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Advancing Automation and Robotics Technology for the Space Station *Freedom* and for the U.S. Economy

Progress Report 15
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Advanced Technology Advisory Committee
National Aeronautics and Space Administration

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Cover: Space Station Freedom
Permanently Manned Capability

Insets: Lunar Base
Planetary Exploration

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ORIGINAL PAGE
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Control Center Complex Extended Realtime Failure Environment Analysis Tool and Thermal Control System Flight Detection Isolation and Recovery

Extended Realtime Failure Environment Analysis Tool (FEAT) and the Thermal Control System FDIR projects are being evaluated in the Control Center Complex (CCC) Advanced Technology Testbed located at Johnson Space Center. The projects are developing and demonstrating advanced technology for autonomous fault detection, isolation, and recovery (FDIR). The knowledge-based logic provides for model-based sensor validation augmented with fault management through model-based component diagnosis. Design accommodations are being identified for SSF baseline and for evolution. The advanced automated FDIR technology will provide enhanced safety, increased reliability, and increased productivity for SSF science, operations, and maintenance. The technology will be implemented first in SSF ground mission control centers and eventually migrated to SSF on-board systems, if funding becomes available.

Executive Summary

Background

In 1984, Congress directed NASA to develop and implement an Automation and Robotics (A&R) program with the intent to focus and transfer the A&R technologies into the U.S. industrial sector and economy by using Space Station Freedom as the focused application.

In response to this mandate, NASA established in 1984 the Advanced Technology Advisory Committee (ATAC) to review, assess, and report NASA's progress in carrying out its Congressional mandate. This is the fifteenth in the series of progress updates and covers the period of February 27, 1992 through September 17, 1992.

A&R Technology Transfer

ATAC is still concerned that there does not exist an *integrated agency plan* to evaluate, validate, and transfer the advanced A&R technologies to the SSFP. The Congressional mandate that directed NASA to develop and implement an A&R program with the intent to focus and transfer the A&R technologies into the U. S. industrial sector and economy by using Space Station Freedom as the focused application is not being met.

Recommendations

Ground-Based SSF Science, Operations, and Maintenance

Ground-Controlled Telerobotics

Recent cost reduction redesigns of the Canadian Mobile Servicing System (Space Station Remote Manipulator-SSRMS and Special Purpose Dextrous Manipulator-SPDM) indicate that the Intravehicular Activity (IVA) timelines for on-board telerobotic operations could be considerably increased. This increase of IVA to support on-board telerobotic operations could impact the ability to complete on-board payload and science operations unless the on-board telerobotics crew workload is reduced. With 7 degrees of freedom on the SSRMS and 14 degrees of freedom on the SPDM, the arm motions will become very difficult to visualize and teleoperate from on board the SSF. Tests have been completed that indicate that the up-link/ down-link telemetry delays in telerobotic signals can be accommodated through the implementation of qualified and proven telerobotic technologies. More emphasis should be placed on developing the capability of ground teleoperation of the SSRMS/SPDM.

ATAC recommends that SSFP assess the need, due to SSRMS/ SPDM redesign, to operate robotic systems from the ground, and if required, incorporate ground-controlled telerobotics as a baseline SSF capability.

On-Board SSF Science, Operations, and Maintenance

Redesigned SSRMS/SPDM Operation

Removal of the five degree-of-freedom "body" of the Special Purpose Dexterous Manipulator (SPDM) reduces the functionality and capability of the system and causes almost all servicing actions to be completed with the SPDM attached to the end of the large seven degree-of-freedom Space Station Remote Manipulator System (SSRMS).

The complexity of the 14 degree-of-freedom SPDM operating from the end of the 7 degree-of-freedom SSRMS creates a very complex kinematic and dynamic problem. Lack of coordinated control will significantly lengthen the timelines required to accomplish robotic maintenance tasks. Extensive ground support will be required to plan the movement of the robot arms. The complexity of the compound SSRMS/SPDM robotic system will also make collision avoidance difficult. The baseline system for collision avoidance is completely visual based on the astronaut operator's ability to see and avoid unintended contact. There is currently a minimum of cameras and viewpoints planned for operations of the Space Station. Technologies for non-visual collision avoidance have been developed. The Canadian Space Agency should be encouraged to investigate these technologies and incorporate or leave hooks and scars for incorporation of an on-board collision avoidance system.

ATAC recommends that SSFP assess the impact of SSRMS/SPDM redesign on telerobotic operations, specifically including task timelines and collision avoidance issues, and report results at the February 1993 ATAC review.

Data Management System

The Data Management System (DMS) was redesigned with a channelized architecture. The organization of the power and data buses was changed to provide redundancy throughout the system to allow for fault recovery. Most of the non-time-critical functions that were to execute on the SDPs have been moved to the ground to reduce the load on the SDPs. However, there was no analysis presented to indicate that the utilization of the SDPs would be under 100%. Time critical functions remaining to execute on the SDPs were grouped into 0-fault, 1-fault, and 2-fault tolerant according to criticality.

The computational capability of the restructured DMS does not appear to have any computational reserve for any contingencies. Although the hooks and scars are there for the expansion of the DMS, the expansion may be constrained and/or improbable due to the power availability.

ATAC recommends that SSFP conduct a system simulation and analysis of DMS (SDPs, MDMs, sensors, and effectors) in a simulated operational environment to determine the computational reserve of the restructured DMS and its capability to meet the mission objectives and requirements.

A&R Technology Evolution

Control Center Complex Advanced Technology Testbed

Recent developments which have combined the STS and SSF Mission Control Centers, now designated as the Control Center Complex, have enhanced the potential of migrating advanced automation techniques into the CCC. Considerable progress has been made on the development of an advanced technology testbed at JSC that will enhance the capability to migrate automation techniques into the newly configured CCC. Currently the only automation techniques being tested on the new CCC automation testbed are those being developed through the SSF Level I Engineering Prototype Development (EPD) program. Due to the reduced SSF budget, the funding for the EPD program is reduced to a level that could delay the migration of the EPD automation techniques into the CCC. Considering these new developments, other technology organizations should be encouraged to evaluate new automation technologies that can be migrated through the CCC advanced technology testbed.

ATAC recommends that SSFP continue to support and encourage testing of new automation technologies from Level I EPD and OAST in the CCC advanced technology testbed for migration into the CCC.

Advanced Automation Technology Manager

ATAC has a continuing concern with the lack of a well coordinated and integrated Agency effort for implementation of advanced automation on SSF. OAST is the Agency's leader in AI research and is recognized as having a preeminent AI research capability and knowledge. OAST is knowledgeable about the applicable work being conducted in industry, academia, and other government organizations. Effective integration of the OAST advanced automation technologies with SSF requirements for ground mission operations and on-board flight system operation and management will lead to significant cost savings to the Agency, in the CCC and the HOSC as well as SSF.

ATAC recommends that OAST provide an Advanced Automation Technology Manager to SSFP Level I who will coordinate, integrate, and propose advanced automation technologies from within the research community to meet SSF mission requirements.

Introduction

Background

Congressional Mandate

In 1984, Congress directed NASA to develop and implement an A&R program with the intent to focus and transfer the A&R technologies into the U.S. industrial sector and economy by using Space Station Freedom as the focused application.

ATAC Establishment

In response to the mandate of Congress, NASA in 1984 established the Advanced Technology Advisory Committee (ATAC) to prepare a report identifying specific Space Station Freedom (SSF) systems which advance automation and robotics (A&R) technologies. In March 1985, as required by Public Law 98-371, ATAC reported to Congress the results of its studies (ref. 1). The first ATAC report proposed goals for automation and robotics applications for the initial and evolutionary space station. Additionally, ATAC provided recommendations to guide the implementation of automation and robotics in the Space Station Freedom Program (SSFP).

A further requirement of the law was that ATAC follow Space Station Freedom's progress in this area and report to Congress semiannually. In this context ATAC's mission is considered to be the following.

ATAC Mission

Review, assess, and report NASA's progress in carrying out its Congressional mandate for A&R technology development and application to Space Station Freedom. Specifically, independently review conduct of the Space Station Freedom Program to assess applications of A&R technology with consideration for safety, reliability, schedule, performance, and cost effectiveness (including life-cycle costs). Based upon these assessments, develop recommendations to enhance A&R technology application, and review the recommendations with NASA management for their implementation. Report assessments and recommendations twice annually to Congress.

The Space Station Freedom Program is charged with developing a baseline station configuration that provides an initial operational capability and which, in addition, can be evolved to support a range of future mission scenarios in keeping with the needs of space station users and the long-term goals of U.S. space policy.

The ATAC has continued to monitor and prepare semiannual reports on NASA's progress in the use of automation and robotics in achieving this goal. The reports are documented in ATAC Progress Reports 1 through 14 (refs. 2-15). Progress Reports 1 through 5 covered the definition and preliminary design phase (Phase B) of Space Station Freedom. Progress Reports 6 through 10 covered the design and development phase (phase C/D) of the SSF. Reports 11 and 14 covered the restructured design of SSF which was required as a result of SSFP budget reductions in FY 1991. Phase C/D will lead to a completely assembled station to be operational in the late 1990's.

ATAC Progress Report 14, like previous ATAC reports, received wide dissemination. ATAC Progress Report 14 was distributed in the following categories:

Congress	25 copies
NASA	235 copies
Industry	110 copies
Universities	50 copies
CSA, ESA, NASDA	5 copies
GAO	2 copies
Coord. Committees	23 copies
Total	450 copies

This report is the fifteenth in the series of progress updates and covers the period of February 27, 1992 through September 15, 1992. To provide a useful, concise report format, all of the committee's assessments have been included in the section "ATAC Assessments." This section of the report includes comments on SSFP's progress in responding to the ATAC recommendations in Report 14. Also, a summary of progress in A&R in the Space Station Freedom Program as written by the program is provided as an appendix. The report draws upon individual ATAC members' understanding and assessments of the application of A&R in the SSFP and upon material presented during an ATAC meeting held September 15-17, 1992, at JSC for the purposes of reviewing the SSFP A&R activities and formulating the points of this report.

Climate

ATAC reported in May 1992 (Report no. 14) that it was concerned that NASA "... did not have an integrated advanced automation program which addressed the needs of SSCC, the POIC, and the SSFP scientific investigators ..., that little progress ... was being made in standardizing or integrating the NASDA and ESA space robotic elements with the RSIS format..., and, ... that there is not an integrated Agency plan to evaluate, validate, and migrate the advanced automation technologies to the SSF on-board systems for the PMC phase."

ATAC is happy to report that SSFP has established and implemented an effective advanced automation program designed to validate and accelerate the transfer of evolving automation technologies into the operational environment. Included in this effort is the development of several SSFP advanced automation testbeds located at JSC, MSFC, and LeRC.

Due to significant budget reductions, the STS and SSF mission control centers have been merged into a new, integrated Control Center Complex (CCC) with two subcenters, one for ascent/entry and one for orbital control. Since many on-orbit operations are common to both missions, this integration represents an excellent, cost-effective decision. The development and integration schedule for the new CCC is optimistic and requires the early leveraging, validation, and transfer of advanced automation technologies to complete the new complex within the budgetary constraints.

Much progress has been made in the standardization of the Canadian robotic interfaces with the U. S.-developed ORUs including the scientific payloads. The standardization of the robotic interfaces will allow for the cost-effective integration of evolving robotic devices from potential U. S. manufacturers. In addition, it will reduce the long-term costs for maintenance, operation, and training. However, the Canadian robotics system has recently been restructured to meet a reduced development budget. This reduction resulted in decreased mobility for the robotics system and very little time, if any, for the flight validation and evaluation of the system prior to its operational use on-board the SSF. The development schedule is optimistic and an alternate backup system is not readily available due to the termination of the U.S. FTS Program.

An in-depth assessment of the Data Management System (DMS) as it applies to the baseline operation and maintenance of the SSF infrastructure as well as its scientific payloads was conducted as part of this report. The computational elements represent old technology but this is to be expected if cost is the primary driver and minimum risks are to be incorporated into the DMS development. The current DMS technology is adequate for the near term but does not provide the computational reserve required for the resolution of unanticipated events (mission requirements). Although there are sufficient "hooks and scars" to provide for the expansion of the SSF on-board computational capability, the available power may be too constrained to allow for additional computational expansion. There are currently no plans for conducting a system simulation and analysis of the DMS in a simulated operational environment to determine the computational reserve of the restructured DMS and its capability to meet the mission objectives and requirements.

The resulting restructuring of the SSF caused by congressionally-imposed budget reductions will still allow the SSF to meet most of its mission objectives and requirements although there is no reserve

for any contingencies. It is ATAC's opinion that any further reductions in the SSFP budget may result in a Station than cannot meet its mission requirements and objectives.

ATAC Concerns

Ground-Based SSF Science, Operations, and Maintenance

With the restructuring and integration of the SSF Space Station Control Center (SSCC) with the STS Mission Control Center into a new Control Center Complex (CCC), there appears to be a commonality of software in the on-orbit operation of both the STS and the SSF. Hence, the creation of the CCC appears to be a cost-effective decision over the life cycle of the project. However, the successful development of this new CCC within its budgetary constraints is highly dependent on the leveraging, validation, and transfer of the applicable advanced automation technologies in the CCC operational environment. Both SSF and STS have existing testbeds which can be used for early evaluation and validation of the evolving advanced automation concepts. However, ATAC is concerned that

1. The available testbeds at JSC, MSFC, and LeRC will not be maintained and funded at an adequate level to evaluate, validate, and transfer the required advanced automation technologies into ground operations.
2. A common set of software development tools are not being used which would allow efficient evaluation, analysis, and transfer of the appropriate software. It appears that the software development tools are chosen at the discretion of the developer, which does not provide for an effective and integrated software development program. In addition, the knowledge gained by individual developers in the resolution of problems and its application to the overall system cannot be shared with other software developers if different development tools are used.

ATAC is concerned that NASA is not taking full advantage of the available SSF and STS testbeds to accelerate the transfer of advanced automation technologies applicable to the CCC, and that a common set of software development tools to support the testing and evaluation of advanced automation technologies is not being used.

On-Board SSF Science, Operations, and Maintenance

ATAC was briefed on the restructuring of the Canadian robotic system and the SSF DMS caused by budgetary constraints. The restructured designs for both activities had not progressed to a sufficient level at the time of the ATAC briefing to allow ATAC to assess the potential impacts caused by the restructuring.

Sufficient information was provided for **ATAC to be concerned that:**

1. More mission time may be required for replacement of ORUs due to the lack of mobility of the SPDM. In addition, there does not appear to be sufficient time to evaluate and validate the robotic system prior to its use in a flight operational environment.

2. Ground operation of the flight robotic system may be required for operations and maintenance of the SSF prior to PMC. Hooks and scars for such an operation are not yet being considered and could be a major cost factor if plans are not developed now to implement the process.

3. The computational capability of the restructured DMS does not appear to have any computational reserve for any contingencies. Although the hooks and scars are there for the expansion of the DMS, the expansion may be constrained and/or improbable due to the power availability.

A&R Technology Evolution

SSFP has continued to make considerable progress towards the evaluation and early validation of advanced automation technologies applicable to the development of the CCC. OAST briefed ATAC on its automation, robotics, and data systems focused technology development program, originally funded under the Civil Space Technology Initiative (CSTI); however, the presentation lacked sufficient technical content to allow ATAC to assess OAST's technology applicability and transfer to SSFP. It is **critical that OAST focus their automation, robotics, and data systems development programs to SSFP needs and requirements** – without OAST's assistance, SSFP will lack the technologies required to develop SSF in a cost-effective manner.

ATAC is still concerned that there does not exist an *integrated agency plan* to evaluate, validate, and transfer the advanced A&R technologies to the SSFP. The Congressional mandate that directed NASA to develop and implement an A&R program with the intent to focus and transfer the A&R technologies into the U. S. industrial sector and economy by using Space Station Freedom as the focused application is not being met.

Focus of Next ATAC Meeting

The next ATAC meeting and report, Progress Report 16, will focus on a detailed review of the A&R progress in launch processing and operations, and a detailed review of the OAST A&R Program. The meeting will be held in February, 1993 at Kennedy Space Center.

ATAC Assessments

Basis of Assessments

The ATAC assessments for this reporting period are based upon the committee's appraisals of progress in advanced automation and robotics for Space Station Freedom. A review of the progress on the recommendations from ATAC's most recent report, Progress Report 14, will be discussed first, followed by a review of topics explicitly addressed during the September 15-17, 1992 ATAC meeting, and then a discussion of new A&R issues.

It is ATAC's understanding that Congress directed NASA to develop and implement an A&R program with the specific intent to focus and transfer the A&R technologies into the U. S. industrial sector and economy by using Space Station Freedom as the focused application. Due to the congressional budget constraints, the SSFP, as currently restructured, is focusing the incorporation of advanced A&R technology only into ground operations; however, OAST has not provided ATAC with sufficient information to determine relevance of its A&R program to SSF requirements and needs.

Assessment of Progress on ATAC Report 14 Recommendations

Recommendation I: Space Station Control Center Automation.

"The SSFP Level I Engineering Prototype Development manager coordinate an SSFP program effort with OAST to assure that applicable existing automation technologies are considered for the SSCC baseline system; and present a specific plan for the effort at the July 1992 ATAC review."

SSFP Response to ATAC

"Due to funding reductions in development and operations, Space Station Control Center (SSCC) activities have been consolidated and merged with Shuttle activities. The resultant facility has been designated the Control Center Complex and is split into on-orbit and ascent/entry operations. As part of this baseline architecture, an advanced technologies testbed has been established at JSC to evaluate key innovative technological solutions targeted for control center operations. This testbed provides the introduction and assessment of new approaches in parallel with baseline operations. The first suite of technologies to be evaluated within this testbed are advanced fault management techniques being investigated by Level I Engineering Prototype Development. Advanced fault detection and management prototypes in thermal control, electrical power distribution, and environmental control and life support are scheduled for review within the next two years. These prototypes are being developed consistent with the Program's baseline Fault Detection and Management (FDM) subsystem to ensure a smooth transition and integration. Similarly, the FDM subsystem is being designed so new techniques and algorithms can be more easily incorporated as they become available. The advanced thermal control system fault management prototype is currently being evaluated, with the electrical power system and environmental control and life support system assessments following in six month increments respectively."

"In November of 1991, SSF automation technology requirements were presented to the OAST Artificial Intelligence Intercenter Working Group (AIIWG). These requirements included functional needs in fault management, system monitoring and control, mission planning and scheduling, mission operations, training, human-computer interaction, and system-software engineering. Each functional need included aspects of control center operations. In December of 1991, control center personnel met with members of the AIIWG to discuss potential areas for future technology support. At that time, ground status and control monitoring, failure management and recovery planning-scheduling, Digraph conversion, and intelligent textual search and retrieval were identified as areas of potential support. In February of 1992, the SSFP was given the opportunity of reviewing the FY93 AIIWG proposals for their relevance in meeting a variety of SSF needs. Only one proposal offered support to Space Station Control Center operations. That proposal involved merging Digraph analysis with selective monitoring techniques and is pertinent because the SSCC's baseline approach for fault identification relies heavily on the use of Digraphs. Unfortunately, the funding allocated to this proposal has placed its original objectives in jeopardy. In June of 1992, SSF automation technology requirements were again presented to the OAST AIIWG. This time however, both control center and payload operations center requirements were more formally addressed. Control center functional needs revolved around improved methods of detecting anomalies and managing potential failures. Also, the ability to access voluminous technical documentation was addressed. Payload-operations center functional needs included payload telemetry assessment, activity model development, and payload data management console automation. Also at that time, the concept of the advanced technology testbed was introduced, explained, and advertised as a means of transferring advanced operations technology into the Space Station Control Center. It is expected that the SSFP will continue its dialogue with OAST and that a significant piece of that communication will involve control center and payload operations automation."

ATAC Assessment

SSFP Level I Engineering Prototype Development (EPD) manager presented a specific plan at the ATAC review for assuring that applicable existing automation technologies are considered for the SSCC (now Orbital Control Center (OCC) portion of Control Center Complex (CCC)) baseline system. However, although SSFP automation technology requirements were presented to the AIIWG, attempts to enlist substantial OAST participation in CCC testbed activities were largely unsuccessful. The plan consists of two major elements:

1. The baseline architecture of the CCC includes a Fault Detection and Management system for automated fault detection and analysis for both SSF and on-orbit Shuttle Systems. The system includes fault detection using knowledge-based systems, automated fault analysis using extended realtime FEAT (Failure Environment Analysis Tool, a directed graph representation or model of failure modes of equipment), and additional monitoring and diagnosis capabilities evaluation for incorporation through an advanced technologies testbed (see section on SSCC below under A&R Status Review for more details on CCC, FDM, and testbed). Future plans include the incorporation of recovery planning technology and fuzzy logic applications.
2. Level I EPD advanced technology prototypes for TCS, EPS, and ECLSS are being developed for evaluation in the CCC testbed.

The SSFP Level I EPD manager and the JSC MOD Control Center Systems Division are commended by ATAC for this plan and CCC design which initiated use of intelligent systems to achieve improved reliability and productivity for SSF.

ATAC urges OAST to re-assess its plans for artificial intelligence research so as to be able to develop improved capabilities to be evaluated in the CCC testbed.

Recommendation II: Payload Operations Integration Center (POIC).

"The SSFP Level I Engineering Prototype Development manager determine if one of the existing advanced planning and scheduling tools being developed within their program or one being developed within the OAST program could be implemented for the POIC baseline operations."

SSFP Response to ATAC

"In September of 1991, the Space Station Freedom Level I Engineering Prototype Development activity sponsored a planning and scheduling workshop with the specific objective of addressing the planning and scheduling requirements for major Space Station applications (e.g., training, facilities, payloads, crew time). Unlike previous gatherings, this workshop placed special emphasis on identifying common technology that exists or that can be developed and shared to meet specific Space Station needs. A significant portion of the meeting was spent in working groups dealing with issues such as "common user interfaces," "common data representations," "common algorithms," and "common protocols for distributed scheduling"."

"The Huntsville Operations Support Center (HOSC) is the home for payload operations within the Agency and has responsibility for both Space Station and Spacelab payloads. They have recognized the need for greater planning and scheduling flexibility in order to meet their mission requirements and have expressed a strong desire to build bridges to the planning and scheduling R&D community for technology to meet their needs. Therefore, another workshop is currently being planned for Huntsville, Alabama and will be cosponsored by both SSF Level I Engineering Prototype Development and the OAST Artificial Intelligence Program."

"This workshop will focus primarily on Space Station operations and will explore the domain of payload operations in greater detail. The workshop will acquaint participants with the full scope of payload scheduling technical requirements including ground processing at KSC, Network Control Center scheduling at Goddard, crew operations scheduling at JSC, coordination with international partners, as well as actual payload scheduling at MSFC. Participants will specifically review the detailed technical requirements of Spacelab and Spacehab missions that offer reasonable comparison to Space Station operations. Ultimately, the workshop should identify those requirements that provide the greatest technical challenges and which emerging techniques and technologies seem to address them."

"In conjunction with the workshop, SSFP Level I Engineering Prototype Development and the HOSC have initiated an activity designed to define, demonstrate, and document the baseline functionality required to support payload operations scheduling. This initiative includes developing a series of incremental specification and representative data set packages. These packages will include payload operations scheduling requirements and payload scenarios which substantiate those requirements and provide some context for their occurrence. Benchmark data will also be included which can be used to exercise the capabilities of candidate scheduling systems. Ideally, these packages will be used to focus planning and scheduling research and development and will aid in fair evaluation of the multitude of planning and scheduling approaches being pursued by the technology community. These packages will also be useful in the preparation of requirements contained in Requests for Proposal or Task Orders that may be issued for the development of future scheduling systems."

"Additionally, these packages will be maintained in a form and location that facilitates electronic communication between those NASA centers, that wish to apply their industries, and academic institutions scheduling research to this specific domain. Similarly, the requirements, scenarios, data sets, and new technology challenges will be submitted to the artificial intelligence and operations research workshops scheduled for the future."

"This unique approach of collecting requirements, scenarios, and data sets will be evaluated, critiqued, and documented to serve as a guide for future technology development and technology transfer efforts. Hopefully this workshop and scheduling initiative will improve the dialogue between the OAST Artificial Intelligence Program and the SSFP and will form the basis of a joint research and development plan that will guide strategic investment decisions and solve some very critical operational issues."

ATAC Assessment

The SSFP Level I Engineering prototype Development (EPD) manager has been very responsive to ATAC recommendations and in this case has made excellent progress as well.

EPD and the Huntsville Operations Support Center (HOSC), which have responsibility for payload operations for

SSF (POIC), Spacelab and Spacehab, and which have expressed a strong desire for advanced technology to meet their needs for greater planning and scheduling flexibility, have started to define, demonstrate, and document baseline functionality required to support payload operations scheduling, including specifications and data "packages" of payload operations scheduling requirements, payload scenarios, and representative benchmark data sets to exercise and compare the capabilities of candidate AI planning and scheduling approaches. This unique approach of packaging requirements, scenarios, and data sets may serve as a guide for future technology development and technology transfer efforts, though possibly not possessing the same degree of integrated testing of robustness as a testbed might provide. This effort, with feedback from technology developers, is intended to support preparation of POIC and HOSC requests for proposals issued to procure planning and scheduling capabilities to meet their needs.

In addition, EPD has sponsored a planning and scheduling workshop to address these requirements for SSFP applications such as crew time, payloads, facilities, and training. Another workshop is being planned at MSFC in December 1992, co-sponsored with the OAST AI program, to focus primarily on SSF payload operations.

These efforts could and should strengthen the support of SSFP by the OAST AI Program and should form the basis of a joint R&D plan that guides strategic investment decisions to solve some very critical SSF operational issues.

The SSFP Level I EPD manager and the MSFC HOSC POIC management are commended by ATAC for this effort to improve productivity for SSF.

Recommendation III: Science Productivity.

"SSFP coordinate and implement an integrated effort to facilitate and enhance the effective utilization of the SSF laboratory facilities for the conduct of material and life sciences during the MTC phase."

SSFP Response to ATAC

"Payload Accommodations

Payloads will take advantage of many standard capabilities of the Space Station Freedom environment for conducting their operations. The standard resources include: International Standard Payload Rack (ISPR), Electrical Power System (EPS), Thermal Control System (TCS), Communication and Tracking and Video Subsystem, Environmental Control and Life Support System (ECLSS)."

"The basic accommodation for payloads in the pressurized modules is the ISPR which has been designed to effectively take advantage of the SSF internal pressurized environment. This environment is suitable for the performance of microgravity experiments. Acceleration levels of 10–6g or less at frequencies < = 0.1 Hz are maintained for at least 50 percent of the user accommodation locations for continuous periods of 30 days or more, beginning at MTC. These conditions exist at least 180 days per year. For frequencies between 0.1 and 100Hz, the acceleration levels are less than the product of 1 × 10 – 5g/Hz and the frequency. Acceleration levels of < = 1 × 10 – 3g are provided for frequencies exceeding 100Hz. Externally, two locations are available on the external truss during the MTC phase."

"The EPS provides all research and housekeeping electrical power. The EPS generates 18.75 kW of orbital power at MTC. At least 11 kW is available for payload operations. The power supply is available with 3.0 or 6.0 kW capability depending upon the rack location. Some ISPRs in the U.S. Lab, with dual 6 kW inputs, can provide 12 kW to payloads. The EPS provides 120 volt dc power to the payload interface."

"The TCS maintains core system equipment and payloads within required temperature ranges. The TCS is capable of handling heat rejection loads, at certain locations, of 12 kW, 6kW, and 3 kW."

"Video access is available at each ISPR location with a single-video connector with three interfaces for input, output and synchronization and control. The video system accepts a National Television System Committee (NTSC) formatted signal. A payload may send video from inside the payload rack to a Multi-purpose Access Console (MPAC), a video monitor, or a ground facility."

"The Environment Control and Life Support System will maintain an atmospheric pressure of 10.2 psia and an oxygen concentration of not more than 30 percent during MTC. However, the atmospheric pressure may be increased to 14.7 psia and the oxygen concentration reduced to 23.8 percent during MTC to fulfill the needs of principal investigators, except during Mission Build flights."

"In addition to the standard SSF capabilities available to payloads, the SSF also includes capabilities that have been customized for Payload operations. These capabilities include the Vacuum Resource System, Vacuum Exhaust System, Acceleration Mapping System (AMS), Water, General Laboratory Support Facilities and Laboratory Support Equipment."

"The Vacuum Resource System provides a line capable of attaining and maintaining 10-3 torr for a payload at selected ISPR locations."

"The Vacuum Exhaust System provides a gas vent line for the disposal of nontoxic and nonreactive gaseous payload waste at selected ISPR locations. There is no on-orbit storage or treatment available. Principle investigators are responsible for the containment, storage and transport hardware required for all payload generated liquid, solid, and toxic gaseous payload waste."

"The AMS in the U.S. Lab consists of a system of fixed accelerometers to measure quasi-steady acceleration (frequency < 0.01 Hz) and movable accelerometers to measure vibration between 0.001 and 300 Hz. Information characterizing the acceleration environment is routinely available in a timely manner to principal investigators and crew to support payload operations and post-flight data analysis."

"The ISPRs are not plumbed for water distribution. Potable water is available for payloads at a spigot located in the U.S. Laboratory Module."

"The General Laboratory Support Facilities and Laboratory Support Equipment include the following components: Materials Processing Glovebox, Life Sciences Glovebox (in Centrifuge Node), Battery Charger, Cameras, Still and Video, Camera Locker, Cleaning Equipment, Digital Multimeter, Digital Recording Oscilloscope, Digital Thermometers, EM-Shielded Locker, Film Locker, Fluid Handling Tools, Freeze Drier, Freezer 20°C, Freezer 70°C, Freezer, Cryogenic (Quick/Snap and Storage), General Purpose Hand tools, Microscope, Stereo, Micromass Measurement Device, Passive Dosimeter, pH Meter, Portable Glovebox, Refrigerator, Specimen Labeling Device, Small Mass Measurement Device."

"Payload Information System Specialized Hardware

Several unique components have been added to the payload portion of SSF facilities in order to maximize user operations. In particular, the Data Management System (DMS) has been upgraded with several Orbital Replacement Units designed to meet custom payload requirements."

"Standard Data Processor (SDP) no. 7 is a dedicated payload SDP that supports a 1553B local bus for payloads and also serves as the host for the Payload Executive Software (PES). The PES augments the DMS with payload unique functions and features like collecting ancillary data and augmenting simple, low-end payloads into the DMS."

"The Payload Data Processor (PLDP) is a customized processor based on the core system SDP but has been outfitted with additional Input/Output (I/O) capabilities. The SCSI interface, designed to facilitate high bandwidth data transfers, and the RS-232-424 interface, commonly used by the payload science community, are both supported. Additionally, the 1553B standard local bus supports a backplane that allows payload unique boards to be installed. The additional I/O capabilities, along with open slots on the backplane, allows the payload community to develop systems similar to their current systems in their labs. This enhances the productivity of their experiments and keeps costs to a minimum."

"The Payload Fiber Distributed Data Interface (FDDI) Multiplexer/Demultiplexer (MDM) is a customized processor based on the core system MDM but includes a high bandwidth FDDI interface along with additional I/O capabilities (e.g., SCSI, RS-232-424, 1553B). Also included are high and low speed backplanes that allow payload unique boards to be installed. The Payload FDDI MDM uses very little power and allows high fidelity operations with its high speed bus."

"A stand-alone Network Interface Adapter (NIA) provides payload unique ORUs high-bandwidth interfaces into the Payload FDDI Ring. The NIA option gives payload developers the most freedom in building unique payload control systems that require high bandwidth interfaces into the DMS."

"High Rate Links (HRL), the Patch Panel (PP), and Intermediate Rate Gateway (IRGW) provide the capability to route payload science data either to other on-orbit locations or to the ground. Beyond the benefits of moving large amounts of data to the ground, the HRL and PP can also support facility class payloads that need to move large amounts of data (greater than 10Mbps) between various remotely placed rack locations."

"On-board Software Services

DMS Standard Services, Timeliner, and the Payload Executive Software (PES) allow the payload community significant flexibility for automatic, autonomous, and dynamic control of their operations within the limits of on-board resources and safety precautions."

"DMS Standard Services provides high-end payloads the capability to easily access, on a real-time basis, various SSF capabilities like ancillary data and health and status information via the Runtime Object Relation Database (RODB). This capability provides payload developers with the necessary software calls to the DMS to operate their payload on-board Space Station Freedom with maximum access to required resources."

"The Timeliner provides a language specialized for writing sequenced procedures. Scripts are organized into parallel "sequences" with conditional logic controlling the flow of each sequence. These sequences interact with particular systems (e.g., power, cameras, lights) by reading attributes and writing commands. On board Freedom, these sequences can automate procedures, provide upper-level control during Loss Of Signal events when unmanned, and allow procedures to be defined "pre-flight" to aid verification and ensure repeatability. On the ground, these sequences provide simulation executive functions. Payload operations will use the Timeliner capability to execute payload sequences according to various scenarios such as Tier 1 commands and Mode changes."

"The Payload Executive Software serves as a simple, yet robust conduit for low-end payloads into the DMS. PES also augments the DMS with other payload-unique housekeeping chores like the collection of core data for use as ancillary data by payloads in order to have control points and calibrated science data."

"Payload Operations Support

Payload operations support is provided in five different, yet integrated, areas: the Control Center Complex (CCC), Payload Operation Integration Center (POIC), Payload Data Services System (PDSS), U.S Operations Center (USOC), and U.S. User Operations Facilities (UOF)."

"The CCC has the functional responsibility for overall SSF systems management including total operations planning and analysis, monitoring, command and control, voice communication, video processing and distribution, core data processing and archiving, and orbit determination. CCC capabilities provide the integrated services and support necessary for real-time operations and planning for both core and payload activities."

"The POIC facility performs real-time payload operations integration, mission planning, payload operations control, and payload data management. The POIC monitors and controls payload interfaces to the CCC, UOF, and communications network. The POIC includes a Payload Procedure Development and Control System (PDAC), Timeliner Sequence Development Software, Payload Flight Display Definition System, Mission Planning System, and the Operations Management Information System (OMIS). These capabilities are intended to support commanding, remote voice communication, and mission planning and procedure development."

"The USOC is a payload operations facility located adjacent to the POIC. It accommodates payload investigators and operations from each sponsoring user code (e.g., Science, Commercial, and Research-Technology). It provides the essential user capabilities to conduct and execute realtime payload operations by supporting realtime display and processing of payload health status and ancillary data. It also sends realtime payload commands and supports crew voice communication from payload users. The USOC also manages information routing of high-rate payload data to user supplied ground support equipment."

"UOFs are planned to support operational needs that are best suited for a specific discipline or area of experiment expertise. These include the discipline-oriented areas of micro-gravity, lifesciences, and technology. It is anticipated that UOFs will be colocated near their area of expertise. For example, a UOF is expected to be established on or near Ames Research Center, and will concentrate on life science payloads since that is an ARC responsibility. The UOF will provide standard commands, telemetry, voice, data management, mission support, and communications for all payloads supported at their site. UOFs are responsible for archiving, processing, and distributing the data to the investigator."

"The PDSS ties together the major Ground System Elements in terms of distributing Payload Science Data. PDSS provides three major functions for handling high bandwidth (Ku-band) science data: realtime distribution, production processing, and data distribution. The PDSS captures and stores the 50Mbps Ku data stream from White Sands. It demultiplexes the captured data into Virtual Channels (VCs) and CCSDS packets then performs Level Zero Processing on selected VC's. It provides rate buffering of selected data then distributes it using NASCOM and PSCN communication networks."

"The Space Station Freedom program has recently initiated a set of conferences and workshops (i.e., Space Station Utilization Conference and the Payload Data Services Support Workshop) to educate the public and payload engineers on the details of the space station functions and resources for conducting science, technology, and commercial operations on board the space station platform. These forums bring together the engineers, designers, and managers of the Space Station program with the payload community to share lessons learned, and to build a corporate knowledge base."

ATAC Assessment

The SSFP presented a comprehensive description of the physical and environmental interfaces between the payloads and the SSF. Missing from this presentation was recognition of the role that advanced A&R can play in enhancing science productivity during the MTC phase.

ATAC recognizes the importance of well-defined interfaces. However, it appears that the burden to develop or implement any enhancements to science productivity has been transferred to the payload developers and users. For example, any automated sample change-out, manipulation, etc. for each experiment will depend on the ingenuity and innovation of the payload developer, as it appears there is no generic SSF automated capability available for these functions. Additionally, the POIC's ability to plan, schedule, and react to changing conditions will in a large part determine the science productivity. Automation is being implemented in selected areas, such as planning and scheduling.

In summary, ATAC is still concerned about the lack of an effective integrated effort to enhance SSF productivity as a science laboratory, particularly during the MTC. ATAC urges the SSFP to increase program efforts to coordinate more effective integrated Agency activities to enhance SSFP science productivity.

Recommendation IV: Migration of Advanced Automation On-Board SSF.

"SSFP develop a plan including migration of advanced automation technology from ground control centers to on board SSF to address supporting automation advanced development for the SSF PMC operational phase, and present the plan at the July 1992 ATAC review."

SSFP Response to ATAC

"Although the majority of SSFP activities are focused on baseline development, the Program has prudently tried to address growth and evolution. SSF Level I Engineering has been tasked to specifically study and prototype growth and evolution options for the entire Program and does so within the confines of budget availability, schedule pressure, and technology risk."

"The study activities have identified a variety of issues which must be considered when migrating advanced functionality back on-board the SSF. Typical issues are power availability, increased thermal loads, and configuration issues, such as where additional equipment can be located, the routing of additional cabling, and ease of crew access. These issues are interrelated and affect each distributed system and ultimately dictate any growth and evolution strategies. Adding increased functionality in the Data Management System (DMS) provides additional challenges which must be accounted for. Among those issues specifically impacting the baseline DMS are data access, commanding connectivity, compute power, and the physical connectivity of the network."

"The documentation of these and other issues has identified a variety of functional needs. These needs impact artificial intelligence and data systems technology requirements and should drive research and development in those respective technology areas. The SSFP has begun to formally communicate these functional needs to OAST."

"The prototyping activity has focused on packaging advanced automation functionality for compatible insertion into baseline development. Originally, advanced automation fault detection and management prototypes were being developed for on-board implementation but when this functionality was scrubbed from the vehicle these efforts were rescoped to provide advanced functionality within the ground operations distributed system console positions. Currently, advanced fault detection and management prototypes in thermal control, electrical power distribution, and environmental control and life support are scheduled for baseline review and possible integration within the next two years. These prototypes are being developed consistent with the Program's baseline Fault Detection and Management (FDM) subsystem to ensure a smooth transition and implementation."

"Concurrent with this effort to introduce advanced fault detection and management prototypes within the control center environment, the Level I Engineering Prototype Development activity is pursuing three other projects which allow the SSFP to eventually prototype and evaluate the migration of advanced automation back on board the vehicle. The first project is the development of an advanced DMS architecture testbed to independently assess baseline DMS performance and document the design accommodations required for DMS growth and evolution. This testbed serves as the basis of an integrated task plan between Ames Research Center and Johnson Space Center to improve advanced avionics technology transition and insertion. A subtask of this effort is the development of a prototype advanced Embedded Data Processor (EDP) to serve as a potential growth upgrade within the

DMS. The second effort, jointly sponsored by the Defense Advanced Research Projects Agency, investigates the value of portable computing as a mechanism to provide computational resources to the point of action. Advanced portable workstations can support a variety of crew needs and complement the core data system. The third effort is exploration of low cost alternatives in the distribution of real time telemetry. In a joint project with OAST, the ability to link the control center environment with the simulated on-board computational system can now be demonstrated."

"Although these tasks are currently dedicated to individual tactical objectives, they will become much more strategically aligned and integrated in the future. As the advanced fault detection and management prototypes become more robust and mature, they will be hosted on advanced portable workstations for integration and evaluation within the advanced DMS testbed. Links between the control center environment, the advanced DMS testbed, engineering support centers, and the payload operations community are also being planned. This strategic initiative is tentatively planned to last five years subject to budget availability, schedule pressure, and technology risk constraints. Thus, the opportunity to evaluate end-to-end operational scenarios and reexamine early Space Station on-board automated operations management concepts should occur by FY97. At that time, growth and evolution prototypes targeted for PMC improvements can be developed, demonstrated, and evaluated. Ideally, early investments by the research and development community in finding solutions to SSFP growth and evolution functional needs would accelerate the tentative Level I Engineering Prototype Development schedule for migrating advanced automation back on board."

ATAC Assessment

SSFP indicated that it wasn't possible at this time to present a plan showing what would be required and what SSFP would do to accomplish migration of advanced automation on-board SSF for the PMC operational phase at the ATAC review. However, SSFP did present the status on two necessary elements to achieving such a plan, and indicated it would take several years to achieve such a plan.

First, despite the fact that essentially all SSFP activities are focused on baseline development, SSF Level I Engineering has studied growth and evolution options within the confines of budget availability, schedule pressure, and technology risk. These studies have identified a variety of issues related to migrating functionality on board. Power availability, increased thermal cooling, and configuration issues such as where additional equipment can be located, the laying of additional cabling, and ease of crew access are typical issues. The Data Management System (DMS) creates additional issues of data access, commanding connectivity, compute power, and the physical connectivity of the network in the new channelized architecture design. As opposed to the previous distributed architecture, the channelized architecture is more centralized in its approach to systems management, and provides for improved fault analysis and management. All functions requiring two-fault tolerance are hosted in a single two-fault tolerant SDP. All functions requiring one-fault tolerance are hosted in a one-fault tolerant SDP. Designing for evolution and migration of advanced automation on-board SSF requires solutions to these problems.

Second, SSF Level I Engineering Prototype Development is pursuing a five-year strategy of developing prototypes with testbed evaluation, and reexamining migration of advanced automation on board by FY97, which includes:

1. Packaging advanced automation functionality for compatible insertion into base line development for a subset of systems through prototyping,
2. Developing and testing advanced DMS architectures in a test bed to show design accommodations required for DMS growth and evolution including an advanced Embedded Data Processor as a potential growth upgrade within the DMS.
3. Developing an Advanced Crew Personal Support Computer and investigating its value as a mechanism to provide computational resources to the point of action on board and to complement the core data system on board,
4. Exploring low cost alternatives in distributing real-time telemetry and linking the control center environment with the simulated on-board computational system testbed at Ames, including hosting the advanced automation prototypes on advanced portable workstations for integration and evaluation within the advanced DMS test bed,
5. Evaluating end-to-end operational scenarios and on-board automated operations management concepts by FY97, including advanced automation prototypes targeted for PMC improvements, and
6. Attempting to obtain early investments by OAST and others in the R&D community in finding solutions to SSFP growth and evolution functional needs, so that this tentative schedule can be accelerated to achieve migration of advanced automation back on board sooner.

ATAC welcomes this two-pronged effort as a constructive attempt to improve SSF reliability and productivity, and endorses this effort while underlining its importance.

The ATAC wishes to reiterate its support for the eventual development of an on-board SSF automation capability. The autonomous execution of routine decisions and actions, as well as real-time remedial measures, could reduce the level of continual involvement by the Control Center Complex. This should result in significant operational economies over the life of the program. It should also reduce the requirement for very high data rate transmission of all sensor data to be displayed in the CCC. This experience in autonomous space station operation will be invaluable, ultimately, in planetary missions, when long transmission times will preclude ground control.

Recommendation V: Flight Telerobotic Servicer (FTS) Technologies.

"SSFP strongly encourage OAST to organize and implement a timely process to preserve and disseminate, to U.S. industry, the technologies developed during the FTS Program."

SSFP Response to ATAC

"The SSFP shares ATAC's interest in the preservation and dissemination to U. S. industry and academia the advanced technologies developed during the FTS Program. Throughout the Spring of 1992, personnel within the Space Station Freedom Program and the Office of Space Systems Development expressed their encouragement and support to OAST in their efforts to "get the FTS word out." In June, the SSF Level I Engineering Prototype Development manager formally offered to support the OAST Telerobotics program manager in any endeavor intended to improve FTS awareness. At that time, OAST indicated that worthwhile technology and experience developed by the FTS Program would be highlighted at the Space Operations, Applications, and Research (SOAR) symposium and featured at the next Office of Commercial Policy Technology Commer-cialization Conference. An SSFP offer of assistance has been accepted, and is available if called on for support."

ATAC Assessment

An FTS Technology Capture activity was initiated in February 1992, funded by OAST. A Memorandum of Agreement was established between LaRC and JSC and a contract with Martin Marietta Aerospace to complete the ground simulator and assemble the flight arm was negotiated. The Hydraulic Manipulator Test Bed (HMTB) will be completed and delivered to LaRC for test and evaluation in November 1992. The Flight Arm assembly is underway and will be delivered to JSC for environmental qualification and testing in July 1993.

Documentation of the FTS capabilities and test results will be made available to U.S. industries at the completion of the program.

Although some progress has been made in FTS technology dissemination to U.S. industry, ATAC urges SSFP to devote more effort to enhance progress in this area.

A&R Status Review of Levels I and II; WP1, WP2, WP4; CCC, POIC, and OAST

Assessment of Level I.

The Level I Engineering Prototype Development (EPD) effort continues to make excellent progress in developing prototypes in advanced automation applications for SSF.

EPD provides an effective vehicle to demonstrate cost, schedule, and technical risk reduction options and identify minimum impact design accommodations for intelligent systems and robotics. While in general the baseline program budget, schedule and technology freeze constrains implementation and reduces flexibility, EPD can evaluate risk reduction options and technical issues with significantly less cost and time. EPD evaluates selected high payoff options which improve performance and functionality, and leverages complementary activities with other organizations. EPD's tasks are tied to baseline near-term schedules and testbeds.

Engineering Prototype Development focuses on critical baseline issues, such as: the oversubscription of resources (DMS, C&T, EVA, IVA); the proliferation of sensors, software, processors, and the effects of resultant scrubs; the complexity of failure modes and redundancy management; providing flexible capability for users; and the reduction of operations and life cycle costs.

Engineering Prototype Development is now the principal SSFP effort to demonstrate and integrate key innovative technologies. A solid task mix has been established which addresses critical baseline program issues with task demonstrations that are aligned with critical program milestones and decision points. EPD is successfully demonstrating numerous applications that are relevant to baseline program issues.

Recent significant accomplishments of EPD include: 1) Hosting FDIR prototypes on SSF distributed system testbeds and supporting system test and verification, working with Mission Operation Directorate (MOD) to assess validity of EPD FDIR models for insertion into the CCC environment; providing consultance on the use of COTS products; establishing CCC advanced technology testbed, 2) providing DMS performance analysis and design to SSFPO and WP2; providing focus for verifying baseline and payload interfaces and testing access from payloads to DMS services, 3) COMPASS-based scheduler has been prototyped for and adopted by the JSC Shuttle Engineering Simulator; COMPASS being used by Spacehab, 4) a communications network to facilitate telerobotics technology transfer has been established between JPL and JSC, 5) the GSFC capaciflector has been delivered to JSC for evaluation, 6) flat target materials have been subjected to space environmental effects, and 7) EPD is serving as the focus for defining the SSFP technology utilization spinoff process.

ATAC believes that the EPD sponsored TCSAP prototype and the EPS and ECLSS prototypes, are beginning to show reduced cost, schedule, and technical risk to the point that every system on SSF might be evaluated in the future for similar advanced automation applications development to achieve the benefits of improved safety, reliability, and productivity across the SSF.

The ATAC assessment is that EPD is a highly productive activity in addressing some very critical SSF operational issues of the baseline design. ATAC urges SSFP to continue its EPD efforts in advanced automation and robotics at least until the PMC milestone.

Assessment of Level II.

Major progress continues to be made in the implementation of robotics systems and robotics interfaces into the Space Station Program.

Since the commitment of the program to the Robotic System Integration Standards (RSIS) Volumes I and II, the interface problems have been very actively addressed. The appointment of a Robotic Systems Architect to manage the Space Station-wide problem of robotics interfaces and utilization has had a major positive impact. ATAC feels that the Space Station Level II Robotic Systems Architect with support from his Robotics Working Group, which is once again an active and vital group, can handle most of the robotics interfaces and problems associated with the successful incorporation of currently baselined robotics systems and capabilities on Space Station. The Space Station is now committed to robotic servicing.

However, ATAC has a major concern that the Space Station Program has not baselined ground operations of robots on-board Space Station Freedom.

The process of assessing robot compatibility of the Orbital Replacement Units (ORUs) in both hardware and kinematic software evaluations is proceeding well. There are currently 366 robot compatible ORUs representing 41% of the ORUs and 48% of the EVA servicing requirement. This represents a significant capability to offload EVA astronaut activities to robotics. Design and redesign activities to create feasible robotic servicing tasks, serviceable hardware, and interface hardware is proceeding well. Substantial interface questions and design problems remain, but qualified personnel and processes are in place to resolve those issues.

The recent restructuring/descoping of the Canadian Space Agency robotics development program has not decreased the serviceability of the overall Space Station by Canadian Robotics. However, removal of the five degree-of-freedom "body" of the Special Purpose Dexterous Manipulator (SPDM) reduces the functionality and capability of the system and causes almost all servicing actions to be completed with the SPDM attached to the end of the large seven degree-of-freedom Space Station Remote Manipulator System (SSRMS). This will have major ramifications on the timeline required to accomplish robotic maintenance tasks. Control of a compound system of this complexity has never been achieved and research laboratories have had only limited success with much fewer degrees of freedom. Control of the system will be possible, but it will definitely increase the operator workload and the time to accomplish tasks. Kinematic studies are underway to prove the physical feasibility of the maintenance operations. However, dynamic control will be the most difficult aspect of the problem. Information on the dynamics of the SSRMS, SPDM and the compound problem of the SPDM on the end of the SSRMS are not yet available.

The complexity of the 14 degree-of freedom SPDM operating off of the end of the 7 degree-of-freedom SSRMS creates a very complex kinematic and dynamic problem. Extensive ground support will be required to plan the movement of the robot arms. Technology has been developed in U.S. laboratories which could allow control of the robots on board Space Station more quickly and safely than teleoperating them from on board Space Station.

Some of this capability for typical servicing tasks was demonstrated to the ATAC at the Johnson Space Center. An initial Space Station Ground Control Study was conducted using autonomous sequences, teleoperation, and predictive display in a nine second time-delay environment. Initial test results from 11 operators suggest an operator preference and safer operations using a combination of auto sequences and teleoperation with a time delay of 9 seconds over straight teleoperation without time delay. Current Space Station design will result in an on-board time delay of approximately 1 second between the time the astronaut inputs a command from a hand controller and the time the astronaut sees the impact of the input visually. The impact of time delay must be considered in all operations.

The Space Station Program should move quickly to demonstrate the feasibility of operating robotic systems from the ground and, if required, incorporate it as a baseline Space Station capability.

The ability to control the SSRMS/SPDM from the ground would not only reduce the workload requirements of the on-board crew, but would allow early on-orbit checkout of the robotic systems and remote operations during the three years of the Man Tended Configuration. Level II should continue its investigation and demonstrations of remotely operating Space Station robots from the ground and report its progress at the next ATAC meeting.

The complexity of the compound SSRMS/SPDM robotic system will also make collision avoidance complex. The baseline system for collision avoidance is completely visual based on the astronaut operator's ability to see and avoid unintended contact. There is currently a minimum of cameras and viewpoints planned for operations of the Space Station. Technologies for non-visual collision avoidance have been developed. The Canadian Space Agency should be encouraged to investigate these technologies and incorporate or leave hooks and scars for incorporation of an on-board collision avoidance system.

The on-board astronaut teleoperating the robots will not have a world model of the robots, ORUs, or Space Station structure. A world model will be maintained on the ground in the Control Center Complex at JSC to plan operations.

ATAC urges that the Space Station Program evaluate the information required by the astronauts to successfully operate the revised SSRMS/SPDM system, including determination of what information is needed from a world model and how that information will be transferred to the on-board operator.

ATAC has a continuing concern with the lack of a strong focus of advanced automation at SSFP Level II. With the recent restructuring of the Johnson Space Center Combined Control Center, it is possible to do parallel testing and insertion of advanced automation into the program. The Marshall Space Flight Center HOSC is past its preliminary design and is also going into development. It will save the agency time, money, duplication, and frustration if there is a stronger focus at Level II of Advanced Automation.

Assessment of Work Package 1

In Report 14, ATAC expressed a concern that Work Package 1 had not adequately addressed the problem of robotic compatibility of the Unpressurized Logistics Carriers.

ATAC is pleased that Marshall Space Flight Center, Work Package 1, is now committed to making the Unpressurized Logistics Carrier Elements robot compatible.

Although technical problems interface concepts remain to be resolved, the WP1 commitment to a fully robotic compatible interface is a significant step forward in the maintenance and operation of the Space Station Freedom. Commonality in fasteners, robot compatibility, and operations feasibility and timelines remain to be worked.

Work Package 1 also presented to ATAC the automated functions planned for monitoring Space Station hull integrity, fire detection and suppression, internal atmosphere pressure control, trace contaminant monitoring, water quality monitoring, and leak detection for the internal thermal control system. Although these systems do not represent advances in automation technology, any systems which can offload mundane monitoring and control responsibilities from the astronauts are very valuable and are encouraged. As presented to ATAC for its last report, significant advances in monitoring and control are possible if the work on the advanced prototypes in the Level I Engineering Prototype Development Program on the Environmental Control and Life support system (ECLSS) Testbed and the Power Management and distribution (PMAD) Testbed are implemented in the ground control center.

Now that many of the monitoring functions have been moved to ground systems, ATAC is concerned that control of laboratory and habitat module systems from the ground may be seriously degraded. ATAC urges WP1 to conduct an analysis to assure that satisfactory control is possible from the ground. Control with "soft switches" and an evolutionary path to telescience for experiment monitoring and operation from the ground should be available. In like manner, Work Package 1 needs to encourage development of the capability of unloading and loading the Unpressurized Logisitics Carrier with Ground Remote Operations of the Space Station robotic systems.

There are 5,952 internal Orbital Replacement Units (Additional Maintenance Items) on-board Space Station Freedom. Although the internal maintenance time required to service these items is within the assigned limits, attention needs to be paid to the overall design and reliability of the on-board replaceable units to reduce the amount of time required for ORU maintenance. Since 49 of the internal additional maintenance items represent 80% of the maintenance, increasing quality/reliability of filters, lightbulbs, brackets, etc. can lead to a significant reduction on maintenance requirements. A philosophy of continuous improvement on the reliability of additional maintenance items should be followed.

Assessment of Work Package 2

The number of WP2 ORU's, which are baselined for robotic accommodation, has been reduced from 118 to 81. Most of this reduction is due to the deletion of ORU's due to the Space Station restructuring activities. However a few ORU's were deleted from the robotic accommodation list because further analysis indicated that robotic accommodation really was not feasible or that the benefit (in EVA hours saved) to cost ratio was less than had initially been predicted. In addition the requirement for robotic setup of EVA worksites also has been deleted because further analysis indicated that this feature was less significant, in terms of EVA overhead savings, than original predictions.

The CSA/SPAR decision to restructure the Mobile Servicing System (MSS) is expected to have some impact on WP2 use of dexterous robotics and robotic maintenance. A significant factor in determining the list of WP2 robotically compatible ORUs, was the expectation that most ORUs on the list could be serviced by the Special Purpose Dextrous Manipulator (SPDM) mounted directly on the Mobile Remote Servicer Base System (MBS) without requiring the use of the Space Station Remote Manipulator System (SSRMS).

As a result of MBS redesign (SPDM redesign), use of the SSRMS will be necessary for all WP2 robotic ORU operations. This is expected to increase the timelines, and possibly the power, required to perform robotic ORU servicing operations.

Information presented to ATAC indicates that WP2 is now expending a substantial amount of engineering effort in reviewing the program Robotic Systems Integration Standards (RSIS Volumes I and II) and planning and initiating verification analysis and testing to confirm that WP2 robot compatible equipment will satisfy the RSIS requirements. Work Package 2 is supporting the design and outfitting of the Space Station Automated Integration and Assembly Facility (SSAIAF) at Johnson Space Center (JSC). The SSAIAF will be performing real-time dynamic simulations of on-orbit robotic operations with Space Station Freedom (SSF) robotics systems utilizing flight-like hardware.

Work Package 2 continues to pursue three advanced automation tasks. However the program does not presently plan a significant degree of implementation of this technology on-board SSF due to limited computational capability. The Integrated Systems Executive (ISE) Project uses knowledge based system constructs to perform a station wide global failure detection, isolation, and recovery (FDIR) function. As station systems and elements send caution and warning (C & W) messages to the ISE, the ISE is designed to be able to determine the cause of these messages and reconfigure the station's systems appropriately. WP2 is continuing the development of this capability although, at the present time, its use has not been baselined.

Assessment of Work Package 4

ATAC has commented in previous reports on the extraordinary degree to which WP4 has incorporated both automation and robotics into their baseline design and plans for operation of the Electrical Power System (EPS). During the past reporting period, expert systems for normal operations and for fault detection, isolation, and recovery were integrated into the power system test bed and are now being evaluated. Similarly, robotic exchange of power system Orbital Replacement Units (ORU's) was evaluated in test beds and neutral buoyancy tanks. This early test program and evaluation of automation concepts has resulted in valuable suggestions for design improvements and elimination of interface incompatibilities.

WP4 is now testing automated power system health monitoring and operations control expert systems which reconfigure the EPS in response to varying power demand, control battery charge and discharge; exercise thermal control; and point the solar array. At the same time it collects, analyzes, and displays data which documents system safety and faults, and then issues warnings of dangerous trends, and energizes redundant components if advisable. In FY93, these expert systems will be integrated into a prototype operations control console.

The application of automated health monitoring and fault diagnosis for a system as complex as the EPS will require considerably more advanced technology than is presently being tested. The capability must be extended to diagnosis of multiple interrelated faults in a complex network topology. In addition more accurate analytical models and data bases must be developed to portray the configuration and operating characteristics of the system.

ATAC commends WP4 on its early incorporation of automation into its design and operation philosophy, and encourages SSFP to fund and validate appropriate advanced technology to ensure maximum resulting benefits in safe and economical operations.

WP4 reported that of the 213 external ORUs associated with the EPS, 192 have been designed to be robot compatible. (The other 21 will require human manipulation because of access difficulties.) Robotic exchange operations on a number of these modules were tested and evaluated in neutral buoyancy tanks and robotics test beds during June and July. These included Battery ORU's, Electronic Control Unit, Remote Power Controller Module, and Sequential Shunt Unit. Results show that teleoperated operations are feasible. However WP4 suggested design improvements which are already being implemented, new robot tools, and changes to the RSIS volumes (Robotic Standards and Interface System). WP4 has played a major role in updating the RSIS.

Although test results to date have been very valuable, they are only very preliminary. Many more tests are needed. The current test robots do not model the present SPDM. As stated elsewhere in this report, a faithful high fidelity simulation is required of the current SPDM to ensure complete compatibility with WP4 ORU designs and to estimate servicing time lines.

ATAC is concerned that WP4 has no budget to continue test and evaluation of its robotic compatible designs and operations. ATAC believes that full understanding of design implications of robotic operations is needed prior to the CDR dates for the ORUs. This need for continued testing is now more urgent because of the possible serious impact of the SPDM design.

Assessment of Control Center Complex

ATAC was provided briefings at the review by the SSFP's design and implementation agent for the Space Station Control Center (SSCC), JSC Mission Operations Directorate's Control Center Systems Division. Status and progress on including intelligent systems in SSCC since ATAC's last review were provided. The progress was excellent.

Budget reductions have forced reorganization of the Control Center System Division and redesign of the basic concept for the SSCC portion of Control Center Complex (CCC).

In the redesign there are no longer independent Space Station and Shuttle control centers. The old SSCC will become the Orbital Control Center(OCC) with responsibility for operational control of both Shuttle and Station. The Mission Control Center (MCC) will be responsible for Shuttle ascent and entry phases of missions.

This functional split between control centers allows ascent/entry teams and MCC operations to be shut down during orbital operations. But this functional division does not necessarily reduce the manpower complement of these ground systems. No apparent attempt was made to use the same team for both operational phases.

Since SSCC will now be doing Shuttle orbital operations, and MCC upgrades were based on the Real Time Data Systems(RTDS) concept, SSCC will now be more aligned with RTDS. More use would be made of distributed workstations in a highly modular and extensible architecture as well as of advanced automation techniques. Upgrades and enhancements will be easier to accomplish and will be less costly because of this.

SSCC has established a test bed to evaluate and validate the AI/Expert System programs being prototyped by EPD for monitoring various Station subsystems namely, TCS, EPS, and ECLSS. The testbed can accept these programs in many languages and on different workstation platforms for quick look evaluations. Promising programs would then be converted to a common set of languages, platforms and tools, if required. This is a very good approach for SSCC to assess a large number of advanced concepts.

The testbed provides an excellent opportunity for research centers to have their technology reviewed by the end customer and provides an easy, low cost transition mechanism for advanced development products into the CCC operational environment.

ATAC was given a demonstration of the External Active Thermal Control System (EATCS) Fault Diagnosis, Isolation, and Recovery (FDIR) prototype, developed by the Thermal Control System Automation Project (TCSAP), which has model-based sensor validation and model-based component diagnosis, undergoing evaluation in the CCC testbed. The TCSAP prototype has been developed using the G2 knowledge-based system software development tool and a high fidelity simulation of the EATCS. It is worth noting that TCSAP has used human interface guidelines to intelligent systems developed under OAST funding in designing user interfaces, with impressive results. ATAC was shown that the G2 graphics interface can be converted to the CCC Posix standard SAMMI graphics interface as would be used in CCC operations.

The merged MCC/SSCC functions are being implemented earlier and cheaper than previously planned. In spite of this new design, the CCC will meet STS and SSFP mission requirements.

The CCC Fault Detection and Management (FDM) subsystem is being designed for use on both Shuttle and Station. It has a modular design with Knowledge-Based Systems (KBS), limit sensing, etc. Extended real-time FEAT is being baselined. Considerable use is made of Level 1 Engineering Prototype Development (EPD) models. Memory is provided to include advanced reasoning and recovery planning. Fuzzy logic is also being considered for use in the future.

Extended realtime FEAT (FEAT is the acronym for Failure Environment Analysis Tool, a directed graph representation or model of failure modes of equipment) uses knowledge-based systems and realtime telemetry data to interact with FEAT to obtain a narrowed set of candidate failures that are based on the current configuration of the on-board systems. When necessary, more robust reasoners (also model-based) are used in the diagnosis.

In summary, ATAC's assessment is that CCC's modular, extensible, distributed workstation architecture, inclusion of knowledge-based systems, and inclusion of the advanced technologies testbed are all to be commended.

Assessment of Payload Operations Integration Center (POIC)

A brief presentation of overall progress was given at the ATAC review covering the SSFP Payload Operations Integration Center (POIC) at the MSFC Huntsville Operations Support Center (HOSC) as a part of the Enhanced HOSC System (EHS). Status was given on the Data Acquisition and Distribution Services, Telemetry Processing, Database Services, Common User Interface, Scripting Language, Silvabase Data File Management and Utilities Program, System Monitor and Control, CCSDS Packet Generator, and Experiment Scheduling Program.

Current planning for development of the SSF POIC includes the use of state-of-the-art software development tools and a distributed computer architecture which should allow the smooth implementation of automation techniques into the POIC operations and greatly reduce the ground support personnel.

Since the last ATAC Review, HOSC managers of the POIC have expressed their needs for greater flexibility in planning and scheduling and their strong desire for intelligent system technology to meet those planning and scheduling requirements. (See ATAC assessment for progress on Recommendation II above for more information).

ATAC encourages EPD and POIC management to attempt to implement intelligent system planning and scheduling software in the baseline SSF POIC operations prior to the Man Tended Configuration milestone of the SSFP. ATAC's assessment is that this activity is making reasonable progress.

Assessment of Data Management System

ATAC received a detailed briefing of the design simplification of the Data Management System (DMS). The major design changes are:

The DMS was redesigned with a Channelized Architecture. The organization of the power and data buses was changed to provide redundancy throughout the system to allow for fault recovery. This was a very important change.

Most of the non-time critical functions that were to execute on the SDP's have been moved to the ground to reduce the load on the SDP's. However, there was no analysis presented to indicate that the utilization of the SDP's would be under 100%. Time critical functions remaining to execute on the SDPs were grouped into 0-fault, 1-fault, and 2-fault tolerant according to criticality.

System integration and testing facilities consist of the Central Test Facility (CTF), the Avionics Development Facility (ADF), the Central Software Facility (CSF), the Central Avionics Facility (CAF). These facilities and their integration have progressed substantially. This system is driven by an extensive simulation subsystem that provides the environment for testing systems as they are developed. Four releases of architecture and six levels of subsystem and system integration and testing have been defined. These are phased so that each extended release of the architecture arrives in time to develop and test the software for successively higher levels of system integration.

ATAC has the following concerns about system integration and testing in the CTF, ADF, CSF, and CAF:

- The scheduling does not appear to have much slack for unexpected problems.
- The initial fidelity of the evolving models will be low, which will require a corresponding retesting of the systems as the model fidelity improves.
- The CTF developers have had little, if any, involvement with the payload developers. If not brought together soon, the payload developers may proceed in incompatible directions. However, ATAC is very pleased that a series of Utilization Workshops was held to help alleviate this problem.

It is possible for the inputs to a number of control functions to come from any of three sources; an on-board fault detection and recovery system, the crew, or the ground control center. In many cases, the control system cannot distinguish among these; and there is nothing to assure that only a single signal arrives or that if multiple commands are given, that they are consistent.

Prototypes of portable crew support computers (PCSC) are being developed within the EPD program for initially putting advisory functions in new generations of portable workstations that could be brought up with much less effort than a changeout of part of the DMS. The PCSC could be attached to the DMS network for data acquisition and used to advise the crew on such things as diagnosis of faults.

Assessment of OAST A&R Program

The ATAC received an overview briefing on the OAST Operations Technology Program. ATAC had not been briefed on OAST A&R activities since ATAC Report 11, November 1990. The three funded areas of the Operations Technology Program (Artificial Intelligence, Telerobotics, and Space Data Systems) were presented. The briefing attempted to identify specific activities in the AI and Telerobotics Programs which had contributed or were targeted for SSF. However, the briefing was not of sufficient technical detail for the committee to evaluate the relevance, maturity, and potential application to SSF A&R needs.

Many of the ATAC members have detailed knowledge of the OAST program; however, the committee felt it was important to have additional details and technical discussions prior to evaluating the program. The ATAC intends to request a more detailed briefing from OAST at the next ATAC review, and the results will be incorporated in ATAC Report 16.

The emphasis of the review will be to identify all ongoing OAST focused A&R research which has application to SSF, the state of development and projected milestones and deliverables, and the technology integration plan for the transfer of the capability to the SSF program.

New A&R Issues

Ground-Based SSF Science, Operations, and Maintenance

Ground-Controlled Telerobotics

Reports at the ATAC no. 15 meeting indicate that 48% of the SSF ORUs are being designed to accommodate telerobotic maintenance. Recent cost reduction redesigns of the Canadian Mobile Servicing System (Space Station Remote Manipulator-SSRMS and Special Purpose Dextrous Manipulator-SPDM) indicate that the IVA timelines for on-board telerobotic operations could be considerably increased. This increase of IVA to support on-board telerobotic operations could impact the ability to complete on-board payload and science operations unless the on-board telerobotics crew workload is reduced. With 7 degrees of freedom on the SSRMS and 14 degrees of freedom on the SPDM, the arm motions will become very difficult to visualize and teleoperate from on-board the SSF. Tests have been completed that indicate that the up-link/down-link telemetry delays in telerobotic signals can be accommodated through the implementation of qualified and proven telerobotic technologies. These recent developments indicate more emphasis should be placed on developing the capability of ground teleoperation of the SSRMS/SPDM. Also, implementation of ground control of telerobotics will provide a non-tended capability that could prove very useful throughout the Man-Tended Capability (MTC) SSF operational period until Permanent Manned Capability (PMC), currently planned for two and one half years. Hooks and scars for ground telerobotic operations need to be planned as soon as possible to minimize future cost impacts on SSF.

ATAC believes that SSFP needs to undertake a concerted effort to develop and implement a capability to operate the SSF robotic systems from the ground (Control Center Complex). An important part of this effort would be a demonstration of a flight-like architecture performing typical robotics tasks. OAST should be fully included as a member of this development activity. A study should be completed within six months to identify interfaces and impacts of implementing telerobotic ground remote operations.

ATAC recommends that SSFP assess the need, due to SSRMS/SPDM redesign, to operate robotic systems from the ground, and if required, incorporate ground-controlled telerobotics as a baseline SSF capability.

On-Board SSF Science, Operations, and Maintenance

Redesigned SSRMS/SPDM Operation

The recent restructuring/descoping of the Canadian Space Agency robotics development program has not decreased the serviceability of the overall Space Station by Canadian Robotics. However, removal of the five degree-of freedom "body" of the Special Purpose Dexterous Manipulator (SPDM) reduces the functionality and capability of the system and causes almost all servicing actions to be completed with the SPDM attached to the end of the large seven degree-of-freedom Space Station Remote Manipulator System (SSRMS). This will greatly increase the time required to accomplish robotic maintenance tasks. Control of a compound system of this complexity has never been achieved and limited success has been accomplished in research laboratories with many fewer degrees of freedom. Control of the system will be possible, but it will definitely increase the operator workload and the time to accomplish tasks. Kinematic studies are underway to prove the physical feasibility of the maintenance operations. However, dynamic control will be the most difficult aspect of the problem. Information on the dynamics of the SSRMS, SPDM and the compound problem of the SPDM on the end of the SSRMS are not yet available.

The complexity of the 14 degree-of-freedom SPDM operating from the end of the 7 degree-of-freedom SSRMS creates a very complex kinematic and dynamic problem. Extensive ground support will be required to plan the movement of the robot arms. The complexity of the compound SSRMS/SPDM robotic system will also make collision avoidance complex. The baseline system for collision avoidance is completely visual based on the astronaut operator's ability to see and avoid unintended contact. There is currently a minimum of cameras and viewpoints planned for operations of the Space Station. Technologies for nonvisual collision avoidance have been developed. The Canadian Space Agency should be encouraged to investigate these technologies and incorporate or leave hooks and scars for incorporation of an on-board collision avoidance system.

The on-board astronaut teleoperating the robots will not have a world model of the robots, ORU's, or Space Station structure. A world model will be maintained on the ground in the Combined Control Center at JSC to plan operations.

ATAC recommends that SSFP assess the impact of SSRMS/ SPDM redesign on telerobotic operations, specifically including task timelines and collision avodiance issues; and report results at the February 1993 ATAC review.

Data Management System

The DMS was redesigned with a Channelized Architecture. The organization of the power and data buses was changed to provide redundancy throughout the system to allow for fault recovery. Most of the non-time critical functions that were to execute on the SDPs have been moved to the ground to reduce the load on the SDPs. However, there was no analysis presented to indicate that the utilization of the SDPs would be under 100%. Time critical functions remaining to execute on the SDPs were grouped into 0-fault, 1-fault, and 2-fault tolerant according to criticality.

The computational capability of the restructured DMS does not appear to have any computational reserve for any contingencies. Although the hooks and scars are there for the expansion of the DMS, the expansion may be constrained and/or improbable due to the power availability.

ATAC recommends that SSFP conduct a system simulation and analysis of DMS (SDPs, MDMs, sensors, and effectors) in a simulated operational environment to determine the computational reserve of the restructured DMS and its capability to meet the mission objectives and requirements.

A&R Technology Evolution

Control Center Complex Advanced Technology Testbed

Recent developments which have combined the STS and SSF Mission Control Rooms, now designated as the Control Center Complex, have enhanced the potential of migrating advanced automation techniques into the CCC. The new CCC design is being implemented through a distributed computer architecture with a POSIX operating system, which will better accommodate implementation of new automation techniques. Considerable progress has been made in the development of the advanced automation testbed that will enhance the capability to migrate automation techniques into the newly configured CCC. Indications are that the CCC developmental organizations are very eager to test and support the migration of automation techniques into the CCC. Currently the only automation techniques being tested on the new CCC automation test bed are those being developed through the SSF Level I Engineering Prototype Development (EPD) program, and this effort needs to be expanded to include OAST projects. Due to the reduced SSF budget, the funding for the EPD program is being constrained to a point that could delay the migration of the EPD automation techniques into the CCC. Considering these new developments, new sources for automation technologies must be sought that can be migrated through the CCC automation testbed. Other automation development programs exist within NASA, especially the OAST Artificial Intelligence program and the OSSD Advanced Operations program.

ATAC recommends that SSFP continue to support and encourage testing of new automation technologies from Level I EPD and OAST in the CCC advanced technology testbed for migration into the CCC.

Advanced Automation Technology Manager

ATAC has a continuing concern with the lack of a well coordinated and integrated Agency effort for implementation of advanced automation on SSF. OAST is the Agency's leader in AI research and is recognized as having a preeminent AI research capability and knowledge. OAST is knowledgeable of the applicable work being conducted in industry, academia, and other govenment organizations. The restructured JSC CCC architecture employs an RTDS concept orginally sponsored by OAST which allows for efficient parallel testing, verification and validation, and eventual insertion into the CCC operational environment. The definition of the

Marshall Space Flight Center HOSC is past its preliminary design and is also going into development. Effective integration of the OAST advanced automation technologies with SSF requirements for ground mission operations and on-board flight system operation and management will lead to significant cost savings to the Agency, in the CCC and the HOSC as well as SSF.

ATAC recommends that OAST provide an Advanced Automation Technology Manger to SSFP Level I who will coordinate, integrate, and propose advanced automation technologies from within the research community to meet SSF mission requirements.

ATAC Progress Report 15 Recommendations

Ground-Based SSF Science, Operations, and Maintenance

Recommendation I: Ground-Controlled Telerobotics

"SSFP assess the need, due to SSRMS/SPDM redesign, to operate robotic systems from the ground, and if required, incorporate ground-controlled telerobotics as a baseline SSF capability."

On-Board SSF Science, Operations, and Maintenance

Recommendation II: Redesigned SSRMS/SPDM Operation

"SSFP assess the impact of SSRMS/SPDM redesign on telerobotic operations, specifically including task timelines and collision avoidance issues; and report results at the February 1993 ATAC review."

Recommendation III: Data Management System

"SSFP conduct a system simulation and analysis of DMS (SDPs, MDMs, sensors, and effectors) in a simulated operational environment to determine the computational reserve of the restructured DMS and its capability to meet the mission objectives and requirements."

A&R Technology Evolution

Recommendation IV: CCC Advanced Technology Testbed

"SSFP continue to support and encourage testing of new automation technologies from Level I EPD and OAST in the CCC advanced technology testbed for migration into the CCC."

Recommendation V: Advanced Automation Technology Manager

"OAST provide an Advanced Automation Technology Manager to SSFP Level I who will coordinate, integrate, and propose advanced automation technologies from within the research community to meet SSF mission requirements."

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Appendix A

Space Station Freedom Program A&R Progress

The Space Station Freedom Program (SSFP) is applying A&R technologies to the design, development, and operation of the baseline Space Station when found to be appropriate within the context of overall system design, to have a favorable cost-to-benefit ratio, and where the enabling technology is sufficiently mature. A&R technologies are experiencing rapid change, exhibiting varying levels of readiness, and have unique requirements for successful integration with conventional design approaches and system engineering methodologies. Consequently, the provision for design accommodations and mature technologies which permit the program to fully capitalize on A&R advances during the development and evolution of Space Station Freedom is an important consideration. As such, the program intends to leverage the significant momentum in A&R research and technology development within NASA, other government agencies, industry, and academia.

Progress by the SSFP is described in the following sections.

Level I A&R Progress

The Advanced Programs activity at Level I was initially divided into two major components, Evolution Studies and Advanced Development. A detailed overview of Advanced Programs was provided in ATAC Progress Report 7, Appendix B, "Overall Plan for Applying A&R to the Space Station and for Advancing A&R Technology." Additional information can be found in ATAC Progress Report 8, Appendix A, "OSS A&R Progress," and ATAC Progress Reports 9, 10, 11, 12, 13, and 14 Appendix A. Advanced Programs has been reorganized within the Level I Space Station Engineering Division to reflect the priorities resultant from Program Restructuring. The Advanced Development Program has been retitled Engineering Prototype Development and placed within the Systems Development Branch of Level I Engineering. This move more closely ties advanced technology developments to baseline issues and concerns and facilitates the opportunity to insert new technology where appropriate. Evolution Studies has been placed within the Systems Engineering and Analysis Branch to more closely align growth and evolution concepts with baseline scenarios.

The Engineering Prototype Development activity enhances baseline Station flight and ground systems capabilities by prototyping applications of advanced technology. These improvements will lead to increased system productivity and reliability, and help constrain operations and life cycle costs attributable to technological obsolescence. The activity evaluates and demonstrates technologies needed for Freedom's flight and ground systems. This is accomplished by building user/technologist teams within flight and research centers, developing applications using a mix of conventional and advanced techniques, addressing transition and implementation issues, and evaluating performance and documenting design accommodations for technology insertion and implementation. Specifically, cooperative arrangements have been pursued with the Office of Advanced Concepts and Technology; the Office of Space Systems Development Advanced Programs Development activity; the Office of Space Science and Applications; DARPA; and other DoD programs.

As a result of these efforts, the SSFP is acquiring mature technologies, tools, and applications for key systems. In addition, performance specifications and design accommodations are being developed for the insertion of advanced technologies in both flight and ground systems.

Currently, the majority of the Engineering Prototype Development FY93 budget of $7.35M is dedicated to A&R applications and technology demonstration. Tasks are focused on fault detection and management, planning and scheduling, real-time telemetry distribution, advanced data management architectures, system and software engineering, and extravehicular robotics. Twenty-six tasks are divided between four work elements; Flight and Ground Systems Automation ($2.35M), Space Station Data Systems ($2.125M), Advanced System & Software Engineering ($1.25M), and Telerobotic & EVA Systems ($1.625M). Sixteen of the tasks are leveraged by joint funding from the Office of Advanced Concepts and Technology, the Office of Space Systems Development Advanced Programs Development, Shuttle, and the Defense Advanced Research Projects Agency (DARPA). The joint funding adds $7.4M to the tasks and enables Engineering Prototype Development to have considerably greater impact within the Station program than its funding level would indicate. Also worthy of note is the significant participation of Work Package contractors within the activity. Several have focused their own internal Independent Research and Development funding to address complementary objectives of Engineering Prototype Development. The Small Business Innovative Research (SBIR) program is another significant facet of Engineering Prototype Development. Many of the activity's task managers participate in the SBIR program as proposal reviewers and task monitors. This joint funding and coordination significantly augments the amount of resources devoted to building SSF A&R applications, and facilitates technology transition to the baseline station.

In Flight and Ground Systems Automation, advanced fault detection and management applications are being developed for Power Management and Distribution and the Environmental Control and Life Support System at Marshall Space Flight Center, the Thermal Control System at Johnson Space Center, and Power Management and Control at Lewis Research Center. Additionally, a distributed architecture and an advanced failure analysis software package is being designed to support the integration of these techniques into the Control Center Complex baseline Fault Detection and Management (FDM) subsystem. A Spacelab scientific experiment is also serving as the focus of applying advanced automation to support payload experimentation. These applications focus heavily on Fault Detection, Isolation and Reconfiguration (FDIR) and provide a range of support in system status monitoring, safing, and recovery. All are a mix of conventional and Knowledge-Based System (KBS) techniques and each provides a powerful user interface to support interactions in an advisory mode. The primary benefits of these applications are improved system monitoring, enhanced fault detection and isolation capabilities, and increased productivity for SSF mission control personnel and crew members. Increased system reliability via the detection and prevention of incipient failures, reduced IVA maintenance time, and better monitoring with fewer sensors are added benefits of advanced FDIR techniques.

These tasks provide an understanding of the design accommodations required to support advanced automation (e.g., instrumentation, interfaces, and control redundancy) and identify KBS implementation issues (e.g., integration of KBS and conventional algorithmic techniques, processing, data storage, communication requirements, and software development, testing, and maintenance procedures) required for KBS development and support. As more and more functions are scrubbed to a ground implementation, the value and importance of these tasks increase, for they provide the necessary R&D foundation to develop ground-based capabilities and to later migrate those functions back to space. The most significant accomplishments during this reporting period follow.

Advanced fault management knowledge based systems have been hosted on the Work Package 4 Power Management and Distribution (PMAD) testbed and are currently supporting baseline evaluations of the primary power distribution system. The conceptual design of a prototype electrical power system console position has been completed. This conceptual design integrates multiple expert systems, telemetry data, and a sophisticated human-system interface. This FDIR application serves as a bridge between the baseline testbed, the Work Package contractor's automation activities, the LeRC Engineering Support Center, and the JSC Control Center Complex in support of SSF power system operations.

Advanced fault management knowledge based systems have been hosted on the Marshall Space Flight Center (MSFC) PMAD testbed and are currently supporting MSFC assessments of the baseline tertiary power distribution system. This activity has been supporting the Small Business Innovative Research (SBIR) Program for advanced power management and distribution techniques. Two initiatives appear quite promising. One involves using a more sophisticated remote power controller while the other proposes a software solution for coordinating distributed, autonomous, functionally redundant intelligent systems.

Advanced automation fault management activities continue to support the baseline Environmental Control Life Support System (ECLSS). The advanced automation team has been supporting the baseline ECLSS requirements analysis team by providing advanced failure management models for ECLSS Failure Modes and Effects Analysis (FMEA). Additionally, expertise in automated diagnosis has been provided on those activities involving sensor placement and fault isolation which have arisen during the FMEA process.

The Thermal Control System (TCS) advanced fault management project has been integrated into the baseline TCS testbed at Johnson Space Center and continues to support the TCS verification process. The knowledge-based system has shown its worth by improving the TCS test engineer's ability to detect and diagnose system anomalies. The TCS advanced fault management team has also been supporting the baseline TCS models assessment team, Control Center Complex Fault Detection and Management (FDM) system integration, and Space Station Training and Verification Facility activities.

The Control Center Complex is currently assessing the feasibility of using EPD fault management models for SSF operations and is developing a plan to integrate and evaluate these fault management projects within the control center architecture. The TCS advanced fault management prototype is the first of the EPD tasks to be assessed with EPS and ECLSS to follow.

Within Space Station data systems, the computer and network architectures of Space Station Freedom's Data Management System are being analyzed to provide increased performance and reliability and to determine long-range growth and evolution requirements. Additionally, advanced mission planning and scheduling tools are being developed and demonstrated for use on board Freedom as well as on the ground during SSF operations. The most significant accomplishments during this reporting period follow.

The Advanced DMS Architectures task continues to evaluate existing and proposed uni- and multiprocessors; network, protocol and connectivity options; and data management software. Two issues recently explored were the performance of the upper layer network protocol in the DMS and the performance of the LynxOS on embedded processors in the DMS. As a low cost evaluation capability, the architectures testbed has provided focus for early verification of baseline and payload interfaces and for testing access from payloads to DMS services. Results continue to be reported to baseline personnel, the prime contractors, and the DMS subcontractors.

Evaluation of DMS system interface options and computer hardware and software interfaces continues to be supported via Shuttle Development Test Objective (DTO) tasks. A Macintosh portable, whose display format has the same general look and feel of the baseline Multi-Purpose Application Console (MPAC) display, is being used on STS-52 to investigate inventory stowage, on board advanced failure analysis, and orbital map applications using graphics-based interfaces.

The COMputer Aided Scheduling System (COMPASS) continues to improve in functionality and be used in a variety of scheduling applications. It is being used as a backbone for building consensus within the SSF scheduling community. Recently, the development of a report program generator for the Control Center Complex has been initiated. Advanced scheduling techniques from JPL are currently being integrated within the COMPASS framework thereby providing more sophisticated automated scheduling functionality.

In Advanced System and Software Engineering, tools, methodologies, and environments are being pursued to support the design, development, and maintenance of SSFP advanced software and system engineering applications. The most significant accomplishments of this reporting period follow.

The Failure Environment Analysis Tool (FEAT) is the standard SSFP tool for integrating and documenting system and subsystem Failure Modes Effects Analysis (FMEA) and hazard analysis data. The baseline version of FEAT supported by the Technical Management Information System (TMIS) is called the DiGraph Data System (DDS). FEAT is now supported within the UNIX environment and on the Macintosh computer. The development of an intelligent editor which improves the creation of connectivity models has been initiated.

A series of intelligent training systems are being prototyped for the Space Station Training Office (SSTO) to demonstrate the value of Intelligent Computer Aided Training (ICAT) architectures and their feasibility for baseline training operations. The first prototype being developed is for training on the SSF Thermal Control System. A prototype ICAT for familiarity training on the SpaceHab has also been developed. Additionally, ICAT tools have been provided to the SSTO for further evaluation and support of baseline training requirements.

Telerobotic and EVA Systems focuses on IVA and EVA time and safety critical issues and concerns. Telerobotic activities pursue the reduction of IVA teleoperation time for dexterous robotics tasks, even in the presence of significant communications or computation time delays. Advanced telerobotics reduces an operator's workload by allowing the robot to control fine parameters (such as force exerted against a surface) while the operator directs the task. With improved sensing, planning and reasoning, and displays and controls, simple tasks like unobstructed inspections and translations may be accomplished by remote operators in the presence of significant communications time delays. Supervised autonomy can help free the on-orbit crew from routine, repetitive, and time consuming inspection and maintenance tasks whenever possible. The most significant accomplishments during this reporting period follow.

Shared control software algorithms have been developed that permit simultaneous human and/or computer-generated control, local-remote control algorithm partitioning to handle time delay, User Macro Interface (UMI) software to build and execute sequence of task steps (macros) under supervised control, and Operator Coached Machine Vision (OCMV) to allow humans to correct and update vision-based world models and have been extensively tested on the JPL Telerobotics Testbed. These technologies are being transferred to the integrated PIT-segment dual-arm workcell under development at JSC. JPL and JSC have linked their two telerobotics labs together over an existing Internet network so that robotic simulations can be driven remotely from either of the two sites.

An Automated Robotic Maintenance testbed is being established at JSC to integrate and evaluate advanced telerobotics technology in parallel with baseline robotic operations assessments (fig. A1). Work has concentrated on the assembly of an SPDM emulator, implementation of Ada software for the Robotic Fore Arm Pan and Tilt controller, integration of advanced technologies from JPL and GSFC, and overall operational checkout of the complete system.

To allow collision prediction and avoidance within a reduced computational environment, work continues on the evaluation of capacitance-based proximity sensors. Capacireflectors have been shipped to JSC for integration into their testbed and are currently being further evaluated.

The flat target project has made significant progress. This activity has prototyped a series of robotic targets that offer substantial savings within weight and volumetric constraints. It has received strong endorsements from Level II for its potential savings on SSF ORUs and payloads. Flat target prototypes using microstructures have been designed, fabricated, and environmentally tested. Prototypes have been initially demonstrated in laboratory workcell environments. Initial results suggest significant potential.

Level II A&R Progress

Level II dedicates two full-time civil servants, several part-time civil servants, and a number of contractors to manage the integration of A&R in the baseline program. These individuals are responsible for ensuring integration across Work Packages and International Partners (e.g., Orbital Replacement Unit (ORU) standards, End-to-End Extravehicular Activity (EVA)/ Extravehicular Robotics (EVR) Maintenance Study). They also address issues that impact at the program level, such as hand controller commonality, Mobile Servicing System (MSS) restructuring, and verification. Additionally, overall on-orbit assembly and maintenance responsibility resides at Level II in which robotics play an extensive role in achieving these objectives.

Much of the Level II A&R activity is focused on the Robotics Working Group (RWG). This forum meets approximately three times per year at various locations to address A&R topics of interest at Level II and Level III. Some of the major topics addressed at recent RWGs include: CSA and NASDA Program Status, Robotic Systems Integration Standards (RSIS), ground control, Robotic Systems Architect, collision avoidance, viewing, human/machine interfaces, and robotics verification.

Since ATAC Report 14, significant progress has been made on the RSIS document and associated robot-compatible ORUs. RSIS Volume II – Robotic Interface Standards was baselined on June 4, 1992 and distributed throughout the Program. Associated cost impacts were approved at the Program Liens Review in June, 1992, and funds have been transferred to the Work Packages. Both RSIS Volume I – Robotic Accommodation Requirements and RSIS Volume II are being updated to Revision A status, which will occur in the final quarter of CY92. RSIS interface testing is underway at JSC and CSA/SPAR, with an emphasis on box-level testing. The Program Definition and Requirements Document (PDRD) Section 3, Table 3-55, which is the mechanism for identifying ORUs to be made robot

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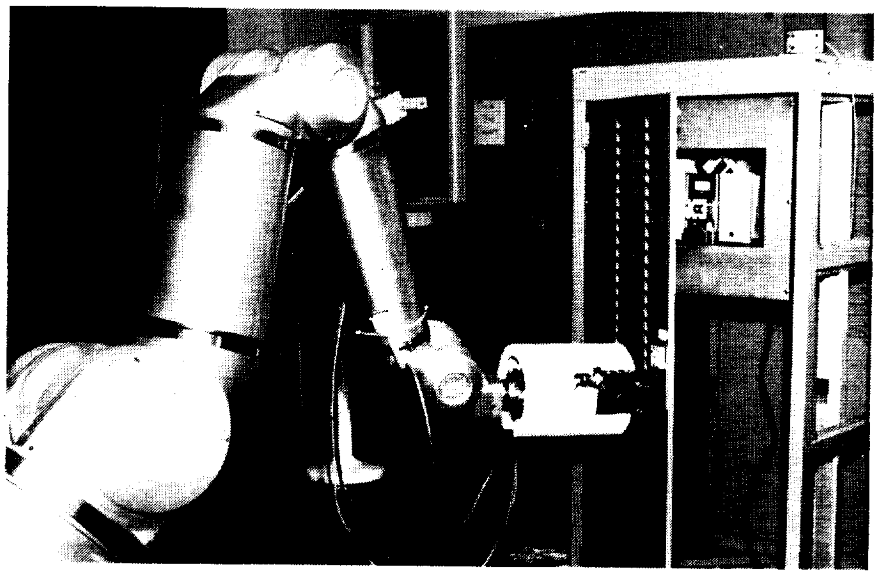
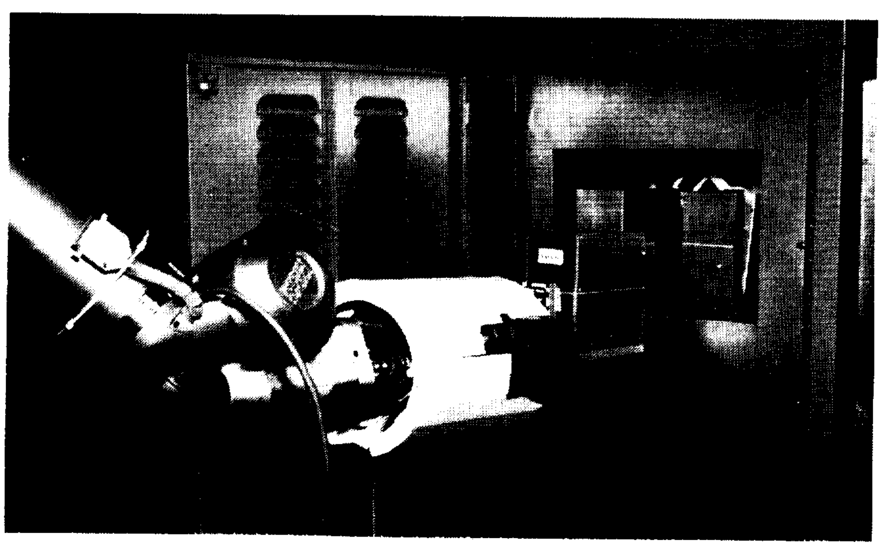


(a) Testing telerobotic task of opening door.



(b) Testing telerobotic task of removing ORU.

Figure A1. Ground-controlled telerobotic testing in laboratory at JSC.

compatible, was baselined on June 4, 1992 (along with RSIS Volume II) and incorporated into the PDRD. This table identifies 366 ORUs, which comprise 41% of the external ORUs of SSF and represent a potential 48% offload of EVA maintenance time to robotics.

Proposals for modification to Table 3-55 are entertained at each RWG, and a Change Request (CR) for a block update to the table will be submitted in December 1992.

The End-to-End EVA/EVR Maintenance Study has progressed since ATAC Report 14. In order to ensure that SSF hardware, infrastructure, servicing agents, and logistics and operational concepts are compatible, efficient, and cost-effective for end-to-end maintenance missions by EVA and robotics, a multicenter team has performed an end-to-end task assessment and developed and recommended an end-to-end infrastructure. The end-to-end task assessment involved developing a candidate task flow and performing an ORU traffic analysis, from which several disconnects and opportunities to improve task efficiencies were identified. The recommended end-to-end infrastructure includes both a hardware concept and an interface concept to accommodate ORU adapter plate, subcarriers, ORU handling at the worksite, and robotic setup of EVA worksites. The results of this study will be presented to program management in November 1992.

Level II is responsible for integrating A&R requirements and plans with the International Partners (IPs), who both develop and utilize robotic systems on the SSF. NASA had the final responsibility in matters of safety, operational commonality, and resources for users, which it exercises through an active dialogue with the IPs and through participation in all major IP program reviews such as PDRs and CDRs. A clear process exists to resolve issues between NASA and the IPs, beginning with biannual Joint Program Reviews (JPRs) and ultimately the Level I Program Coordination Council (PCC). At the technical level, CSA and NASDA report their program status at each RWG, with the JPR serving as the approved management forum if issue resolution cannot be reached in the RWG.

NASA and CSA held a meeting in February 1992 to define roles and responsibilities relating to simulations and math model interchange, Robotic Systems Architect (RSA), and robotic task analysis and verification. The results of this meeting were finalized in a jointly signed agreement and presented to the Program Liens Review in March 1992. Key aspects of that agreement relate to the provision by CSA of kinematic and dynamic models of the Space Station Remote Manipulator System (SSRMS) and Special Purpose Dexterous Manipulator (SPDM), and the assignment of SPDM task analysis and verification to CSA and SSRMS task analysis and verification to NASA.

Work Package 1 A&R Progress

Work Package 1 automation activity is directed at operational functioning of Work Package 1 systems, as well as fault detection and isolation within those systems and elements. The HISS (Hull Integrity Sensor System) consists of a sensor array whose function is to locate through mapping acoustics any penetration to the primary pressure shell. The FDS (Fire Detection and Suppression) System for the Space Station Freedom is based on a plumbed suppressant coupled to a volume isolated smoke sensor system. This system allows for the detection and isolation of fires to individual confined volumes, i.e., racks, end cones, or standoffs. The Element Total Pressure Control System is a closed loop control system which will maintain specified pressure through a combination of gas supply and positive pressure relief. GCA (Gas Conditioning Assembly) pressure control is accomplished through the use of a firmware controller physically located with the GCA. Positive pressure relief is provided through closed loop logic controls. Pressure and temperature are utilized to determine usable gas quantity. The Trace Contaminant Monitoring System utilizes a central GC Mass Spectrometer tied to remote sampling lines in all pressurized elements. The system utilizes a control sequence for sampling and analysis. The process water quality monitor is an automated inline monitoring system which utilizes the ECLSS Water Processor. ITCS (Internal Thermal Control System) leak detection is an automated sequence utilizing pressure differential for leak detection and pressure relief for leak control. Baseline robotic activities have concentrated on support to program-wide robotic interface standards to ensure the compatibility of Work Package 1 ORUs to the ULC and SSF robots.

Work Package 2 A&R Progress

Space Station Automation and Robotics (A&R) is centered in the Project Integration Office of the Space Station Projects Office. This office is responsible for defining requirements for A&R while the actual implementation is done by the various system and element organizations. Engineering management support from the organization comes mainly from the A&R Division which is organized into five branches: Intelligent Systems, Flight Robotic Systems, Robotic Systems Technology, Dynamics Systems Test (including the Space Systems Automated Integration and Assembly Facility (SSAIAF)), and A&R Laboratory Management. The requirements tracking, integration analysis, technical management, and liaison for robotics comes from the Flight Robotic Systems Branch.

Most of the robotics activities for this period have been internal to the Work Package in implementing the decisions of the December 4, 1991 SSCB. Budget constraints, design changes, and deferred hardware deliveries have reduced the robot compatible ORU list. The group of ORUs selected (81 total) to be made robot compatible includes 6-B Avionics ORUs and Thermal Control System Fluid Box ORUs. Although these ORUs account for only about 17% of the total ORUs within this work package, they represent a much more significant percentage of the total maintenance activity that is projected to occur during operations. Robotic setup of the EVA Worksite has been found to be a less significant contributor to EVA overhead savings than originally predicted and has been deleted from the current plan. JSC is negotiating Robotic Track Tasks with MDSSC-HB to take advantage of certain JSC kinematic simulation and hardware testing capabilities.

The current Work Package 2 Advanced Automation applications include: Data Management System (DMS) Fault Detection Isolation and Recovery (FDIR) prototype, Integrated Systems Executive (ISE) Caution and Warning synthesis software capability, and a Crew Health Care System (CHeCS) medical support capability. Support is also provided for the Thermal Control System Automation Project (TCSAP) which is funded by Level I.

The DMS FDIR prototype has been completed and the results documented. Included are lessons learned about organizing knowledge based systems to comply with real time performance requirements. The team lead for this effort is now supporting two baseline activities: (1) creation of the FDIR requirements for DMS System Management, and (2) support for the development of an integrated station wide FDIR approach as part of the Avionics Integration Teams and System Management Team.

The ISE Caution and Warning synthesis function had early prototypes developed in CLIPS and then translated to Ada. These prototypes show how a set covering approach could be used to diagnose intersystem fault propagation and help synthesize numerous systems alarms caused by one fault into a message identifying the root cause. Because of restructuring, this effort has been deferred to the PMC release of station software. There is presently no baseline approach to performing this function since restructuring has deferred requirements development in this area.

There are several medical decision support systems available to the medical community. A project plan had been developed to evaluate these systems and integrate them into the onboard platform along with a customized medical knowledge base specific to the astronaut population. An adaptation of this project recently became part of the CHeCS software baseline when the latest revision of the inflight medical requirements was approved. With this capability available onboard to support the Permanently Manned Configuration (PMC), it may be possible to reduce the need for onboard or ground based medical personnel to be available on a constant basis. An additional possible benefit would be a standardized protocol for medical diagnosis. This is the only currently known advanced automation application planned for onboard usage in the Space Station Freedom Program.

The JSC Automation and Robotics Division, assisted by MDSSC, is outfitting the Space Station Automated Integration and Assembly Facility (SSAIAF) for real-time dynamic simulations of on-orbit robotic operations. Test system capabilities will be delivered in phases including an upgraded SRMS capability for SSF flights 1-3, SSRMS capability for flights 4-6, and full SSF capability for Post MTC activities. SSAIAF plans to support SSFP for the complete life cycle with engineering evaluations, crew familiarization, and real time mission support during assembly and maintenance operations.

The Canadian Space Agency decision to restructure the Special Purpose Dexterous Manipulator (SPDM), eliminating the five degree of freedom body and replacing it with the SSRMS for almost all ORU operations, has resulted in some Work Package 2 hardware impacts and significant operational impacts. The change in the operational philosophy of not being able to use the SPDM directly from the MBS without the SSRMS will increase operational timelines and may increase power requirements. Hardware required to accommodate the restructured SPDM robotic activities includes the addition of an estimated 32 H-Fixtures and targets for stabilization on the front three faces of the truss.

Work Package 4 A&R Progress

The automation activity within Work Package 4 has concentrated on developing decision-support expert systems to aid the operators of the electric power system. The approach integrates the work package's Engineering Support Center (ESC) and the Power Management and Distribution (PMAD) testbed to provide an environment for experimenting with automating the ground-based control process. Since the last ATAC report, the Engineering Prototype Development team has completed a communication link between the ESC and the PMAD testbed. This link simulates the communications expected between the power system's flight control computer and a ground-based control center.

The first experiment in this environment demonstrated human consultation using the TROUBLE failure detection and diagnosis system. New human interfaces were built using Goddard's TAE+ graphics program. Ohio State University's Cognitive Systems Engineering Laboratory personnel provided counsel on human factors. A second set of displays was created to interface with the BATTMAN battery monitoring expert system. In both instances, the displays show system functional status as well as supporting dialog with the diagnostic expert systems.

Future efforts will expand the detection and diagnostic software's competence to include the photovoltaic arrays, their voltage regulation systems, and the battery charge control regulators. The objective is to demonstrate electric power system command and control from a mission operations console position using decision support information from expert systems.

Work Package 4's prime contractor, Rocketdyne, Inc., is pursuing an automation design for the flight system that features automatic regulation of battery charging, battery temperature, beta gimbal position control, and array voltage regulation. All of these systems require setpoints specified by ground control. In addition, all pertinent system parameters are subject to automatic operating limit violation detection and reporting.

Rocketdyne's IR&D program is investigating health monitoring, failure diagnosis, and human interfaces. A power system advisory controller (IPAC) has been integrated with a detailed simulation of the power system. The simulation produces a telemetry stream which is received by the IPAC. Taken together, they emulate the data retrieval process of a ground support system. The IPAC currently detects low and high impedance short circuit paths in the distribution network. Its capabilities will be extended to include multiple failures and trend analysis.

The robotics effort of Work Package 4 has focused on increasing the level of compatibility between the Work Package 4 ORUs and the robotic systems planned for SSF. The effort maximizes the use of telerobotics as the method for maintenance. Almost all external Work Package 4 ORUs are designated for robotic compatibility. Over the last six months, the main emphasis in the robotics area has been on neutral buoyancy testing at the Oceaneering Space Systems facility. Major test series were conducted on high fidelity mockups of the Battery Box, the Remote Power Controller Modules (RPCMs), and the Beta Gimbal Electronic Control Unit (ECU). The battery box ORU is the largest of the Work Package 4 standard ORU boxes and thus is representative of the Battery Charge/Discharge Unit (BCDU), the Pump Flow Control Subassembly (PFCS), the DC-to-DC Converter Unit (DDCU), the Main Bus Switching Unit (MBSU), and the DC Switching Unit (DCSU). Overall, these test results demonstrated improved alignment guide capabilities and attempted to direct the development of visual cues used by the teleoperator. It is not possible to verify the robot compatibility of these ORUs at this time due to the absence of program-wide testing standard parameters, however, the tests have provided a high level of confidence in the robotic interfaces (alignment guides, etc,) developed to date. 1-G tests have been performed on mockups of the Work Package 4 ORUs in Canada at Spar Aerospace and other labs in the U.S. Computer analysis and simulation have further developed the operational scenarios. Work Package 4 continues to be involved in design reviews and technical interchanges with CSA. Also, a Work Package 4 version of the Robotics Systems Integration Standards has been implemented to quickly respond to program and robot/interface changes in order to remain current in planning the robotic maintenance scenarios.

Mission Operations Projects Office A&R Progress

Automation and Robotics technology use within the Mission Operations Projects Office (MOPO) is driven by the needs of operators to monitor, command, and control the various distributed systems and subsystems of Space Station Freedom.

Due to significant budget reductions for SSFP ground facility development, greater system commonality in the development of SSFP and SSP control centers has become the approach taken by the Mission Operations Project Office (MOPO) in order to achieve improved quality, more efficiency, and lower development and operations costs. MOPO has embraced a new operations concept and architecture for the Space Station Control Center (SSCC) as well as the Mission Control Center (MCC).

The resultant Control Center Complex (CCC) is the collection of control center systems which support ground monitoring and control of both the space station and space shuttle vehicles. The new operations concept calls for the SSCC to be utilized as an Orbital Control Center (OCC), which will combine SSFP and SSP orbital operations support. Once the OCC facility development is complete, the MCC will be transformed into an SSP Ascent/Entry Control Center. Operationally, the Ascent/Entry Control Center will be deactivated post insertion and reactivated to support entry and landing of the space shuttle vehicle. This concept of permanent facilities addresses the cost reductions in facility development, sustaining engineering, and maintenance and operations by allowing programs to share costs, as well as provides modernized ground facility support to the orbital operations of the space shuttle vehicle. Overall, the CCC provides the basic core command and control capability for SSFP, achieves replacement of existing MCC command and control capabilities by sharing the new SSFP capability, and permits the removal of outdated MCC equipment to achieve major maintenance and operations cost savings.

The CCC facility development is achieved by providing a series of deliveries and releases. An early Commercial Off The Shelf (COTS) platform is the first release of capability, which will be delivered by the end of this calendar year. This initial release will demonstrate a dual telemetry stream capability in a distributed environment using tools already available commercially or within NASA. Incrementally phased releases of capabilities are planned in order to provide early feedback and iteration on those capabilities with a shorter turnaround time than has been achievable in the past.

The extensible CCC architecture allows for the incorporation of Artificial Intelligence (AI) applications, which can be shared between flight programs where applicable. The Fault Detection and Management (FDM) subsystem is utilizing the strengths of the distributed architecture by providing a modular design which supports the incorporation of new technologies at minimal cost and operational impact. Within FDM, the Extended Real-time FEAT (ERF) project provides a real-time fault analysis capability by utilizing heuristics and real-time data to emulate mission controller interactions with FEAT. Knowledge-based systems from the Real Time Data System (RTDS) project will be rehosted to the CCC platform and utilized for space shuttle fault detection and analysis. Level I Engineering Prototype Development (EPD) program models are being assessed for use as potential space station fault detection and analysis applications within FDM as well. Software hooks are being designed into FDM to provide the capability to integrate these technologies into the system, as well as to provide a growth path toward the use of future technologies. The CCC is striving to provide a state-of-the-art integrated fault detection and analysis capability by not only developing applications in-house, but also by further development of technologies developed by external organizations as they become available.

A models assessment plan has been developed, which provides the criteria and procedures by which externally developed fault detection and analysis models and applications will be evaluated. The Level I EPD model for the SSFP Thermal Control System (TCS) is currently under evaluation by the Models Assessment Team (MAT). This model has been installed in the CCC testbed facility, where hands-on evaluations by mission controllers and the facility development organization have been achieved. Upon completion of the assessment, documentation will be provided on changes deemed to be necessary to allow for the integration and use of the model within FDM. It is anticipated that models will be evaluated tentatively every six months, with the Level I EPD models for the SSFP Electrical Power System (EPS) and Environmental Control and Life Support System (ECLSS) following the TCS.

The CCC testbed facility has been established for early standalone development and assessment of AI tools, and will provide an integration function allowing existing RTDS platform resources to become an extension of the CCC testbed to the flight controller office environment. This approach will allow early investigation of new applications by the flight controller user community with minimal impact to ongoing work requirements. The CCC testbed will provide technical support for demonstrations and evaluations, as well as AI prototyping efforts. Currently, this testbed is being utilized to support the evaluation for selection of a baseline AI tool to be utilized throughout the CCC, FDM models assessment activities, and RTDS platform integration planning.

Payload Operations Projects Office A&R Progress

The automation activity within the Mission Operations Laboratory for the Payload Operations Projects Office is driven by the needs of operators to integrate, plan, monitor, command, and design and control SSF payload activities. These activities are directed to design and development of the Payload Operations Integration Center (POIC), the SSF Work Package 1 Engineering Support Center (ESC), and the SSF United States Operations Center (USOC). This development focuses on a generic core system utilizing distributed computing, integrated systems monitoring and control, standardized user interfaces, centralized data base management and an open, flexible system environment. Since this core system is generic, it provides multi-project support, realizing extensive savings across the agency in executing payload operations.

Since the last report, the following developments have occurred. The Enhanced HOSC System (EHS) Preliminary Design Review (PDR) was conducted. Work was begun on the Critical Design Review. The first iteration of the EHS user interface design was completed and the user interface evaluation team has conducted approximately 45 highly successful end-user interface evaluation sessions. Work is in progress to complete the first draft of the EHS Common User Interface Standard. The new Data Distribution System (DDS) was delivered and installed. Studies were completed on the use of a relational database management system for near-real time data logging and prototypes of telemetry processing graphical user interfaces were developed for user evaluation. Relational Data Base Management System (RDBMS) prototypes of telemetry and command characteristics data bases and file management are nearing completion. The power of RDBMS technology to validate data base data as it enters the system, whether the point of entry is user-interactive or batch mode, is being investigated. In the area of integrated systems monitor and control, operations, systems and development personnel have defined how the system will automate job functions utilizing technology of state-of-the-art COTS products.

Appendix B

Acronyms

A&R	Automation and Robotics
AC	Assembly Complete
AMS	Acceleration Mapping System
ARC	Ames Research Center
ATAC	Advanced Technology Advisory Committee
AWP	Assembly Work Platform
C&T	Communications and Tracking
CCC	Control Center Complex
CDR	Critical Design Review
CETA	Crew and Equipment Translation Aid
COMPASS	Computer Aided Scheduling System
CR	Change Request
CSA	Canadian Space Agency
CSP	Canadian Space Program
DARPA	Defense Advanced Research Projects Agency
DKC	Design Knowledge Capture
DMS	Data Management System
DTF-1	Development Test Flight (first FTS test flight)
DTLCC	Design to Life-Cycle Costs
ECLSS	Environmental Control Life-Support System
EMI	Electric-Magnetic Interference
EMST	External Maintenance Solutions Team
EPD	Engineering Prototype Development
EPS	Electrical Power System
ESA	European Space Agency
EVA	Extravehicular Crew Activity
EVR	Extravehicular Robot Activity
FDIR	Fault Detection, Isolation, and Recovery
FEAT	Failure Environment Analysis Tool
FEL	First Element Launch
FSE	Flight Support Equipment
FTS	Flight Telerobotic Servicer
GN&C	Guidance, Navigation, and Control
GSFC	Goddard Space Flight Center
HOSC	Huntsville Operations Support Complex
IDR	Integrated Design Review
IROP	Integration Requirements on Payloads
IR&D	In-House Research and Development
ISE	Integrated Station Executive
IVA	Intravehicular Activity
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KBS	Knowledge-Based Systems
KSC	Kennedy Space Center
LaRC	Langley Research Center

LCC	Life-Cycle Cost
LeRC	Lewis Research Center
MCC	Mission Control Center
MDM	Multiplexer/Demultiplexer
MOD	Mission Operation Directorate
MSAD	HQ Microgravity Science and Applications Division
MSC	Mobile Servicing Center
MSFC	Marshall Space Flight Center
MTC	Man-Tended Capability
MUT	Mission Utilization Team
NASA	National Aeronautics and Space Administration
NTSC	National Television System Committee
OAST	Office of Aeronautics and Space Technology
OMIS	Operations Management Information System
OMS	Operations Management System
ORU	Operational Replacement Unit
OSSA	Office of Space Science and Applications
OSSD	Office of Space Systems Development
PDR	Preliminary Design Review
PES	Payload Executive Software
PDRD	PDR Document
PDSS	Payload Data Services System
PI	Principal Investigator
PIT	Pre-Integrated Truss
PMAD	Power Management and Distribution
PMC	Permanently Manned Capability
POIC	Payload Operations Integration Center
POP	Program Operating Plan
RSIS	Robotic Systems Integration Standards
RTDS	Real-Time Data System
SPAR	Spar Aerospace Limited
SSFPAH	Space Station Freedom Payload and Accommodations Handbook
SSSAAS	Space Station Science and Applications Advisory Subcommittee
SDP	Standard Data Processor
SDTM	Station Design Tradeoff Model
SPDM	Special Purpose Dexterous Manipulator
SSCC	Space Station Control Center
SSE	Software Support Environment
SSF	Space Station Freedom
SSFP	Space Station Freedom Program
SSRMS	Space Station Remote Manipulator System
TCS	Thermal Control System
TEXSYS	Thermal Expert System
WETF	Weightless Environmental Test Facility
WP	Work Package

Codes

Code D	NASA HQ Code for the Office of Space Systems Development
Code M	NASA HQ Code for the Office of Space Flight
Code MT	NASA HQ Code for the Office of Space Flight, Space Station Engineering
Code R	NASA HQ Code for the Office of Aeronautics and Space Technology
Code S	NASA HQ Code for the Office of Space Science and Applications

Appendix C

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13. ABSTRACT ***(Maximum 200 words)***

In April 1985, as required by Public Law 98-371, the NASA Advanced Technology Advisory Committee (ATAC) reported to Congress the results of its studies on advanced automation and robotics technology for use on Space Station Freedom. This material was documented in the initial report (NASA Technical Memorandum 87566). A further requirement of the law was that ATAC follow NASA's progress in this area and report to Congress semiannually. This report is the fifteenth in a series of progress updates and covers the period between February 27, 1992 to September 17, 1992. The report describes the progress made by Levels I, II, and III of the Space Station Freedom in developing and applying advanced automation and robotics technology. Emphasis has been placed upon the Space Station Freedom program responses to specific recommendations made in ATAC Progress Report 14. Assessments are presented for these and other areas as they apply to the advancement of automation and robotics technology for Space Station Freedom.

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