Telescience Testbed Pilot Program Interim Report

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1. Introduction and Summary

The Universities Space Research Association (USRA), under sponsorship from the NASA Office of Space Science and Applications, is conducting a Telescience Testbed Pilot Program. The purpose of this pilot program is to:

- Validate the user-oriented rapid-prototyping testbed approach as a means for addressing the critical issues in design and specification for the Space Station Information System (SSIS) and the Science and Applications Information System (SAIS) so as to assure 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 are conducting various scientific experiments using advanced technology under subcontract to USRA.

This report represents an interim set of recommendations based on the experiences of the first six months of the pilot program. Because of delays in initiating the university subcontract activities, the majority of the recommendations deal with programmatic and infrastructure issues.

1.1. Summary of Recommendations

1. NASA must coordinate the various testbeds associated with the information system of the Space Station era.
2. OSSA should develop its data systems in a coordinated manner, and should coordinate such development with the data systems efforts in other NASA organizations, such as Space Station.
3. OSSA should develop and use a process of cross-validating the overall SAIS architecture against the requirements and design of the discipline-specific data systems. Such a process should use a combination of paper design studies and experimental validation.
4. A set of critical issues to be addressed via rapid prototyping testbedding should be developed and incorporated in the Announcment of Opportunity used for selection of the testbed participants in the next phase of the effort.
5. NASA should continue to use a non-government organization to select and fund the various experiments of the testbed. The contractual arrangement must recognize the needed flexibility in dealing with a rapid-prototyping testbed.
6. NASA should develop a flexible approach for dealing with ADPE in a rapid-prototyping environment.
7. NASA should establish methods for coordinating between the testbed program, the general user community and the contractor community responsible for implementing the systems.
8. NASA should cooperate with the other Federal agencies in establishing widespread computer networking service to the broad scientific research community.
9. In the process of providing ubiquitous networking to the scientific community, particular attention should be paid to providing the required administrative functions needed for facilitating electronic mail.
10. NASA should develop highly functional interfaces between the conventional computer communications services provided by NSI and the high- performance systems associated with specific Space/Ground data systems.
11. NASA should develop standards to promote interoperability between heterogeneous data systems. These standards should be based on national and international standards where

possible, and should be enhancements of those standards where required.

12. NASA should develop and install gateways between SPAN and networks based on TCP/IP. These gateways should allow transparent interoperability to users across the multiple networks.

2. Telescience Testbed Pilot Program Overview

The NASA's Office of Space Science and Applications (OSSA) has initiated a pilot program to validate the user-oriented rapid-prototyping testbed approach to address a range of operations and information system issues. Fifteen universities, under subcontract to the Universities Space Research Association (USRA), are conducting a variety of scientific experiments emulative of the scientific research of the Space Station era and aimed at resolving critical issues in critical issues in space station operations concepts and information system design. The goal 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. The following is a short synopsis of the testbed experiments currently ongoing as part of the pilot program.

University of Arizona is conducting two experiments. The first involves teleoperation of a forerunner of the Astrometric Telescope Facility, which will be an attached payload for Space Station. The second is developing systems and software for remote fluid handling in support of microgravity and life sciences. Arizona is also participating in the SIRTF project described below.

University of California, Santa Barbara is exploring 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 Colorado is conducting three experiments. The first involves distributed and interactive operation of an astronomy telescope and its instrumentation at a remote ground observatory and addresses a range of teleoperations issues. The second is in coordination with UC Santa Barbara, Wisconsin, Purdue and Michigan, is using the interactive control opportunities and the science database from the Solar Mesosphere Explorer Mission to investigate coordinated teleoperations and teleanalysis issues. In the third area, researchers are prototyping and evaluating on-board operations management concepts to verify that teleoperations can function safely without command pre-checking.

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

Rensselaer Polytechnic Institute is establishing a testbed to experimentally determine the level of communications capability required to successfully perform remote controlled materials processing experiments of the Space Station era. Three different types of experiments will be tried with the cooperation of the Microgravity Materials Science

Laboratory at Lewis Research Center.

University of Michigan is experimenting with 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 is providing a bridge from NSFnet to McIdas, allowing any TTPP participant with access to NSFnet to acquire existing meteorological products from McIdas.

Stanford University is experimenting 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.

MIT is conducting two experiments. The first is a Remote Life Sciences Operation using the KSC sled with multi-media tests and evaluation of real video needs and implementation options. They also are investigating the remote operation of a telescope at Wallace Observatory using a high bandwidth (T1) link and dissemination of data on campus-wide Project Athena network.

The Space Infrared Telescope Facility (SIRTF) team, consisting of Cornell University, Smithsonian Astrophysics Observatory, CalTech, University of Rochester and University of Arizona, are investigating several issues regarding telescience applied to a Space-based astronomical facility. They are evaluating 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 will be 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 is investigating trade-offs between on-line local processing and processing at the user's 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.

University of California at Berkeley is extending control and simulation systems developed for 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 Rhode Island is investigating a novel image compression technique with "zoom" capability to help progress from

browsing to detailed analysis of selected areas using modest bandwidths from remote sites.

RIACS (Research Institute for Advanced Computer Science) is integrating various networking and local computing capabilities into a "telescience workstation", intended to provide a local computing environment for telescience.

These experiments all share the characteristic that they are attempting to apply new technologies and concepts of science operation to ongoing scientific activities. Through such an experimental prototyping activity actively investigating various technical and procedural trade-offs, a better understanding will be gained of the future scientific modes of operation and the systems architectures, concepts, and technologies required to support such operational modes.

3. Recommendation Discussion

In this section, we discuss the rationale and details of the recommendations listed in Section 1. We first address the programmatic recommendations and then the technical recommendations.

3.1. Programmatic Recommendations

The programmatic recommendations made here are a result of the experience gained in carrying out the pilot program with its associated interfaces to other programs. Recognizing that a rapid-prototyping testbed relies on being able to rapidly put into place experiments that use advanced technologies, most of the recommendations deal with being able to expedite the experiments in a way that is most cost-effective in addressing the critical questions.

3.1.1. Testbed Coordination

NASA must coordinate the various testbeds associated with the information system of the Space Station era.

NASA, and the Space Station program in particular, is carrying out a number of testbed activities associated with information systems as applied to the Space Station era. These testbeds include those like the TTPP aimed at concept development and validation as well as those more intimately associated with the development of Space Station Information System (SSIS) like the End-to-end Test Capability. Interconnecting these testbeds would allow a desirable close coupling between developers and users in understanding requirements, working together to validate approaches, and providing for user feedback on implementations. Currently, this coordination is taking place on an ad-hoc basis due to the recognition by those involved of the value of such coordination. It would be helpful to all involved, as well as NASA as a whole, to have more active coordination. This would provide for administrative infrastructure (e.g. information flow, funding of joint activities) as well as technical assistance (e.g. development of standard approaches to provide for interoperability.)

3.1.2. Coordination of Data Systems Development

OSSA should develop its data systems in a coordinated manner, and should coordinate such development with the data systems efforts in other NASA organizations, such as Space Station.

Each of the space science disciplines have need for considerable support in the area of data systems including communication networks, data archiving and processing, and analysis tools. There is great value to being able to develop these data systems to satisfy discipline specific requirements in a coordinated manner. These benefits include but are not limited to the cost benefits of sharing network facilities, the cost and schedule benefits of using standardized software packages, and the programmatic benefits of having interoperable data systems. In addition, since the Space Station is to be an integral part of all of

the Space Sciences programs, OSSA should coordinate its data systems development with those of the Space Station.

Experience in the Pilot Program to date has shown that there is considerable value to the individual disciplines in coordinating their data systems developments with those of other disciplines and the Space Station. For example, participation in the Pilot Program has had impact on the direction of data systems development for the SIRTF program and consequently the Astronomy and Astrophysics data systems. This was apparent in the Astrophysics Data Systems Workshop which took place recently.

The Science and Applications Information System (SAIS) program is intended to develop an OSSA-wide data systems architecture which would encompass all the discipline data systems requirements. Such an architecture is not intended to restrict the development of discipline-specific data systems, but rather provide a unifying architecture under which individual discipline-specific data systems can be integrated to assure interoperability.

3.1.3. Paper Design and Experimental Validation

OSSA should develop and use a process of cross-validating the overall SAIS architecture against the requirements and design of the discipline-specific data systems. Such a process should use a combination of paper design studies and experimental validation.

As seen above, there is great value to having a unifying architecture (called SAIS) to allow the various discipline specific data systems to be developed in a cost effective manner and achieve the most benefit for the science community. It is imperative that such an architecture be able to accomodate the requirements and consequent designs of the data systems developed for the individual Space Science disciplines. Thus, it is important that such an architecture be validated against the planned discipine data systems designs. Furthermore, it is expected that the SAIS architecture will have positive impact on the discipline data systems designs, by providing a unifying framework and standards for interoperability.

To ensure that these benefits are realized, the SAIS architecture and approach must be validated against the planned designs. At this time, the concepts developed under the SAIS program are fairly abstract, and can only be made more concrete by applying them to the discipline data systems. This can be achieved through a combination of paper design studies and experimental activities such as the rapid-prototyping testbed of the Pilot Program.

Therefore, SAIS developers should work closely with the designers and developers of the individual discipline data systems to understand how the discipline data systems can be designed in the context of an overall SAIS architecture, and what impact such an architecture will have on the design. This can be done through a series of workshops involving SAIS and discipline personnel working together to do a strawman discipline data system design. In

addition, specific issues should be determined from such paper studies that can be best answered through experimental activities, and such experiments be carried out through the testbedding program.

3.1.4. Experiment Selection

A set of critical issues to be addressed via rapid prototyping testbedding should be developed and incorporated in the Announcment of Opportunity used for selection of the testbed participants in the next phase of the effort.

In the Pilot Program, due to the need to move forward rapidly in establishing the testbed and validating the rapid-prototyping concept, the issues addressed were selected based on the best efforts of the proposing institutions. The experiments, while addressing critical issues, were selected using a "bottom-up" approach, where the various institutions proposed what they felt were the best approaches to address what they felt were the most critical issues. While this was mitigated somewhat by having a number of meetings prior to contract award where those present represented the community in discussing what was felt to be the most critical issues, there was not an institutional procedure for selecting those issues to be addressed. The process used for the Pilot Program was as follows:

1. Prior to contract award, a series of meetings was held amongst the interested parties in order to outline possible experiments.
2. Once a contract was awarded to USRA, an Announcement of Opportunity was published, and proposals were received. This Announcement was quite general in terms of which issues should be addressed and how they were to be addressed.
3. A Proposal Review Group (PRG) was selected to review the proposals for technical merit and approach, and for appropriateness of the issues to be addressed. The PRG took a global view, meeting jointly to review the proposals in a batch process, which allowed appropriate comparisons and priorities to be addressed.
4. Based on the recommendations of the PRG, proposals were selected and funds allocated to proceed with the experiments.

This process proved to be extremely effective in all but one aspect. It allowed for a program level review of the intent and goals of the individual experiment proposals with respect to the goals of the overall program, and resulted in a sound set of funded experiments. However, there was not a set of prioritized issues to be addressed up front. If such a set of critical issues was

available prior to the Announcement of Opportunity, it would have provided better guidance to the potential participants and allowed them to propose approaches to addressing these issues.

Thus, we recommend that in follow-on phases of the testbedding efforts, an expert team representing the science, technology, and development communities be assembled to develop a prioritized list of the critical issues to be addressed, and this list be included in the Announcement of Opportunity used to select proposed experiments.

3.1.5. Contracts Award Process

NASA should continue to use a non-government organization to select and fund the various experiments of the testbed. The contractual arrangement must recognize the needed flexibility in dealing with a rapid-prototyping testbed.

The Pilot Program is being carried out through a contract to USRA and resulting subcontracts to various University participants. This has had some significant benefits over having individual contracts to the various testbed participants.

1. It has allowed the USRA Program Manager to coordinate the various programs and structure the program to maximize the effectiveness of the individual experiments in achieving the overall program objectives.
2. It has encouraged the development and use of common infrastructure (networking, workstations, etc.) in the carrying out of the program.
3. It has encouraged the application of solutions developed for one scientific discipline to another discipline's problems through the coordination and information exchange derived from having a single program.
4. It has minimized the administrative overhead by creating a single administrative and programmatic interface to the government.
5. Most importantly, it has allowed the development and carrying out of a single coordinated program.

The rapid-prototyping concept results in new requirements for dealing with the administrative aspects of the program. Rapid-prototyping demands the incorporation and use of state-of-the-art technology. This results in iteration and modification of the technical approaches to the various experiments.

The Pilot Program has resulted in a learning process in order to deal with a number of these issues. This learning process has resulted in some delay in the initial phases of the program. For example, there has been delay in the approval by NASA of the subcontracts even though the approved Subcontract Acquisition Process was followed. Nevertheless, the process used has been quite effective. A team of University participants has been assembled to address the various critical issues, and this team is making substantial progress on both technical and organizational fronts.

It would be extremely counter-productive to attempt to deal with these various issues on a individual University participant basis, forcing each of the Universities to deal with the administrative aspects of the rapid- prototyping environment without the support of a single integrating organization.

Furthermore, having the Universities participate through a single organization encourages an integrated technical program to address the various issues, and is much more likely to result in meaningful recommendations to NASA. For these reasons, we strongly recommend that NASA continue to use a non- profit organization to manage the overall program and administer the component experimental activities at the Universities through subcontracts.

3.1.6. ADPE Acquisition

NASA should develop a flexible approach for dealing with ADPE in a rapid-prototyping environment.

The weakest part of the contractual arrangement between USRA and NASA has proven to be the inability of NASA to deal effectively with the experimental and prototyping nature of the activity in the contractual and administrative areas. This has shown up in several areas, but has been most pronounced in the acquisition and use of ADPE. The nature of a rapid-prototyping approach demands that the participants be able to select flexibly from available computer equipment, since the purpose of the testbed is to use advanced computer and communications capabilities coupled with advanced scientific experiments to determine future requirements and validate potential approaches.

Such a rapid-prototyping testbed activity would seem to fall outside of the area intended for the high degree of monitoring and approvals associated with ADPE justification. The testbed activities are all experimental evaluations of approaches and technologies and are not (nor are they intended to be) selections of equipment for systems development or procurement. A blanket waiver of normal ADPE justification and approval processes would seem to be in order so that rapid-prototyping can indeed serve its primary purpose to NASA; a rapid evaluation of concepts and approaches. It is our belief that such a waiver falls within the congressional guidelines for ADPE and can be developed as part of NASA regulations. (Note that the congressional guidelines provide for heads of agencies waiving certain parts of the ADPE selection and approval process based

on considerations such as those discussed above.)

3.1.7. Coordination Mechanisms

NASA should establish methods for coordinating between the testbed program, the general user community and the contractor community responsible for implementing the systems.

The participants in the user-oriented rapid-prototyping testbed program are investigating many fundamental issues regarding the information systems of the space station era. These systems are being developed, however, by a large and fairly diverse contractor community. It is imperative that strong lines of communication be established between the users (and the programs developing requirements and architectural approaches) and the developers of the systems intended to satisfy those requirements.

3.2. Technical Recommendations

The purpose of the Pilot Program is primarily to validate the rapid-prototyping testbed concept for development and validation of requirements, concepts, and approaches for the information system of the Space Station era and to develop an approach for effectively carrying out such a rapid- prototying testbed activity. Eventually, specific technical recommendations will result from the program regarding requirements and technical approaches. At this early stage, the experimental activities have not progressed enough to develop such detailed recommendations.

A great deal has been learned, though, concerning the needed technical infrastructure to carry out not only the testbed activity but also the types of multidisciplinary scientific activities represented by Space Station. The recommendations here therefore are primarily in this area.

3.2.1. Ubiquitous Networking Service

NASA should cooperate with the other Federal agencies in establishing widespread computer networking service to the broad scientific research community.

The value of computer networking capabilities such as electronic mail, file transfer, and remote access to computers has been well established. Each of the Federal agencies is establishing a computer network to serve its community of researchers. In particular, NSFnet, ESnet (DOE), and NSI (NASA) are all being established based on similar requirements and approaches. The NASA Science Internet (NSI) in particular is being established to ensure that satisfactory basic and enhanced networking service is provided in a cost-effective manner through use of a number of networks (including SPAN and the NASA Science Network, a new TCP/IP based network.) The NSI program is aimed at cost-effectiveness and ubiquitous connectivity through the use of shared communication resources both internally to NASA (using SPAN and NSN) and with other agencies and

through the use of interoperability approaches such as gateways between the various networks.

The science community, though, is multidisciplinary and multi-agency. Typical science activities require operation across agency boundaries. For example, exploration of global environmental issues requires cooperation amongst oceanographers, climatologists, atmospheric scientists, and earth scientists. Such activities are funded by several agencies including NOAA, NSF, USGS and NASA. Networking approaches based on discipline specific or agency specific requirements alone will not provide the wide-spread connectivity and interoperability needed by such multidisciplinary activities, nor will it provide for the effective cost-sharing required if the needs are to be satisfied within feasible resources.

For these reasons, activities such as NSI have been addressing the sharing, interoperabilty, and cross-support requirements through joint discussions with other agencies. We recommend that these discussions continue with the goal of providing a single "virtual" network to all scientific activities. This network should allow for transparent interaction between scientists and the resources they require, including access to remote computers, databases, experimental laboratories, and other scientists. Such interaction should only be limited by permission to use the resources rather than limitations in the network connectivity. It is imperative that OSSA take the lead in providing such services to NASA scientists as the space science community has need for communications with scientists resources beyond those reachable through normal NASA communications (such as PSCN and NASCOM).

Recognizing the need to provide such ubiquitous networking capability to the scientific community, the FCCSET Committee on Computer Research and Applications has developed a set of recommendations in conjunction with the White House Office of Science and Technology Policy for putting in place such a national research network. To achieve this goal, questions of circuit sharing, access control, accounting, interoperability standards, and gateways will have to be addressed. The agencies involved are continuing discussions at the working level to resolve these issues and move forward to establish this broad based network. We recognize these ongoing activities, believe they are critically important to the science community, and recommend that they continue.

3.2.2. Universal Mail Connectivity

In the process of providing ubiquitous networking to the scientific community, particular attention should be paid to providing the required administrative functions needed for facilitating electronic mail.

The Pilot Program has made heavy use of electronic mail to carry out the distributed program. This started with the development of the initial concept papers on the testbed and continued through today where the activities are coordinated through the use of such structures as monthly informal electronic

mail reports.

USRA has attempted to facilitate this ongoing electronic interaction by maintaining a list of electronic mail addresses for the various participants and interested parties, and providing automatic mailing to subsets of interest groups. (For example, a list is maintained for participants involved in earth sciences.) In maintaining this list, USRA has had to validate the various electronic mail addresses to insure that they result in reliable delivery. This has turned out to be a non-trivial task due to the large variety of electronic mailing systems being used (e.g. Internet, SPAN, telemail, nasamail, gsfcmail, OMNET, Bitnet) and the need to deal with changing routing and gateways between systems. For example, the cutover from telemail to nasamail caused a considerable effort in assuring accuracy of addresses in the mailing lists.

Based on this experience, we believe that any attempt to provide for and use electronic mail to support multidisciplinary scientific research will require administrative support of the gateways and directory services. Rather than asking the individual scientific researchers or their organizations to provide this function, we believe it would be much more cost-effective to provide such functions on a community wide basis. The logical organization to provide such a function would be the NASA Science Internet.

3.2.3. Space/Ground Data Systems and NSI

NASA should develop highly functional interfaces between the conventional computer communications services provided by NSI and the high-performance systems associated with specific Space/Ground data systems.

The NASA Science Internet is designed to provide widespread access to conventional computer communication services, such as electronic mail, file transfer, and remote machine access, as well as a number of enhanced services (e.g. multimedia conferencing and directory services.) Space system information systems (e.g. SSIS) need to cope with a number of specific and unique requirements beyond the NSI functionality, such as the extremely high bandwidth of the flow from sensors and the unique nature of the space ground link. For that reason, it is unlikely that technical approaches adopted for use in the NSI will completely satisfy the requirements of the systems associated with specific platforms.

Nevertheless, it is critical that the overall system (SAIS) be designed for flow of information between payloads and the scientist. This often will require use of both platform specific systems and the NSI. Hence, appropriate interfaces must be developed. An example of such an interface is the use of the Internet Protocol (ISO 8473) to support transaction services. Use of a standard virtual-network service such as provided by ISO 8473 will allow for end-to-end flow of data between payloads and the scientists over the combination of the networks provided by the platform specific communication systems and the NSI.

3.2.4. NASA Interoperablity Standards

NASA should develop standards to promote interoperability between heterogeneous systems. These standards should be based on national and international standards where possible, and should be enhancements of those standards where required.

It is well recognized that interoperability between the various science and operations data systems is a prime requirement in any future system. The days of being able to develop and deploy a mission specific system in isolation are long past. There are two possible approaches to solving this problem. The first is for NASA to develop and deploy a NASA-wide data system using NASA-standard hardware and software. This approach will not work for many reasons, amongst them the rapid availability of new computer and communications technologies and the interdisciplinary nature of much of scientific research.

Thus, only the second approach is feasible, which is to engineer the NASA data systems to a set of standards, based on national and international standards where possible, that promote interoperability and cross-support between the various individual and local systems.

3.2.5. Gateways between SPAN and TCP/IP

NASA should develop and install gateways between SPAN and networks based on TCP/IP. These gateways should allow transparent interoperability to users across the multiple networks.

The Space Physics Analysis Network (SPAN) provides extensive computer communications for the space science community based on a set of protocols known as DECnet. Similarly, there is a large system of networks, known as the Internet, that provide similar computer communications services throughout the science community based on a set of protocols known as the DARPA Internet Protocol Suite, or commonly known as TCP/IP.

Although there are numerous gateways between the two systems, there is no straightforward way of doing remote logins and file transfers between the two systems. This is because current gateway technology requires the user to have an account on a specific gateway machine. There are mail gateways between the systems and these have proven to be invaluable.

A NASA policy of allowing automatic access to gateway machines in order to do remote logins and file transfers without explicit actions by the users at the gateway machine would increase the effectiveness of both network systems in supporting science. The NASA Science Internet program is already attempting to interconnect these systems, and such gateways would further its objectives.

4. Conclusions

The first six months of the Pilot Program have been highly productive in establishing the infrastructure of the testbed activity and understanding what is required to make such an activity succeed. While there have been significant delays in establishing the subcontracts, the process has led to a number of recommendations. These recommendations should lead to a follow-on program that is effective in achieving the goal; to provide scientists with an information system in the Space Station era that satisfies their requirements in a cost-effective manner.

Acknowledgement

The ideas in this report represent those of the various participants in the Telescience Testbed Pilot Program and are not those of the author alone. However, the author does assume all responsibility for the expression of these ideas in this report.