysical Observatory (SAO)

David Koch (PI)

Steve Criswell
Giovanni Fazio
John Geary
Kirk Gilmore
Charles Maxon
Steve Willner
Bill Wyatt

Stanford University

Peter M. Banks (PI)

Rock Bush
Mike J. Wiskerchen

University of Arizona (Astronomy)

Erick T. Young (PI)
George H. Rieke

University of Arizona (Engineering & Mines)

Larry C. Schooley (PI)

Richard Bienz
Francois Cellier
Reza Fardid
Byron Hack
Jerry Hunter
Alfie Lew
YaDung Pan
Ephraim Raize
Don Schultz
Wendy Walker

University of California, Berkeley (UCB)

Supriya Chakrabarti (PI)

Carl Dobson
Walter Herrick
J. Garrett Jernigan
George Kaplan
Michael L. Lampton
Roger Malina
Will Marchant
Herman Marshall
Jerry Penegor
Dan Quinlan

University of California, Santa Barbara (UCSB)

John E. Estes (PI)
Jeff Star (PI)

Mark Friedl
Kenneth McGwire
David Stoms

University of Colorado

Elaine R. Hansen (PI)

John R. Cowley
Randal Davis
Phil Evans
Jack A. Faber
Chris Grasso
Eric Hillis
Alain J. Jouchoux
David Judd
Pieter Kallemeyn
Margi Klemp
Fred Lacy
George Ludwig
Jane Pavlich
Pat Sirr
Gail Tate
John Wisneski
Kwok Wong

University of Maryland

Michael F. A'Hearn (PI)

Roger A. Bell
Jason Meyer
David M. Zipoy

University of Michigan

Richard A. Volz (PI)

George Carignan
Lynn Conway
Mike Walker

University of Rhode Island

James G. Kowalski (PI)
Peter C. Cornillon

University of Wisconsin

Verner E. Suomi (PI)

Ralph Dedecker
William L. Smith

USRA Program Management

USRA Headquarters

David Holdridge

Deborah Cook
Beverly Johnson

Research Institute for Advanced Computer Science (RIACS)

Barry M. Leiner

Robert L. Brown
Dee Doyle
Lorraine L. Fisher
Maria L. Gallagher
Michael A. Slocum

Affiliated Organizations

NASA/Ames Research Center (ARC)

Vicki L. Johnson (RIACS)
Richard F. Haines (RIACS)
Frank King
Daryl Rasmussen
John Stauffer (SIRTF Project Office)

NASA/Johnson Space Center (JSC)

Floyd Bednarz

NASA/Kennedy Space Center (KSC)

Ken Anthony (Lockheed)
Richard J. Brown
Carol Carlson (EG&G)
Luis Delgado
Richard L. Fiser
Matthew S. Galloway
Douglas J. Gruendel
Robert Marzig (Grumman)
William R. Munsey
Marc G. Timm
David A. Tipton
Deborah S. Vordermark (Bionetics)

NASA/Lewis Research Center (LeRC)

M. J. Bonner
J. C. Johnston
Thomas Glasgow

California Institute of Technology (Cal Tech)

T. N. Gautier, III

University of Rochester

William J. Forrest

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Appendix B
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.

Rasmussen, Daryl, Arshad Midan, and John Bosley, "Telescience Testbedding for Life Science Mission on the Space Station," *AIAA Aerospace Science Meeting*, Reno, NV, January 1988.

Rasmussen, Daryl, Vicki Johnson, and Arshad Mian, "Telescience Concept for Habitat Monitoring and Control," *18th Intersociety Conference on Environmental Systems*, San Francisco, CA, July 1988.

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.

Schooley, Larry C., and Francois E. Cellier, Don G. Schultz, *Teleoperation of a Fluid Handling Laboratory*, Technical Report TSL-023/89 (videotape), Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, January 1989.

Schultz, Don G. and R. Fardid, *An Automated Remote Fluid Handling System*, Technical Report TSL-015/88 (videotape), Systems and Industrial Engineering Department, University of Arizona, Tucson, AZ, July 1988

Secord, Terry, *Life Sciences Facility Control and Telescience Systems*, Technical Report MDCH3658, McDonnell Douglas, Huntington Beach, CA, July 1988.

Starks, Scott, David Elizandro, Barry M. Leiner, and Michael Wiskerchen, "Computer Networks for Remote Laboratories in Physics and Engineering," 1988 Annual Conference of the American Society for Engineering Education, June 1988, (also available as RIACS TR 88.13, 7 pp., April 1988).

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.

Tody, D., "The IRAF Data Reduction and Analysis System," National Optical Astronomical Observatories, Tucson, AZ, 1986.

Walker, M. T., S-Y Sheu, R. Volz, and L. Conway, "A Low Cost Portable Tele-Autonomous Maintenance Station," *SOAR 88: A Workshop on Space Applications of Artificial Intelligence, Human Factors and Robotics*, Wright State University, Dayton, OH, July 20-23, 1988.

Walker, W. T., *Video Data Compression for Telescience*, Technical Report TSL-017/88, Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ, September 1988.

White, O.R. and G.J. Rottman, *SME as a Testbed for Telescience - A Case Study*, LASP Report 89-2, University of Colorado, Boulder, CO, February 1989.

Wiskerchen, Michael J. and Barry M. Leiner, "Telescience Testbed Pilot Project: Evaluation Environment for Space Station Operations," AIAA'88, AIAA Flight Simulation Tech., Atlanta, GA, September 1988

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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Appendix C
Statement of Work

Attachment J-1

Telescience Testbed Pilot Program
Procurement Request 10-39111

SECTION C - Statement of Work

1. Background

NASA's Office of Space Science and Applications (OSSA) recognizes the need for scientists to be able to conduct experiments in conjunction with the Space Station Program and perform correlative data analysis from their home institutions -- the telescience concept. In order to explore the needed application of modern Information System technology to enable telescience, the OSSA is creating a pilot Telescience Testbed Program. This first phase of this Program will identify the prerequisite high-level requirements for the design of the OSSA and Space Station Information and Instrument Control Systems, assure that telescience capabilities can be built into the initial design of Space Station Information and Instrument Control Systems, and establish a continuing review mechanism for the design and implementation of the capabilities needed to accommodate the needs of Telescience in a manner consistent with the desires of the OSSA user community.

2. Scope

This contract represents the first phase of the Telescience Testbed Program. The Contractor will subcontract to, manage and integrate 6-10 teams to perform testbed experiments, provide technical support, and issue a final report and program plan for a continuing telescience development program. The first phase will establish proof of concept and a specific set of system prerequisites to be integrated into Space Station design and the design of future OSSA Information Systems.

3. Description of Effort

The Contractor shall support the Science and Applications Information System (SAIS) Program Manager and Program Scientist in overseeing and integrating the overall interdisciplinary telescience testbed pilot program. The Contractor shall issue subcontracts to 6-10 teams derived from institutions such as those represented on the Task Force on the Scientific Use of Space Station (TFSUSS). These teams will develop and test system concepts, using existing equipment and prototypes to investigate real science problems. The Contractor shall closely coordinate the work of the teams, share information among them, provide expertise in state-of-the-art technologies relevant to the work, coordinate the teams' work with other NASA offices and field centers, and write a Program Plan for the continuation of the telescience development program in the final report.

In performance of this contract, the Contractor shall report to the SAIS Program Manager and Program Scientist and work in close cooperation with the OSSA discipline divisions, the Office of Space Station (OSS) and all the Universities and NASA centers active and interested in the telescience testbed program.

a. The contractor will receive from NASA at the time of award, a candidate list of testbed experiments and selection criteria which is consistent with the objectives of the Telescience Testbed Program. The contractor will utilize this information as a core in soliciting additional testbed experiment ideas from the scientific community, as well as in developing an approach which will ensure optimum participation in the Program and accomplishment of its objectives. Parallel to this effort, the Contractor shall form, with the approval of the SAIS Program Manager and Program Scientist, a Telescience Testbed Working Group, consisting of representatives from Universities and NASA organizations, to participate in the evaluation of proposals and the coordination of the resulting individual experiments and the overall activity.

b. The contractor will be responsible for advocating this Program and communicating this opportunity to the scientific community, soliciting proposals, and evaluating potential testbeds consistent with the selection criteria and Program objectives. In communicating the opportunity to submit proposals for subcontracts, the contractor will provide information concerning candidate testbed experiments, and solicit additional testbeds as part of such proposals. The contractor shall submit recommendations for award of subcontracts to the SAIS Program Manager and Program Scientist, who will approve the testbed teams. These telescience testbed teams will be selected from institutions such as those represented on the TFSUSS, and shall represent a cross-section of the NASA space science disciplines. The testbed experiments shall be performed in an environment that will enable scientists to develop and evaluate new multi-media telecommunications and information system technologies as they relate to actual scientific research functional requirements. The contractor will develop a management plan for the conduct of these testbeds and submit it to the SAIS Program Manager and Program Scientist for approval prior to awarding subcontracts.

c. The Contractor shall award and administer, according to the submitted management plan, subcontracts to the University teams who will carry out the collaborative testbed experiments.

d. The Contractor shall establish needed contact between testbed teams and experts in state-of-the-art computer science, telecommunications, networking, automation, robotics, and other relevant technologies, so that testbed teams can work with these experts in the design, conduct and evaluation of the experiments. The Contractor shall ensure that the teams develop meaningful experience working with network communications between heterogeneous computers, supercomputers, databases and scientific workstations emphasizing distributed scientific user access.

e. The Contractor shall assist in developing meaningful working relations between the Working Group and the Space Station Information System design teams to exchange information, examine problems, evaluate options, set priorities, and review progress towards the capabilities desired by the OSSA community.

f. The Contractor shall provide assistance to the testbed teams in the installation and use of state-of-the-art computing and telecommunications technologies.

g. The Contractor shall ensure that all important system developments within any of the testbed teams is shared with the other teams.

h. The Contractor shall collect, assess, and synthesize final results of the various testbed experiments in order to make final recommendations to NASA on how Space Station can accommodate telescience. Based on the testbed results, dealings with Space Station hardware development teams, and interaction with related equipment and systems developers, the Contractor's final report shall provide recommendations to the OSSA on the conduct and structure for the continuation of the testbed development program.

i. The Contractor shall deliver the following items to the SAIS Program Manager and Program Scientist:

Item	Description	Schedule
(1)	Management Plan for conducting the Testbed Program	Prior to award of subcontracts, no later than 30 days after award of this contract.
(2)	Status reports on technical achievements of the testbed and problems encountered related to on-going activities.	Quarterly
(3)	Working Group meeting documentation with minutes and action items.	2-3 month intervals
(4)	Interim Testbed recommendations for follow on NASA activities and directions for on-going program.	6 months
(5)	Recommendations on organizational and technical interfaces with Space Station Program activities to be pursued in the follow-on program.	9 months
(6)	Draft final report which will include a summary of Program accomplishments and recommended follow-on activities along with the justification for each.	11 months
(7)	Final report and Follow-on Program Plan.	12 months

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Appendix D
Subcontracts Acquisition Plan

The following is the plan for selecting the University participants in the USRA Telescience Testbed Pilot Program, being funded by OSSA.

Announcement of Opportunity

An Announcement of Opportunity (AO) is attached (see Attachment 1) stating the objectives and nature of the program and how to submit proposals. This AO calls for short proposals describing the nature of the proposed experiments and answers to a number of specific questions, such as the issues to be resolved and the telecommunication requirements, as well as experience and background. The AO will be released at the earlier of 6 May 1987 or approval by NASA. The AO will be distributed to the eleven universities mentioned in the USRA proposal along with certain other selected organizations which have demonstrated through prior conversations and efforts their background, experience, and preparation to carry out an initial productive effort. These universities (both the original eleven and any additional organizations) have been selected by USRA because of their experience and expertise appropriate to the telescience investigations. This selection (and the selection of USRA as prime contractor) was made based on USRA's experience and familiarity with the university space science community. Attachment 2 lists the proposed initial distribution list.

Proposals are to be submitted to USRA by 27 May 1987. To facilitate review, advanced copies submitted electronically will be encouraged.

Proposal Review Group

A Proposal Review Group (PRG) is established to conduct peer review of the proposals. The PRG is intended to advise USRA in the selection of proposals to be funded, and is chaired by the USRA Program Manager. Members of the PRG are nominated by USRA and approved by NASA. Approval/disapproval shall take place within five days of submission. No response after seven days shall be taken to signify approval of the proposed PRG membership.

Members of the PRG are selected to represent technological and discipline expertise. The NASA Program Manager and Program Scientist will sit on the PRG to facilitate discussion and understanding. The proposed members of the PRG are listed in Attachment 3.

USRA Proposal Selection

A meeting of the PRG will be held approximately 1 June 1987 to review the proposals received. Based on that review, the USRA Program Manager will select a set of proposals to be funded, subject to approval by NASA. This list, with the proposals, will be forwarded to NASA for approval, NLT five days after the PRG review.

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NASA Approval

Approval by NASA will be required before award of any subcontract. This approval shall take place within five days after receipt of the list of selected proposals from USRA. No response within ten days shall be taken to signify approval of the list.

Subcontract Award

Simultaneously with submitting the list of selected proposals to NASA for approval, USRA will begin the negotiation process with the selected Universities. Once approval by NASA has been received by USRA, the subcontracts will be awarded as rapidly as possible. It is anticipated that this negotiation process will be completed within two weeks after approval.

Attachment 1

RIACS TR 89.8

C-2

...uary 1989

Announcement of Opportunity

Background

Space Station and its associated instruments and laboratories, coupled with the availability of new computing and information system capabilities, have the potential of significantly enhancing scientific research. To assure that this potential is met, scientists and managers associated with the Space Station project must gain significant experience with the use of these technologies for scientific research, and this experience must be fed into the development process for the Space Station Program.

In its March 1986 Summer Study Report, the Task Force for Scientific Uses of the Space Station (TFSUSS) recommended that NASA initiate a program where university researchers would conduct rapid prototyping testbeds employing new telescience technologies and ideas. From this program would emerge additional and modified functional requirements for the Space Station Information System (SSIS). These testbeds would be specific research experiments within the scientific discipline areas that will use the Space Station complex. The experiments would be carried out in a coordinated manner to allow the critical questions to be answered by groups of scientists working with technologists in a rapid prototyping testbed environment.

The rapid prototyping testbeds are not like other more typical testbeds. Rather than being used to evaluate and integrate systems on the way to deployment, the telescience testbeds constitute a Technology Evaluation Environment (TEE), allowing users to interact with advanced technologies in the conduct of scientific research in order to develop the required base of experience to permit development and evaluation of requirements and specifications.

Program Description

The Telescience Testbed Pilot Program, being performed by the Universities Space Research Association under contract to the Office of Space Science and Applications (OSSA), is the first step towards establishment of a TEE. It is intended to establish a university based group of SSIS users which will conduct several scientific experiments using advanced information processing and communications technologies. The results will then be evaluated to determine the technological and operational feasibility of requirements and their relative priorities in support of telescience. 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. The latter will result in a scientific community able to intelligently contribute to NASA's review of SSIS requirements and proposed design prior to development of Space Station hardware.

To assure that the critical questions and issues are being addressed in the Pilot Program, a Telescience Testbed Working Group (TTWG) will be formed. The TTWG will consist of representatives of the various participating universities as well as certain other selected organizations developing relevant technologies. The TTWG will meet roughly three times during the program to review and coordinate the testbed activities. The TTWG will also assist in the planning for the follow-on NASA program.

USRA has been funded to coordinate and manage this pilot program. Subcontracts will be issued to several universities to carry out experiments in different aspects of telescience. These subcontracts will be based on proposals received in response to this Announcement of Opportunity. Proposals will be selected by USRA and NASA based on recommendations by an independent Proposal Review Group. Funding availability and the quality of the received proposals will determine the exact number and funding level of the approved proposals. At this time, it is anticipated that roughly 10-15 proposals will be funded at levels between $50K (for initial activities) and $250K (for significant augmentations of ongoing relevant research.)

Submission of Proposals

Ten copies of proposals, not to exceed ten pages in length describing the technical program, should be sent to the USRA Program Manager (listed below). Proposals should be submitted by 27 May 1987. To facilitate the proposal review process, submission of advanced copies of the proposal by electronic mail to the USRA Program Manager is encouraged. The proposals should contain the following items:

- A description of the experiments to be performed. The technologies to be used and evaluated in performing the experiments.
- A discussion of the questions and issues to be resolved through the conduct of the experiment.
- A discussion of the importance of doing the work being proposed.
- A discussion of ongoing relevant efforts.
- A description of the current computer networking technology available and the required enhancements.
- A discussion of the other organizations (NASA, university, or other) participating or collaborating in the experiment.
- A proposed budget, which should address funding for the proposed research itself, the required computing and communications infrastructure, travel for attending meetings of the TTWG (anticipated to be on the West Coast), and any necessary travel for the proposed research activity. Any cost-sharing or required Government Furnished Equipment (GFE) shall be clearly identified.

The following are the tentative evaluation criteria to be used in evaluating the proposals:

Consistency of Objectives

Alignment of the objectives of the proposed testbed with the general objectives of the overall Science Applications Information System (SAIS) program.

Adherence to Concept

Adherence to the testbed concept of rapid prototyping for the determination of telescience applicability.

Increased Operability

Degree to which the testbed can contribute to an improved mode of user operations and scientific productivity making non-relevant technical issues transparent and with an improved user interface which allows the Scientist to concentrate on strictly scientific issues.

Increased E iciency

Degree to which the testbed contributes to an improvement in a more efficient use of human and system resources. Increased efficiency in the use of system capabilities can lower overall ops costs and increase the overall system productivity

Expanded Capability

Degree to which the testbed can contribute to increased functionality of the end-to-end information system. New scientific and technological capabilities can contribute to the support of new or improved scientific methods. These in turn can improve the quality of the science process and improve system productivity.

Demonstrate Technical Effectiveness

Degree to which the testbed can demonstrate and assess the applicability and effectiveness of the proposed technical approach.

Effective Usage of Resources

Degree to which the testbed makes effective use of available and potential resources or integrates commercially available resources in a cost effective manner.

Ability to Promote Usage of Results

Degree to which the testbed proposal can promote the use of the testbed results in the development of, or transition to, the operational system.

Relationship to On-going Programs

Degree to which the testbed relates to the on-going program and its participants. A coherent testbed program will improve the effectiveness of the resources employed and promote the exchange of information among projects.

Cost Effectiveness and Financial Expediency

Testbed projects must be cost effective and financially expedient commensurate with their proposed benefits.

Potential for Future Cost Savings

Potential for future cost savings resulting from more efficient use of technical and human resources.

Uniform Applicability

The ability of the resultant application to address multi-disciplinary concerns or to have a high potential for universal applicability. Ability to increase interactions among scientific disciplines.

Potential for Increased Responsiveness to User Needs

Ability of testbed result to increase the overall functionality of the operational system in meeting user needs and perceived requirements.

Ability of Proposer to Accomplish Work

Ability of institution and institutional resources to accomplish what has been proposed and also their ability to build on what they start.

Further Information

For more information on the technical aspects of the program, contact the USRA Program Manager:

Dr. Barry M. Leiner
Senior Research Scientist
Research Institute for Advanced Computer Science
NASA Ames, MS 230-5
Moffett Field, CA 94035

(415) 694-6362
Arpanet: Leiner@RIACS.EDU
Telemail: BLeiner

For information concerning administrative aspects, contact:

Mr. David Holdridge
Universities Space Research Association
Suite 201 W
600 Maryland Avenue, SW
Washington, DC 20024

(202) 479-2609
Arpanet: DHoldridge%telemail@Ames.ARPA
Telemail: DHoldridge

Attachment 2

AO Distribution List

Massachusetts Institute of Technology

Purdue University

Rensselaer Polytechnic Institute

Smithsonian Institution Astrophysical Observatory

Stanford University

University of Arizona

University of California, Berkeley

University of California, Santa Barbara

University of Colorado

University of Maryland

University of Michigan

University of Rhode Island

University of Wisconsin

Attachment 3

Proposed PRG Membership

Richard desJardins	CTA
Ralph Kahn	University of Washington
Barry Leiner (chairman)	RIACS
Daryl Rasmussen	NASA ARC
Erwin Schmerling	NASA HQ
Peter Shames	STScI
Jim Weiss	NASA HQ
Denny Xenofos	NASA MSFC

Appendix E
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

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

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RIACS
Mail Stop 230-5
NASA Ames Research Center
Moffett Field, CA 94035
(415) 694-6363

The Research Institute for Advanced Computer Science
is an Institute of the
Universities Space Research Association
The American City Building
Suite 212
Columbia, MD 21044
(301) 730-2656