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Space Station Freedom
Engineering Prototype Development

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Space Station Freedom Evolution
Beyond The Baseline

August 8, 1991

Alan Fernquist
Code MT
NASA, Headquarters

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Briefing Outline:

- Background
- Objective
- WBS Elements
- Summary

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Engineering Prototype Development

Program Content Guided by a Series of Focused Studies

The content of the Advanced Development Program and subsequent Engineering Prototype Development activity has been guided by a series of focused studies. These studies Started with the report of the Advanced Development Task Force led by Ray Hook in 1988. An outline of issues relating to Automation, Data Systems and Telerobotics was projected for Space Station. Subsequent studies built upon and reaffirmed a focus on development and prototyping of Automation Technology for subsystem monitoring and problem diagnosis, Data System growth to accommodate more sophisticated automation, and use of Telerobotics technology to assist in the reduction of required EVA and IVA task time.

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Program Content Guided by a Series of Focused Studies:

- Advanced Development Task Force (LaRC/Hook), 2/88
- SSF Advanced Automation Study, 5/88
- FTS Evolution Plan, 10/89
- SSFP Automation Review & Testbed Study, 12/89
- Astronaut Productivity Study, 3/90
- NASA Computational Requirements Workshop, 7/90
- External Maintenance Task and Solutions Team, 7/90
- NASA Telerobotics Testbed Study, 10/90
- DMS Baseline Assessment & Evolution Study, 1/91

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Restructuring Issues Emphasizing Automation and Robotics

Even prior to restructuring it was widely recognized by the Space Station community that operations would be constrained by the availability of crew and system resources. With the restructuring of Space Station Freedom even more emphasis must be placed on utilizing the available resources in an efficient manner. With a minimal Manned Tended Configuration and Permanently Manned Configuration (PMC) resources such as Power, Crew, DMS, C&T, etc must be utilized efficiently. With the several years of Manned Tended operation, the systems will be manned on-orbit for only small fraction of the time. As a result it is important to assure high productivity during Shuttle visits and utilize Station as much as possible during unmanned periods via remote monitoring, control, and reconfiguration of systems.

In addition, long term operation in the PMC time period with manually intensive systems might require more than the two housekeeping Crew for IVA and EVA activity. Assuring sufficient Crew for payload operations will be accomplished through emphasis on reducing system IVA tasks and task time.

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Restructuring Issues Emphasizing Automation and Robotics:

- **Minimal MTC, PMC configurations have reduced resources & redundancy -- Power, Crew, DMS, C&T, Racks**
- **Longer time between MTC and PMC configurations**
  - **High productivity during Shuttle visits important**
  - **Utilization during unmanned periods important**
  - **Remote monitoring, control, and reconfiguration of systems during unmanned periods critical**
- **PMC configuration Crew/systems reduction impacts operations and utilization**
  - **Manually intensive systems might require >2 housekeeping Crew (IVA and EVA)**
  - **Reduction of crew dedicated to payload operations at PMC**

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Objectives

The objective of Engineering Prototype Development is to independently evaluate current baseline system function and performance and develop prototypes to enhance baseline SSF flight and ground systems capabilities. Task objectives include improving productivity and reliability of selected subsystems by applying appropriate technologies; reducing EVA and IVA task time to reduce Crew workload and provide time for high priority applications; Reducing technological obsolescence by identifying system problem areas, and growth options; and identifying options for reducing power consumption and weight.

In addition to the baseline focus indicated above, a secondary aspect of Engineering Prototype Development is to provide enabling technology for SSF evolution by developing prototypes for advanced automation and robotic applications for EVA Systems, ECLSS, and DMS.

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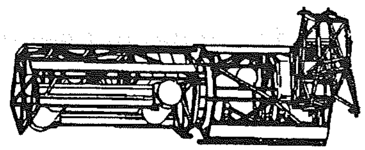
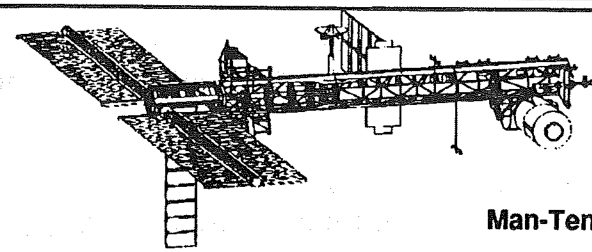
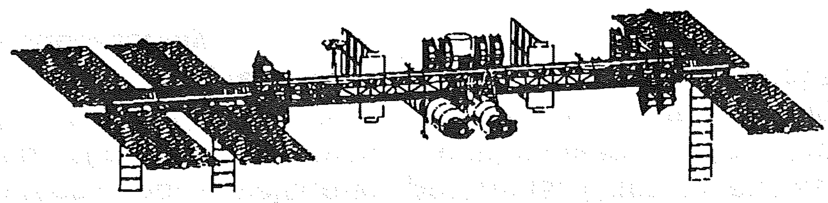


First Element Launch



Man-Tended Configuration



PMC and Beyond

OBJECTIVES:

- Enhance baseline SSF flight and ground systems capabilities
  - Improve productivity & reliability
  - Prevent technological obsolescence
  - Reduce EVA, IVA task time
  - Reduce power consumption and weight
- Provide enabling technology for SSF evolution
  - Advanced EVAS, ECLSS, DMS, automation & robotics applications

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Approach

The approach for Engineering Prototype Development is to evaluate technologies for selected flight and ground systems via focused studies and subsystem evaluations. An important aspect in deciding on focus for the work is developing programmatic relationships with other NASA offices and Government agency research and technology development programs. Often the expertise for understanding the approach or application of an advanced system requires teaming of technologists and operations or user organizations. Building such teams is an important aspect in assuring effective technology transfer. As has been often stated, technology transfer is a "body contact sport" requiring close working relationships to do it successfully.

Each application or prototype is unique in the mix of conventional and advanced techniques. It is incumbent on the task team to decide on the appropriate mix of these techniques in developing a prototype that realistically takes the Space Station resource and operational environment into consideration. As such, transition and implementation issues are addressed early.

Developing and testing technology in a laboratory is only the first step in developing successful prototypes and evaluating systems. Demonstrating the prototypes on high fidelity testbeds and performing operational evaluations with technologist , engineering and operations personnel involved is imperative in evaluating the success or progress of a prototype development. Included in the approach is documenting performance requirements and design accommodations for technology insertion and implementation in the SSF baseline systems.

Engineering Prototype Development

__APPROACH__:

- **Evaluate technologies required to achieve objectives for SSF and ground systems**
- **Leverage NASA and other Government agency research and advanced technology development programs**
  - **OAET, NSTS, OSSA**
  - **DARPA, USAF, Navy, SDIO**
- **Build user/technologist teams within, and between, flight and research centers**
- **Develop applications using mix of conventional & advanced techniques**
- **Address transition and implementation issues early**
- **Demonstrate applications using high fidelity testbeds and "operational" evaluations**
- **Document performance requirements, design accommodations for technology insertion and implementation**

Engineering Prototype Development

Products and Benefits

As a result Engineering Prototype and Development tasks provide high fidelity demonstrations and evaluation of candidate applications using advanced technology where appropriate. The SSF program is provided with an understanding of requirements, performance specifications and design accommodations required for improving the functionality or performance of monitoring and diagnostics or operations of a system. In addition, a level of maturity in technology, tools and applications can be demonstrated for SSF flight and ground systems so that informed decisions can be made in the application of technology on the Program.

Engineering Prototype Development

PRODUCTS & BENEFITS:

- "Engineering" fidelity demonstrations and evaluations of advanced technology
- Detailed requirements, performance specifications, and design accommodations for insertion of advanced technology
- Mature technology, tools, and applications for SSF flight and ground systems
- Increased confidence in, and reduced risks associated with, new technologies

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Tasks evaluated for their potential to

As with any activity of this nature, there is always more work to do than resources to apply. In addition, it is necessary on a periodic basis to evaluate or prioritize new projects which are candidate additions. We have developed a set of criteria, along with a process for evaluating and prioritizing the work in Engineering Prototype Development. The process involves weighted criteria and subjective elements.

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Tasks evaluated for their potential to:

- **Address Baseline and Restructuring Issues**
- **Impact program phases (FEL, MTC, PMC)**
- **Improve baseline system/subsystem functionality**
- **Reduce baseline development costs and risk**
- **Reduce operational costs**
- **Reduce life-cycle costs**
- **Increase scientific return**
- **Enhance safety**

Engineering Prototype Development

WBS Structure

The four areas of Engineering Prototype Development include:

Flight and Ground Systems which is focused on providing prototype monitoring and diagnostic systems.

SSF Data Systems which focuses on characterizing baseline DMS performance, growth options, and evaluation of candidate DMS user interfaces.

Advanced Software Engineering which is developing tools methodologies to support the design, development and maintenance of advanced software applications.

Telerobotic Systems which is focused on providing hardware and software technologies to improve operator-telerobot interfaces and to enhance telerobotic control.

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WBS STRUCTURE:

- **Flight and Ground Systems**
- **SSF Data Systems**
- **Advanced Software Engineering**
- **Telerobotic Systems**

Engineering Prototype Development

Flight and Ground Systems

Advanced automation applications are being developed to make SSF flight and ground systems more reliable. The approach relies heavily on Fault Detection, Isolation and Recovery (FDIR) methods and provides a range of support in system-status monitoring, safeing and reconfiguration. A mix of conventional and Knowledge-Based System (KBS) techniques is used and each application provides a powerful user interface to support advisory mode interactions. The primary benefits are increased systems reliability through improved systems monitoring, enhanced fault detection and isolation capabilities, and increased productivity for Mission Control Center (MCC) personnel and SSF crew members.

Application prototypes are being developed for selected SSF distributed systems and control centers. Intelligent FDIR advisory systems already have been developed and demonstrated in support of Shuttle flight operations.

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Flight & Ground Systems Automation WBS Element Summary

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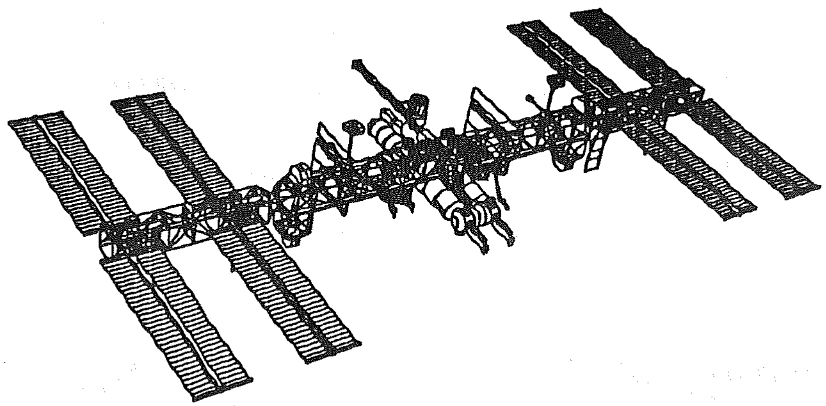

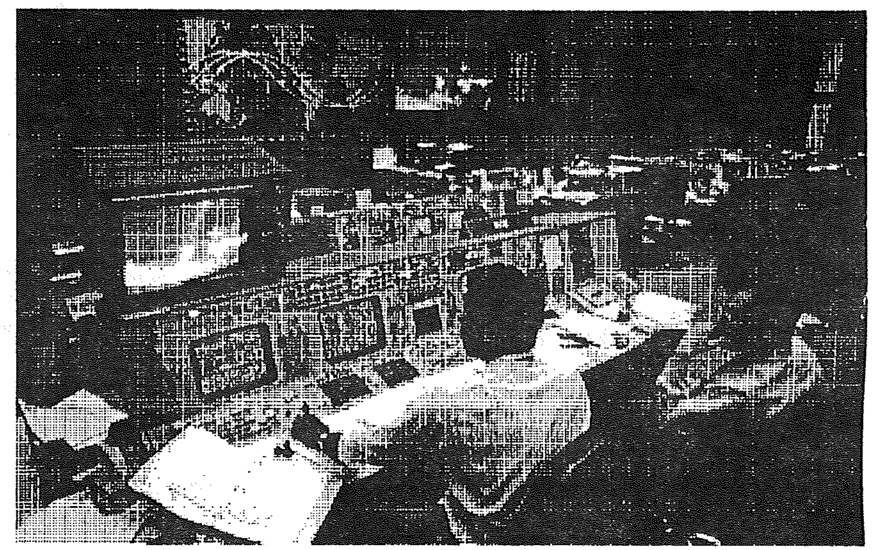

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OBJECTIVES:

- **Provide mature technology for distributed monitoring & FDIR**
- **Identify and document design accommodations**
  - **Instrumentation, redundancy management**
  - **Interfaces with DMS,C&T,conventional SSCC and POIC s/w & h/w**
  - **Software development and verification**
- **Demonstrate FDIR and data monitoring for payloads**
  - **Troubleshoot Rapidly**
  - **Improve timeline utilization**
  - **Manage available experiment resources**

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Flight & Ground Systems Automation
WBS Element Summary

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APPROACH:

- **Combine conventional monitoring and FDIR procedures with knowledge-based approaches to develop "intelligent" advisors for mission operations**
- **Develop FDIR application prototypes for selected SSF systems, the SSCC, and Engineering Support Centers**
- **Develop and validate software using established MCC policy and procedures. Use a mix of DMS/SSE tools and demonstrate on DMS-equivalent hardware**
- **Demo to SSF Work Package and contractor mngt and engineers on high fidelity program testbeds and in "operational" evaluations**
- **Coordinate transition of documented requirements, applications, and s/w development tools to Work Packages, MCC, SSC, etc**
- **Joint Funding with SSP, OAET, OSSA, DARPA**

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Flight & Ground Systems Automation WBS Element Summary

PRODUCTS & BENEFITS:

- **Detailed system requirements, performance specifications, & design accommodations**
- **"Intelligent" FDIR advisory systems have been developed and demonstrated in the MCC**
  - **INCO, SSME, RMS, EGIL, GN&C, Flt Dir Wind Advisor**
  - **Used operationally since STS-26**
- **FDIR applications under development for Power Management and Control/Distribution; Thermal Control; Environmental Control and Life Support; & SLS-2 Life Sciences Payload**
- **Improved fault isolation, detection of incipient failures, increased system reliability with a reduced mean time to repair; reduced instrumentation, reduced EVA/IVA maintenance, reduced backroom workforce, reduced life-cycle costs**

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Flight & Ground Systems Automation WBS Element Summary

FY91 Tasks:

- Thermal Control Automation, JSC
- ECLSS Automation, MSFC
- ECLSS Predictive Monitoring, JPL
- Power Management & Distribution Automation, MSFC
- Power Management & Control Automation, LeRC
- Astronaut Scientific Associate, ARC
- Real Time Data Systems, JSC

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Data Systems

The computer and network architectures of the SSF Data Management System (DMS) are being analyzed to provide increased performance and reliability and to determine long-range growth requirements. Additionally, advanced mission planning and scheduling tools are being developed and demonstrated for use onboard, as well as on the ground.

Advanced DMS architectures are being evaluated with respect to : existing and proposed uni- and multiprocessors; network, protocol and connectivity options; and system management software. In addition, DMS interface options and computer hardware and software interfaces are being evaluated on Shuttle flights to resolve user interface problems.

The development of planning and scheduling systems using Ada-based KBS software tools should result in improved productivity and reduced software lifecycle costs. The Computer-aided Planning and Scheduling System (COMPASS) interactive scheduling tool, which includes optimization techniques is being used to judge the validity of short-term plan event execution. There is significant potential for using COMPASS on a variety of ground- and flight-based resource and event scheduling applications.

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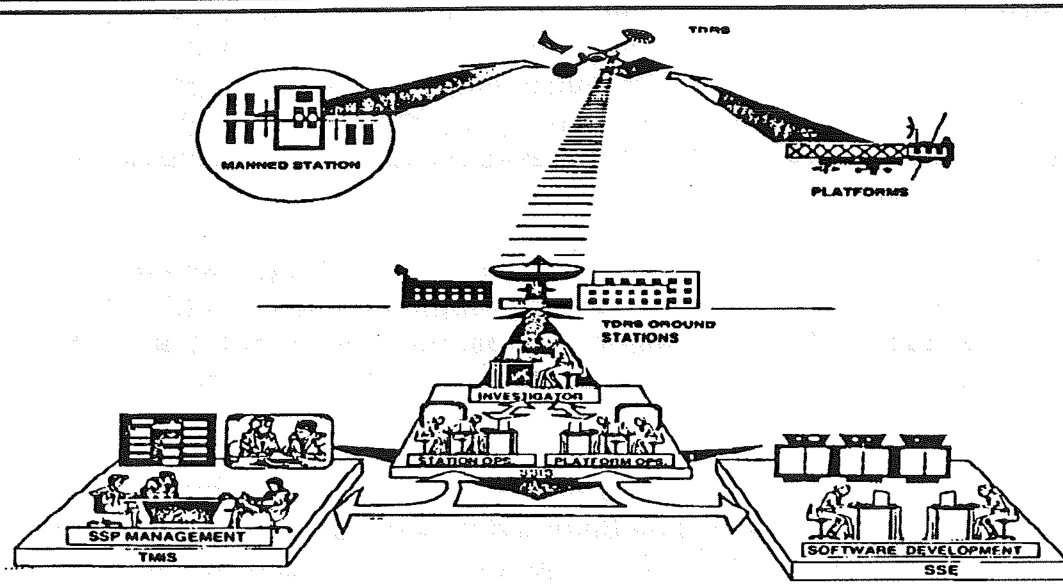
Space Station Data Systems
WBS Element Summary



OBJECTIVES:

- **Increase Space Station DMS performance and reliability**
  - **Reduced power & weight, increase throughput and storage**
- **Demonstrate advanced processors, storage devices, displays, and network components; document long-range growth requirements**
- **Develop and demonstrate advanced ground-based and on-board mission planning and scheduling tools for the ISE, SSCC, & POIC**

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Space Station Data Systems
WBS Element Summary

APPROACH:

- **Analyze baseline DMS using a mix of hardware and dynamic simulations**
- **Evaluate DMS component upgrades incrementally to determine performance/power benefits and compatibility with baseline DMS architecture**
- **Develop and demonstrate KBS planning and scheduling tool using Ada language and ISE/DMS software and hardware constraints**

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Space Station Data Systems
WBS Element Summary

PRODUCTS/BENEFITS:

- **Enable growth of DMS and OMA infrastructure and prevent technological obsolescence**
    - **Extensible hardware, software architectures**
    - **Improved performance in processors, mass storage, data networks**
    - **Reduced power and weight; increased reliability**
- **Reduced cost for software development, testing, and maintenance of mission planning and scheduling systems**

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Space Station Data Systems
WBS Element Summary

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FY91 Tasks:

- **Advanced DMS Architectures, ARC**
- **Optical Protocols for Advanced Networks, JPL**
- **Advanced Portable Crew Support Computer, JSC**
- **ISE Advanced Scheduling System, JSC**
- **KBS Scheduler Re-host, JPL**

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Advanced Software Engineering

Space Station Freedom will require a significant amount of application and support software. Development of software tools, methodologies, and environments is being pursued to support the design development, and maintenance of advanced software applications. Tasks have included investigating Ada cross-compilers for existing KBS tools and benchmarking their performance using operational automation prototypes. Also, Computer-Aided Software Engineering (CASE) tool sets supporting the reuse of design information are being developed. In addition, tools and techniques for software verification, validation, testing, and maintenance are being developed and demonstrated.

Because of SSF complexity, the demand for training operations staff and crew is even greater than that for Shuttle missions. The extension of Shuttle training methods to SSF may prove impractical. Using artificial intelligence technology provides the ability to simulate individualized training to many personnel in a distributed workstation environment. Intelligent Computer-Aided Training (ICAT) architectures are being developed and demonstrated in operational settings. ICAT technology offers training improvements by reducing the overhead involved in setting up training environments, scheduling classes, and developing simulations.

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Advanced Software Engineering
WBS Element Summary

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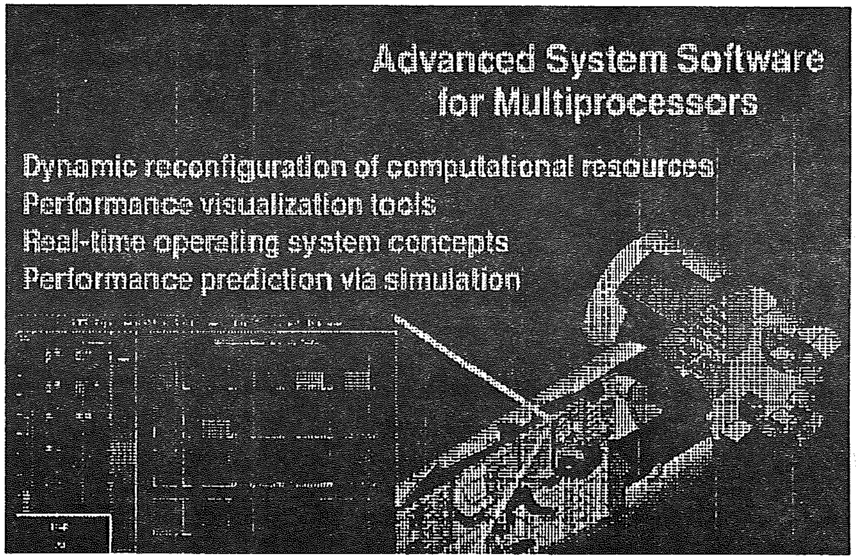

***OBJECTIVES*:**

- **Develop and demonstrate programming tools that reduce software development and maintenance overhead**
- **Provide software development tools for knowledge-based system (KBS) applications for integration with the SSE**
  - **KBS tools (rule-, frame-, and model-based) that produce Ada code**
  - **KBS verification and validation techniques**

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Advanced Software Engineering WBS Element Summary

APPROACH:

- Develop & demonstrate Ada cross-compilers for commercial KBS tools
- Benchmark their performance using flight systems automation prototypes (e.g., ECLSS, PMAC, PMAD)
- Develop and demonstrate verification, validation, testing, and maintenance tools and techniques for conventional and KBS software
- Coordinate closely with SSE personnel (JSC, Lockheed, PRC)

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Advanced Software Engineering
WBS Element Summary

<u>*PRODUCTS & BENEFITS*</u>:

- **Established DMS performance and memory requirements for KBS software in Ada**
- **Demonstrated ability to develop, deploy, test, and maintain KBS software compliant with SSE language and methodology & DMS requirements**
- **Reduce cost, time for development, and maintenance of conventional & KBS flight and ground system software**

Engineering Prototype Development

Advanced Software Engineering
WBS Element Summary

FY91 Tasks:

- **Software Life Cycle Methodologies & Environments, JSC**
- **SSF Software Reconfiguration, JSC**
- **Failure Environment Analysis Tool, JSC**

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Telerobotic Systems

Key hardware and software technologies are being advanced to improve operator-telerobot interfaces and to enhance telerobotic control. These technologies will allow telerobots to do more work in less time, with greater safety and reliability. The increased use of telerobotics reduces the need for EVA, while enhanced control reduces the IVA time required to perform telerobotic tasks.

The development of a "shared control" capability will provide a robust operator interface and better management of control loop time delays. A human operator may select the level of autonomous control desired to move the robot faster and accomplish tasks with fewer commands and less stress. Development of a standardized, segmented control architecture compensates for telecommunication or computation-induced time delays, improving teleoperation by IVA crew and allowing remote operation of the Station's telerobots from ground-based consoles.

Proximity sensors have been developed to improve telerobotic collision detection and avoidance. A break-through technology has created reflecting capacitor sensor arrays that may be mounted on the outside of the telerobot, much like an extended skin. Sensors and associated logic, integrated into a flexible applique' covering, can direct the telerobot to stop, back away from, or work around any object within 12 inches of the robot. This results in greatly simplified dynamic model-based approaches, and ultimately, less time needed for the telerobot to complete a task.

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Telerobotic Systems
WBS Element Summary

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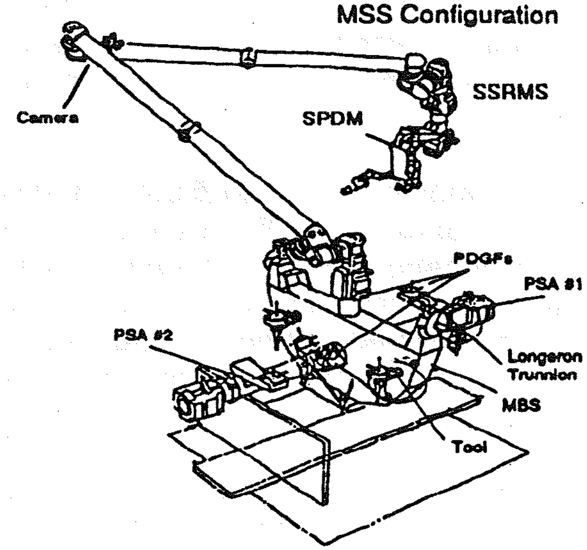

OBJECTIVE:

- **Improve operations capability through more effective use of baseline SSF systems**
  - **Reduce required manned EVA operations time**
  - **Enhance EVR teleoperations safety & reliability margins**
  - **Reduce IVA teleoperations time at MTC and beyond**

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Telerobotic Systems
WBS Element Summary

APPROACH:

- **Utilize existing NASA robotic testbeds (JSC, JPL, GSFC) to integrate and demonstrate advanced robot control, task and spatial planning, and collision avoidance algorithms**
- **Transition advanced algorithms to Ada and demonstrate on dexterous tasks**
  - **Collect performance data, determine DMS requirements**
  - **Determine integration path into SSF subsystems**
- **Assemble mockups and perform maintenance/inspections using mix of teleoperation and autonomy**
- **Develop collision avoidance sensor arrays and demonstrate on laboratory robots**
  - **Investigate control strategies and integration with model-based collision avoidance**

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Telerobotic Systems
WBS Element Summary

PRODUCTS & BENEFITS:

- **Improved robotic capabilities to reduce EVA time required for inspection, assembly, and maintenance**
- **Improved interface and shared control to increase safety of teleoperation and reduce IVA time required for robotic operations**
- **Increased telerobot resource utilization through multiplication of operators effecting ground remote operation of SSF telerobots**
- **Semi-autonomous assembly of SSF structures will reduce long-term EVA requirements**

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Telerobotic Systems
WBS Element Summary

FY 91 Tasks:

- **Flat Target (JPL)**
- **Automated Robotic Maintenance of SSF (JSC)**
- **Advanced Telerobotic Control and Interfaces (JPL)**
  - **User Macro Interface & Shared Control**
  - **Operator Coached Machine Vision**
- **Collision Avoidance Sensor (GSFC)**

Engineering Prototype Development
Summary

- Engineering Prototype Development is the Space Station Freedom effort to enhance flight and ground system capabilities by prototyping applications of advanced technology
- The FY91 restructuring of Advanced Development has been completed successfully
- Solid task mix in place that addresses critical baseline program issues (e.g., reduced instrumentation, minimal DMS/ISE, oversubscribed EVA and IVA)
- Task demonstrations are aligned with critical program milestones