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(NASA-TM-108724) TECHNOLOGY FOR SPACE STATION EVOLUTION. EXECUTIVE SUMMARY AND OVERVIEW (NASA) 369 p

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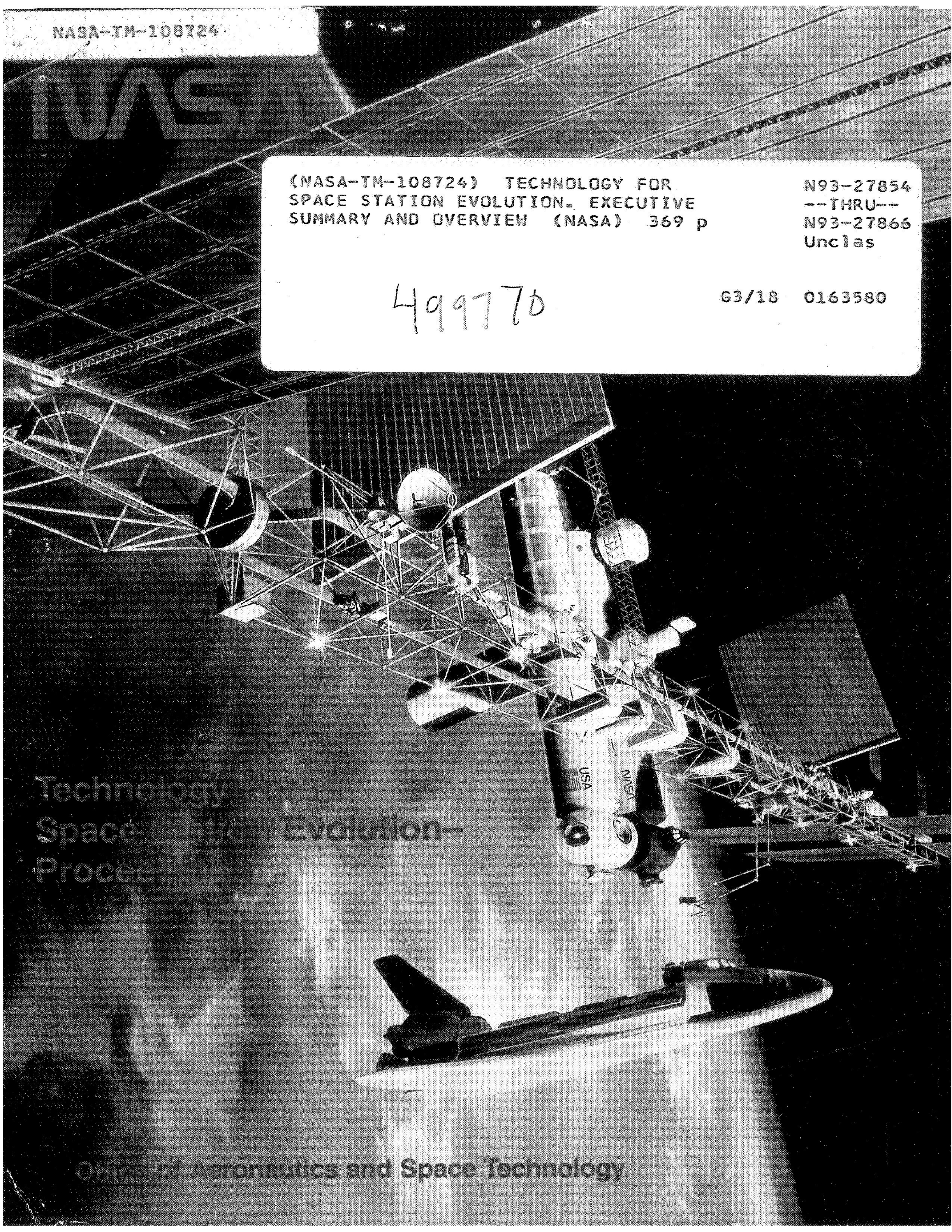

NASA

Technology for Space Station Evolution—Proceedings

Office of Aeronautics and Space Technology omit to p.23

FOREWORD

Space Station *Freedom*, now under development, is a manned low Earth orbit facility which will become part of the space infrastructure. Starting in the mid 1990s, *Freedom* will support a wide range of activities, including scientific research, technology development, commercial ventures and, eventually, serve as a transportation node for space exploration. While the initial facility will not be capable of meeting all requirements, the space station will evolve over time as requirements and on-board activities mature and change. The space station design, therefore, allows for evolution to:

- expand capability,
- increase efficiency, and
- add new functions.

It is anticipated that many of the evolutionary changes will be accomplished through on-orbit replacement of systems, subsystems, and components as technology advances. Therefore, technology development is critical to ensure the continuing operation and expansion of the facility.

The Office of Aeronautics, Exploration and Technology (OAET) has sponsored development of many of the technologies that are now part of Space Station *Freedom'* s baseline design. Evolutionary and operational aspects of *Freedom* continue to be an important thrust of OAET's Research and Technology (R&T) efforts.

This workshop has been an important step in our understanding of the space station's baseline systems, the evolutionary scenarios including the station's role in space exploration, and the technologies that will be necessary to meet evolutionary and growth requirements.

It is anticipated that application of the information acquired through the workshop will lead to further technology development efforts to benefit *Freedom* and will lead to continued collaboration between the Space Station *Freedom* Program and the technology development community.

Arnold D. Aldrich
Associate Administrator for Aeronautics, Exploration and Technology

CLARIFICATION

Since the workshop was conducted in January of 1990, there have be organizational changes throughout the agency. The Office of Aeronau Space Technology (OAST) has been reorganized to include the former Exploration and is now called the Office of Aeronautics, Explorati Technology (OAET). Also, the Human Exploration Initiative (HEI) h expanded and renamed the Space Exploration Initiative (SEI). Some materials in these proceedings were prepared after the workshop, and, th references to new organizational entities and new programs may be found i sections.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP
Executive Summary and Overview

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INTRODUCTION

NASA's Office of Aeronautics and Space Technology (OAST) conducted a workshop on technology for space station evolution January 16-19, 1990, in Dallas, Texas. The purpose of this workshop was to collect and clarify Space Station *Freedom* technology requirements for evolution and to describe technologies that can potentially fill those requirements. OAST will use the output of the workshop as input for planning a technology program to serve the needs of space station evolution. The main product of the workshop is a set of program plans and descriptions for individual technology areas. These plans are the cumulative recommendations of the more than 300 participants, which included researchers, technologists, and managers from aerospace industries, universities, and government organizations.

The identification of the technology areas to be included, as well as the development of the program plans, was initiated by assigning NASA chairmen to the eleven technology disciplines under consideration. The disciplines are as follows:

- Attitude Control and Stabilization (ACS)
- Communications and Tracking (C&T)
- Data Management System (DMS)
- Environmental Control and Life Support Systems (ECLSS)
- Extravehicular Activity/Manned Systems (EVA/MANSYS)
- Fluid Management System (FMS)
- Power System (POWER)
- Propulsion (PROP)
- Robotics (ROBOTICS)
- Structures/Materials (STRUCT)
- Thermal Control System (THERM)

Each chairman worked with a panel of experts involved in research and development in the particular discipline. The chairmen, with the assistance of their panels, were responsible for selecting invited presentations, identifying and inviting Space Station *Freedom* Level III subsystem managers, and focusing the discussion of the participants. In each discipline session, presentations describing status of the current programs were made by the Level III subsystem managers and by OAST program managers. After invited presentations by leading industry, university, and NASA researchers, the sessions were devoted to identifying technology requirements and to planning programs for development of the identified technology areas. Particular attention was given to the potential requirements of the Human Exploration Initiative (HEI). The combined inputs of the participants in each session were incorporated into a package including an overall discipline summary, recommendations and issues, and proposed development plans for specific technology within the discipline. These technology discipline summary packages were later supplemented by the chairmen and their panels to include the impact of varied funding levels on the maturity of the selected technologies. OAST will review the program plans and recommended funding levels based on available funding and overall NASA priorities and incorporate them into a new OAST initiative advocacy package for space station evolution technology.

These proceedings are organized into an Executive Summary and Overview and five volumes containing the Technology Discipline Presentations.

The Executive Summary and Overview contains an executive summary for the workshop, the technology discipline summary packages, the keynote address, "Mission Requirements and Evolution Scenarios", a presentation on the "Space Station as a Transportation Node", and a discussion of the "Importance of Automation". The executive summary provides a synopsis of the events and results of the workshop, and the technology discipline summary packages are as described above. In the keynote address, Dr. William B. Lenoir, Associate Administrator for Space Station, discussed the significance of the space transportation/space station infrastructure as the first steps towards the future of mankind in space. The "Mission Requirements and Evolution Scenarios" were described by Dr. Earle Huckins, III. "Space Station as a Transportation Node" was Dr. Jeffrey Rosendhal's description of the status of the Space Exploration Program. Finally, in the "Importance of Automation", Dr. Henry Lum explained the significance of systems autonomy for space station operations and evolution. The appendices to this volume include a final workshop agenda and a list of attendees.

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

INTRODUCTION

For the next 30 years or more, Space Station *Freedom* (SSF) will be the keystone of the space infrastructure. It will serve as a facility for advancing space science, a laboratory for space technology development, a manufacturing process laboratory and pilot plant, and a servicing center for spacecraft. Most importantly, it will serve as the training ground for men and women to operate in the space environment with increasing self sufficiency for long periods of time, and it will ready them for human exploration of the moon and Mars. Eventually, it will evolve into the transportation node -- the way station -- for those journeys.

The necessity to fulfill these functions places novel and difficult constraints on the spacecraft's designers. For its lifetime, the space station will have to be maintained on orbit. Starting as a multipurpose facility, its primary functions may change over the years; it will have to adapt to new requirements and to change and grow in size and capability.

Therefore, it is of prime importance that all space station systems be designed to be not only easily maintained with original spares, but also transparent to advanced technology and capable of expansion. The importance of advanced technology, to be developed hand in hand with the spacecraft design, cannot be overemphasized.

The objective of "Technology for Space Station Evolution -- A Workshop" was to drive out the requirements and the technologies that would enable the space station to:

- become more maintainable, safer, and more capable and
- evolve into the first and key element of the space exploration missions.

APPROACH

Eleven parallel workshops were organized along the lines of space station systems and elements as follows:

- Attitude Control and Stabilization (ACS)
- Communications and Tracking (C&T)
- Data Management System (DMS)
- Environmental Control and Life Support Systems (ECLSS)
- Extravehicular Activity/Man Systems (EVA/MANSYS)
- Fluid Management System (FMS)
- Power System
- Propulsion System
- Robotics
- Structures/Materials
- Thermal Control System (TCS)

The workshops were chaired by senior experts in the technology disciplines, and the requirements were presented by space station system/element managers. The workshop included participants from NASA centers, industry, and universities who were either associated with the space station organization or otherwise recognized technology discipline experts.

THE PLENARY SESSION

The topical workshops were preceded by a plenary session led by the Associate Administrator for Aeronautics, Exploration, and Technology, Mr. Arnold Aldrich. Mr. Aldrich emphasized his organization's commitment to advancing technology to enable the President's Space Exploration Initiative. The keynote speech delivered by Dr. William Lenoir, Associate Administrator for Space Flight, detailed the importance of the space transportation/space station infrastructure that will be the first major step towards the future of mankind in space.

The Director of the Space Station *Freedom* Program, Mr. Richard Kohrs, followed with a description of the ongoing space station program. Of particular importance to the workshop was his insight into some technology issues and challenges. These issues, listed below, received serious consideration in all topical workshops:

- design of the attitude control and stabilization system which must enable the partially completed space station to remain in orbit;

- designing the communications and tracking system "right the first time", since it will be difficult to change;

- the large size of the data management system which requires new approaches to the development and verification of software;

- potential problems arising from the decision to leave the oxygen and carbon dioxide loops of the life support system open until assembly complete;

- the need to reduce the EVA man-hours currently projected for maintenance;

- the challenge to ensure adequate redundancy in the fluid management system;

- the amount and source of power (photovoltaic vs. solar dynamic) and the need to maintain hooks and scars for growth;

- potential resupply problems arising from the change to hydrazine for the auxiliary propulsion system;

- defining the requirements for the Flight Telerobotic Servicer;

- design and operational challenges to minimize effects of the micrometeoroid and debris environment, as well as those of shuttle docking and plume loads, on the structure; and

- development of the two-phase thermal control system.

Dr. Earle Huckins discussed current space station evolution scenarios. The status of Space Exploration Program planning was presented by Dr. Jeffrey Rosendhal, who followed Dr. Huckins. The plenary session was concluded by Dr. Henry Lum, who impressed the importance of systems autonomy for operations and evolution on the workshop participants.

THE TOPICAL WORKSHOP SESSIONS

After three days of debate and deliberation, the participants gathered again for a concluding session and presented the results of the topical workshop sessions.

Attitude Control and Stabilization

The guidance, navigation, and control system of SSF will have to handle spacecraft build-up beyond the baseline. Evaluating the evolution scenarios, the workshop participants concluded that advanced control system strategies are necessary to cope with the uncertainties in the orbital environment and dynamically changing spacecraft configurations resulting from docking, build-up, and changing or shifting payloads. The technology development areas identified as key to the solution are:

- attitude control technologies for multi-user accommodations,
- flexible body dynamics and controls,
- computational control techniques, and
- technology for autonomous rendezvous and proximity operations.

Deliverables should include:

- a proof-of-concept design for an integrated on-orbit flexible body and disturbance identification subsystem, including hardware such as a distributed fiber optic sensing system and software containing advanced modal selection and model reduction methods and
- prototype relative navigation sensors integrated with GN&C algorithms, trajectory control and collision avoidance techniques, on-board flight planning, and orbital placement and transfer techniques.

Communications and Tracking

The Space Station *Freedom* will evolve to become the hub of a sophisticated communications network that will require a multiple access system to provide numerous simultaneous links between various spacecraft operating in different zones. This will include proximity, space-to-ground, space-to-space, and potentially space to the moon or Mars communications.

The technology areas that have been identified as contributing highly to evolutionary performance and safety improvements are:

- optical communications and tracking,
- monolithic microwave integrated circuit (MMIC) antenna systems,
- traveling wave tube technology,
- advanced modulation and coding, and
- advanced automation for C&T.

Deliverables would include:

- demonstration of long life, high modulation rate, high power laser transmitters and extremely high sensitivity optical receivers,
- demonstrations of Ka-band MMIC antenna system components, two dimensional fast scanning rate Ka-band phased array antenna, and conceptual design of an on-board millimeter wave orbital debris tracking system,
- analysis and selection of optimal modulation schemes to provide enhanced data rates, and
- demonstration/simulation of autonomous system for selected C&T functions.

The workshop also identified several baseline technical issues, including the expected interference of the SSF multiple access system with the Ku-band. Secure Ka-band allocation with SSF as the primary user was recommended. Baseline insertion of high rate fiber optics was also recommended to enable accommodation of the high rate data transmission requirements that are anticipated as the station evolves.

Data Management System

The SSF data management system is larger and more complex than any system previously developed. It will have interfaces with all other station systems, as well as with all user payloads. The users' requirements exceed the planned capacity even in the early stages, and it is expected that the demand for higher data rates will necessitate growth soon after mature operations commence.

Technology needs include:

- improved performance of embedded data processors,
- improved mass storage,
- evolutionary integration of multicomputers,

- increased bandwidth of existing fibers for on-board communications,
- expanded software support environment (SSE) and guidelines for verification, and
- 3-D display technologies for improved human interface.

Several specific technologies were recommended to address various aspects of improving and growing the system. The major concern, however, was adopting an integrated systems approach to ensure successful system operation.

Environmental Control and Life Support System

At Assembly Complete, the SSF ECLSS will recover potable water via the humidity control system, regenerate the hygiene and urine water, and regenerate oxygen from carbon dioxide. Further technology advances will be necessary for long term and efficient operation of an ECLSS that could be utilized for human exploration missions to the moon and Mars. The highest impact technology areas were identified as:

- crew generated wastes (trash, feces, and brines) processes and reclamation,
- regenerable water reclamation pre- and post-treatment to eliminate expendable chemicals,
- simplified waste water processing,
- improved trace contaminant removal, and
- real-time microbial analysis of water.

Deliverables will include breadboard level components and subsystems and documentation. The payoff will be in lower resupply and returnable weight and volume, improved crew health, and higher maintainability.

The workshop also identified baseline technical issues. It was recommended that increased emphasis be placed on systems analysis to identify the highest payoff subsystem technologies and on system automation with concomitant sensor development.

EVA/Man Systems

Increased crew performance on SSF will be one of the key elements that can lead to a successful exploration mission to the moon or Mars. Technology advancements will be necessary to decrease the crew's time spent on routine tasks without diminishing their skills needed for emergencies, increase the efficiency of acquiring new mission-related skills, and provide an environment that improves motivation required for excellent performance. The high-payoff technology areas identified at the workshop are:

- crew-systems interfaces and interactions,

- training,
- maintainability and supportability,
- habitability and environment, and
- computational human factors/analysis tools.

Technology products recommended include:

- 3-D auditory displays, reliable and flexible speech recognition and production systems, direct manipulation input devices, and virtual workstations;
- AI/expert systems providing automation transparency, easy operator intervention, and robust dynamic task allocation capabilities;
- embedded training techniques for systems and payloads; and
- demonstrations of advanced ORU concepts, systems interfaces accommodating humans and robots, and inventory management systems.

<u>Fluid Management System</u>

Fluid management has been identified as one of the enabling technologies for space exploration. The evolving SSF fluid management system can, therefore, serve as a testbed to answer many of the key questions in this technology area.

The major areas of emphasis have been identified as:

- subcritical cryogenic storage and transfer,
- fluid handling, including liquid slosh dynamics and liquid dumping/venting/emergency relief, and
- component and instrumentation for fluid sampling/species identification, leak detection, and on-orbit calibration.

Deliverables are subcomponents, components, and subsystems that are ground and flight validated and lead to:

- system performance data and validated analytical models that provide design criteria.

<u>Power</u>

The Space Station *Freedom* Program has chosen a photovoltaic power system with nickel-hydrogen battery energy storage and a 120V DC power distribution system. This is the only system for which a growth option is provided in the baseline, i.e., solar dynamic system development can be accelerated to meet increased power requirements if necessary.

The workshop identified the following areas for evolutionary growth of the photovoltaic power system:

- advanced, more efficient solar arrays to reduce mass and increase performance, and
- increased autonomy to facilitate power sharing among multiple users.

The preferred growth option, solar dynamics, would benefit primarily from technologies leading to more efficient, lighter weight receivers and thermal energy storage.

Technology products to be delivered in this area include:

- production-ready advanced solar cells (such as the 19% efficient GaAs/Ge cells),
- verified 60,000 cycle (ten year) lifetime nickel/hydrogen cells, and
- data packages and subscale hardware that facilitate the design of the receiver/thermal energy storage system.

<u>Propulsion</u>

The space station baseline includes monopropellant hydrazine thrusters for backup attitude control and reboost, aided by resistojets utilizing waste gases from the ECLSS. The evolution scenario calls for the modular propulsion system to be replaced with a hydrogen/oxygen system.

Workshop participants called for plans for advanced hydrazine, as well as storable bipropellant, propulsion systems. They concluded, however, that the major emphasis should be placed on advancing the hydrogen/oxygen systems as rapidly as possible, since no other technological improvement in the propulsion area could equal the logistics resupply and fluid management integration payoff of the hydrogen/oxygen system.

The following technologies have been pinpointed as critical:

- high pressure water electrolysis that would allow propellants to be manufactured on orbit and
- waste fluid disposal, including advanced resistojets, arcjets, vaporizers, and gas compressors.

Deliverables include:

- preprototype or prototype components and
- flight demonstrations, as needed.

Robotics

Robotics technology will be a vital factor for the successful and productive operations on Space Station *Freedom*, as well as for any space exploration scenario that will be implemented. The Mobile Servicing System supplied by Canada and the Flight Telerobotic Servicer are both part of the Space Station *Freedom* Program. The need for advanced technologies in this area is indisputable; however, the problem is in applying engineering and management judgment to concentrate resources in the right directions.

The workshop identified four technology categories:

- cross cutting and systems wide research, including systems engineering processes for integrated robotics, man/machine cooperative control, and three-dimensional, real-time perception;
- advanced research in selected, critical areas;
- application-specific research; and
- "other", which includes primarily a constant, vigilant oversight of the on-going program.

The workshop participants laid out program plans and deliverables, as requested. It does, however, beg the question as to whether, with such a vast technology area, it is meaningful to pinpoint components for development without first performing a detailed systems engineering evaluation of the entire space station operations and evolution scenario. It is suggested, therefore, that processes for systems engineering and continuing oversight be established before specific technology development plans are defined.

Structures/Materials

The features that distinguish Space Station *Freedom* from any other spacecraft are:

- its assembly on orbit,
- its lifetime, and
- its physical size.

These attributes make advanced technologies in space construction, space-durable materials, and controls/structures interaction mandatory aspects of any R&T program aimed at the growth of the space station and space exploration.

SSF is going to be the first spacecraft assembled on orbit, but not the last. Present plans call for assembly by EVA; advanced research must find ways to deploy structures or erect them robotically, as well as find new assembly methods, such as mechanical joints or welding. *Freedom* will have to serve as a testbed for controls/structures interactions, since the dynamics of the structure with flexible manipulators, interactions of on-board fluid dynamics with controlled assemblies, the limitation and alleviation of dynamic loads, and management of microgravity levels cannot be modeled at this time.

Advanced technologies should include structural and mechanical concepts, environmental inspection and repair techniques, and analysis methods to ensure structurally robust long life and evolution of the space station. Materials technology must include environmentally tolerant materials and material systems for space applications, as well as processes for on-orbit repair and NDE methods.

The workshop participants identified a number of important issues:

- future in-space construction must minimize EVA;
- the dynamics of station and the performance of attached controlled payloads and manipulators will become increasingly complex as station evolves;
- materials databases for space applications and on-orbit NDE science are poor; and
- ground-based environmental simulations and test methods are inadequate.

The recommendations to alleviate these problems include:

- developing and demonstrating in space the proper mix of EVA, robotic, deployment, and modular assembly technology necessary for EVA minimization;
- developing a well-verified modeling capability for the dynamics of the evolving station; and
- acquiring improved structures input to the development of proposed configurations for growth.

Thermal Management

The present baseline calls for pumped-loop cooling internal to the pressurized modules and for two-phase heat transport and radiators externally. The large capacity two-phase thermal management system is not yet fully developed, and several flight experiments are planned. If the demand for increased power is one of the first evolutionary steps as expected, heat rejection capability will have to grow concurrently.

The major issues identified with utilizing the baseline technology for evolution and growth are:

- an unacceptable increase in radiator sweep volume,
- increased EVA time,
- orbiter manifesting penalties associated with the weight and volume,

- operational ground support, and
- maintenance and repair operations.

The workshop participants identified key technologies necessary to evolve the thermal management system to:

- decrease the heat rejection system size,
- increase capability for heat acquisition and transport,
- assemble external components robotically,
- monitor, control, and detect and isolate faults autonomously, and
- develop essential analytical tools.

SUMMARY

Certain overriding themes emerge from a review of the stated goals and the results of this endeavor. There is no doubt that, in a technology development program focused on space station evolution leading to space exploration, the highest priority technologies must be those related to human performance.

Many topical workshops called for increased systems autonomy, including fault detection and isolation, to enable the crew to spend more time on non-routine tasks. Hand-in-hand with these recommendations go the almost unanimous requirements for more maintainable components in every subsystem and for robotics to decrease EVA time, aid the crew in external maintenance, perform additional construction tasks, and aid in the placement of payloads. A significant aspect of both of these technologies is the need for advanced man/machine interfaces.

Another important aspect of human performance is the requirement for advanced, closed-loop life support. Commitment to long-duration, manned space exploration missions can be made only if a truly closed life support system including trace air and water contaminant monitoring and control has been thoroughly tested on Space Station *Freedom*. Life support system technologies, such as on-board processing of brines and solid wastes and the development of regenerable contaminant control subsystems, are also tied to the need to reduce operational costs by reducing the required logistics resupply. An essential advanced life support system component is a water electrolysis subsystem, which would regenerate oxygen from surplus water. This component could also be used for generating fuel on orbit for an advanced propulsion system, thereby cutting logistics resupply weight.

Another category of critical technologies is coupled to the requirement for physical growth of the space station to accommodate transportation node or satellite servicing demands. This category is control/structure interactions, and the priority is to learn to control the spacecraft structure under constantly changing and shifting load conditions.

Advanced fluid management technologies, including cryogen transport, storage, and handling, will also benefit the evolutionary space station. These advances will enable the life support and propulsion systems to be synergistically integrated and will significantly reducie logistics resupply costs by using water to manufacture hydrogen and oxygen on orbit and by permitting nitrogen to be transported in the cryogenic, instead of supercritical, state. The space station as a testbed for cryogenic fluid management will be of major importance as *Freedom* evolves into a transportation node for space exploration.

This workshop has been the first of many steps required to derive a plan to maximize the benefits of advanced technology for space station evolution and growth. It was, however, an important and productive start that will pay off in major contributions to the low Earth orbit infrastructure that this nation is building. It will help us achieve our goal of extending human presence beyond our planet and will help Space Station *Freedom* to reap benefits for science, technology, and commerce and to become a way station to the worlds beyond.

Judith H. Ambrus

Dr. Judith H. Ambrus
Acting Assistant Director for Space Technology (Space Station)
General Chairman

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CHAIRMEN'S RESULTS

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TECHNOLOGY FOR SPACE STATION EVOLUTION
- A WORKSHOP

ATTITUDE CONTROL AND STABILIZATION TECHNOLOGY
DISCIPLINE

JANUARY 19, 1990

JOHN W. SUNKEL, CHAIRMAN
JOHNSON SPACE CENTER

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TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

TECHNOLOGY DISCIPLINE SUMMARY FOR ATTITUDE CONTROL & STABILIZATION

ADVANCED CONTROLS TECHNOLOGIES REQUIRED FOR SPACE STATION EVOLUTION

TECHNOLOGY DRIVERS

- LARGE MASS PROPERTIES AND CONFIGURATION CHANGES
- CONCURRENT USERS
- LARGE MULTIPLE FLEXIBLE STRUCTURES
- EXPANDED INTER-ORBIT TRAFFIC

TECHNOLOGY DEVELOPMENT AREAS

- ATTITUDE CONTROL TECHNOLOGIES FOR MULTI-USER ACCOMMODATION
- FLEXIBLE DYNAMICS AND CONTROL
- COMPUTATIONAL CONTROL TECHNIQUES
- AUTONOMOUS RENDEZVOUS AND PROXIMITY OPERATIONS

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

ATTITUDE CONTROL & STABILIZATION

ATTITUDE CONTROL TECHNOLOGIES FOR MULTI-USER ACCOMMODATION

BACKGROUND

SCOPE - Advanced control system strategies able to cope with uncertainties in the orbital environment, dynamically changing spacecraft configurations via docking and buildup, and potential hardware failures

OBJECTIVES - To define, develop, and evaluate control system technologies for the evolving Space Station which maintain good performance in spite of disturbances caused by crew motion, mission activity, aerodynamic uncertainty, vehicle mismodeling, and changing configurations.

RATIONALE - Present control system technology does not meet the more demanding operational requirements of the evolutionary Space Station. Due to crew and aerodynamic disturbances, changes in vehicle parameters, dynamic interaction with the control system, and concurrent operations of multiple controllers/users, issues that have not been of concern in the past will become drivers in the design and development of an attitude control and stabilizaiton system for the advanced Space Station.

ATTITUDE CONTROL & STABILIZATION

ATTITUDE CONTROL TECHNOLOGIES FOR MULTI-USER ACCOMMODATION

PROGRAM PLAN

APPROACH :

1. Investigate advanced momentum effectors. These include larger, more efficient shell rotor designs, electro-magnetically suspended rotors, and fluid moment loops replacing spinning rotor designs.

2. Develop mass properties management system. This system might consist of a series of ballast tanks containing consumables (water, propellant) that can be pumped around the Station for the purpose of managing mass properties.

3. Develop an on-board system identification capability. This will produce on-board characterization of the Space Station mass properties and identification of disturbances.

4. Develop an on-line adaptive control system. The adaptive controller develops an updated state feedback controller for the identified updated Station model.

5. Develop scheduling algorithms for Space Station momentum management. This approach schedules the activities of the Station in an optimal manner to insure that sufficient control authority from the CMGs is always available.

DELIVERABLES :

1. Demonstrations of effector hardware.

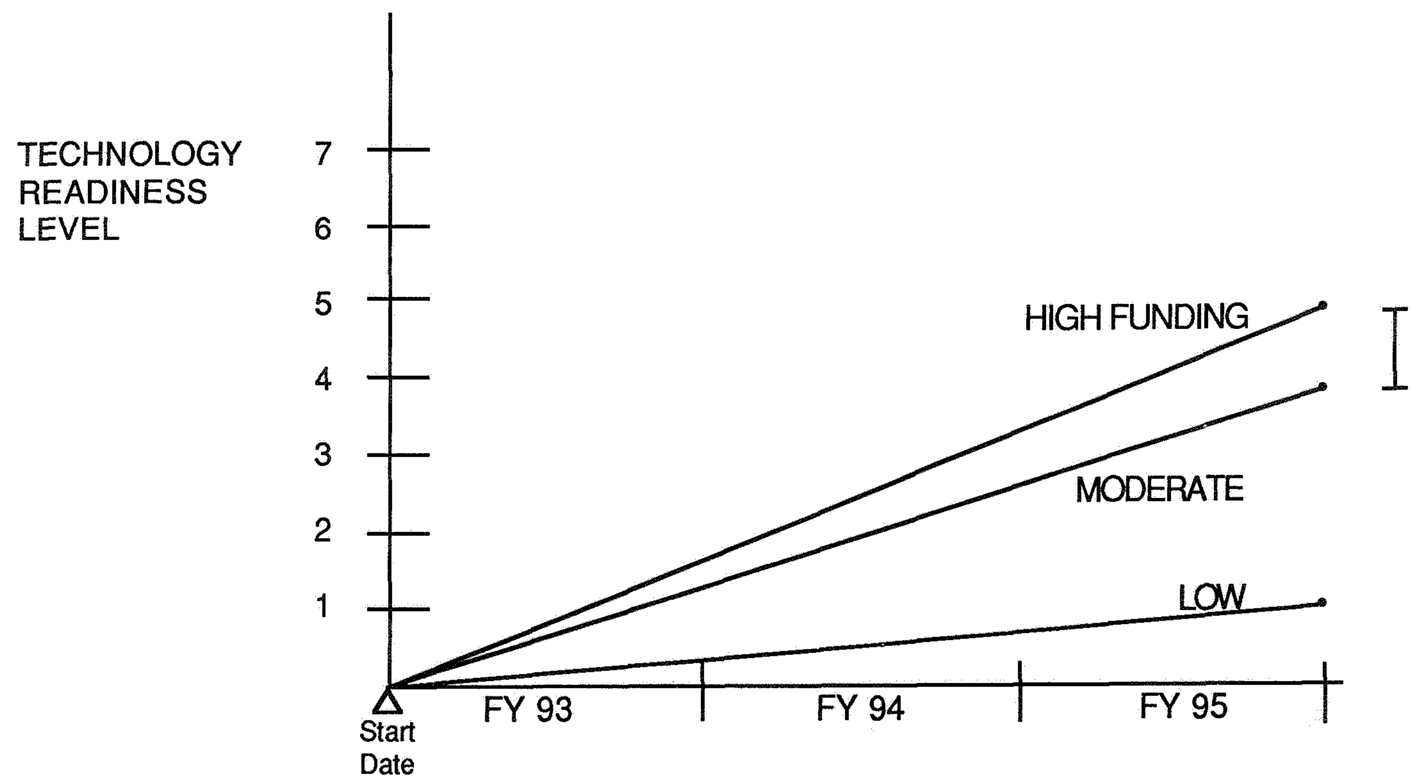
2. Software demonstrations on appropriate Space Station test beds.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

ATTITUDE CONTROL & STABILIZATION

ATTITUDE CONTROL TECHNOLOGIES FOR MULTI-USER ACCOMMODATION

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

ATTITUDE CONTROL & STABILIZATION

FLEXIBLE DYNAMICS AND CONTROL

BACKGROUND

SCOPE - Development of modeling and control methodologies and sensor hardware for flexible dynamics characterization, on-board sensing and vibration control.

OBJECTIVES - To develop the methods, algorithms, and architectures for on-board identification of space station dynamics; math models to describe the characteristics of the system and payloads; techniques for the optimal placement of actuators and sensors; and active/passive methods to control dynamic responses and the propagation of disturbances.

RATIONALE - Due to the limitations of ground testing and to the evolving nature of operations and configuration, an on-board capability is required to characterize the system as it evolves in time. The dynamic interactions and disturbances resulting from the planned concurrent use of the station by multiple users for assembly of Lunar/Mars vehicles, Earth/space/microgravity payloads, etc., will limit the utility and operational performance of the evolving station.

ATTITUDE CONTROL& STABILIZATION

FLEXIBLE DYNAMICS AND CONTROL

PROGRAM PLAN

APPROACH -

1. Develop an on-orbit flexible body and disturbance identification subsystem. This includes an automated system of methods, signal processing algorithm designs and data acquisition, interfacing architecture, and excitation/sensing specifications.

2. Develop a passive and active control technology. This includes control of dynamic response levels and propagation of disturbances. Conduct performance analysis and experimental verifications.

3. Develop an optical system identification and alignment sensor. This will allow real time system identification and control of the system and attached payloads.

4. Develop modal selection and model reduction methods. Both methods will be designed implementing a multi-objective design technique.

5. Develop a distributed fiber optics sensing system. This includes fiber optic rotation, acceleration, stress, and temperature sensors.

DELIVERABLES -

1. An integrated identification subsystem proof-of-concept design.

2. Experimental demonstration of passive and active control technology.

3. Model-based modal selection/model reduction algorithms and software.

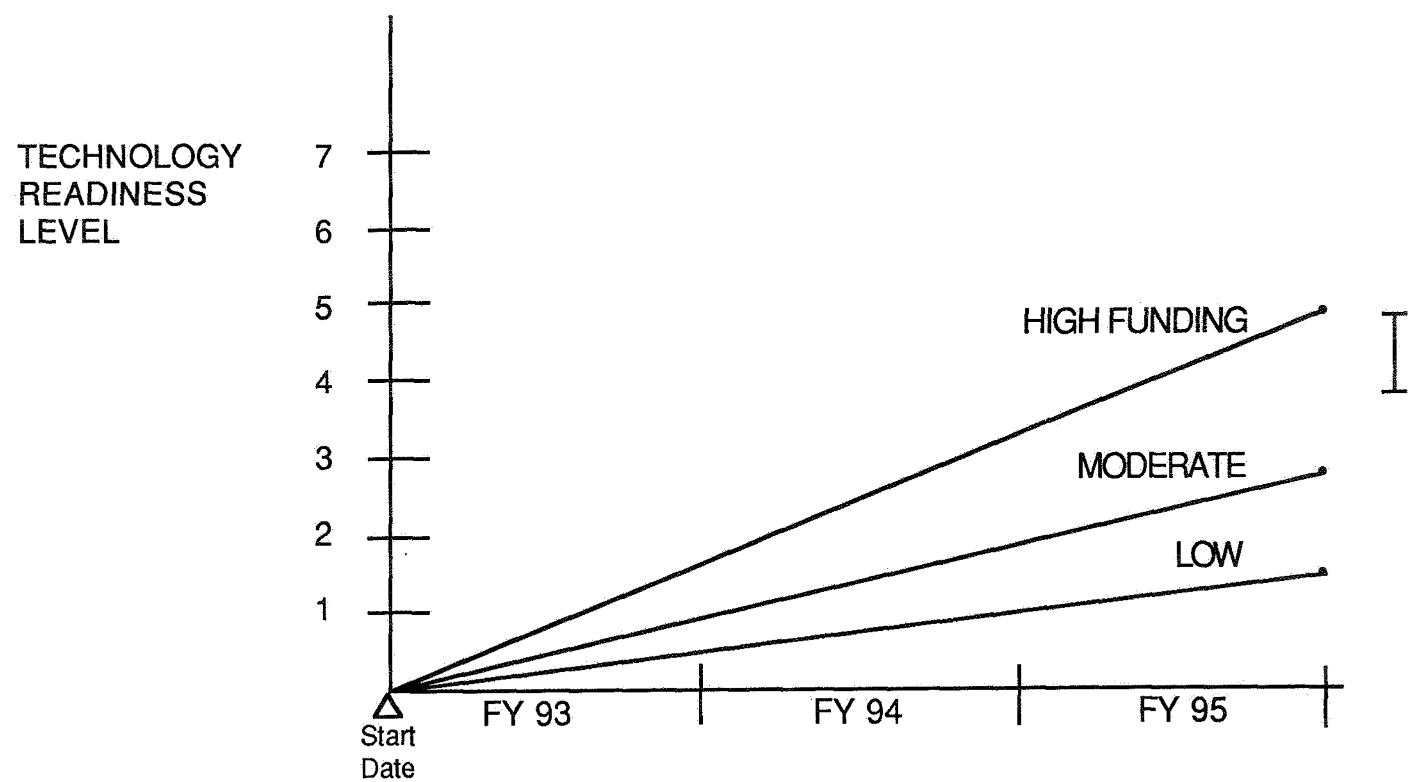
4. Optical system identifier and alignment sensor.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

ATTITUDE CONTROL & STABILIZATION

FLEXIBLE DYNAMICS AND CONTROL

<u>TECHNOLOGY ASSESSMENT</u>



BACKGROUND

SCOPE - A set of computer-aided control systems modeling, design and simulation tools for control system design and real-time hardware-in-the-loop subsystem testing.

OBJECTIVE - To develop fast and cost effective articulated multibody modeling, control design and simulation methods, and prototype software tools. The first specific objective is development of modeling tools for the representation of the plant and control system. The second specific objective is development of high-speed simulation tools with super-real-time hardware-in-the-loop capability. The third specific objective is building an efficient computer-aided control design and analysis capability. The last, but not least, important objective is to produce a computational environment that integrates the above tools into a system that allows high user productivity. These capailities should handle 400 states and 800 states systems by the third and fifth year of the program, respectively.

RATIONALE - The current control design and simulation tools are a limiting factor in today's control design and testing and are inadequate for future needs. The areas of concern are: a) control design tools break down for high order systems; b) spacecraft simulation tools are too slow to be used effectively for design and testing; and c) an integrated computer-aided control design environment is needed to improve productivity.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

ATTITUDE CONTROL& STABILIZATION

COMPUTATIONAL CONTROL TECHNIQUES

PROGRAM PLAN

APPROACH -
Develop effective multibody component model representaion techniques and software tools to capture capture the relevant sytem model using projection and component mode synthesis methods. Then numerically efficient algorithms, based on spatially recursive formulation, will be developed and tuned for serial supercomputers and massively parallel computers for super-real-time simulation. The capability to handle larger problems will be accomplished through a larger hardware system and evolutionary numerical algorithms. Natural problem condensation, scaling and high-order system solution techniquesand algorithms will be developed for control design and analysis tools. Lastly, menu-driven graphics anda data base will be used to integrate the tools into a user-oriented system.

DELIVERABLES -

1. Component model reduction software

2. Super-real-time hardware-in-the-loop simulation system.

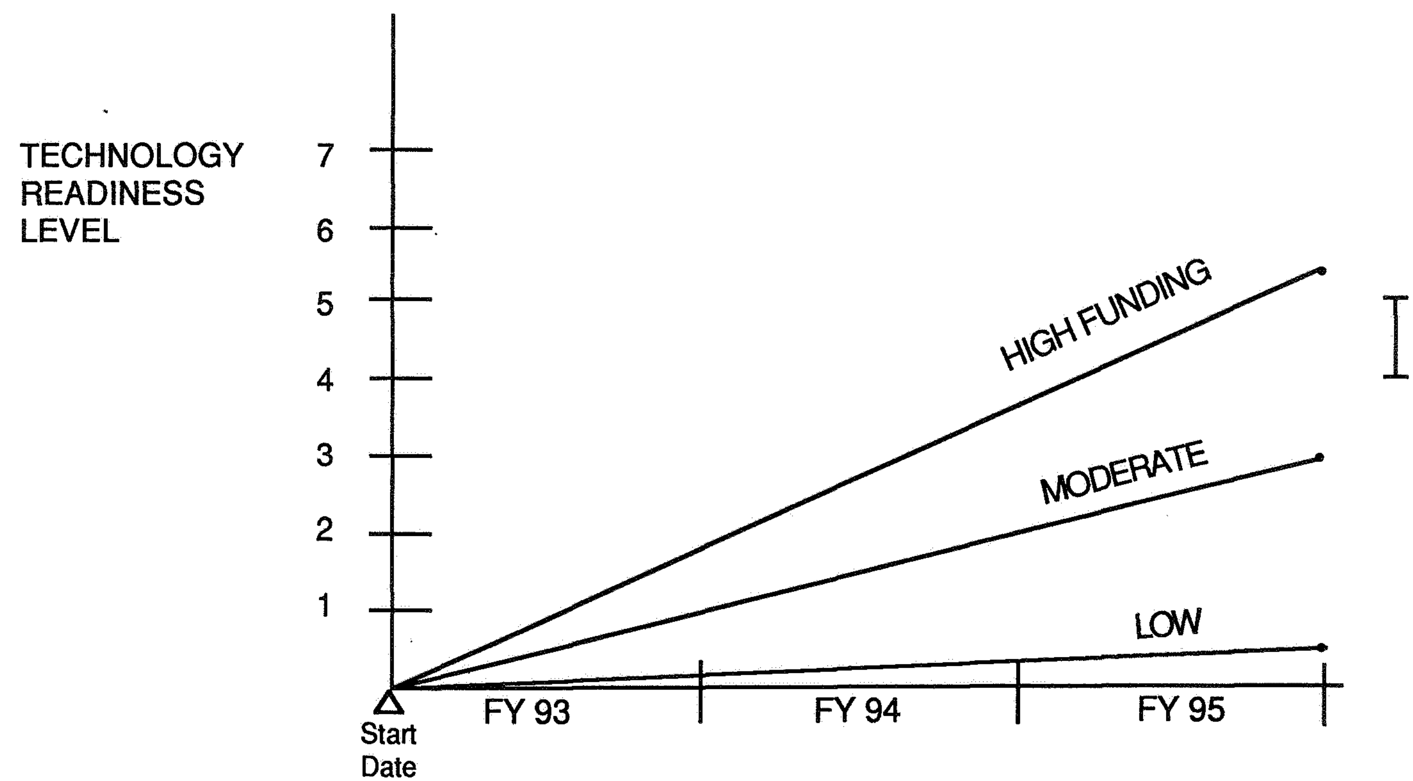
3. High-order control design and analysis software.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

ATTITUDE CONTROL & STABILIZATION

COMPUTATIONAL CONTROL TECHNIQUES

TECHNOLOGY ASSESSMENT



BACKGROUND

SCOPE - Automatic proximity operations to provide safe, cost-effective, reliable, and readily available interactive operations of co-orbiting vehicles/facilities to support transportation nodes and interplanetary exploration missions.

OBJECTIVES - To develop the trajectory control techniques, relative navigation sensors, guidance and navigation algorithms; cooperative, multi-vehicle control algorithms, optimum orbital placements, station-keeping techniques, on-board flight planning, and collision avoidance strategy for integrated, automatic proximity operations capabilities, without requiring flight crew or remote piloting support. The study will focus on accelerating the development of these elements and integrating available and emerging technologies into systems which match mission and user requirements.

RATIONALE - Future on-orbit operations for the Space Station Program, the Human Exploration Initiative, and satellite servicing will result in significantly increased traffic of co-orbiting, interactive manned and unmanned vehicles in Earth, lunar, and planetary orbits. Automatic proximity operations will enhance Earth-orbit operations by reducing flight or ground crew participation and reducing the operational constraints associated with manual or remote piloting. Automatic proximity operations are enabling technologies for the interplanetary exploration missions, where transport lags preclude remote piloting and long transfer times reduce the proficiency of flight crews for complex piloting tasks. A systematic development of these technologies can be facilitated by using current and emerging flight systems such as the NSTS, Space Station Freedom Program, and Orbital Maneuvering Vehicle (OMV) as test beds.

Maximum synergism would be effected with the Autonomous Rendezvous and Docking Project under Project Pathfinder. However, the Pathfinder AR&D funding of approximately $350K is inadequate to support the Space Station evolution needs by itself. There are unique Space Station challenges including station-keeping, sensor obscuration, and berthing/docking approaches around large appendages.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

ATTITUDE CONTROL& STABILIZATION

AUTOMATIC PROXIMITY OPERATIONS

PROGRAM PLAN

APPROACH -

1. Determine requirements for relative navigation sensors required for automatic rendezvous, proximity operations, and docking/berthing approaches and support their development and integration into automatic proximity operations capabilities, including trajectory control techniques, GN&C algorithms, and collision-avoidance techniques.

2. Develop optimum orbital placements of co-orbiting systems, on-board flight planning techniques, and orbital transfer techniques, which reduce transfer propellant and time with safety and low interference among multi-vehicle traffic operations.

3. Demonstrate these integrated capabilities via a series of ground and flight demonstrations. Ground demonstrations will involve math model simulations and hardware/software demonstrations. Flight demonstrations will begin with open-loop sensor demonstrations, progressing to closed-loop flight demonstrations using current and emerging flight systems.

DELIVERABLES -

1. Prototype relative navigation sensors integrated with GN&C algorithms, trajectory control and collision avoidance techniques, on-board flight planning, and orbital placement and transfer techniques.

2. Ground demonstrations of these integrated capabilities using graphics simulations and hardware/software test beds.

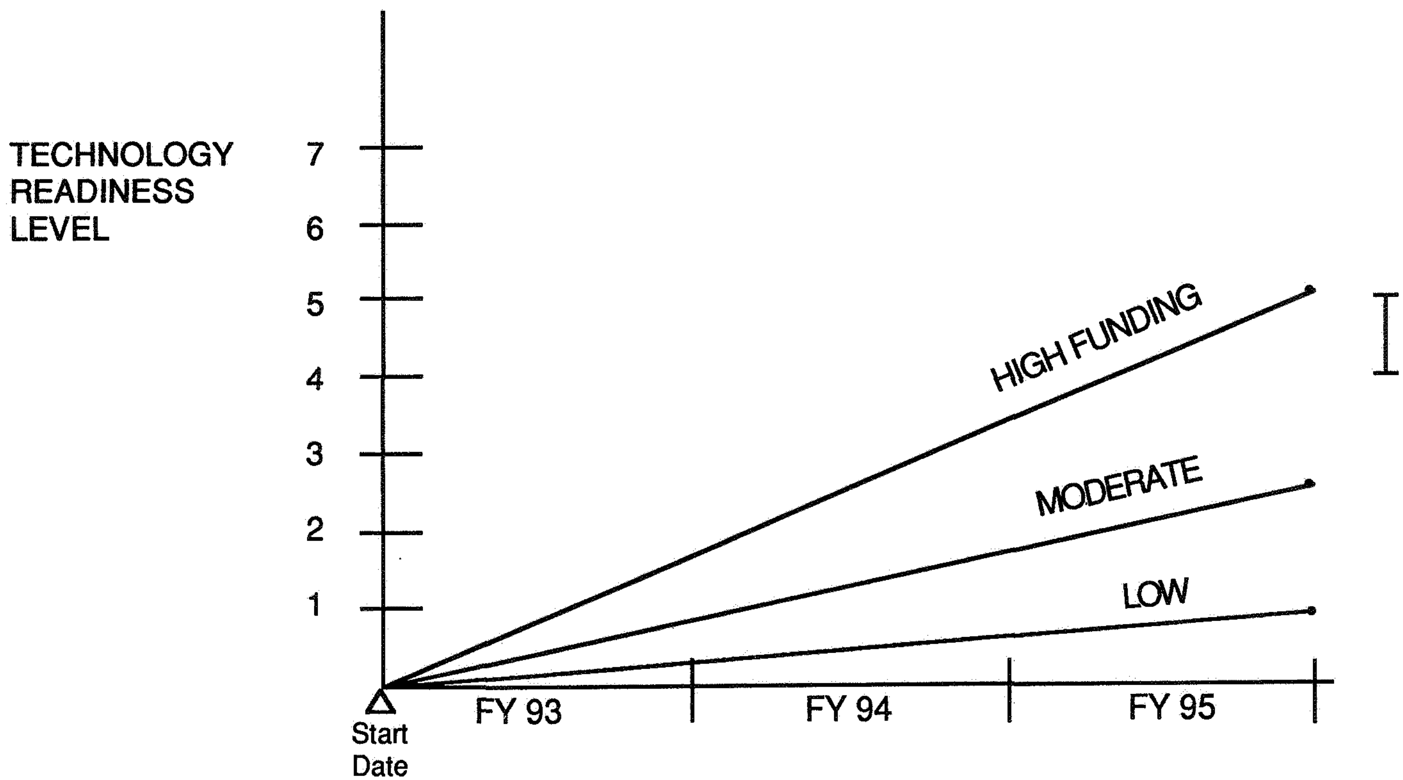
3. Progressive series of flight demonstrations of automatic proximity operations capabilities, commencing with open-loop sensor tests and culminating in full, closed-loop flight performance.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

ATTITUDE CONTROL & STABILIZATION

AUTOMATIC PROXIMITY OPERATIONS

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION
-A WORKSHOP

RECOMMENDATIONS/ISSUES FOR ATTITUDE CONTROL & STABILIZATION

<u>ADVANCED CONTROLS TECHNOLOGIES REQUIRED FOR SPACE STATION EVOLUTION</u>

<u>RECOMMENDATION</u>

A PROGRAM FUNDED AT $13 M/YR IS STRONGLY RECOMMENDED DUE TO THE ENABLING NATURE OF THE TECHNOLOGIES NEEDED FOR AN EVOLUTIONARY SPACE STATION SUCH AS:

- MOMENTUM MANAGEMENT IN A MULTI-USER ENVIRONMENT.
- MULTI-VEHICLE TRAFFIC MANAGEMENT AND PROXIMITY OPERATIONS.
- CONTROL SYSTEM STABILITY FOR MULTIPLE *FLEXIBLE* STRUCTURES.
- ROBUST PERFORMANCE FOR VASTLY CHANGING CONFIGURATIONS.

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TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

COMMUNICATIONS AND TRACKING TECHNOLOGY DISCIPLINE

JANUARY 19, 1990

ROBERT ROMANOFSKY, CHAIRMAN
NASA HEADQUARTERS, CODE RC

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TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

TECHNOLOGY DISCIPLINE SUMMARY FOR COMMUNICATIONS AND TRACKING

OBJECTIVE:

Develop devices, components, and analytical methods to enhance and enable technology to meet space station evolutionary requirements for multiple access (proximity) communications, space-to-ground communications, and tracking as it pertains to rendezvous and docking as well potential orbital debris warning systems.

SUMMARY:

The Space Station function as the hub of a sophisticated communications network presents significant technical challenges. The multiple access system is required to provide numerous simultaneous links between various spacecraft operating in different zones. Five technology areas have been identified which promise to enable evolutionary performance and safety improvements: optical communications and tracking, monolithic microwave integrated circuit antenna systems, traveling wave tube technology, advanced modulation and coding, and advanced automation for communications and tracking. Several issues have also been identified which deserve careful consideration: debris tracking (safety and operations), frequency allocation (ku-band interference), and higher data rates (user need accomodation).

OPTICAL COMMUNICATIONS AND TRACKING

BACKGROUND

SCOPE - Accommodation of intra-station data handling requirements, anticipated to be as high as one gigabit per second for certain user payloads, as well as space-to-ground traffic, projected to approach thirty-four terabits per day. Furthermore, the embodiment of a practical system to detect and track orbital debris which is considered to be a potential threat to Space Station integrity.

OBJECTIVES - Provide adequate internal and space-to-ground data handling capability to satisfy user requirements. Capitalize on available high-rate optical fiber technology and develop advanced optoelectronic interface technology. Accelerate development and deployment of optical technology for space applications. Enable graceful evolution of communications architecture to support sophisticated payloads.

REQUIREMENTS - User needs dictate expanded system capability. Real-time data transmission necessitates gigabit-per-second links. Scrub-back procedures have been insensitive to these requirements. Optical technology enables practical high data-rate systems and promises to enable high spatial resolution tracking.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

COMMUNICATIONS AND TRACKING *OPTICAL COMMUNICATIONS AND TRACKING*

PROGRAM PLAN

APPROACH :

1. Exploit small volume and mass, low power requirements, and interference immunity of optical technology to enable a practical high data-rate communication system.
2. Develop optical integrated circuit, optoelectronic interface and system architecture technology for high speed optical fiber links.
3. Develop high power, solid state laser transmitters and high-sensitivity receivers to provide enhanced data rate space-to-ground links.
4. Investigate optical sensor technology for autonomous docking.

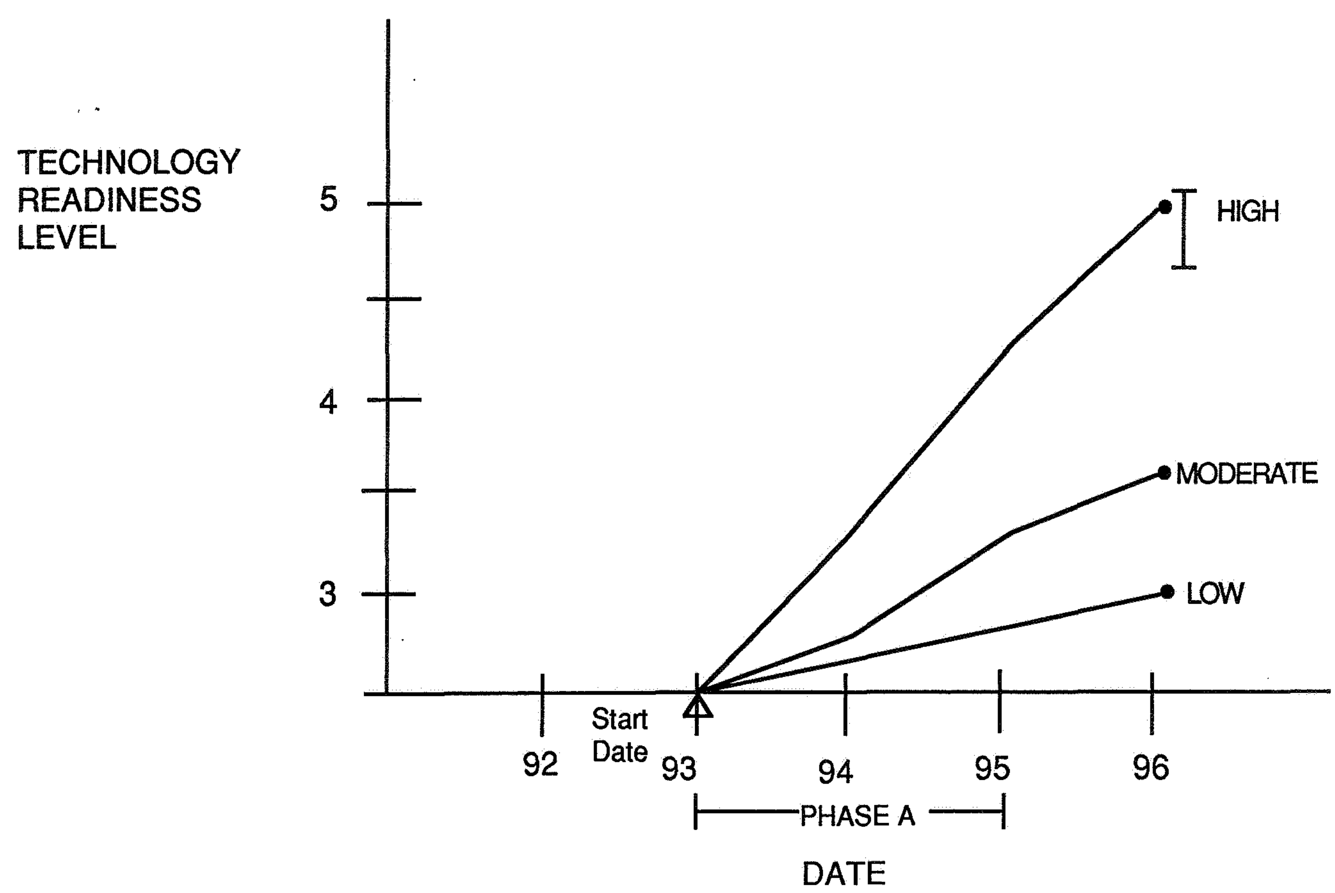
DELIVERABLES:

1. Demonstration of low power consumption, gigabit-per-second optical fiber interconnected transmitter/receiver link. (Requires moderate funding option)
2. Demonstration of long-life, high modulation rate, high-power laser transmitters and extremely high sensitivity optical receivers. (Requires high funding option)
3. Conceptualization and analysis of optically guided autonomous rendezvous and docking. (Requires low funding option)
4. Conceptualization and analysis of optical or hybrid optical/millimeter-wave debris tracking system. (Requires low funding option)

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

COMMUNICATIONS AND TRACKING *OPTICAL COMMUNICATIONS AND TRACKING*

TECHNOLOGY ASSESSMENT



BACKGROUND

SCOPE - Utilization of advanced monolithic microwave integrated circuit (MMIC) technology to provide high-fidelity uninterrupted proximity communications and preemptive orbital debris tracking radar.

OBJECTIVES - Improve versatility and reliability of the multiple-access communications system through the use of active array antennas. Improve confidence and safety of Space Station and station operations through the use of fast scanning rate phased array radar, which is a prerequisite for debris collision avoidance.

REQUIREMENTS - Appreciable interference problems are expected at Ku-band. The eventual transition of Space Station into Ka-band is encouraged by a large constituency. A medium-gain, wide-scan (hemispherical) antenna and a narrow beam scanning phased array antenna for long range (2000 km) operations are candidates for MMIC insertion. The need for power control on return links of the multiple access system has also been identified. Finally, sub-microsecond scanning phased arrays for orbital debris tracking will require millimeter-wave integrated circuit technology.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

COMMUNICATIONS AND TRACKING — *MONOLITHIC MICROWAVE INTEGRATED CIRCUIT SYSTEMS*

PROGRAM PLAN

APPROACH:

1. Exploit Ka-band technology to augment data handling capacity and alleviate Ku-band interference problems.
2. Develop manufacturable monolithic integrated circuit amplifiers and phase shifters to enable Ka-band active array antennas.
3. Integrate MMIC technology with compatible antenna technology to produce fast scanning rate arrays for full coverage proximity communications and orbital debris tracking.

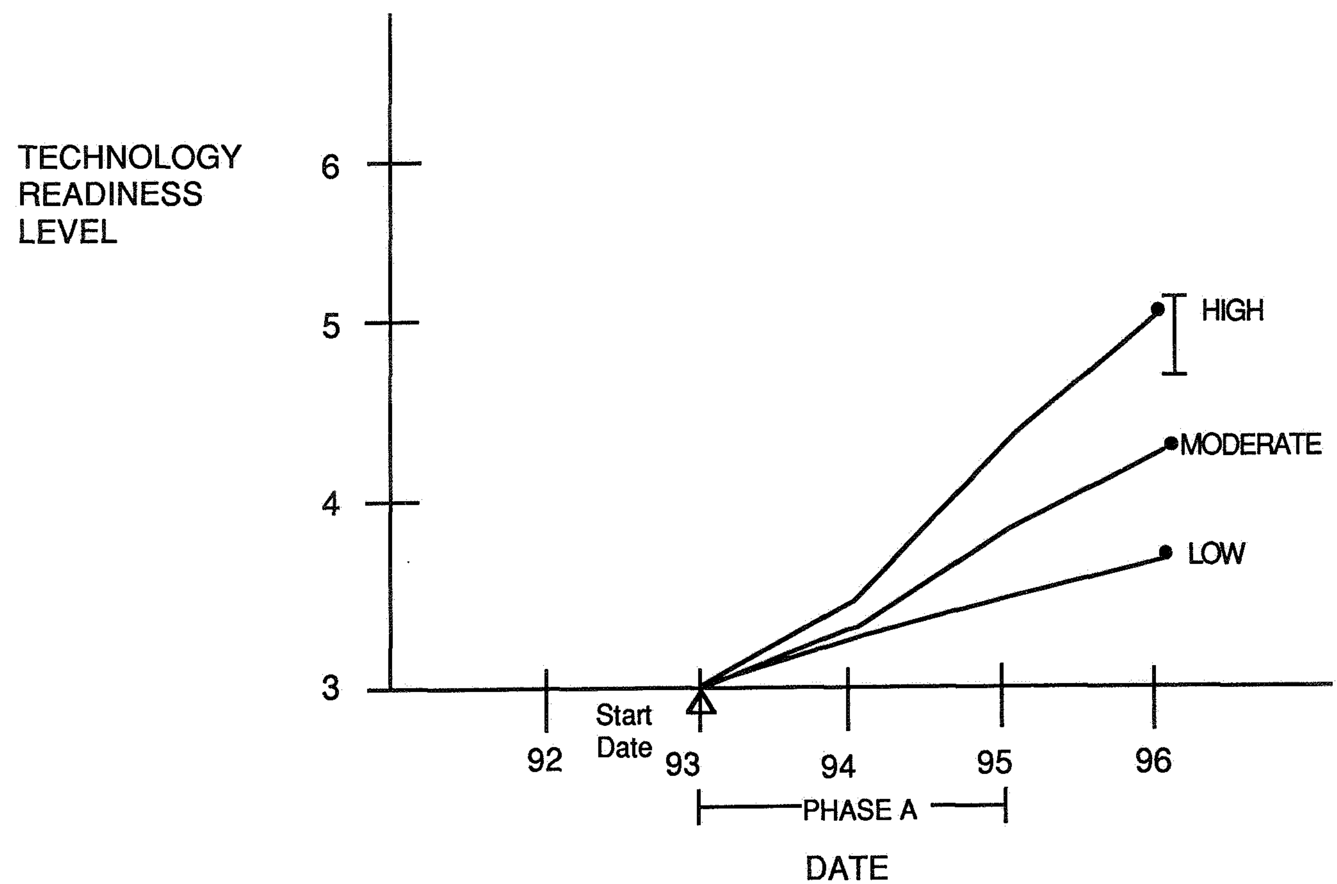
DELIVERABLES:

1. Reproducible, cost effective, reliable Ka-band MMIC: variable power (1 W max.) amplifiers, high power (2 to 4 W) amplifiers, and low-loss phase shifters. (Low funding option does not include reliability assessment)
2. Demonstration of two-dimensional fast scanning rate Ka-band phased array antenna. (Requires high funding option)
3. Conceptualization and analysis of on-board millimeter-wave orbital debris tracking system. (Requires moderate funding option)

TECHNOLOGY FOR SPACE STATION EVOLUTION
-A WORKSHOP

COMMUNICATIONS AND TRACKING *MONOLITHIC MICROWAVE INTEGRATED CIRCUIT ANTENNA SYSTEMS*

<u>TECHNOLOGY ASSESSMENT</u>



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

COMMUNICATIONS AND TRACKING *TRAVELING WAVE TUBE TECHNOLOGY*

BACKGROUND

SCOPE - Adaptation of proven technology for high data rate (wide bandwidth) link from Space Station Freedom to the Advanced Tracking and Data Relay Satellite System.

OBJECTIVES - Provide low risk, evolutionary communications capability to Space Station. Investigate 60 GHz technology for space-to-space links.

REQUIREMENTS - Existing and anticipated demands on Space Station information handling capability encourage enhanced downlink data rates. ATDRSS is expected to utilize Ka-band architecture; hence, a Ka-band crosslink is a logical evolutionary step. Furthermore, traveling wave tube technology is maturing more rapidly than any competitor at millimeter wavelengths. A 60 GHz traveling wave tube operating with 10% bandwidth, a conservative technical specification, offers a data rate which rivals optical technology.

TECHNOLOGY FOR SPACE STATION EVOLUTION
-A WORKSHOP

COMMUNICATIONS AND TRACKING *TRAVELING WAVE TUBE TECHNOLOGY*

PROGRAM PLAN

APPROACH:

1. Exploit high RF output power, high efficiency, and reliability of traveling wave tube technology to enable adequate data rates for Space Station downlink and develop ATDRSS compatible hardware.
2. Unveil low-risk (near term), moderate-cost alternative to optical communications.
3. Develop 60 GHz traveling wave tube technology for space-to-space communications.

DELIVERABLES:

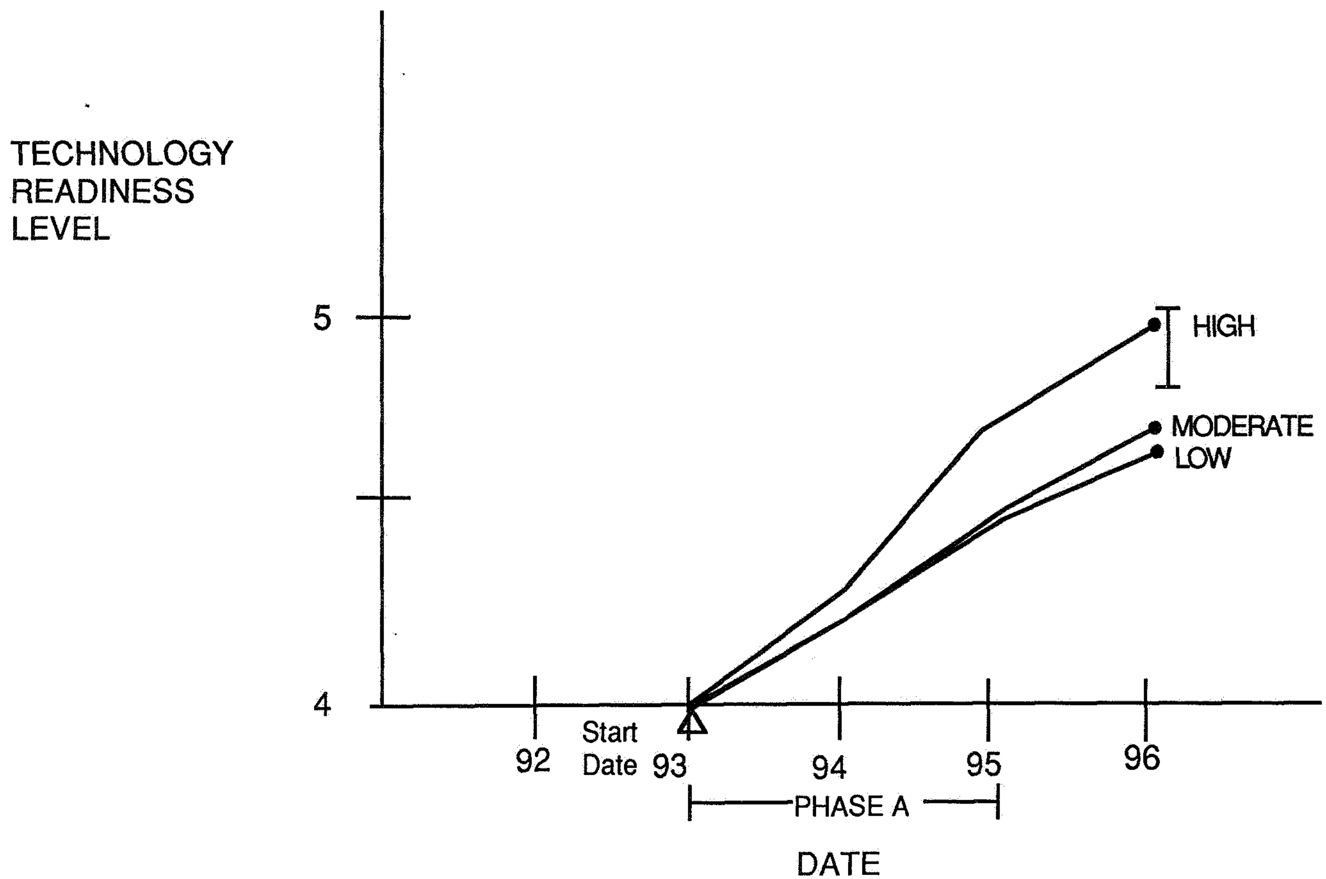
1. Demonstration of high-power, high-efficiency Ka-band traveling wave tube with appropriate power conditioning peripherals for ATDRSS-type crosslink. (Moderate funding option necessitates relaxed performance and eliminates peripherals)
2. Analysis of prospects, technology readiness, and feasibility of 60 GHz link capability for Space Station Freedom. (Requires moderate funding level)

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

COMMUNICATIONS AND TRACKING

TRAVELING WAVE TUBE TECHNOLOGY

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

BACKGROUND

SCOPE - Expansion of modulation rates using data compression, advanced modulation and coding to provide more efficient use of available bandwidth. Exploration of innovative techniques to reduce information volume to useful data and expand information throughput .

OBJECTIVES - Provide promising alternative or supplement to wider bandwidths through improved spectral utilization (greater than two bits per second per hertz).

REQUIREMENTS - Existing needs and anticipated growth of payload data rates demand an increase in information handling capability. Options include moving to much higher frequencies or enhancing data transmission through existing links. Advanced modulation and coding techniques offer the potential to dramatically reduce the bandwidth required for applications such as high frame rate, high definition television.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

PROGRAM PLAN

APPROACH:

1. Investigate data compression techniques and advanced modulation and coding to exploit available bandwidth as opposed to or in addition to extending Space Station communications operations into millimeter or optical wavelengths to permit greater data throughput, improved bit error rate performance, and enhanced bandwidth efficiency.
2. Develop encoding techniques and modulator/demodulator technology to enable novel bandwidth efficiency improvements.

DELIVERABLES:

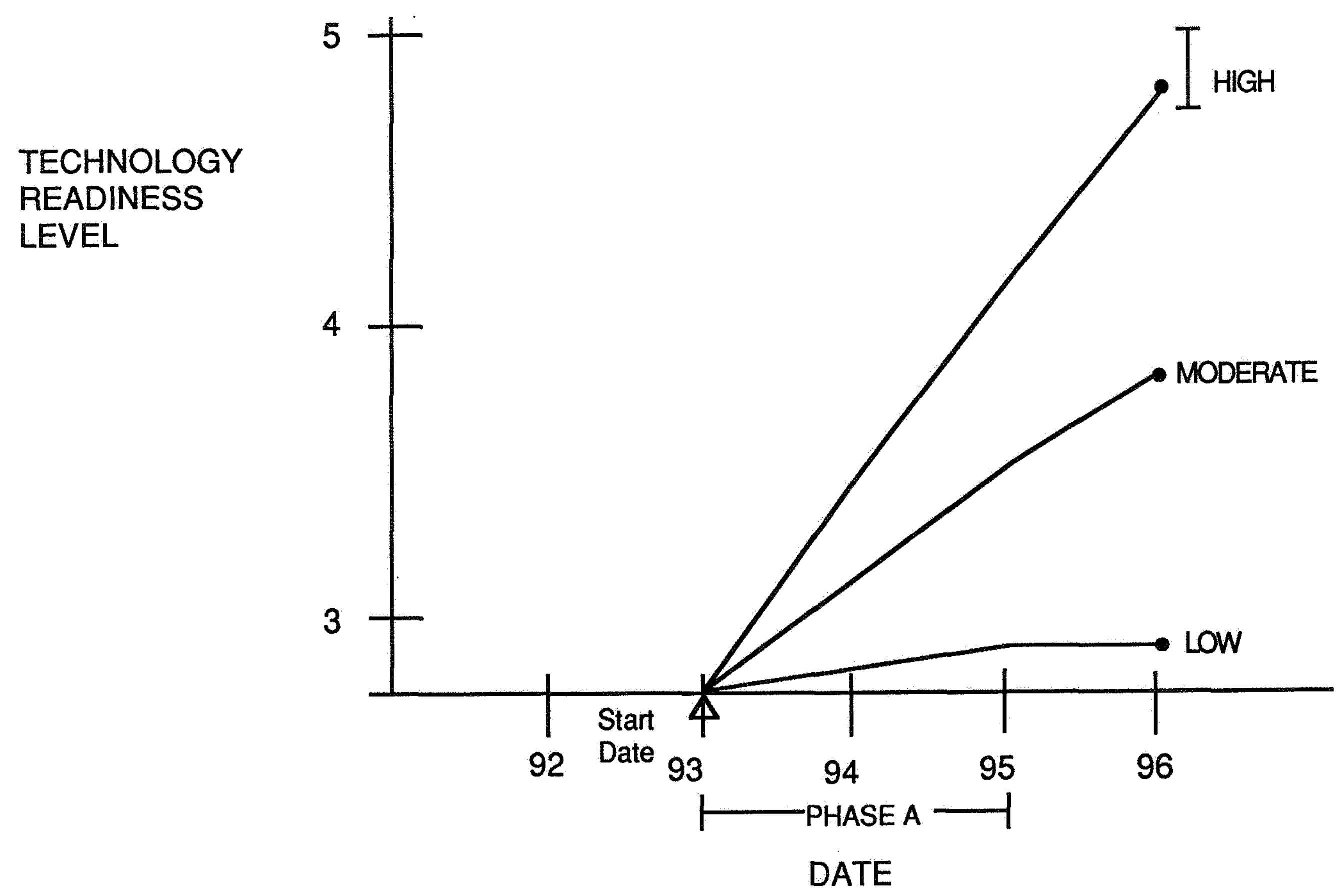
1. Analysis and selection of optimum modulation schemes to provide enhanced data rates for intra-Space Station and Space Station-to-ground communication links. (Requires low funding option)
2. Laboratory breadboard demonstration of modulator/demodulator critical functions. (Moderate funding option does not permit parallel approach development)

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

COMMUNICATIONS AND TRACKING

ADVANCED MODULATION AND CODING

TECHNOLOGY ASSESSMENT



COMMUNICATIONS AND TRACKING *ADVANCED AUTOMATION*

BACKGROUND

SCOPE - Implementation of knowledge-based autonomous systems to improve safety and enhance operations of numerous communications and tracking functions.

OBJECTIVES - Identify candidate subsystems likely to benefit from or requiring expert system interaction. Reduce demand on crew time and optimize utilization of communications and tracking resources. Improve safety and reliability of critical operations such as extravehicular activity (EVA). Provide high levels of fault tolerance and diagnostic capability to communications and tracking architecture.

REQUIREMENTS - A plethora of functions and applications dependent on high levels of autonomy for practical implementation exist. Automation is an enabling ingredient for realistic orbital debris tracking and unmanned rendezvous and docking. Numerous communications resource management enhancements are provided as well, especially ground station scheduling and antenna selection. Safe EVA coordination and monitoring could be an early application. A methodical development of expert system integration is essential.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

COMMUNICATIONS AND TRACKING *ADVANCED AUTOMATION*

PROGRAM PLAN

APPROACH:

1. Select those communications and tracking systems and operations for which complete or partial autonomy is essential and merge associated functions as a prelude to total expert system integration. For example, optimistically, extravehicular activities, high gain antenna selection, and orbital debris tracking would be coordinated through a central expert system manager.
2. Develop selected fully autonomous expert systems as well as user query/interactive systems for identified functions. Develop appropriate interactive communications environment (speech synthesis, graphics, etc.) to facilitate user interface.
3. Integrate multiple interrelated functions with communications/data management system and user interface system.

DELIVERABLES:

1. Demonstration/simulation of autonomous expert system for selected communications and tracking function.*
2. Demonstration of intelligent user interface for integrated interactive communications and tracking system.*

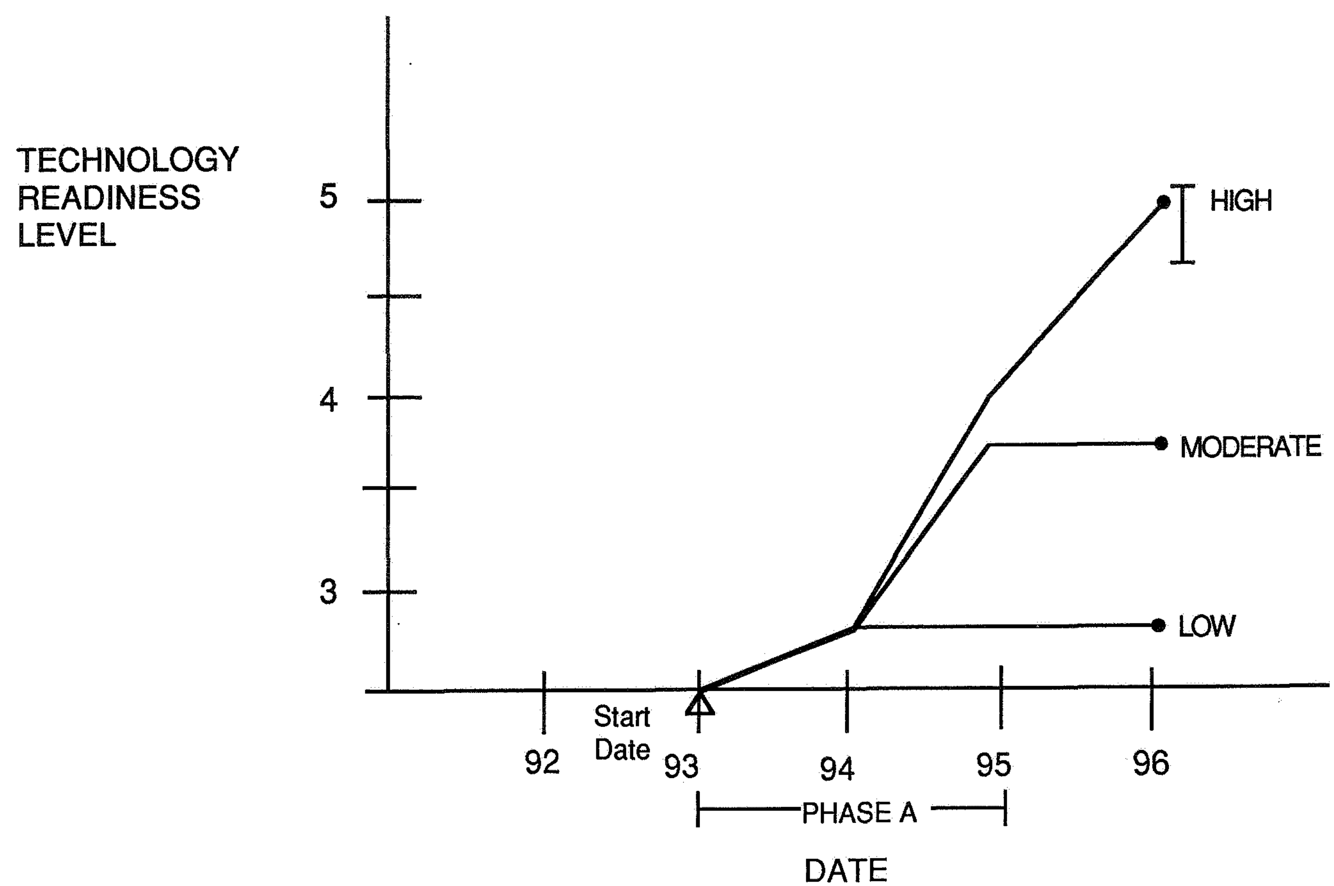
*(Integration phase requires high funding option, development phase requires moderate funding option, concept phase requires low funding option)

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

COMMUNICATIONS AND TRACKING

ADVANCED AUTOMATION

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

RECOMMENDATIONS/ISSUES FOR COMMUNICATION AND TRACKING

ORBITAL DEBRIS

Orbital debris is considered a significant potential threat to the basic safety of the crew and structure of Space Station. It has been predicted that approximately 50,000 0.1 mm particles will impact Space Station per year. This process will cause continual erosion of surfaces, and could be particularly detrimental to optical instruments and solar panels. Primary concern, however, is focused on the far-from-remote possibility that large particles (greater than 1 cm) will collide with the structure over the projected 30 year lifetime. Although the structure is designed to tolerate collisions with particles having dimensions smaller than 1 cm, it is anticipated that Space Station will experience close encounters with much larger particles every year. Currently, there is no method of tracking debris with dimensions smaller than 10 cm. Ten centimeter and larger particles can be monitored through ground based surveillance. Furthemore, the debris problem is malignant since space activities continue to generate additional material.

RECOMMENDATIONS:

1. Continue/expand (optical/radar) studies of debris distribution
2. Develop precision onboard optical/millimeter wave debris tracking system
3. NASA should pioneer efforts to minimize additional debris

RECOMMENDATIONS/ISSUES FOR COMMUNICATIONS AND TRACKING

FREQUENCY ALLOCATION

It is expected that the Space Station multiple-access system will experience significant interference at Ku-band. The primary source of interference will be fixed satellite service very small aperture terminals (VSATs), which are expected to proliferate in the 1990's. The nature of interference can range from noisy degradation to momentary blackout. Crew safety could be jeopardized. It is particularly disconcerting that NASA is a secondary user at Ku-band. Consequently, in addition to enduring intermittent interference, potential liability issues exist since Space Station could interfere with primary commercial users. Finally, the possibility of adjacent channel interference with the multiple access system by TDRSS has also been identified due the high sidelobe levels.

RECOMMENDATIONS:

1. Secure Ka-band allocation which designates NASA as primary user
2. Develop necessary Ka-band monolothic microwave integrated circuit and antenna technology.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

RECOMMENDATIONS/ISSUES FOR COMMUNICATIONS AND TRACKING

HIGHER DATA RATES

Intra-Space Station Freedom data rate requirements have been identified which are in excess of planned throughput capacity. For certain user payloads, rates as high as one gigabit/second might be required. Real-time data transmission necessitates much higher rates than currently planned. Retrofitting beyond Assembly Complete (AC) to accomodate growing demands is an untenable solution. Furthermore, optimal payload utilization is encumbered by marginal downlink rate capacity.

RECOMMENDATIONS:

1. Insert high rate fiber for initial Space Station to accomodate existing and anticipated traffic
2. Transition into optical crosslinks and downlinks for advanced TDRS systems
3. Pursue advanced modulation and coding techniques to permit data rate growth

TECHNOLOGY FOR SPACE STATION EVOLUTION
- A WORKSHOP

DATA MANAGEMENT SYSTEM TECHNOLOGY DISCIPLINE

JANUARY 19, 1990

DR. HARRY F. BENZ, CHAIRMAN
LANGLEY RESEARCH CENTER

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

DATA MANAGEMENT SYSTEM

<u>DISCIPLINE ISSUES - SUMMARY</u>

SYSTEMS - Improve Performance of EDP

STORAGE - Improve Mass Storage, Buffers and Block Storage

PROCESSORS - Evolutionary Integration of Multicomputers

ON BOARD COMMUNICATIONS - Increase Bandwidth of Existing Fibers

SOFTWARE - Expanded SSE with Tools and Guidelines for Verification

HUMAN INTERFACE - 3-D Display Technologies

MANAGEMENT - Must Approach SSF as an Integrated System, with System Wide V and V

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM *SYSTEMS TECHNOLOGY AREA NEEDS*

NEEDS:

- HIGH PERFORMANCE COMPONENTS
- LOWER POWER COMPONENTS
- AUTOMATED SYSTEMS DIAGNOSIS
- SYSTEM (HW &SW) VERIFICATION
- FAULT TOLERANCE OVER LONG TERM WITH GRACEFUL DEGRADATION

ISSUES:

- HOW DO WE EVOLVE A SYSTEM?
- END-TO-END SYSTEMS ENGINEERING VS. END-TO-END SYSTEMS DESIGN

TECHNOLOGY FOR SPACE STATION EVOLUTION
A WORKSHOP

DATA MANAGEMENT SYSTEM *STORAGE TECHNOLOGY AREA NEEDS*

NEEDS:

- MASS STORAGE - BOTH BUFFER AND BLOCK ACCESS HIGH PERFORMANCE STAGED MEMORY SYSTEMS

ISSUES:

- OPTICAL DISK RECORDER NEARING TECHNOLOGICAL MATURITY

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM | *PROCESSOR TECHNOLOGY AREA NEEDS*

NEEDS:

- HIGH RATE SCIENCE PROCESSOR, IMAGE PROCESSOR, DATA COMPRESSOR
- EVOLUTIONARY INTEGRATION OF MULTICOMPUTERS
- SPECIAL-PURPOSE COPROCESSOR - NEURAL NETS

ISSUES:

- SIGNIFICANT IMPROVEMENTS IN SPEED/POWER IN EDP WOULD GREATLY HELP SSF

NEEDS:

- METHODS TO UPGRADE PERFORMANCE OF FIBERS
- HIGHER RATES/THROUGHPUT

ISSUES:

- ACCOMMODATION NECESSARY TO PLAN FOR FIBER REPLACEMENT

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM *SOFTWARE SYSTEM TECHNOLOGY AREA NEEDS*

NEEDS:

- SSE DEVELOPMENT
- ABILITY TO PERFORM STAGE IMPLEMENTATION OF SOFTWARE

ISSUES:

- SOFTWARE VERIFICATION ... FORMAL PROOF VS. EXHAUSTIVE TESTING
- DISTRIBUTED DATA BASE ... ACCESS CONTROL, CONCURRENCY, DISTRIBUTION

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM *HUMAN INTERFACE TECHNOLOGY AREA NEEDS*

NEEDS:

- 3-D DISPLAY TECHNOLOGIES FOR TELEROBOTIC AND COMPLEX DATA VISUALIZATION
- LARGE AREA, COLOR, FLAT PANEL DISPLAYS
- HIGH-RESOLUTION CAMERA INPUTS

ISSUES:

- STANDARD JOYSTICK AND INTERFACE FOR WORKSTATION

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

BACKGROUND

SCOPE - Higher performance, lower power system technologies that meet end-to-end system design requirements for a higher performance fault-tolerant, ultra-reliable DMS system.

OBJECTIVES - Develop end-to-end system models to analyze reliability, performance, power and latency requirements. Identify key system design parameters and develop and demonstrate system technologies to achieve the system requirement.

RATIONALE - Present and anticipate DMS requirements either stress DMS's capabilities or in fact exceed DMS's capabilities. NASA needs an end-to-end modeling and analysis capability to identify and analyze system requirements that are at risk.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM *SYSTEMS*

PROGRAM PLAN

APPROACH:

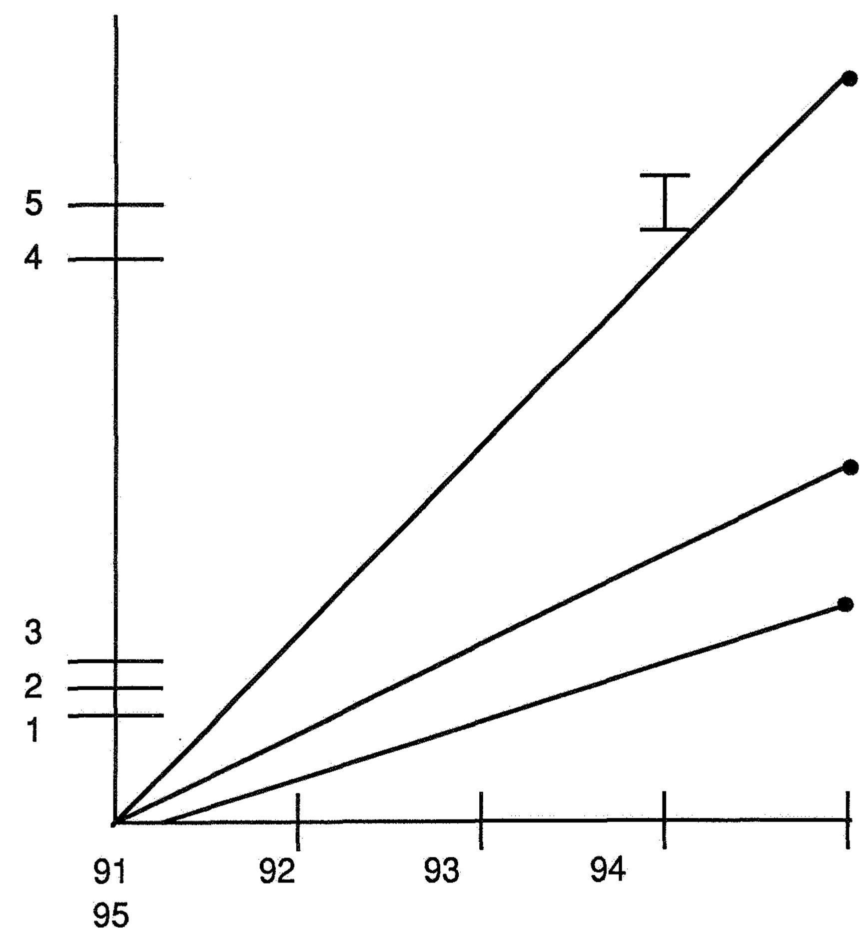
1. ASSESS AND PROCURE TOOLS FOR MODELING AND ANALYZING END-TO-END SYSTEM REQUIREMENTS.
2. DEVELOP MODELS FOR END-TO-END SYSTEMS.
3. ANALYZE END-TO-END REQUIREMENTS AND IDENTIFY REQUIREMENT RISK AREAS AND POTENTIAL TECHNOLOGY ENHANCEMENT TO REDUCE RISK.
4. DEVELOP TECHNOLOGIES TO INCREASE PERFORMANCE, RELIABILITY, AND FAULT TOLERANCE.
5. IMPLEMENT A BRASSBOARD FOR HIGH PERFORMANCE, RELIABILITY, AND FAULT TOLERANT TECHNOLOGIES TO REDUCE REQUIREMENT SHORT FALLS.
6. DEMONSTRATE TECHNOLOGY COMPATIBILITY WITH DMS SYSTEM.

DELIVERABLES:

1. DEVELOP REQUIREMENT MODELS
2. TECHNOLOGY BRASSBOARDS

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM *SYSTEMS*



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM *MASS STORAGE SYSTEM*

BACKGROUND

SCOPE:

RELIABLE HIGH-DENSITY MASS STORAGE THAT IS ABLE TO SUPPORT PHASE I PAYLOAD OPERATIONS ONBOARD AND PROVIDE AN EVOLVABLE BASIS FOR ENHANCED STORAGE TECHNOLOGIES REQUIRED TO ENABLE LATER PHASES OF STATION OPERATION AND HUMAN EXPLORATION OF THE MOON AND MARS.

OBJECTIVES:

TO DEVELOP THE KEY TECHNOLOGIES AND SYSTEM CONCEPTS AND DELIVER MASS STORAGE SYSTEMS ONBOARD SPACE STATION FREEDOM THAT WILL PROVIDE ON-LINE RAPID ACCESS CAPACITY TO SYSTEM AND PAYLOAD USERS. TO EVALUATE AND DEVELOP NEW STORAGE TECHNOLOGIES AS WELL AS ENHANCED VERSIONS OF THE SSF SYSTEMS TO SATISFY THE REQUIREMENTS ON THE HEI.

RATIONALE:

THE PRESENT MASS STORAGE SYSTEM PROPOSED FOR SSF PROVIDES INADEQUATE STORAGE FOR BUFFERING PAYLOAD DATA FOR DELAYED PROCESSING AND/OR TRANSMISSION. SOME OF THE PAYLOADS REQUIRE TERABYTE DATA CAPACITY AND EXTREMELY HIGH INGEST RATES. ENHANCED STORAGE PROVIDED BY VARIOUS TECHNOLOGIES IS ESSENTIAL TO REDUCE THE LOAD ON RESTRICTED DOWNLINK CAPABILITY AND TO ALLEVIATE THE UNACCEPTABLE SITUATION OF SCHEDULING PAYLOAD ACTIVITIES AROUND DATA TRANSMISSION AVAILABILITY. DATA REQUIREMENTS FOR LATER PHASES OF STATION OPERATION, LUNAR EXPLORATION AND THE MISSION TO MARS WILL BE MORE STRINGENT THAN THOSE OF THE PMC.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM *MASS STORAGE SYSTEM*

PROGRAM PLAN

RECOMMENDATIONS/ISSUES:

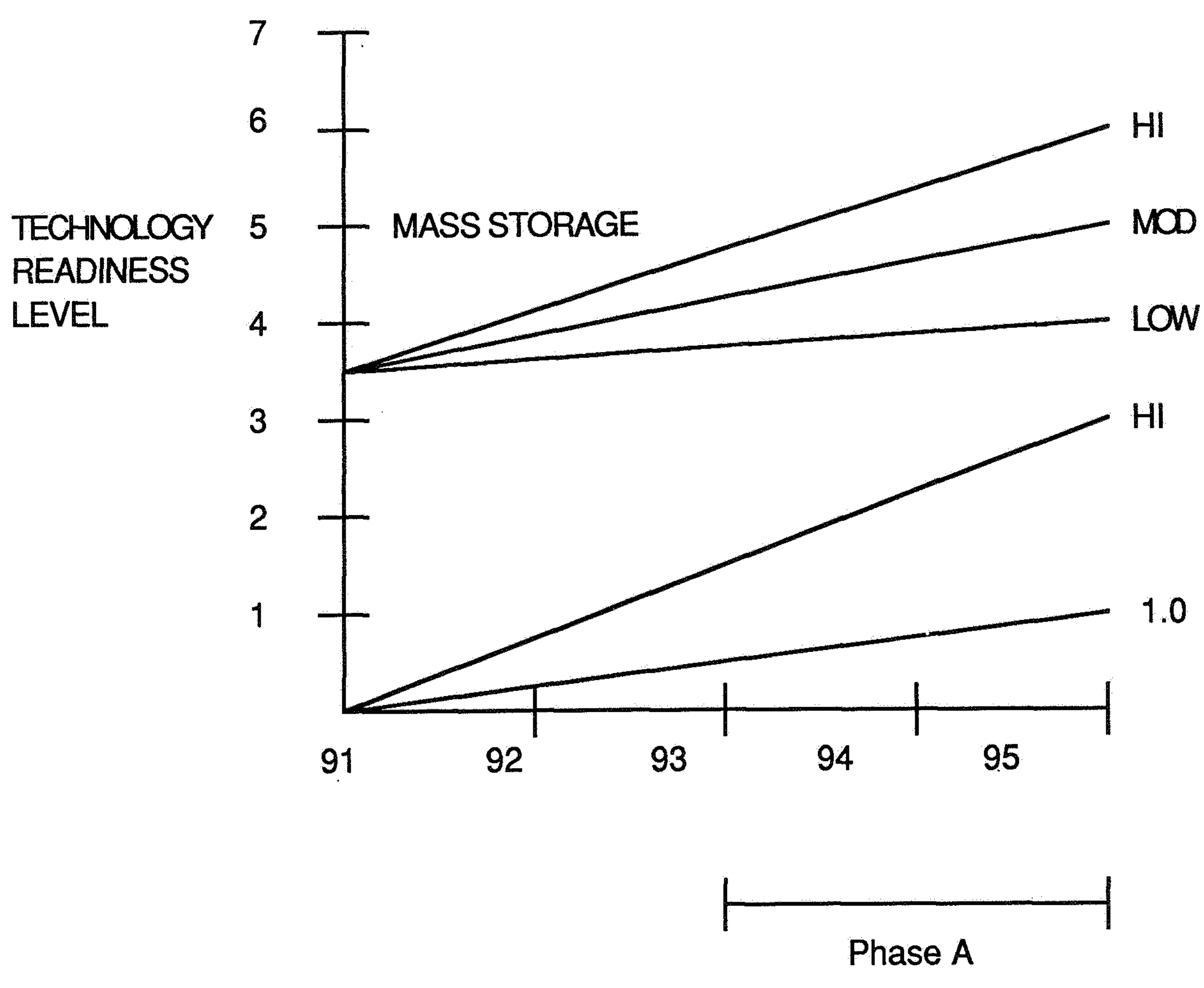
SEVERAL OF THE TECHNOLOGIES THAT CAN ENABLE PAYLOAD OPERATIONS ON SPACE STATION FREEDOM CAN BE MADE READY IN THE NEAR TERM. FOR EXAMPLE, WORK IN THE AREAS OF REWRITABLE MAGNETO-OPTIC DISK TECHNOLOGY IS AT LEVEL 3 AND IS READY TO BE INCORPORATED INTO A FLIGHT EXPERIMENT AND QUALIFIED. THE FURTHER DEVELOPED TECHNOLOGIES DO NOT "DEAD-END" ON THE STATION, THEY CAN BE ENHANCED SERVE INTO THE HEI ERA. THE OTHER YOUNGER TECHNOLOGIES SHOULD BE PURSUED AS THEY TOO CAN OFFER BENEFITS LATER IN THE HEI.

MAJOR CHALLENGES FOR ALL THESE TECHNOLOGIES INCLUDE THE USUAL SPACEFLIGHT CONSTRAINTS OF WEIGHT, POWER, AND VOLUME AS WELL AS RELIABILITY, MAINTAINABILITY, AND EVOLVABILITY REQUIRED FOR THE LONG-TERM MISSIONS.

A SUITE OF TECHNOLOGIES MUST BE EVALUATED, BECAUSE NO ONE TECHNOLOGY CAN MEET THE SPECTRUM OF USER REQUIREMENTS (E.G., DATA RATE, CAPACITY).

TECHNOLOGY ASSESSMENT *MASS STORAGE STYSTEM*

TECHNOLOGY ASSESSMENT



DATA MANAGEMENT SYSTEM *PROCESSORS*

BACKGROUND

SCOPE:

SPECIAL- AND GENERAL-PURPOSE COMPUTER AND OPERATING SYSTEMS TECHNOLOGIES TO ENABLE ENHANCED ONBOARD DATA PROCESSING AND CONTROL.

OBJECTIVES:

TO DEMONSTRATE THE CAPABILITY TO REPLACE GENERAL-PURPOSE PROCESSORS ONBOARD THE STATION WITH MULTIPROCESSOR BASED ON ADVANCED COMPONENTS WHICH WILL PERFORM THE EXISTING FUNCTIONS AND, IN ADDITION, INCLUDE SIGNIFICANT CAPABILITY FOR EXPANSION; TO DEMONSTRATE HIGHLY PARALLEL PROCESSORS CAPABLE OF HIGH THROUGHPUT IMAGE AND SCIENCE DATA PROCESSING; AND TO DETERMINE AND DEMONSTRATE THE APPLICABILITY OF SPECIAL PROCESSING ARCHITECTURES FOR NEURAL AND SYMBOLIC PROCESSING TO SPACE STATION TASKS.

RATIONALE:

CURRENTLY, OAST IS FUNDING SEVERAL GENERIC PROCESSOR TECHNOLOGY DEVELOPMENTS. THESE DEVELOPMENTS, TOGETHER WITH COMMERCIAL AND DOD DEVELOPMENTS, WILL PRODUCE SPECIAL- AND GENERAL-PURPOSE COMPUTING TECHNOLOGIES WHICH COULD YIELD A TEN-FOLD INCREASE IN ONBOARD COMPUTING CAPABILITY WITH NO INCREASE IN ELECTRICAL POWER REQUIREMENTS. A SIGNIFICANT CAPABILITY INCREASE IS NEEDED TO SUPPORT INCREASE SCIENCE USAGE, TO SUPPORT ASSEMBLY AND ON-ORBIT CHECKOUT, AND TO REDUCE CREW TIME REQUIRED FOR DIAGNOSIS AND MAINTENANCE. BEFORE THESE ADVANCED TECHNOLOGIES CAN BE USED ON SPACE STATION FREEDOM, HOWEVER, THEY MUST BE MADE COMPATIBLE WITH THE STATION'S EXISTING HARDWARE, SOFTWARE, AND DEVELOPMENT AND SUPPORT ENVIRONMENTS. IN ADDITION, FOR THE SPECIAL-PURPOSE PROCESSORS, ALGORITHMS AND ARCHITECTURES APPROPRIATE TO KEY SPACE STATION NEEDS MUST BE DEVELOPED AND DEMONSTRATED.

DATA MANAGEMENT SYSTEM *PROCESSORS*

PROGRAM PLAN

APPROACH:

1. DEMONSTRATE A BREADBOARD/BRASSBOARD MULTIPROCESSOR EDP UPGRADE PERFORMING A SELECTED SET OF DMS SOFTWARE AND APPLICATIONS INTEGRATED IN THE GROUND-BASED DMS TESTBED. (THIS PLAN ASSUMED ADEQUATE SUPPORT UNDER CSTI DATA SYSTEMS TO DEVELOP THE MULTIPROCESSOR AND ITS OPERATING SYSTEM.)

2. DEVELOP AND DEMONSTRATE A HIGHLY PARALLEL IMAGE AND SCIENCE DATA PROCESSOR BRASSBOARD PERFORMING SIMULATE STATION DATA REDUCTION TASK. (ASSUMES CSTI DATA SYSTEMS ADVANCED IMAGE PROCESSOR)

3. DEMONSTRATE THE CAPABILITY TO INTEGRATE FRONT-END SIGNAL PROCESSING ON FOCAL-PLANE SENSORS.

4. DEVELOP NEURAL AND/OR SYMBOLIC PROCESSING ARCHITECTURES FOR SPECIFIC SSF APPLICATIONS TO DEMONSTRATE THE FEASIBILITY AND EFFECTIVENESS OF USING THESE INNOVATIVE APPROACHES.

DELIVERABLES:

1. DEMONSTRATE EDP UPGRADE BRASSBOARD INTEGRATED INTO THE SPACE STATION INTEGRATED TESTBED.

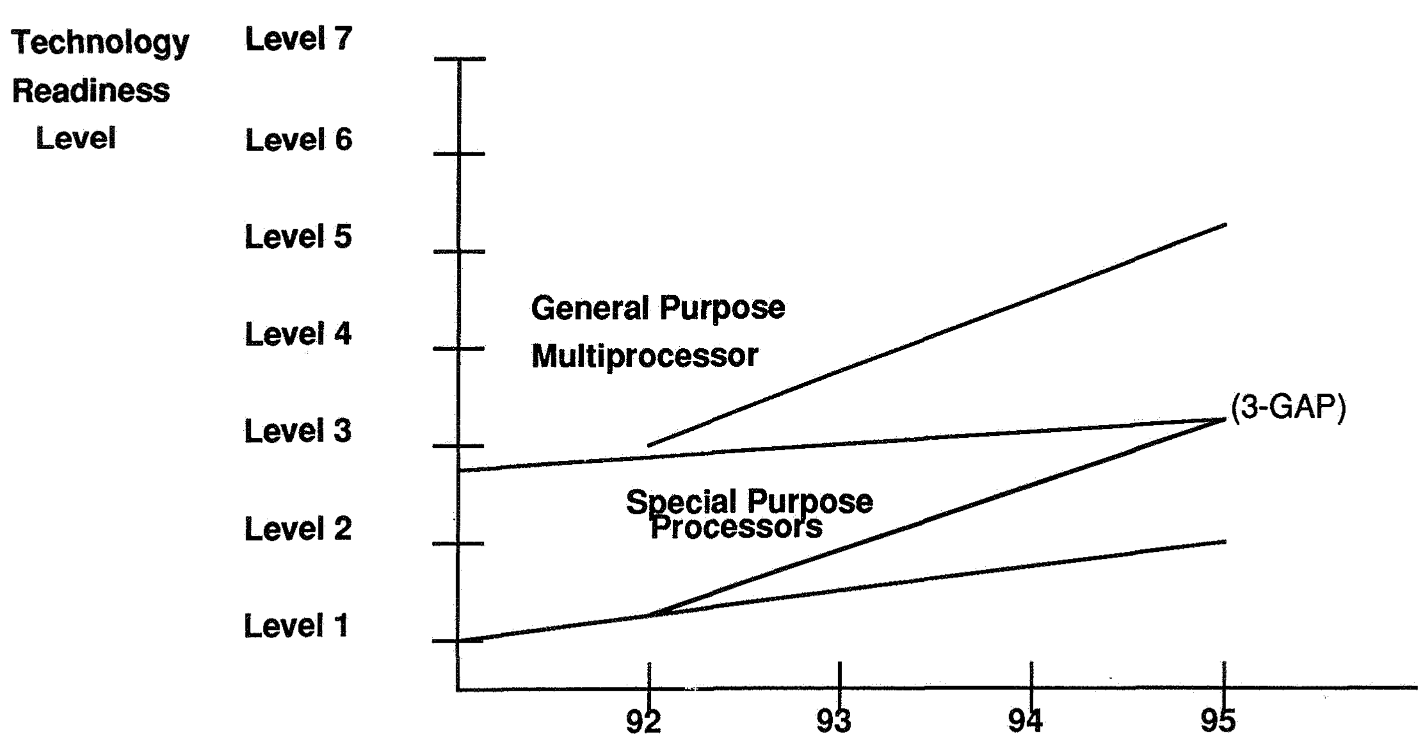
2. BRASSBOARD DEMONSTATION OF HIGHLY PARALLEL IMAGE DATA PROCESSING.

3. TEST DEVICE INTEGRATING FRONT-END SIGNAL PROCESSING WITH FOCAL-PLANE SENSORS.

4. BREADBOARD DEMONSTRATION OF A NEURAL PROCESSING APPLICATION IN ROBOTICS, STRUCTURE CONTROL, DATA ANALYSIS, OR PLANNING ASSISTANCE.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION - WORKSHOP

DATA MANAGEMENT SYSTEM *SOFTWARE DEVELOPMENT AND VERIFICATION*

BACKGROUND

SCOPE:

AN EXPANDED SSE THAT INCLUDES TOOLS AND GUIDELINES FOR SOFTWARE VERIFICATION, SOFTWARE METRICS AND ANALYSIS, SSE PERFORMANCE AND UTILIZATION METRICS, AN ENHANCED REUSABLE LIBRARY LINKED TO DESIGN SUPPORT AIDS, AND SUPPORT FOR MANAGEMENT AND CONTROL OF DISTRIBUTED DATABASE OF SSFP SOFTWARE OBJECTS (DESIGN REPRESENTATIONS, SOURCE CODE SEGMENTS, OBJECT CODE PACKAGES, TEST PROCEDURES AND DATA).

OBJECTIVES:

TO DEVELOP ENHANCEMENTS TO THE SSE THAT ADDRESS SOME AREAS CURRENTLY DEFERRED DUE TO BUDGET AND TECHNOLOGY CONSTRAINTS BUT WHICH WILL GREATLY IMPROVE THE SOFTWARE DEVELOPMENT AND VERIFICATION PROCESS FOR FUTURE SPACE STATION SOFTWARE.

RATIONALE:

THE SSE IS BEING DEVELOPED TO SUPPORT SOFTWARE DEVELOPMENT AND SSF LIFE-CYCLE SOFTWARE SUPPORT AND TO ENCOURAGE USE OF COMMON SOFTWARE ELEMENTS. THE INITIAL SSE IS PRIMARILY A COLLECTION OF COTS WITH SOME SUPPORTING SOFTWARE. THE SSE PROJECT IS FOCUSED ON MEETING THE IMMEDIATE NEEDS OF THE WP CONTRACTORS. THE ISSUES OF SOFTWARE VERIFICATION, SOFTWARE METRICS, AND A DISTRIBUTED REUSABLE LIBRARY WILL RECEIVE LITTLE ATTENTION IN THE NEAR TERM. METHODS ARE NEEDED TO INSURE SSF SOFTWARE WILL PERFORM AS EXPECTED WITHOUT DEPENDING ON THE PROHIBITIVELY EXPENSIVE, EXTENSIVE TESTING METHODS CURRENTLY EMPLOYED FOR THE SHUTTLE ORBITER.

TECHNOLOGY FOR SPACE STATION EVOLUDTION - A WORKSHOP

DATA MANAGEMENT SYSTEM *SOFTWARE DEVELOPMENT AND VERIFICATION*

PROGRAM PLAN

APPROACH:

1. DEVELOP AN INTEGRATED TEST SUITE TO SUPPORT SOFTWARE VERIFICATION TESTING INCLUDING GUIDELINES ON HOW TO APPLY THE SPECIFIC TOOLS. THIS SUITE WILL INCLUDE COTS TOOLS AND EXISTING SSE TOOLS WHEN POSSIBLE.

2. SELECT AN APPLICATION FROM SSF AND APPLY A FORMED SPECIFICATION AND VERIFICATION AND COMPARE EFFORT AND RESULTING CONFIDENCE WITH THE STANDARD METHODOLOGY USED FOR THE SAME APPLICATION BY THE SSFP SOFTWARE DEVELOPERS.

3. SELECT A SET OF SOFTWARE METRICS, INSTRUMENT THE SSE TO COLLECT THESE METRICS FOR SSE PERFORMANCE AND OPERATION, INSTALL THESE INSTRUMENTS IN A SPECIFIC OPERATIONAL SPF, COLLECT THESE METRICS OVER AT LEAST A 30-DAY OPERATIONAL PERIOD, ANALYZE THE RESULTS, AND MODIFY THE DATA COLLECTION AND METRICS TECHNIQUES AND REPEAT THE EXPERIMENT.

4. INVESTIGATE DISTRIBUTED DATABASE MANAGEMENT TECHNIQUES AND IDENTIFY THOSE WHICH ARE APPROPRIATE FOR MANAGING A DISTRIBUTED SOFTWARE LIBRARY. DEVELOP A PROTOTYPE DISTRIBUTED LIBRARY MANAGEMENT AND DEMONSTRATE THE UTILITY OF THESE TECHNIQUES FOR CONTROLLING ACCESS, INTEGRITY ASSURANCE, DISTRIBUTION, AND DATA UPDATE. INVESTIGATE PERFORMANCE ISSUES AND POSSIBLE REQUIREMENTS FOR LOCAL (DUPLICATE) COPIES OF ACTIVE DATA AND METHODS FOR MAINTAINING INTEGRITY OF ALL COPIES.

5. BUILD A PROTOTYPE SYSTEM WHICH COMBINES CASE TOOLS WITH A LIBRARY BROWSER TO SERVE AS A DESIGNER'S AID COUPLED TO A REUSE LIBRARY.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM — *SOFTWARE DEVELOPMENT AND VERIFICATION*

PROGRAM PLAN (CONTINUED)

DELIVERABLES:

1. DOCUMENT THE GUIDELINES FOR INTEGRATED TESTING FOR SOFTWARE VERIFICATION. IDENTIFY ADDITIONAL TEST TOOLS TO BE ADDED TO SSE TOOLSET TO ENHANCE SOFTWARE VERIFICATION.

2. REPORT ON THE APPLICATION OF FORMAL VERIFICATION TO THE SPECIFIC SSFP APPLICATION SELECTED, INCLUDING COMPARISON OF THE EFFORT REQUIRED AND RESULTING QUALITY OF SOFTWARE.

3. (A) REPORT ON SELECTED SOFTWARE METRICS AND RESULTS OF EXPERIMENTS WITH INSTRUMENTED SSE.

   (B) RECOMMENDATIONS FOR SOFTWARE METRICS TO BE COLLECTED DURING SSFP SOFTWARE DEVELOPMENT AND SPECIFIC METRIC ANALYSIS TOOLS TO BE ADDED TO SSE TOOLSET.

   (C) DRAFT GUIDELINES FOR USE OF SOFTWARE METRIC TOOLS.

   (D) RECOMMEND CHANGES TO SSE TO IMPROVE PERFORMANCE OF THE SSE BASED ON THE SOFTWARE METRICS ANALYSIS.

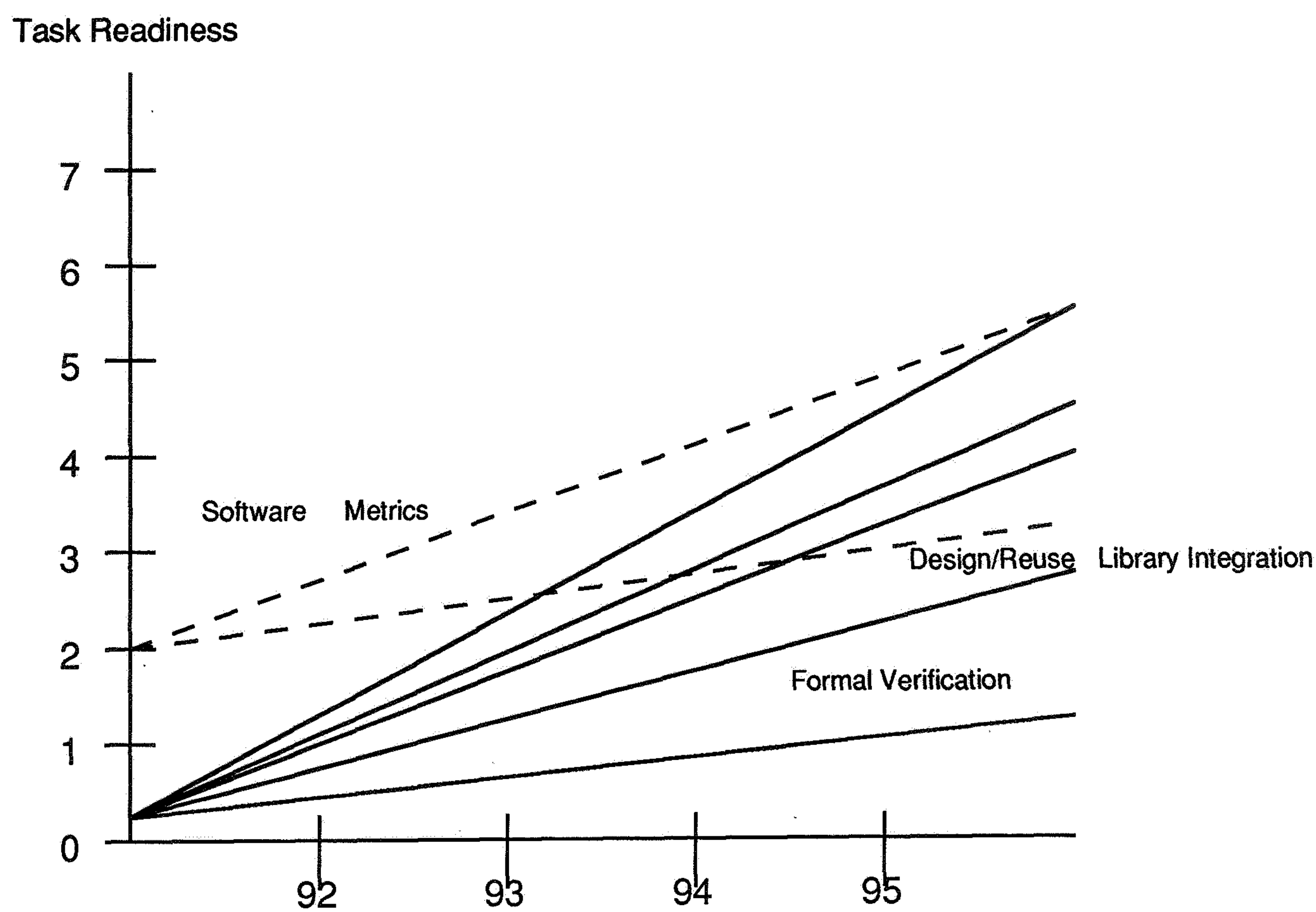
4. DEMONSTRATE PROTOTYPE DISTRIBUTED LIBRARY SYSTEM. RECOMMEND TECHNIQUES TO ENHANCE SSE LIBRARY SYSTEM.

5. DEMONSTRATE PROTOTYPE DESIGN/LIBRARY SYSTEM TO ILLUSTRATE ENHANCED REUSE LIBRARY SYSTEM APPROACH.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM *SOFTWARE DEVELOPMENT AND VERIFICATION*

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM *ONBOARD COMMUNICATIONS*

BACKGROUND

SCOPE:

UPGRADE THE DMS DATA RATE HANDLING CAPABILITY INDEPENDENT OF THE FIBER-OPTIC CABLE LIMITATION BY USING EMERGING NEW TECHNOLOGY TO SUPPORT HARDWARE PAYLOADS AND SYSTEM UPGRADES.

OBJECTIVES:

TO DEVELOP METHODS OF INCREASING THE DMS DATA RATE CAPACITY OVER THE FIBER-OPTIC CABLE LIMITATION TO SUPPORT HIGH-RATE SCIENCE AND TO ENABLE DMS USERS TO INCREASE THEIR DMS REQUIREMENTS AS NEW TECHNOLOGY IS IMPLEMENTED.

RATIONALE:

THE DMS COMMUNICATION RATE IS LIMITED BY THE FIBER-OPTIC CABLE CAPACITY, AND THE ABILITY TO UPGRADE THE FIBER-OPTIC CABLE IS NOT PRACTICAL DUE TO INACCESSABILITY. ANY TECHNOLOGY UPGRADE IN THE DMS COMPONENTS WILL BE LIMITED THE FIBER-OPTIC CABLE DATA RATE CAPACITYL.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM *ONBOARD COMMUNICATIONS*

PROGRAM PLAN

APPROACH:

1. INVESTIGATE METHODS OF MODULATION ON A SINGLE FIBER THAT WOULD ENABLE INCREASED INFORMATION CAPACITY WITHOUT INCREASING THE CLOCK RATE.

2. INVESTIGATE THE USE OF MULTIPLE FIBER OPTIC CABLE CONFIGURATIONS THAT WOULD INCREASE THE DMS DATA RATE CAPACITY.

3. INVESTIGATE THE USE OF NON-FIBER OPTIC COMMUNICATION METHODS SUCH AS LASER LINKS TO WIRE AS THE DMS DATA RATE CAPACITY.

DELIVERABLES:

1. DEMONSTRATE A MODUALTION SCHEME THAT INCREASES THE DATA RATE CAPACITY OVER EXISTING FIBER OPTIC CABLES.

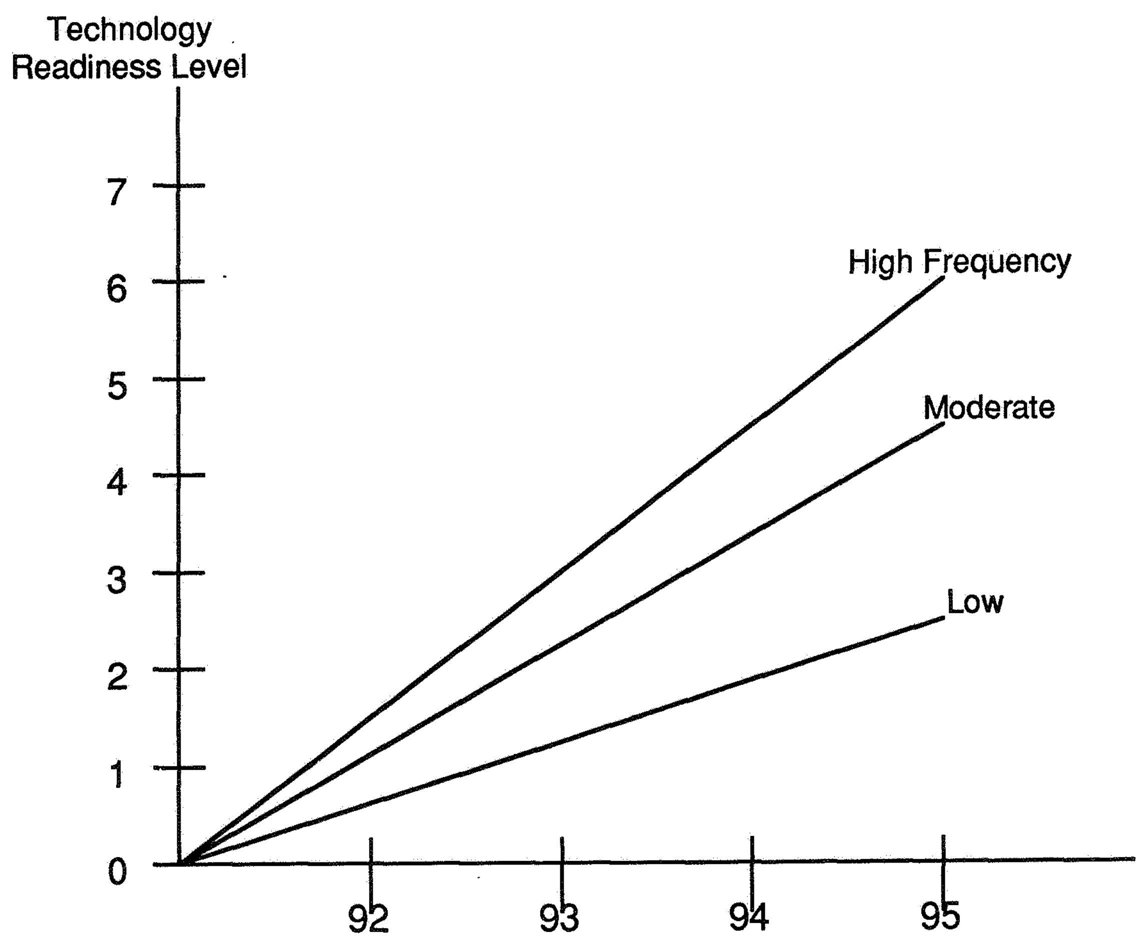
2. DEMONSTRATE A MULTIPLE FIBER OPTIC CONFIGURATION USING ALL OF THE EXISTING FIBER OPTIC CABLES THAT INCREASES THE DATA RATE CAPACITY.

3. DEMONSTRATE A NON-FIBER COMMUNICATION SYSTEM THAT INCREASES THE DATA RATE CAPACITY.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

DATA MANAGEMENT SYSTEM

ONBOARD COMMUNICATIONS



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

RECOMMENDATIONS / ISSUES

- APPROACH SSF AS AN INTEGRATED SYSTEM
- BETTER INTERPERSONAL COMMUNICATIONS
  - NEED: STANDARD, CONTROL, ENFORCEMENTS
  - NEED: MULTIPLE SYSTEM INTEGRATION FACILITY
- SYSTEM RETIREMENT ISSUES
  - SOFTWARE, HARDWARE, CUTOVERS
  - FLIGHT PROCESSOR EVOLUTION ... COMMERCIAL/DOD/SDIO
- SSIS TO C&T TO DMS NOT DISCUSSED
- A PROVISION OR MECHANISM FOR SRU LEVEL REPLACEMENT ON BOARD
- NEED ACCOMMODATION TO ALLOW UPGRADE/REPLACE FIBERS ON GLOBAL NET AND HIGH RATE LINKS

DMS OPPORTUNITIES

- AI MAINTENANCE ASSISTANT SUBSYSTEM ... AI AUGMENTED TESTS
- OVERLAY OF DATA AND VIDEO, MIXED GRAPHICS, DIGITAL HDTV, ANIMATED GRAPHICS

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TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

JANUARY 19, 1990

CHARLES D. RAY, CHAIRMAN
MARSHALL SPACE FLIGHT CENTER

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

CREW GENERATED WASTES PROCESSING AND RECLAMATION

Background

Scope – This effort includes the design, development and evaluation of a waste processing system for recovery of useful products from crew generated wastes (e.g., urine, feces, brines, crew trash, etc.).

Objectives – Develop advanced waste processing technologies for the recovery of usable water and gases such as oxygen and nitrogen from heterogeneous wastes such as feces and non-metallic trash. Application of the technology to liquid wastes will also be explored with the goal of developing a single waste processing system which is operable on any waste regardless of its liquid or solid state. Significant reduction in the amounts of water and gases needed to be resupplied may be possible through on-orbit processing of these wastes. Additional life-cycle savings are also possible by reducing these wastes to high density residues. Development of a technology suitable for simultaneously processing heterogeneous wastes and liquid wastes such as urine, humidity condensate and waste hygiene water will reduce on-board resources by combining separate processes into a common, single unit.

Requirement – Crew trash and ECLSS waste can be as high as 6-8 lb/man-day. This represents a significant storage or return-to Earth logistics problem. Waste processing has the potential to reduce this penalty while providing useful products such as water, N_2 and CO_2.

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

CREW GENERATED WASTES PROCESSING AND RECLAMATION

Program Plan

Approach - The effort will begin with the screening of candidate technologies through analysis, literature surveys and small-scale laboratory studies. The most promising candidate technologies identified in these studies will be further developed through analysis and laboratory experiments for detailed parametric studies. These studies will be used as the basis for selecting the most promising candidate(s) and developing, designing and fabricating a breadboard subsystem. The breadboard will be used in extensive performance evaluations and optimization studies. Results from the breadboard testing will be used to develop, design and fabricate an optimized breadboard system which will be tested to determine overall performance, safety, reliability, resource requirements, reclamation products, etc. Analytical models will be validated and refined as the development program progresses.

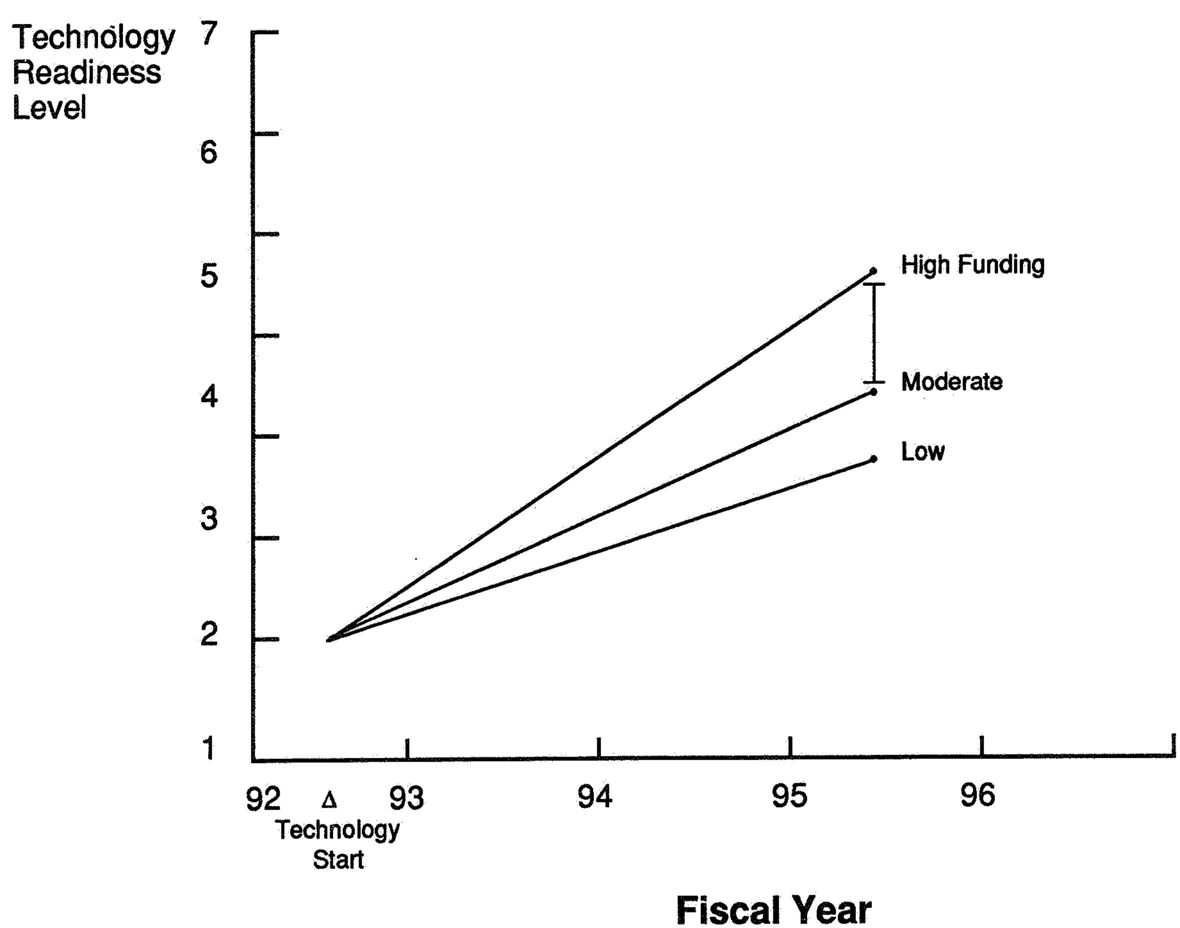
Deliverables - Development documentation (e.g., trade-off data, test results, etc.).

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

CREW GENERATED WASTES PROCESSING AND RECLAMATION

Technology Assessment



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

WATER RECLAMATION - PRE- AND POST-TREATMENT

Background

Scope – Space station baseline uses expendable chemicals for urine pretreatment and thermal stabilization for potable and hygiene waste water pretreatment. Expendable sorption beds and biocide addition are used for post treating both potable and hygiene product waters. This effort will evaluate existing pre- and post-treatment processes and will identify and characterize alternatives that eliminate or minimize expendables. Candidate processes will be selected and demonstrated at a breadboard level.

Objectives – To improve waste water pre- and post-treatment processes for urine, hygiene, and potable water processors.

Rationale – The payback for developing alternative pre- and post-treatment processes that eliminate/minimize expendibles and maximize water recovery efficiency is the reduction of IVA tasks and logistics (resupply/return) penalties.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

WATER RECLAMATION - PRE- AND POST-TREATMENT

Program Plan

Approach-

1) Quantify existing baseline pre- and post-treatment processes
2) Identify alternate processes through literature search
3) Develop analytical models and trade candidate processes
4) Select most promising processes for development
5) Characterize processes at bench top level
6) Select and develop pre- and post-treatment hardware at breadboard level
7) Conduct breadboard performance characterization tests

Deliverables-

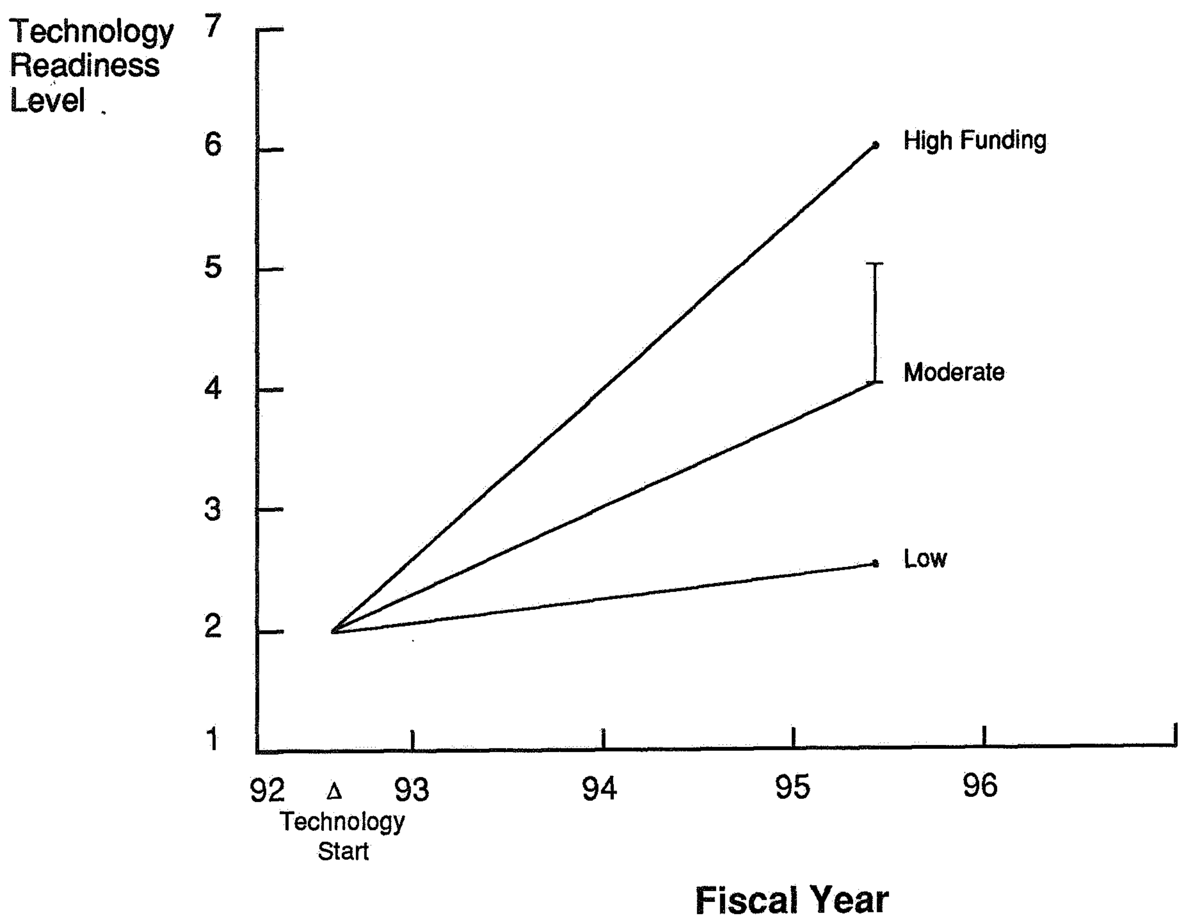
1) Development documentation, i.e., literature search, analytical models, tradeoffs, test results, etc.
2) Deliver breadboard hardware

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

WATER RECLAMATION - PRE- AND POST-TREATMENT

Technology Assessment



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

SIMPLIFIED WASTE WATER PROCESSING

Background

Scope – Baselined space station waste water processing incorporates three waste water streams with individual processors and separate finished water post-treatment and storage requirements. Evaluation of waste water sources, baseline urine/hygiene/potable water processors and finished water distribution are required to identify and evaluate system simplification and resulting scarring. Concept validation tests will provide basis for selection, development and testing of an integrated breadboard system.

Objectives – Simplification of multiple waste water stream processing.

Requirement – Combining waste water sources and processing into a single waste stream will simplify water recovery processing; post treatment, storage, and distribution. Single stream processing results in reducing system complexity.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

SIMPLIFIED WASTE WATER PROCESSING

Program Plan

Approach -

1) Identify and evaluate system simplification and scarring impacts
2) Analyze and model candidate approaches
3) Evaluate candidate integrated system compatibility with single stream water processing approach
4) Select single stream process concept
5) Concept verification testing at fractional capacity

Deliverables -

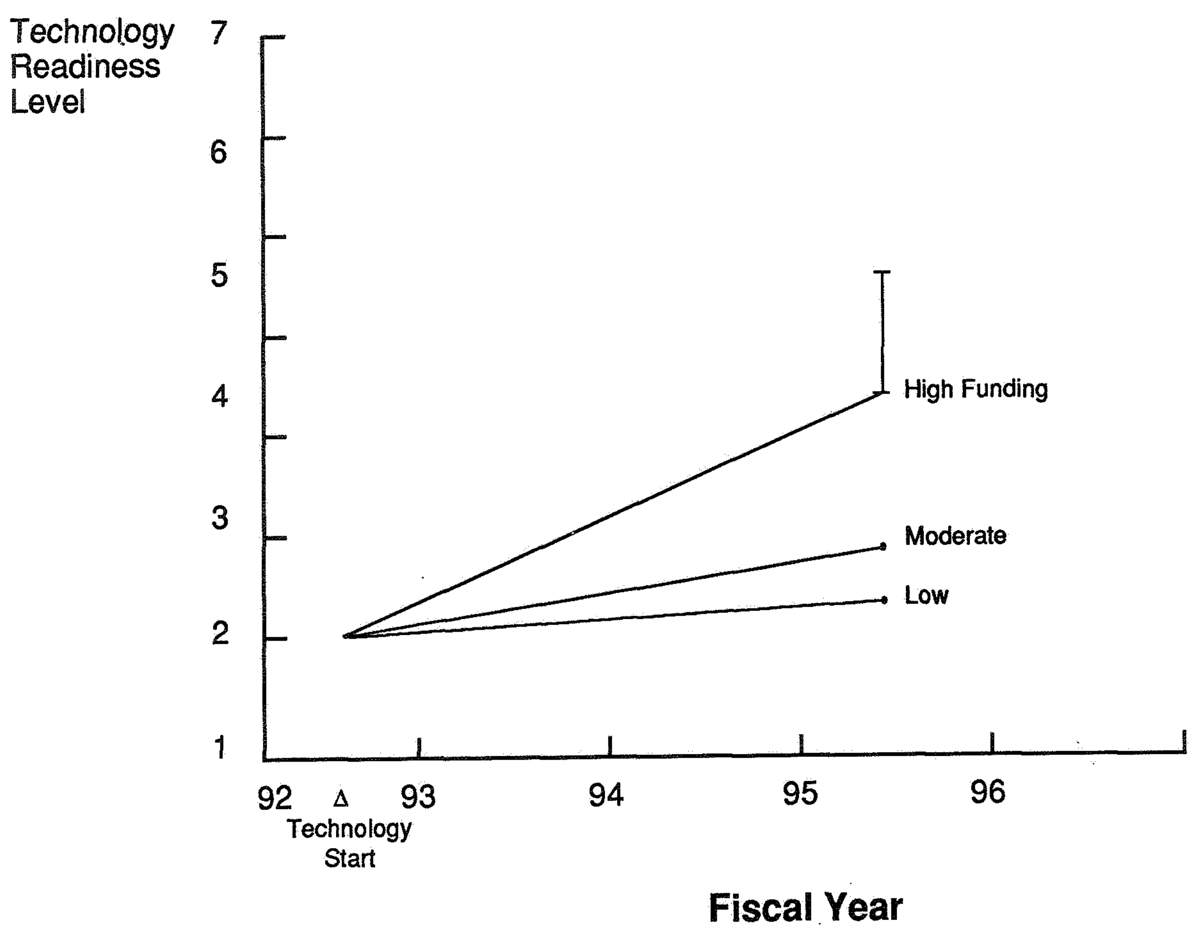
1) Development documentation, i.e., analytical model, tradeoffs, test data, etc.
2) Preliminary system design

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

SIMPLIFIED WASTE WATER PROCESSING

Technology Assessment



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

IMPROVED TRACE CONTAMINANT REMOVAL

Background

Scope – The Present Trace Contaminant Control (TCC) subsystem is designed for continuous contaminant removal with only selected fire upset control capability. No experiment upset capability is included. Expendable TCC sorbent beds are replaced on 90-day intervals.

Objectives -

1) Increased TCC system flexibility is necessary to accommodate upsets due to fire & hazardous upsets.
2) Expendable sorbents are to be reduced or eliminated.
3) Scarring required to handle upset conditions are to be defined.

Requirement – Eliminate or minimize expendables to reduce resupply and return logistics, crew time, and storage requirements. Improved flexibility of TCC to support space station utilization as an experimental platform is required.

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

IMPROVED TRACE CONTAMINANT REMOVAL

Program Plan

Approach – Investigate alternate or improved high-temperature catalytic oxidizers and improved sorbent beds. Evaluate techniques for IN-SITU bed regeneration, plasma catalysis, and high effectiveness catalysts. Define TCC designs to process upset conditions and test feasibility and breadboard concepts, and fabricate a prototype unit.

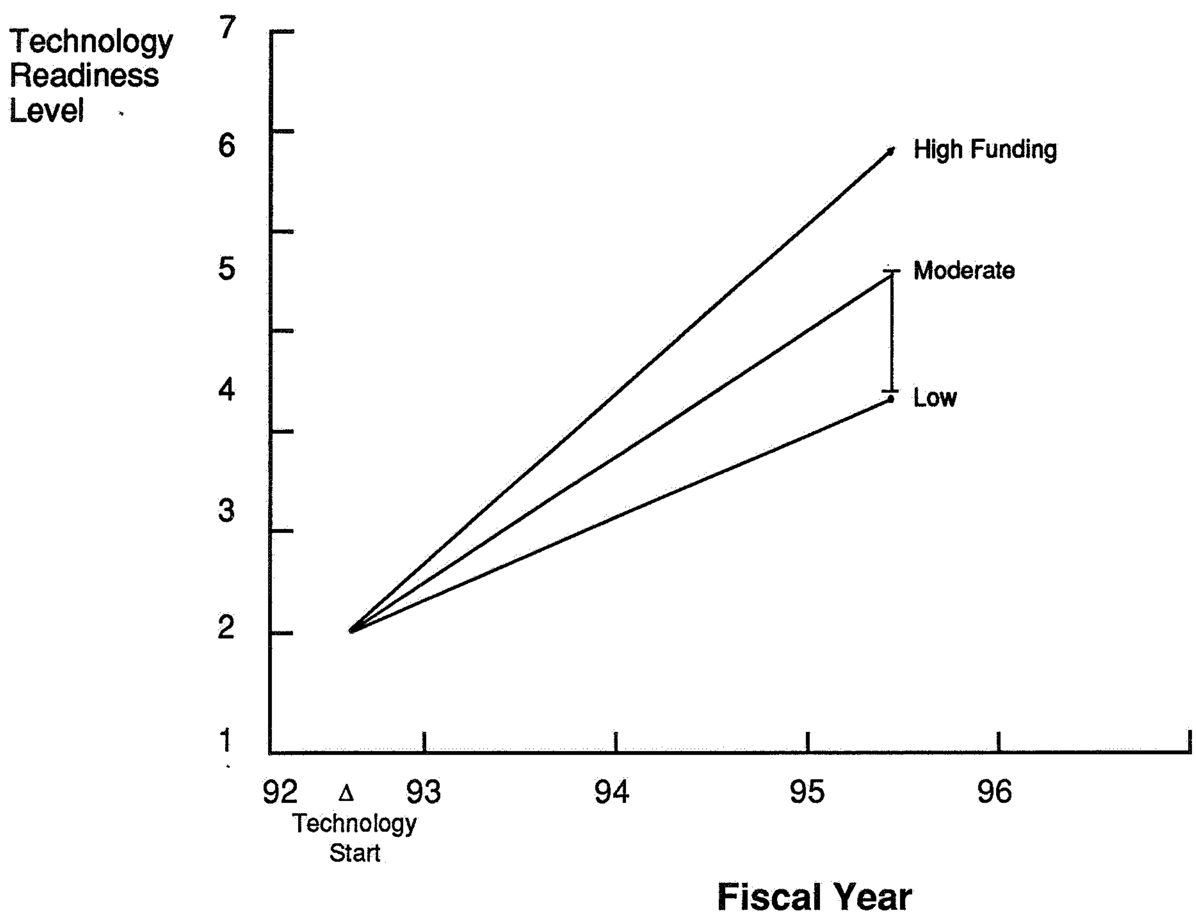
Deliverables – Deliverables include a technology assessment report, feasibility and breadboard test reports. Design data and prototype unit will be delivered for integrated system testing. A continued evaluation of evolving space station requirements will be made. Program and cost plans will be generated for flight hardware.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

IMPROVED TRACE CONTAMINANT REMOVAL

Technology Assessment



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

REAL TIME MICROBIAL ANALYSIS

Background

Scope – The safety of the space station crew depends in the effective control of water reclamation systems as well as the verification of an uncontaminated on-orbit water supply. Micobiological contaminants such as bacteria, yeasts and molds, and viruses are particularly troublesome. Routine enumeration of total bacteria counts at concentrations below 1 CFU/100ml will be required to verify the acceptability of reclaimed water prior to use. Additional enumeration of aerobic, anaerobic, gram positive, gram negative, coliform, and enteric bacteria, as well as yeasts and molds will also be required on a less frequent basis. Present off-line culture technologies used to perform these monitoring functions are inherently labor intensive, require excessive sample quantities from the limited water supply in order to meet sensitivity requirements, require a minimum of 48 hours for the confirmation of results, and have substantial recurring costs associated with the resupply of expendables and return of wastes. This effort includes the design, fabrication and evaluation of a breadboard unit for on-line real-time microbiological monitoring of water.

Objectives – The objective of this effort will be to develop a microbiological analysis method that is amenable to on-line, real-time microbiological monitoring and to demonstrate the feasibility of the application via the development, design, fabrication, and testing of a breadboard unit.

Requirement – The payback from the successful development of a suitable microbial monitor will be the reduction of demands on crew time and other resources as well as the provision of a sensor and instrumentation unit that will be compatible with an overall life support system automation and control strategy.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

REAL TIME MICROBIAL ANALYSIS

Program Plan

Approach – The effort will begin with identification and laboratory assessment of potential methods for on-line, real-time enumeration of total bacteria. Laboratory testing to confirm sensitivity, selectivity, and overall reliability will be conducted. Parametric studies will be used to optimize the most promising method(s). The feasibility of adapting the total bacteria method(s) to provide additional enumeration of aerobic, anaerobic, gram, positive, gram negative, coliform, and enteric bacteria, as well as yeasts and molds will be evaluated. Results of these studies will be used to establish a breadboard design which will be fabricated and tested to confirm that the required sensitivity and selectivity demonstrated in the laboratory testing have been maintained as well as to assess mechanical reliability, resource requirements, ultimate automation potential, etc. The effort will culminate with the delivery of an optimized breadboard device for additional testing, to be supported by the contractor for a period of six months.

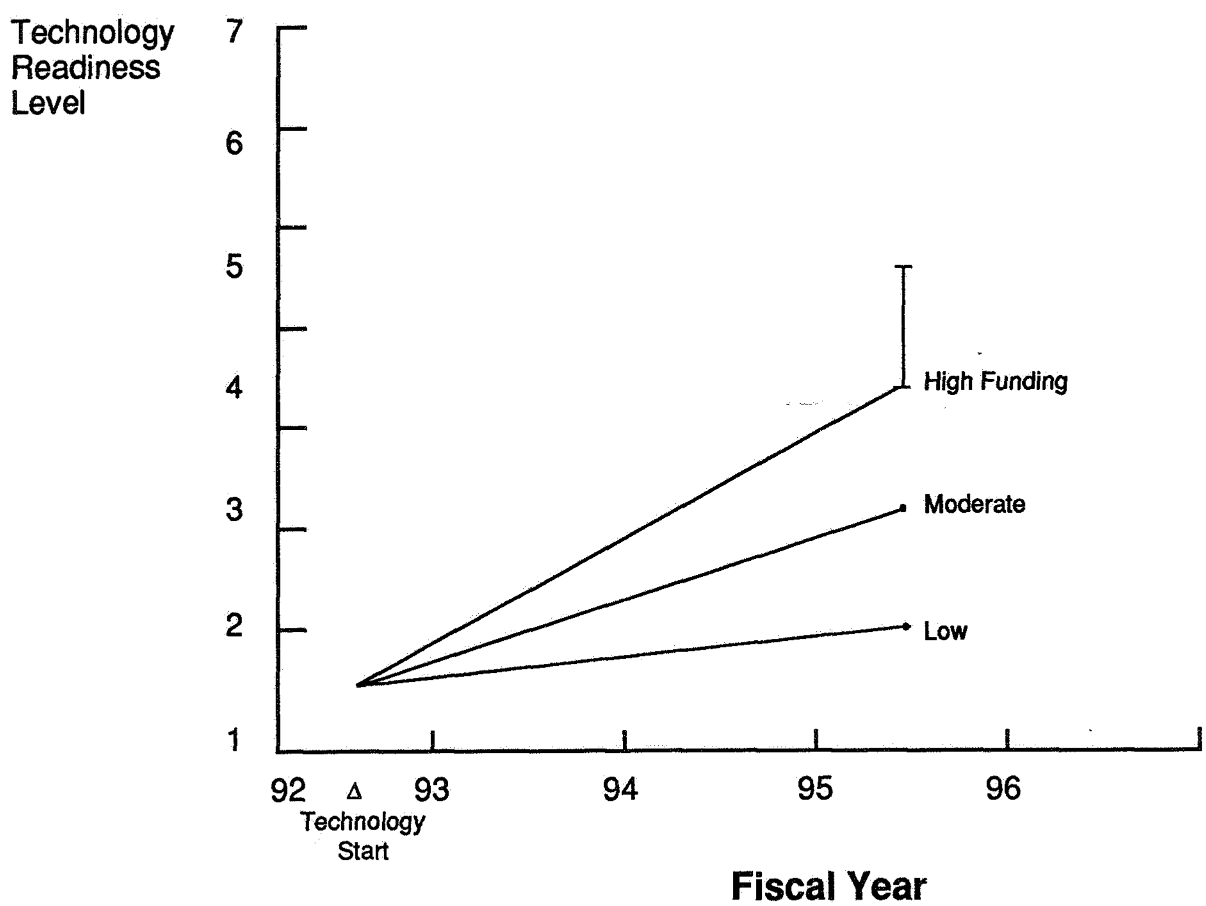
Deliverables – Development documentation (final report)
Breadboard on-line real-time microbial monitor
Instruction and Maintenance manual.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

REAL TIME MICROBIAL ANALYSIS

Technology Assessment



TECHNOLOGY FOR SPACE STATION EVOLUTION –A WORKSHOP

Recommendations/Issues for Environmental Control and Life Support Systems

Issues

- Regenerable System Long Term Process Evaluation (Air and Water)
- Microgravity Fire Signature Identification

Recommendations

- Continued Emphasis on Systems Analysis Relative to Technology Development
- Continued Emphasis on Automation/Sensors

Additional Technology Areas for Consideration

- CO_2 Reduction by Products Utilization and Catalysis
- "Smart" Fire Detection and Improved Suppression System
- Improved Liquid/Gas Separation
- Noise Reduction (Rotating Equipment)
- N_2 Generation (From N_2 Sources Such as Crew Metabolic Byproducts)

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TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

EXTRAVEHICULAR ACTIVITY
TECHNOLOGY DISCIPLINE

JANUARY 19, 1990

DR. BRUCE W. WEBBON, CHAIRMAN
AMES RESEARCH CENTER

TECHNOLOGY FOR SPACE STATION EVOLUTION
-A WORKSHOP

TECHNOLOGY DISCIPLINE SUMMARY FOR EXTRAVEHICULAR ACTIVITY (EVA)

Extravehicular Activity includes all activity outside the pressured volume of the space vehicle, although common usage tends to imply only manned activity. The scope of the activities describe herein will focus on manned EVA systems including interfaces with robotic work aids and systems.

Traditionally, manned extravehicular activities have been costly and perceived to be risky. In order for ELBA to become a routine, cost-effective mission resource, particular attention needs to be given to reducing logistics requirements and increasing productivity. EVA operations also tend to be very uncomfortable and tiring, and involve extensive preparation. Current suits, for example, operate at 4.3 psi and require the astronaut to perform extensive pre-breathing to reduce the bends risk to an acceptable level. Suits used for advanced Space Station Freedom EVA operations will be pressurized to 8.3 psi. This means that greater attention must be placed on glove and joint mobility.

A new dimension has been added to EVA operations for future missions, i.e., cooperative efforts involving EVA crew members with telerobots. This will require that particular attention be given to how best to interface the EVA crew members with telerobotic operations physically and logically. This will include work in information display, information transfer, and system control.

The key work system elements involved in Extravehicular Activity are the following:

Extravehicular Mobility Unit (EMU)
Air Lock and EMU Support Equipment
Tools, Mobility Aids and Work Stations
Telerobotic Work Aids Interfaces

These elements are addressed in the sections that follow.

BACKGROUND

SCOPE - The major subsystems comprising the Extravehicular Mobility Unit are the Portable Life Support System (PLSS) and the Pressure Suit Assembly.

Major issues which must be addressed for the PLSS are life cycle cost, reliability, logistics and productivity. Technological advances are needed in (a) life support processes (understanding and conceptual development), (b) oxygen supply, (c) carbon dioxide and humidity control, (d) prime movers (e.g., fans and pumps), (e) automatic control, (f) heat rejection, power sources, and (g) avionics.

Major issues which must be addressed for the Pressure Suit Assembly are high cost, limited life, increase in the EVA environmental envelope, productivity, reliability, safety, serviceability and maintainability. Technologies which must be addressed include (a) gloves, (b) pressure vessel (suit), and (c) materials.

OBJECTIVE - The objective for this technology area is to develop, demonstrate and space qualify in earth orbit prototype Portable Life Support and EVA Suit systems responsive to the needs of future Space Station Freedom missions.

RATIONALE - Current EVA systems are uncomfortable, require extensive pre-breathing procedures, are reliable only for limited use and are extremely costly to maintain and prepare for operation. New technologies being developed (AX-5 and ZPS suit systems) and advanced portable life support systems are needed if man is to maintain a permanent presence in space and perform the required routine EVA operations safely, reliably and economically.

PROGRAM PLAN

APPROACH -

1. PLSS: (a) Conduct research efforts to develop a basic understanding of the life support processes and to identify and assess promising new concepts in order to reduce weight, volume, servicing and logistics requirements, (b) develop innovative concepts for storage and regulation of oxygen supplies to achieve small volume and increased operational flexibility, (c) develop regenerative techniques for control of carbon dioxide and humidity to reduce weight and resupply requirements, (d) improve understanding of thermal and physiological processes to improve crew productivity, comfort and system efficiency, (e) develop alternative processes and materials for heat rejection for reduced weight, volume and power requirements, (f) develop new power sources concepts for long life and low resupply weight, and (g) apply advanced avionics techniques for communication and control, e.g., voice systems, advanced displays and miniaturization, to achieve low power requirements, improved productivity and easier training.

2. Advanced Pressure Suit Assemblies: (a) Develop glove manufacturing techniques and (b) improved glove materials in order to prolong glove life, improve EVA crew productivity, improve glove producibility, and lower manufacturing cost; and (c) conduct pressure suit materials research and development efforts in order to provide lighter-weight suits with improved environmental protection.

3. Use the technologies developed in tasks 1 and 2 above to develop an integrated PLSS and Pressure Suit Assembly for test and evaluation in orbit.

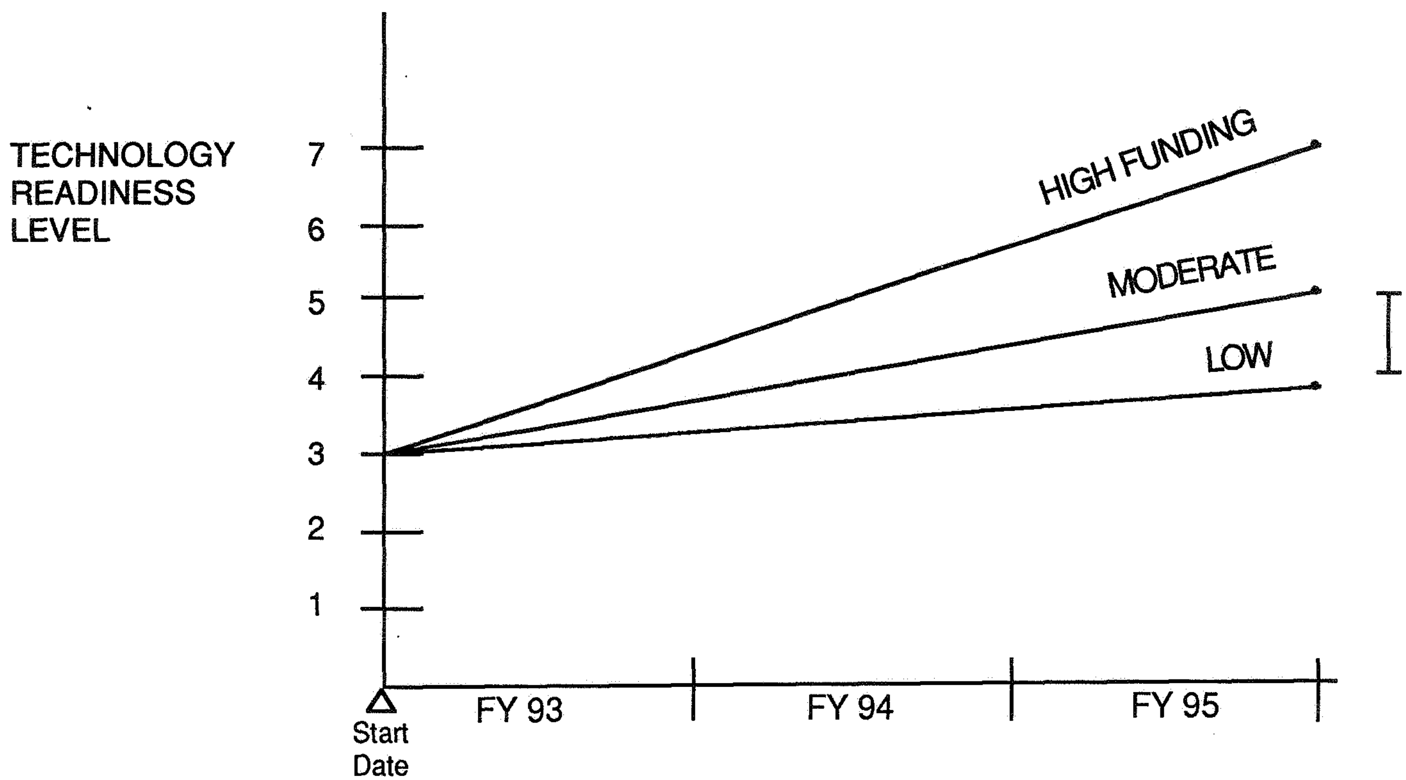
DELIVERABLES -

1. Advanced-technology Portable Life Support System
2. Advanced-technology Pressure Suit Assembly
3. Integrated EMU for test in orbit

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

EVA *EXTRAVEHICULAR MOBILITY UNIT*

TECHNOLOGY ASSESSMENT



BACKGROUND

SCOPE - Software, oxygen supply, fluid interfaces, electrical interfaces, automation, and materials. Major issues which must be addressed include crew productivity and system reliability, safety, serviceability and maintainability.

OBJECTIVES - Objectives of this technology area are to develop (a) software for automatic EVA systems checkout; (b) oxygen supply systems to reduce portable life support systems volume requirements, increase durability and reduce power; and (c) fluid and electrical interfaces to facilitate management of umbilical connections.

RATIONALE - Operational costs and time spent in servicing current portable life support and suit systems are extremely high. Space Station Freedom and other future space missions will require order of magnitude improvements in serviceability and performance checkout; it will no longer be practical to rely on ground-based maintenance and checkout of EVA systems to the extent we do on current STS operation. More and more of the maintenance, servicing and checkout must be performed on-orbit. This will require adaptation of new procedures and technologies.

PROGRAM PLAN

APPROACH -

1. Automated Checkout: Develop software programs to perform automated checkout of critical portable life support and suit systems. Base these programs on artificial intelligence techniques (i.e., knowledge-based techniques), and apply to the EMU design as it evolves.

2. Oxygen Supply: Develop high-pressure recharge techniques. Conduct research to identify and develop improved materials. Fabricate and test a prototype oxygen supply system.

3. Fluid and Electrical Interfaces: Develop a rotary coupling to facilitate management of umbilical interfaces between the portable life support systems and the fluid and electrical supply systems on board the space station. These umbilicals are for use prior to exiting from the EVA air lock before performing extravehicular activities, and after return to the air lock.

DELIVERABLES -

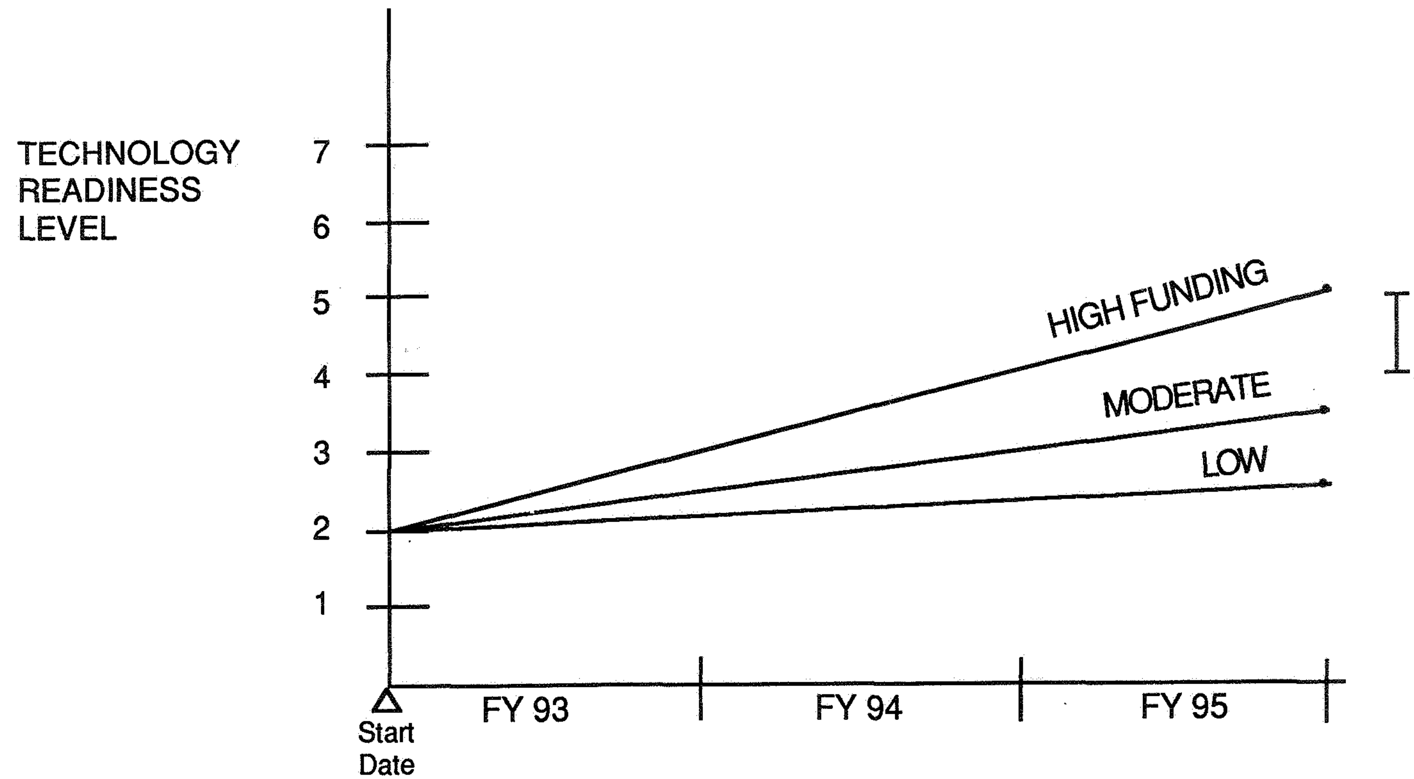
1. A prototype, knowledge-based automated checkout system for the EMU.

2. A prototype, high-pressure oxygen supply system for the portable life support system.

3. A prototype, rotary coupling for fluid and electrical interfaces between the EMU and the airlock fluid and electrical supply systems.

EVA *EXTRAVEHICULAR MOBILITY UNIT*

TECHNOLOGY ASSESSMENT



BACKGROUND

SCOPE - Productivity, safety, cost, end effectors, tools, repair/maintenance processes and kits, EVA work stations, and crew rescue and equipment retrieval.

OBJECTIVES - The objectives of this technology area are to develop and evaluate procedures, concepts and equipments for: (a) end effectors and tools which will allow the EVA crew member to work more productively; (b) repair and maintenance processes and kits to maintain and restore EVA system operations; (c) EVA work stations for increasing EVA productivity and safety; and (d) crew rescue and equipment retrieval.

RATIONALE - A goal of automation and telerobotics programs is to minimize the amount of manned extravehicular activity required for Space Station Freedom and other future space missions. However, substantial amounts of EVA activities will still be required, even after achieving this "minimum" level. Long-duration missions onboard the space station will probably benefit greatly from the use of end effectors and tools designed either for performing specific tasks, where it makes sense to do so, or for more general-pupose applications, e.g., wrenches, pliers, etc. Extensive EVA operations will also require the use of EVA work stations. Long-duration missions will also require a capability to repair and maintain EMU systems on orbit; repair and maintenance processes and kits are needed. Finally, for safety purposes, there is need for a capability to rescue an EVA astronaut in the event that he should lose his tether and drift away from the space station; similarly there is a need for a capability to retrieve equipment which may also be adrift.

PROGRAM PLAN

APPROACH -

Develop and evaluate (a) advanced technology end effectors and tools (e.g., smart tools and end effector which may either simplify greatly the EVA astronaut's task or reduce his work load substantially), (b) EVA work stations which are articulable and compatible with robots and humans, (c) repair and maintenance processes and kits, and (d) crew rescue and equipment survival concepts. Facilities required include ground laboratories, water tank facilities, the KC-135 Variable-Gravity In-Flight Simulator, and the Space Shuttle. Depending on individual requirements, one or more of these facilities may be required to evaluate a particular technology.

DELIVERABLES -

1. Prototype end effectors and tools for evaluation in ground simulation facilities, the KC-135 Variable-Gravity In-Flight simulator, and the Space Shuttle.

2. Prototype EVA work stations for evaluation in neutral-buoyancy test facilities, the KC-135 Variable-Gravity In-Flight Simulator, and the Space Shuttle.

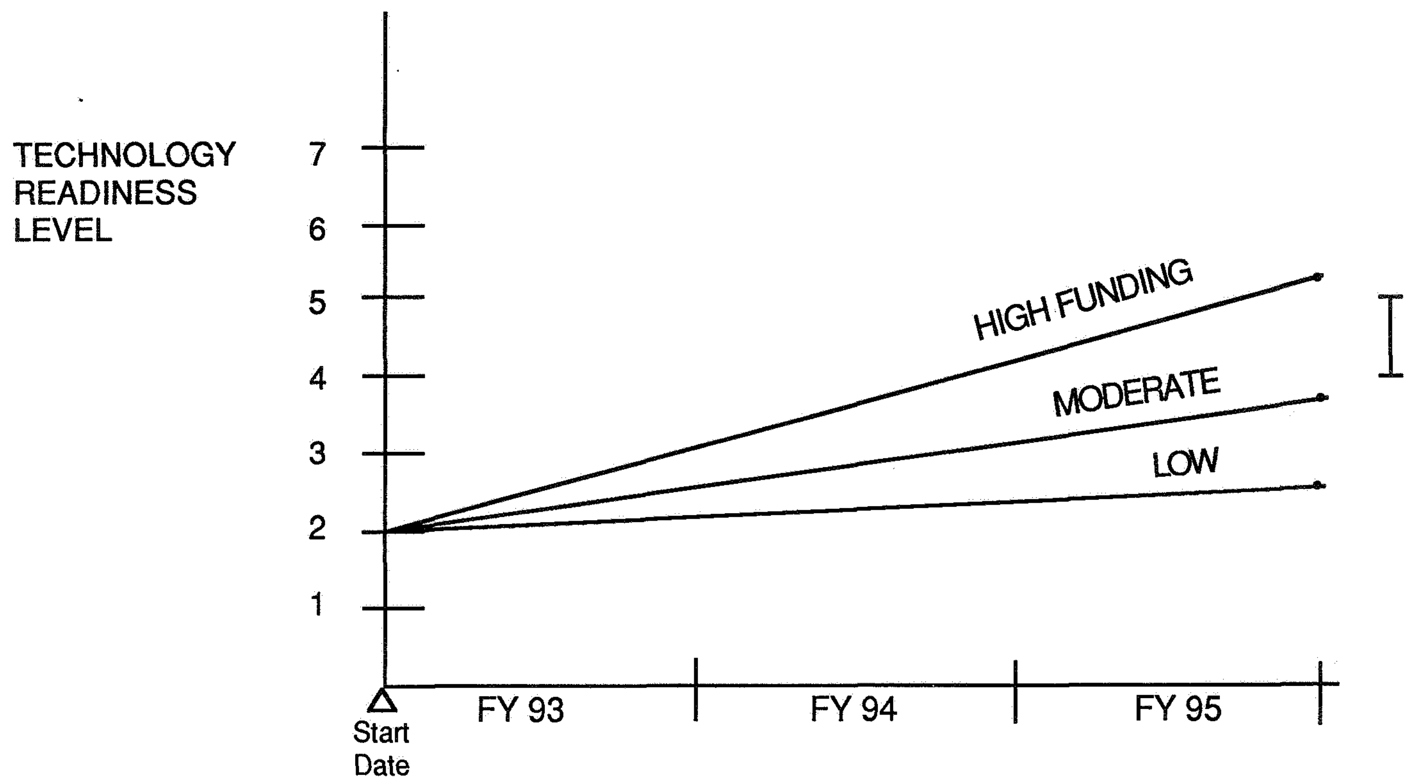
3. Prototype repair and maintenance processes and kits for evaluation in neutral buoyancy test facilities, the KC-135 Variable-Gravity In-Flight Simulator, and the Space Shuttle.

4. Concepts, simulations and prototype hardware for crew rescue and equipment retrieval.

TECHNOLOGY FOR SPACE STATION EVOLUTION
-A WORKSHOP

EVA — *TOOLS, MOBILITY AIDS AND WORK STATIONS*

<u>TECHNOLOGY ASSESSMENT</u>



BACKGROUND

SCOPE - Information acquisition, information transfer, information display, artificial intelligence, proximity operations, sensors, command and control.

OBJECTIVE - The objective of this technology area is to achieve compatibility between EVA Astronauts and telerobots through a synergistic relationship between the two in performing EVA tasks.

RATIONALE - Robots are being developed to help reduce the amount of EVA time required of the EVA astronaut, to perform those tasks which may be performed more effectively through application of telerobotic technology, and to make most productive use of human and other resources of Space Station Freedom. There will certainly be many tasks which can be performed most productively through a cooperative or interactive relationship between EVA astronauts and one or more telerobots. This relationship needs to be understood and exploited in order to accomplish missions and tasks safely, economically and productively.

PROGRAM PLAN

APPROACH -

1. Information Acquisition and Display: Develop versatile multi-modal sensory display systems for use in the space suit which (a) are easy to adjust (spatial and temporal resolution, dynamic range vs. band width, etc.), and (b) provide easy information capture, storage and retrieval. Displays may be visual, aural, tactile, or some combination.

2. Control Systems and Artificial Intelligence: (a) Develop human-oriented control systems for use in controlling the telerobot either by the EVA astronaut, the IVA astronaut, or some combination, (b) develop techniques for automation transparency, smooth operational mode change and graceful human intervention, and (c) apply artificial intelligence techniques which provide a proper and effective amount of "autonomy" to the telerobot - enough so that the astronaut's work load is reasonable and productive, but in such a way that safety is not compromised.

3. Proximity Sensors: Develop sensors which do not depend on line-of-sight in order to minimize the likelihood of collision between the EVA astronaut and robot; develop passive sensors for safety override and active path control around obstacles.

4. control and Command Input Techniques: Develop non-manual techniques such as voice or by movement to control motions and tasks of the telerobot in order to reduce manual input requirements and EVA astronaut work load, and to increase productivity.

PROGRAM PLAN
(CONTINUED)

DELIVERABLES -

1. Advanced information acquisition and display concepts, systems and procedures for use in cooperative efforts between EVA astronauts and robots.

2. Advanced control systems concepts, techniques and hardware to facilitate the interaction between the EVA astronaut and robot in carrying out EVA missions and tasks.

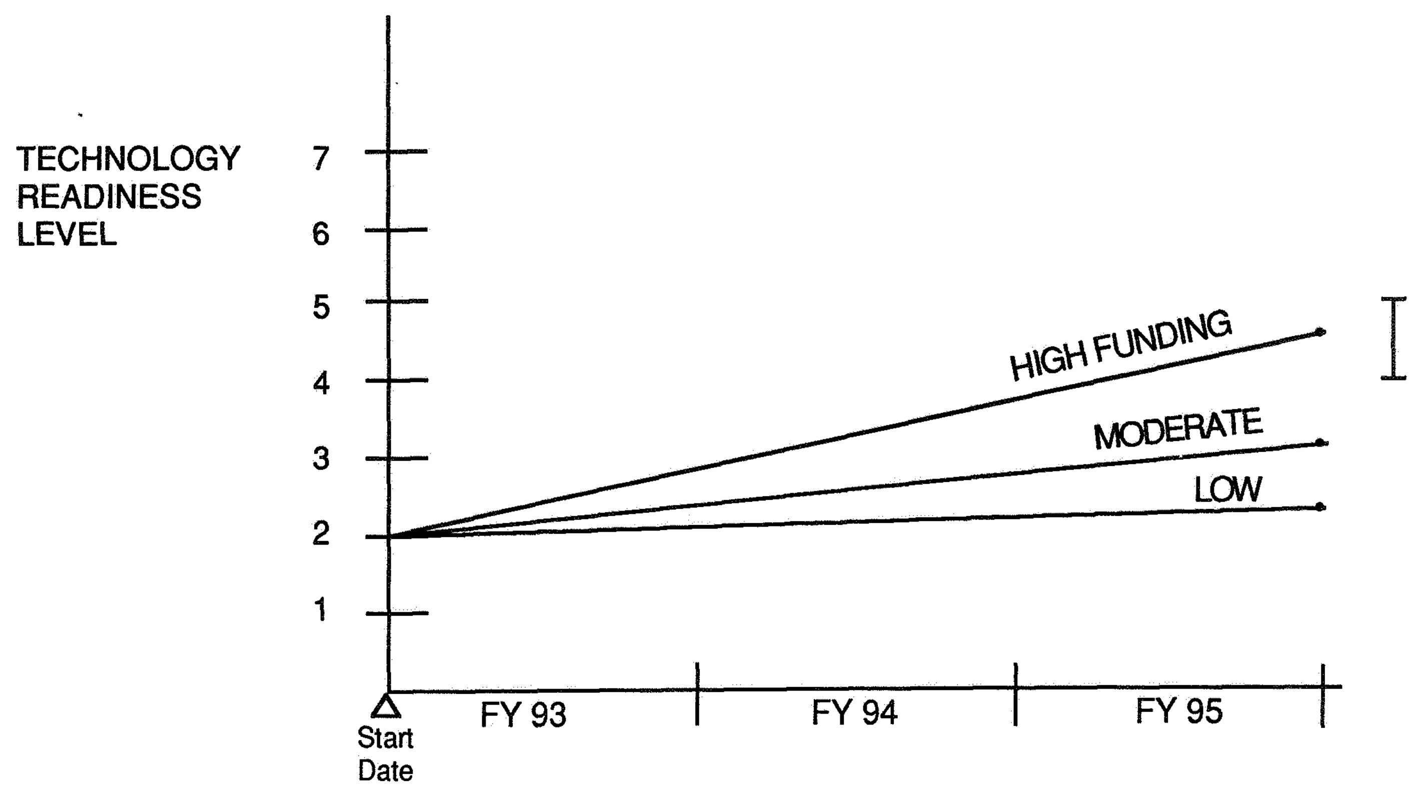
3. Sensor concepts, hardware and procedures for minimizing the likelihood of collision between EVA astronaut and robot; and passive sensors for override and active path control.

4. Concepts, hardware and procedures for non-manual control of robot motions and tasks, e.g., use of aural inputs or eye movement.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

EVA *TELEROBOTIC WORK AIDS INTERFACES*

TECHNOLOGY ASSESSMENT



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TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

MANNED SYSTEMS TECHNOLOGY DISCIPLINE

JANUARY 19, 1990

REMUS BRETOI, CHAIRMAN
AMES RESEARCH CENTER

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

TECHNOLOGY DISCIPLINE SUMMARY FOR MANNED SYSTEMS

As Space Station Freedom evolves toward its full capability to support scientific and human exploration missions with relatively large crews and long tours of duty (sixty days or more), economy, performance and safety become increasingly important. This implies that: (a) relatively little of the crew's time should be devoted to performing routine tasks and monitoring on-board systems (i.e., their skills should be directed primarily toward performing their missions); (b) crew members must be able to maintain their skills under both normal and emergency conditions; (c) they must be able to maintain and support the on-board systems as necessary to ensure their availability and safety; (d) they must be provided with an environment in which they can remain motivated and reliable; and (e) systems designers and mission planners need improved capabilities to evaluate and synthesize alternative designs and procedures consistent with future program and mission objectives. These are some of the factors which influenced the Manned-Systems Workshop Session in developing their recommendations. The technology areas which evolved quite naturally as a result of considering these factors are as follows:

Crew-Systems Interfaces and Interactions
Training
Maintenance and Support
Habitability and Environment
Computational Human Factors / Analysis Tools

BACKGROUND

SCOPE - Effective crew-systems integration applies the systems approach during system development to enhance functional effectiveness, while maintaining or enhancing human well-being and system performance. In this approach, the human operator is considered a component or subsystem of the total, integrated Man-Machine System. Thus, limitations, capabilities, and expectations of the operator must be taken into account to form efficient and productive crew-system interfaces and interactions. The human operator interacts with the system through the Man-Machine Interface (MMI). Through this interface, the operator must sense or perceive the state of the system and environment, then process that information, make a decision, and select a response before putting that response into the system. It is the MMI, in its broadest sense, that is the scope of the technical area. This includes not only the hardware input and output devices, but the human-computer interface and artificial intelligence/expert systems.

OBJECTIVES - The objectives in this technology area are to design and develop innovative approaches, techniques, hardware, and software that will enhance system performance by improving the crew-systems interfaces and interactions. By enhancing the operator performance and well-being, the overall system performance benefits. Thus, the goal is a more symbiotic, synergistic Man-Machine System.

RATIONALE - Greater demands will be placed on Space Station Freedom as it evolves. There will be larger and more complex systems, more payloads (in both quantity and variety), and more required EVA (generally assembly and servicing operations, such as attached payloads, free flyer servicing, and transportation node operations). This in turn will place greater demands on the crew in both the number and complexity of tasks to be accomplished. In many cases, the crew will have to sense and comprehend the system status, make decisions, and respond more quickly and efficiently. In other cases, there will be a need to off-load many of the tasks the crew would normally do, perhaps through automation, while still providing the crew the capability for insight into the systems' configuration, operation, and status. In essence, in order to meet the demands of the evolving space station, crew productivity must be enhanced. To attain this goal, sufficient resources must be focused on improving the crew-systems interfaces and interactions.

PROGRAM PLAN

APPROACH -

1. Human-Computer Interfaces and interactions: Develop improved Man-Machine Interfaces (MMI) and Human-Computer Interfaces (HCI) that enhance the operator's perception of, and interaction with, systems' operations. MMI improvements should exploit alternate sensory modalities and permit more "natural" response selections. Audition might be employed via 3-D auditory displays and speech production. Speech recognition and direct manipulation could permit more natural methods for system input. The HCI might be improved through display format standardization, advanced methods for multi-tasking management, and more rapid input and access. Improvements in both the MMI and HCI should be guided with the eventual goal of a virtual workstation in mind.

2. Teleoperations Interfaces and Interactions: Develop improved MMI's that enhance operator performance in teleoperations, including EVA (both large and dexterous manipulators), proximity operations (free flyers), telescience, and telerobotics. An improved MMI should provide a more "natural" interface to the user. Anthropomorphic input devices and force-reflective feedback are necessary advancements in this area. Three-Dimensional situation awareness must also be enhanced. This might be accomplished using improved 3-D visual and auditory displays.

3. Artificial Intelligence/Expert Systems Interfaces and Interactions: In the drive towards increased automation, attention must be paid to the limitations, capabilities, and expectations of the operator. The degree of system complexity must take into account operator intervention and take-over, and enhance crew autonomy. Efforts should focus on Artificial Intelligence/Expert Systems that provide robust Decision Support Systems (DSS), including information processing and aids to understanding consequences; troubleshooting and diagnostics support, including Failure Mode Effects Analyses; and dynamic task allocation between the operator and the system, taking into account the user's expertise, need to know, workload, etc., and the system's health and status.

PROGRAM PLAN
(CONTINUED)

APPROACH (CONTINUED) -

4. In-Situ Maintenance Interfaces and Interactions: Develop and integrate portable input and output devices that allow the user "hands-free" access to text and graphics databases (e.g., procedures, checklists, schematics, etc.). These devices are to be designed for operations performed in physically constrained work envelopes (e.g., in-situ maintenance) where the user is away from a "fixed" workstation. In addition, locations and volumes for attaching a "portable" (e.g., laptop) workstation are limited or non-existent, and the user requires frequent access to the database. The design should be modular, capable of operating both stand-alone and through a wireless interface to the Data Management System, and "wearable" by the user. Color and video capabilities should be available on the monitor.

5. Analytical Tools and Methods: This technology element is fully addressed in the "Computational Human Factors" section below.

DELIVERABLES:

1. (a) 3-D auditory displays (speech and non-speech), (b) Reliable, flexible speech recognition and production systems, (c) Direct manipulation input devices (e.g., touch screens, 3-D display manipulation, 0-G cursor control devices), (d) Virtual workstation.

2 (a) Anthropomorphic input devices with force-reflective feedback, (b) 3-D auditory displays (for auditory tracking and positioning), (c) Compact 3-D visual displays (not requiring special glasses).

3 (a) AI/Expert Systems providing automation transparency, easy operator intervention, robust DSS and dynamic task allocation capabilities.

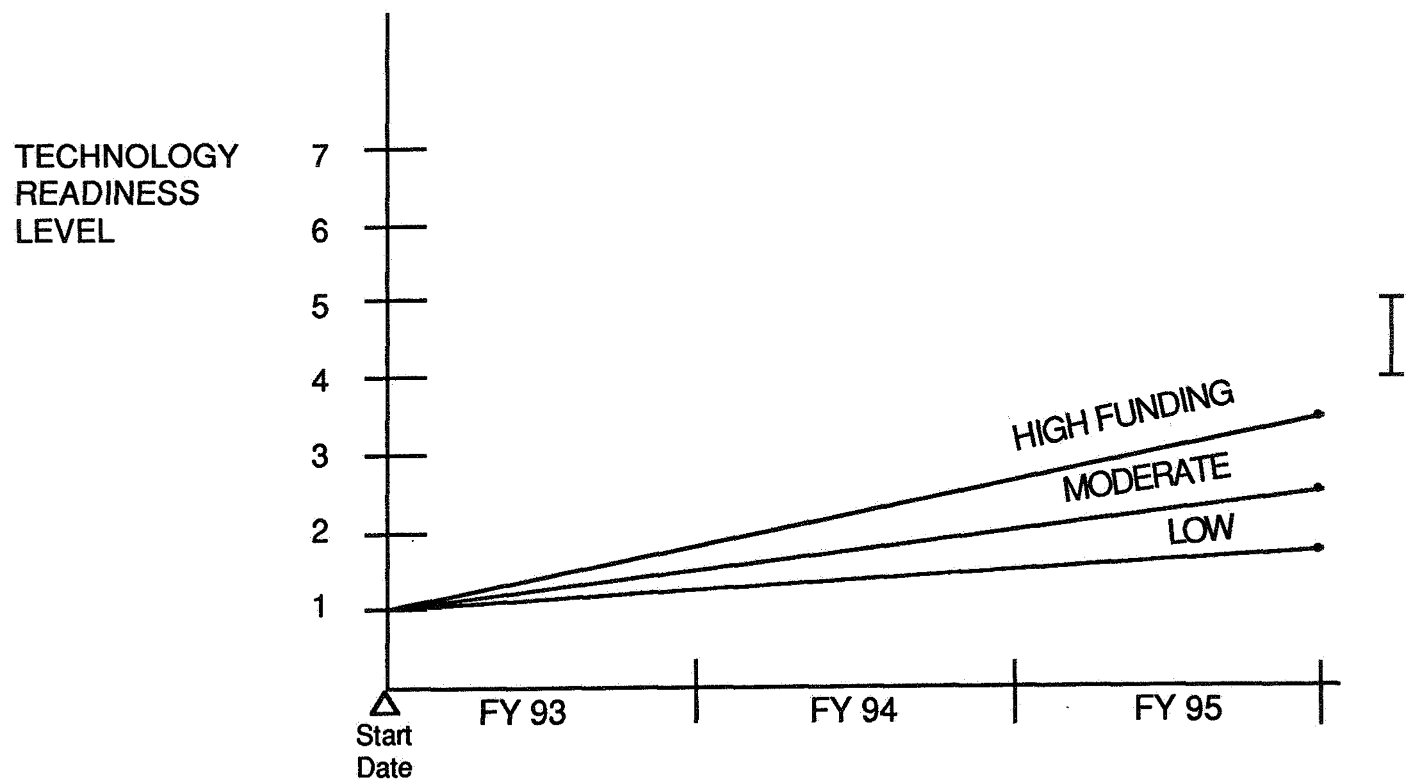
4. (a) Modular, portable, "wearable" input and output devices, (b) "Wearable" monitors with color and video capabilities.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS

CREW-SYSTEMS INTERFACES AND INTERACTIONS

TECHNOLOGY ASSESSMENT



BACKGROUND

SCOPE - Skill retention, human performance, embedded training, crew operation of back-up systems, and back-up system design guidelines.

OBJECTIVES - To develop techniques, concepts and design guidelines for (a) advanced systems and payloads embodying embedded training capabilities, and (b) design of automated systems with operator-backup in mind.

RATIONALE - Space Station Freedom crews will function in space for sixty days or more on a routine basis. The Space Station will probably also be used for research on the ability of crews to function for longer periods of time to support future human lunar and martian human exploration missions. The issues which must be addressed here are (a) skill retention and maintenance of performance during relatively long tours of duty, and (b) crew operation of back-up systems in the event of system failure. This must be done in order to satisfy safety requirements, and to maintain human reliability and performance.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *CREW TRAINING*

PROGRAM PLAN

APPROACH -

1. Embedded Training: Conduct studies and simulations involving the kinds of systems and payloads which will be used in future space missions. Develop training techniques and concepts for use of operational systems and payloads in space to maintain crew skills, performance and reliability; develop guidelines for design of future systems and payloads so that they may provide an in-space capability for crew skill maintenance and training; and identify hooks and scars to systems being developed so they may accommodate evolving embedded training concepts.

2. Back-up System Design: Conduct studies and simulations of critical on-board functions such as environmental control. These will include one or more crew members operating in a back-up mode to a highly-automated system. Define and evaluate back-up systems concepts and develop systems design guidelines for future systems.

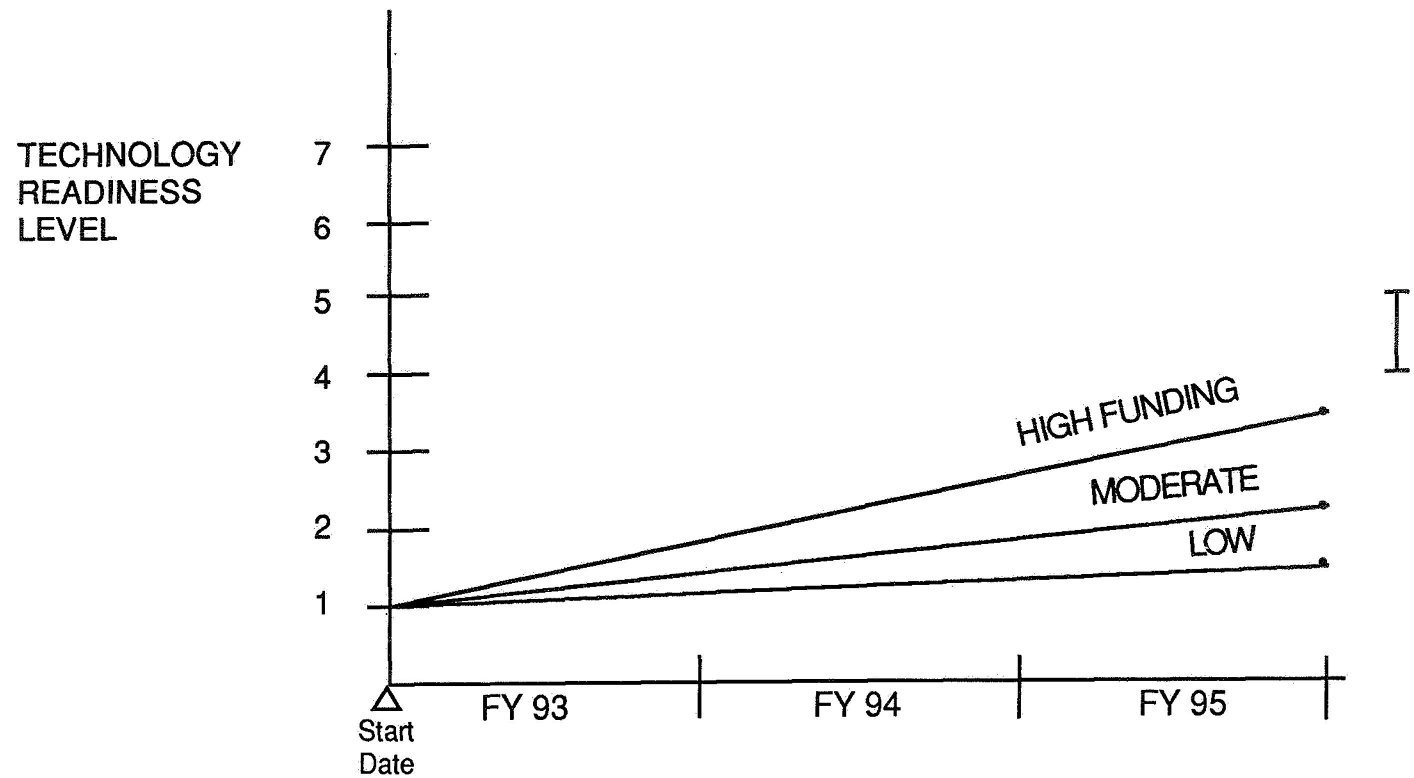
DELIVERABLES -

(1) Embedded training techniques, concepts and design guidelines for systems and payloads.

(2) Back-up systems concepts, operational procedures and design guidelines.

MANNED SYSTEMS *CREW TRAINING*

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *MAINTENANCE AND SUPPORT*

BACKGROUND

SCOPE - Techniques and guidelines for improved maintainability and supportability of on-board systems, including: fault detection identification and resolution; design concepts for maintainability; inventory management techniques; loose item tracking and location; and modeling and simulation.

OBJECTIVES - To develop techniques, concepts and design guidelines for on-board systems in order to minimize crew time devoted to performing maintenance and support tasks.

RATIONALE - The large number of complex systems on board the space station, their criticality for safety and mission performance, the limited crew time available for performing mission and maintenance tasks, the cost of maintaining an in-space inventory, the relatively long times between re-supply, etc., require application of advanced techniques for performance of maintenance and support tasks. Further, design guidelines are needed to aid the systems designer in developing systems which are easily diagnosed, maintained and supported.

PROGRAM PLAN

APPROACH -

1. Diagnostics: Develop improved techniques for fault detection, identification and resolution. These techniques will be based on application of Artificial Intelligence (AI), Expert Systems, and computer graphics. Computer and laboratory simulations of representative on-board systems will be used to (a) evaluate alternative technical approaches, (b) establish guidelines for role and task allocation between automated diagnostics systems and the human, (c) evaluate alternative methods for interaction between the human and the diagnostic system, including computer and display interfaces, and (d) establish guidelines for design of on-board systems to ensure that they can be easily diagnosed.

2. Design Concepts: Develop design concepts for improving the ability of the in-space crew member to maintain in-space systems. These include ORU concepts; interfaces that accommodate humans, robots and tools; and improved EVA/IVA tools.

3. Inventory Management Techniques: Develop inventory management techniques based on computer simulations which will anticipate failure of system components or ORU's, and provide that information to flight and ground personnel. This information will be used to decide when to replace specific items, when to transport them to orbit, when to place them in the pipeline, etc.

4. Loose Item Tracking: Develop and evaluate concepts for keeping track of tools and other items which may be loose or lost in the space station modules.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *MAINTENANCE AND SUPPORT*

PROGRAM PLAN
(CONTINUED)

DELIVERABLES:

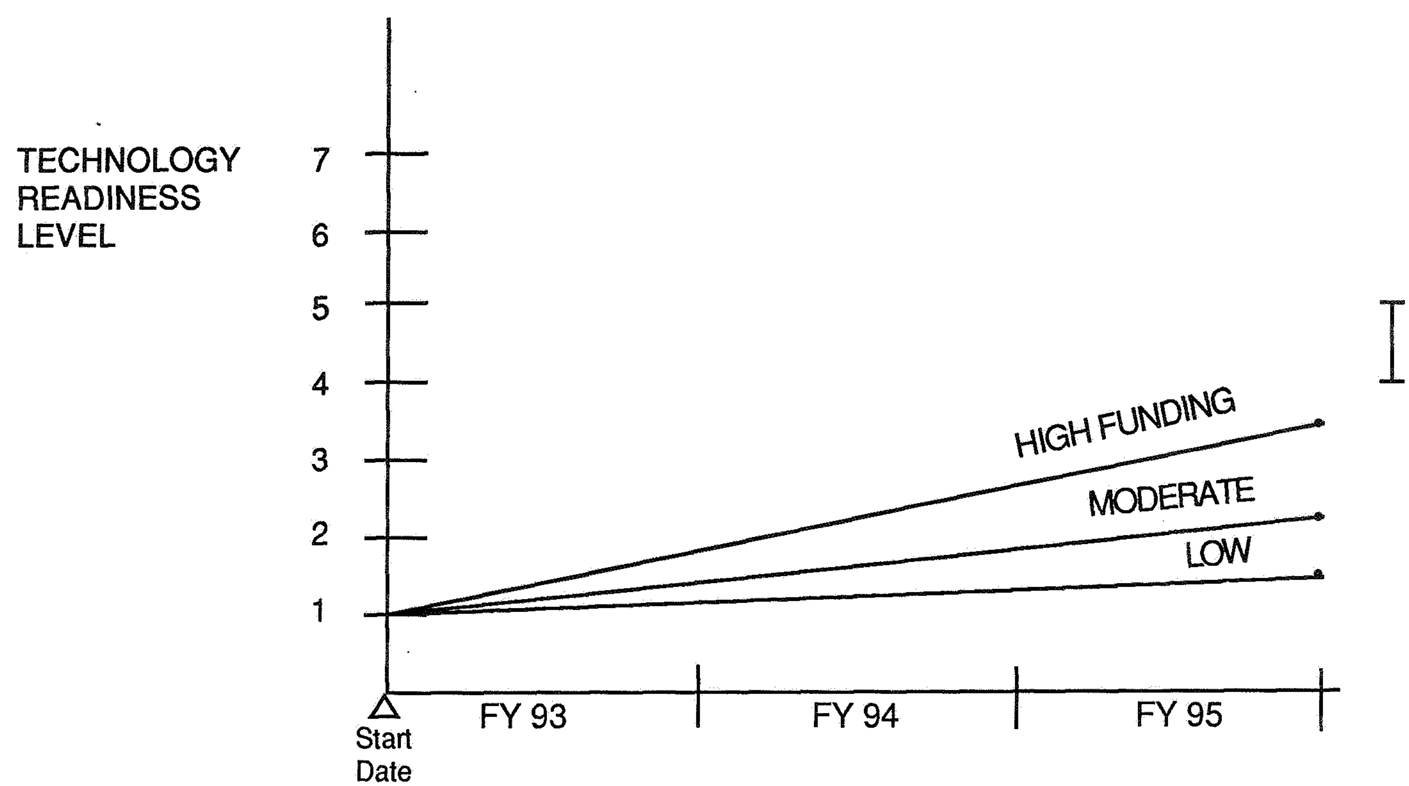
1. (a) Advanced diagnostic systems concepts and technical approaches, (b) guidelines for role and task allocation between automated diagnostic systems and the human operator, (c) techniques and procedures for interaction between the human and the diagnostic system, and (d) design guidelines for design of on-board systems design to ensure that they can be easily diagnosed.

2. Demonstrations of ORU concepts; systems interfaces accommodating humans, robots and tools; and tools for improving the ability of the in-space crew member to maintain in-space systems.

3. Computer simulations of an inventory management system, focusing on a representative on-board system such as portable life support. Identification of data requirements (e.g., reliability, re-supply schedule, test requirements, etc.) required to develop and use the inventory management system.

4. A sensing and tracking system for items which may be loose or lost in the space station.

TECHNOLOGY ASSESSMENT



BACKGROUND

SCOPE - Interior design and architecture, stress reduction, motivation, human reliability, crew scheduling and work-rest cycles, mobility aids, restraints and trash disposal.

OBJECTIVES - To (a) develop an understanding of human behavior on long-duration space missions, and (b) develop crew organizational and architectural concepts which will provide crews an environment which will relieve stress, and improve performance and safety.

RATIONALE - Space crews on missions lasting several weeks or more tend to exhibit adverse behavior for a number of reasons: high work loads, the stress of operating in a hostile environment; confinement to small work and living spaces; lack of privacy, etc. Furthermore, tasks which may seem routine and simple on earth are much more difficult to perform in a micro-gravity environment. The combination of these factors tends to cause in-space crews to manifest symptoms of stress, including hostility. This can result in adverse effects on performance, motivation, judgment, performance, and inter-personal relationships. These problems can be even more severe on evolving space station missions which may be of relatively long duration, perhaps several months, and which may involve relatively large crews, perhaps 15 or more crew members. In this case the problem of trash disposal also can become compounded because of the quantity involved and because, if it gets out of hand, it can adversely affects physical and mental well-being (i.e., visual pollution).

The factors affecting crew behavior and performance need to be better understood, and countermeasures to the adverse effects of long-duration operations in a space environment need to be developed.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *HABITABILITY AND ENVIRONMENT*

PROGRAM PLAN

APPROACH -

1. Conduct analytical and simulation efforts using reconfigurable simulators or test-beds with crew sizes representative of those for the evolving space station and consistent with the particular issue to be investigated.

2. Conduct experiments to evaluate the effects of alternative volume, furniture, texture and color configurations.

3. Conduct experiments to evaluate the effects on interpersonal relationships of alternative organizational structures, tasks, work loads, and work-rest cycles.

4. Conduct experiments to evaluate concepts for stress reduction, including rest, relaxation, entertainment, communication with family, photographic projections, external views, color schemes, etc.

5. Develop and evaluate concepts for body restraints and mobility aids in the neutral-buoyancy test facility and, when feasible, in space.

6. Develop and evaluate techniques for handling and disposing trash.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *HABITABILITY AND ENVIRONMENT*

PROGRAM PLAN
(CONTINUED)

DELIVERABLES:

1. Design guidelines and concepts for providing attractive and practical work and living spaces.

2. Guidelines for interpersonal working relationships and organization, work-rest cycles, and crew selection criteria.

3. Concepts and guidelines for stress reduction, including rest, relaxation, entertainment, communication with family, photographic projections, external views, color schemes, etc.

4. Concepts, recommendations and design guidelines for body restraints and mobility aids.

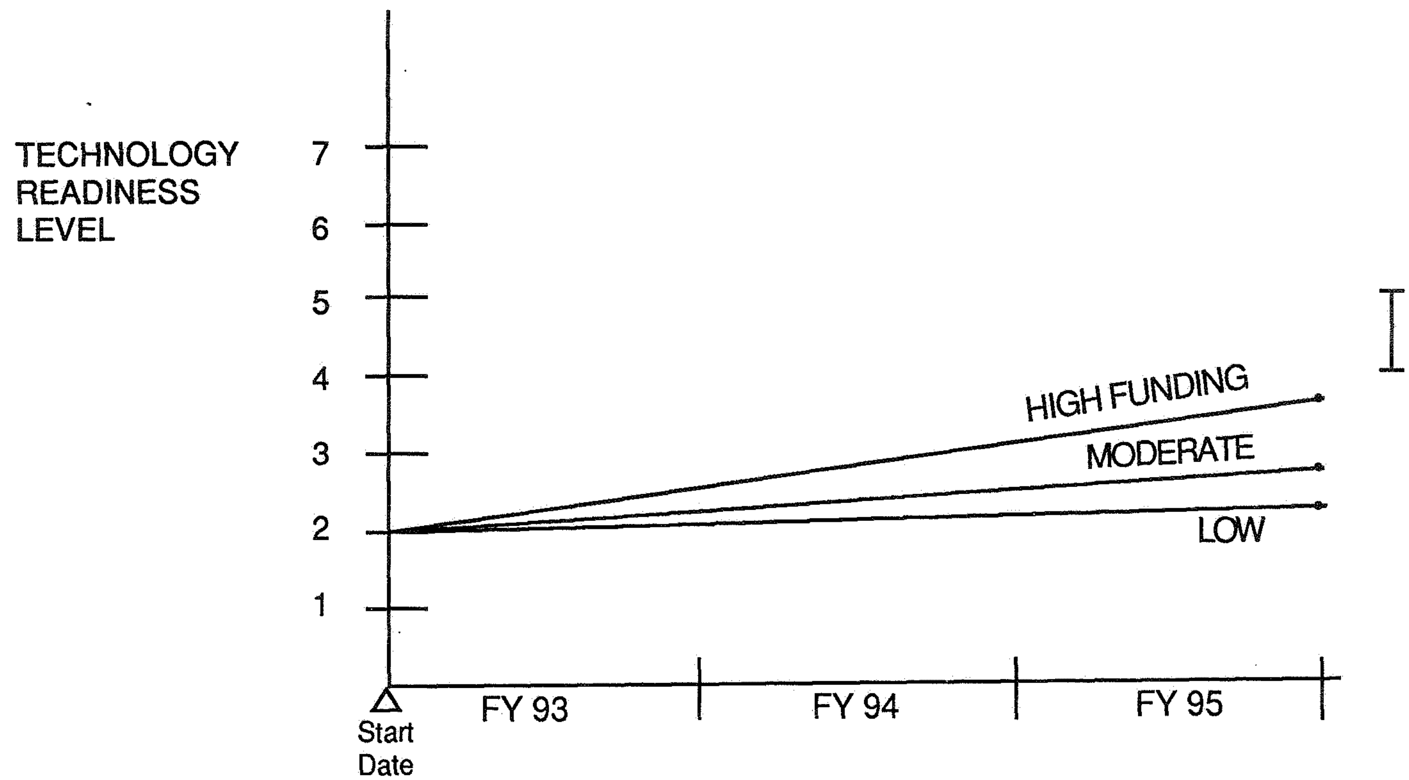
5. Techniques and design guidelines for handling and disposing trash.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS

CREW TRAINING

<u>TECHNOLOGY ASSESSMENT</u>



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS | *COMPUTATIONAL HUMAN FACTORS*

BACKGROUND

SCOPE - (1) Computer-aided design tools for use in: (a) anthropometry/size and fit; (b) interfaces developemtnt for visibility, placement, and information presentation; (c) procedures, considering workload aand sequence; and (d) training. (2) Digital video using perceptual components architecture.

OBJECTIVES - (1) To develop computer-aided design tools for use in interfacing the human with on-board systems and developing operational procedures, thereby reducing design costs, improving efficiency and timeliness, optimizing system performance and safety, and providing a means for effective comparative evaluation of alternative concepts before committing to hardware. This woiuld result in better designs, lower costs, less reworking, and anticipation of training needs. (2) To develop video display techniques which satisy human information requirements within the limits of available band widths aor channel coapacities.

RATIONALE - *Computer Aided Design*, Manned simulation time, design and fabrication of comples systems, and in-space experimentation are very expensive. There is a need to develop techniques for modeling the human operator interacting with complex space systems. These systems often may be highly automated, perhaps employing artificial intelligence or expert systems technologies.

Computational modeling has revolutionized most physical engineering disciplines. For example, finite element analysis has changed the design process in structures, airframe design, and electronic circuit layout. These Computer Aided Design (CAD) tools permit the engineer to ask "what if" questions about the performance of potential designs before they are built or physically prototyped. This has greatly reduced the cost of producing new systems. Computational models are also used to predict performance in new or novel situations for existing systems or to predict the impact of modifications to existing systems on their future performance characteristics.

BACKGROUND
(CONTINUED)

RATIONALE (CONTINUED) - CAD tools for human factors are now in their infancy. However, both JSC's PLAID system and ARC's Army/NASA Aircrew-Aircraft Integration system (A31) are capable of predictive modeling in the human factors engineering domain. Anthropomorphic issus such as size, fit, reach envelope, etc., can now be computed prior to system construction. Other attributes such as display visibility, workload, and trainability are computable.

This emerging technology has many applications in the aerospace industry. This technology needs to be developed further and applied to the evolving Space Station Freedom and Human Exploration Initiative programs.

Digital Video using Perceptual Components Architecture. Many on-orbit tasks in space require digital communications, e.g., telerobotics, ground/space collaboration on experimental procedures, etc. There is not a single requirement for spatial and temporal resolution for image size, or for its color rendering properties. Further, in many situations there will be a need for multiple images. The band width or channel capacity of the communication linkage is limited and, therefore, current video technology will not satisy the operational needs.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS *COMPUTATIONAL HUMAN FACTORS*

PROGRAM PLAN

APPROACH -

1. *Computer-Aided Design:* Efforts will focus on developing tools for modeling the human operator interfacing with on-board systems, using JSC's PLAID and ARC's Army/NASA Aircrew-Aircraft Integration Program (A31) as points of departure. This includes simulation tools to estimate training needs, task difficulty/work load, and timeliness.

2. *Digital Video using Perceptual Components Architecture:* Digital video using something like a packet network could satisfy the operational needs of the evolution space station. A system with the ability to re-size the image, vary the spatial, temporal and chromatic resolution is technically feasible now. A full digital system using a perceptual components architecture (PCA) would have the following features: (1) images could be sized for any display, (2) the viable resolution could reduce to a minimum the communication band width requirement, and (3) by using PCA coding the system could "hide" quantization noise in the noise of the human visual system and segregate the image "energy" -- perceptually "vital" energy could be transmitted with multiple redundancy and less vital image energy could be transmitted with less redundancy (less error correction) without perceptual loss to the human. Finally, smoothing algorithms can be developed to temporally, spatially, and chromatically smooth sub-sampled digital image sequences. These smoothing algorithms would reduce the "perceptual" impact of sub-sampling the image sequence. Ideally, in theory, nearly static and/or low entropy scenes could be transmitted "without loss" over a low band width communication link. A digital video system based upon PCA coding can achieve this ideal.

PROGRAM PLAN
(CONTINUED)

DELIVERABLES -

1. A *Computational Human Factors-Based Computer Aided Design capability* which can be used by an interdisciplinary team of human factors specialists and systems designers as a part of the systems and systems interface design process. This CAD system will be applicable for (a) analysis and evaluation of existing and conceptual systems designs, and (b) comparative evaluation and optimization of alternative concepts and operational procedures, and (c) resolution of issues relating to economics, performance, reliability and safety.

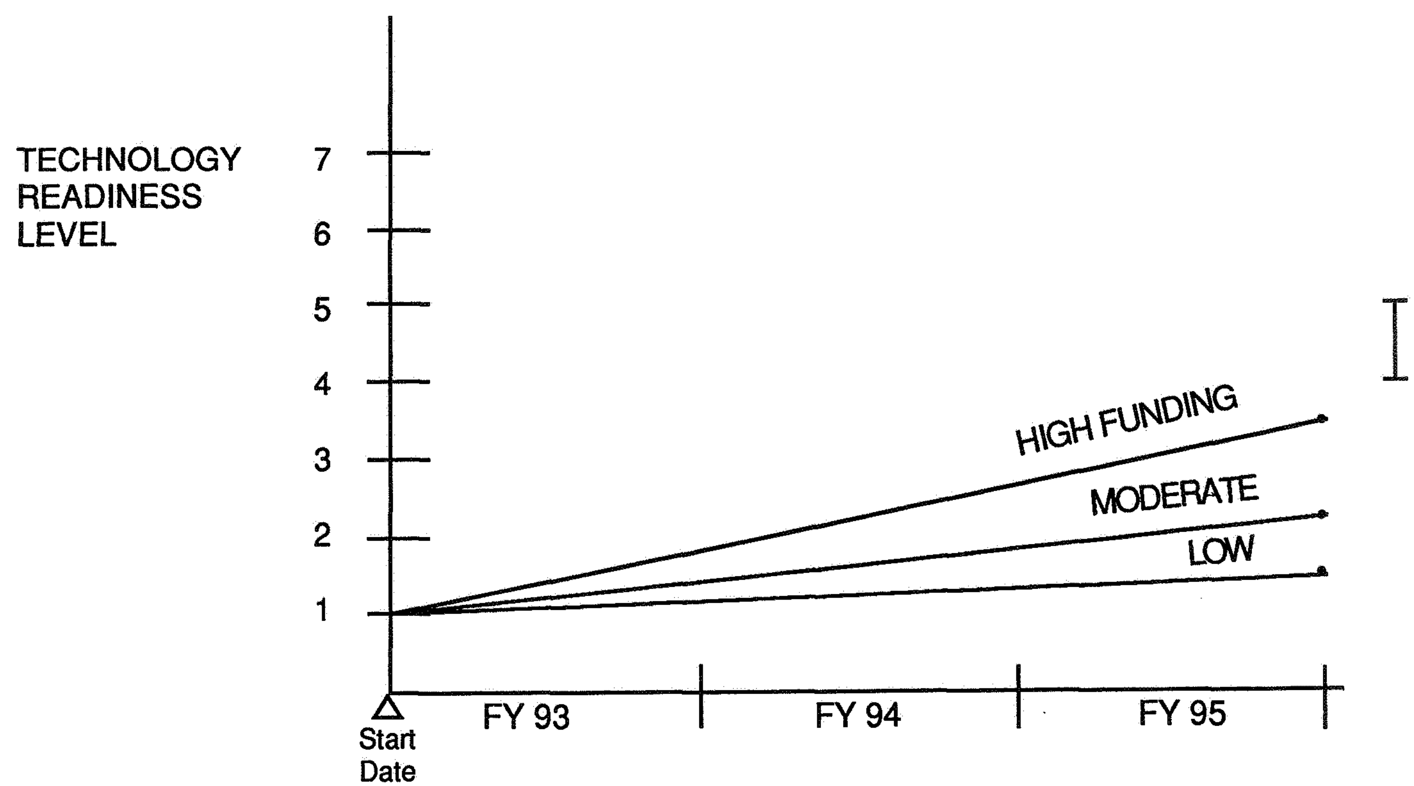
2. A demonstration Digital Video System using Perceptual Components Architecture (PCA) based on the specific needs of the human operator. This system will have (a) the ability to re-size the image and vary the spatial, temporal and chromatic resolution and (b) smoothing algorithms and chromatically smooth, sub-sampled digital image sequences to reduce the "perceptual" impact of sub-sampling the image sequence. Nearly static and/or low entropy scenes will be able to be transmitted "without loss" over a low-band-width communication link.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

MANNED SYSTEMS

COMPUTATIONAL HUMAN FACTORS

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

FLUID MANAGEMENT SYSTEM TECHNOLOGY DISCIPLINE

JANUARY 19, 1990

E. PATRICK SYMONS, CHAIRMAN
LEWIS RESEARCH CENTER

FLUID MANAGEMENT SYSTEM

TECHNOLOGY DISCIPLINE SUMMARY

- CURRENT SYSTEM
  - INTEGRATED NITROGEN SYSTEM (INS)
    - LAB EXPERIMENT GAS
    - SYSTEM PRESSURIZATION GAS
    - SYSTEM MAINTENANCE PURGE GAS
    - PROVIDES EXLSS EMERGENCY ACCESS TO NITROGEN (MANUAL CONNECTION)
  - INTEGRATED WATER SYSTEM (IWS)
    - WATER TO LAB EXPERIMENTS
    - PROVIDE ECLSS DIRECT ACCESS TO SCAVENGED NSTS FUEL CELL WATER
  - INTEGRATED WASTE GAS SYSTEM (IWGS)
    - COLLECT, STORE, AND DISPOSE OF WASTE GAS BY AC
      - LAB EXPERIMENT BULK "SAFE" WASTE GASES
      - ECLSS WASTE GASES
      - SYSTEM PRESSURIZATION VENT GASES
      - SYSTEM MAINTENANCE PURGE GASES

FLUID MANAGEMENT SYSTEM

TECHNOLOGY DISCIPLINE SUMMARY

- EXPANSION OF STATION SCIENCE ACTIVITIES
  - ADDITIONAL USER FLUIID SUPPLY SERVICES
    - GASES: Kr, Ar, He, CO_2
    - CRYOGENS: He, N_2
  - INCREASED CAPACITY OF EXISTING SYSTEMS (INS, IWS, IWGS)
- TRANSPORTATION NODE
  - HANDLING OF SUBSTANTIAL QUANTITIES OF SUBCRITICAL LH_2 AND LO_2 TO SUPPORT HEI
  - EXPANSION OF EXISTING SYSTEMS (INS, IWS)
  - SERVICING OF FREE FLYERS (OMV, COP, MTFF, AXAF, ETC.)

FLUID MANAGEMENT SYSTEM

TECHNOLOGY NEEDS NOT ADEQUATELY FUNDED

- SUBCRITICAL CRYOGENIC STORAGE AND TRANSFER
- FLUID HANDLING
- COMPONENTS / INSTRUMENTATION

FLUID MANAGEMENT SYSTEM

SUBCRITICAL CRYOGENIC STORAGE AND TRANSFER

SCOPE: This technology area addresses the general in-space fluid management issues associated with:

1. Storage of subcritical cryogenic fluids in-space including thermal control systems and pressure control systems.
2. Supply of single phase liquid to an end user including liquid acquisition systems and pressurization systems.
3. Transfer of liquids from one container to another in low gravity.

OBJECTIVES:

1. To develop the technologies of storage, supply, and transfer by performing in-space experiments for the purpose of:
   a. developing an adequate experiment data base
   b. validating analytical models of the important thermal, fluid, and thermodynamic processes
   c. demonstrating components, systems, and subsystems in a relevant environment

REQUIREMENTS:

LIQUID STORAGE-Requirements exist to store cryogenic liquids in the low-gravity space environment for periods of several hours to perhaps several years while minimizing liquid boiloff and controlling tank pressure. Minimizing liquid boiloff generally requires very efficient tank thermal insulation systems, and controlling tank pressure may require liquid mixing and thermodynamic vent systems.

LIQUID SUPPLY-Requirements exist to feed single-phase cryogenic liquids from a tank in the low-gravity environment of space. This technology area typically involves studies of continuously supplying single-phase liquid to the tank outlet and pressurization gas requirements during expulsion of liquid from the tank. Preferred techniques for liquid acquisition use fine mesh screen materials as capillary devices. However, the effectiveness of such techniques with cryogenic liquids in space remains unproven. Pressurization techniques for discharging cryogens from propellant tanks were developed for rocket vehicles with high expulsion rates and have not been characterized for the low expulsion rates anticipated for low-gravity transfer operations.

FLUID TRANSFER-Requirements exist to transfer cryogenic liquids from one tank to another in the low-gravity environment of space. Fluid losses associated with the transfer process must be minimized, and the tank pressures must be controlled. A "thermodynamic" technique for low-gravity transfer of fluids is the recommended approach to be investigated. This technique consists of alternately chilling, with a small quantity of cryogen, and venting the tank to be filled until the tank is cold enough to be filled without venting (tank chill-down and no-vent fill). Another approach to be explored is the positioning of the accumulating liquid away from the tank vent by use of a low-thrust propulsive system to provide liquid settling.

FLUID MANAGEMENT SYSTEM — SUBCRITICAL CRYOGENIC STORAGE AND TRANSFER

PROGRAM PLAN

APPROACH:

1. Continue to develop analytical models of the important fluid, thermal, and thermodynamic processes describing the anticipated behavior of the subcritical cryogenic storage and transfer systems under existing programs being supported by OAST, OSSA, and OSF.

2. Perform extensive ground-based experimentation utilizing the cryogenic fluids of interest in order to validate those portions of the analytical models which are insensitive to the gravitational environment by continuing existing programs being supported by OAST, OSSA, and OSF.

3. Design, fabricate, qualify, and carry into space flight experiment(s) to validate those processes which are sensitive to the gravitational environment. Immediate data and in-space experimentation is required with subcritical liquid nitrogen; future experiments with subcritical liquid hydrogen are required.

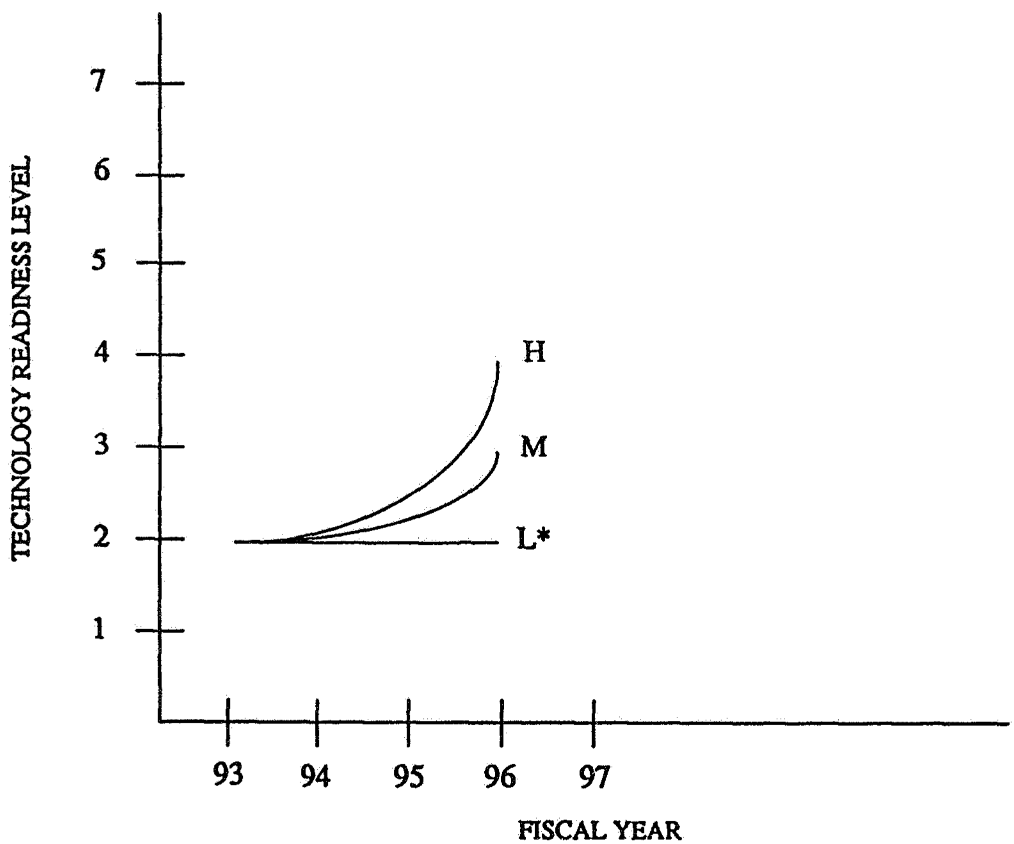
DELIVERABLES:

1. System performance data and validated analytical models that provide design criteria for the development of evolutionary subcritical cryogenic fluid storage and transfer systems.

FLUID MANAGEMENT SYSTEM

SUBCRITICAL CRYOGENIC STORAGE AND TRANSFER

TECHNOLOGY ASSESSMENT



* LOW INVOLVES NO FUNDING
BEYOND EXISTING OAST, OSF, OSSA PROGRAMS

BACKGROUND

SCOPE: This technology area addresses the general in-space fluid management issues associated with:

1. Liquid slosh dynamics and control
2. Liquid dumping/venting/emergency relief

OBJECTIVES:

1. To obtain fundamental data on low-gravity liquid slosh dynamics phenomena and to validate analytical models.
2. To assess and evaluate the effectiveness of several techniques to accomplish on-orbit dumping of liquids.

REQUIREMENTS:

1. Control of tankage and complete spacecraft (SSF, STV, Depot, Tankers, Etc.) with large fluid inventories is dependent on the ability to predict fluid motions and their attendant forces which arise from attitude control system firings, spacecraft docking, assembly operations, etc. The impact of these motions and the resulting forces and acceleration environment needs to be understood and predictable in order to effectively control space station.
2. On-orbit fluid dumping may take place under both normal as well as contingency (emergency) operations. Currently, no analytical models have been validated by experiment data. Under certain conditions of rapid depressurization, significant quantities of liquid may freeze in tanks and could cause safety problems. This process is very poorly understood at present.
3. A low-gravity data base is needed for all fluids (storable and cryogenic).

FLUID MANAGEMENT SYSTEM

FLUID HANDLING

PROGRAM PLAN

APPROACH:

1. Continue on-going efforts to develop analytical models describing both sloshing and venting/dumping/emergency relief.
2. Perform ground-based testing for partial model validations.
3. Design, fabricate, and carry into space experiments which will provide essential data. These experiments could be performed with small scale tanks using the STS.

DELIVERABLES:

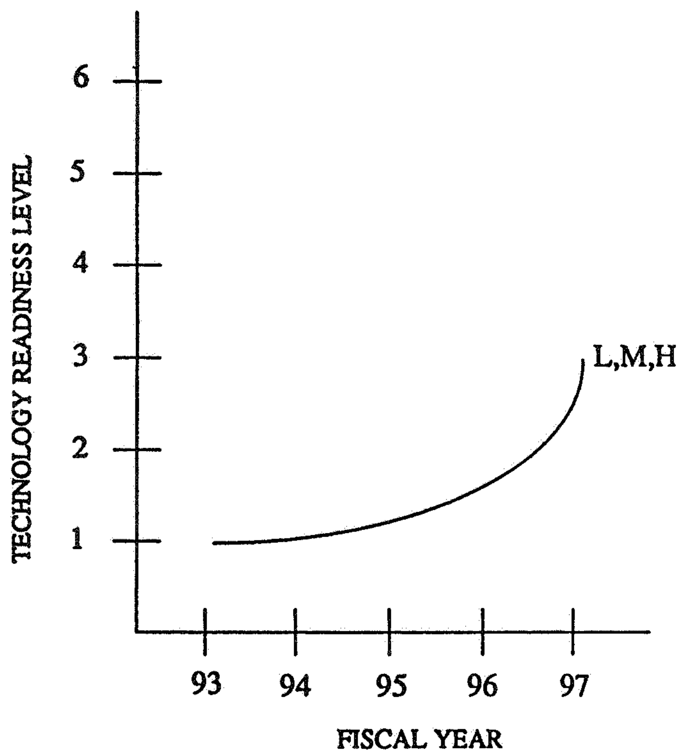
- In-space experiment data to aid in the design and development and to provide validation of analytical models which describe the low-gravity slosh dynamics phenomena.

- In-space experiment data on dumping (venting/emergency relief) which will provide fundamental understanding of the problem and help to establish design criteria and operating procedures.

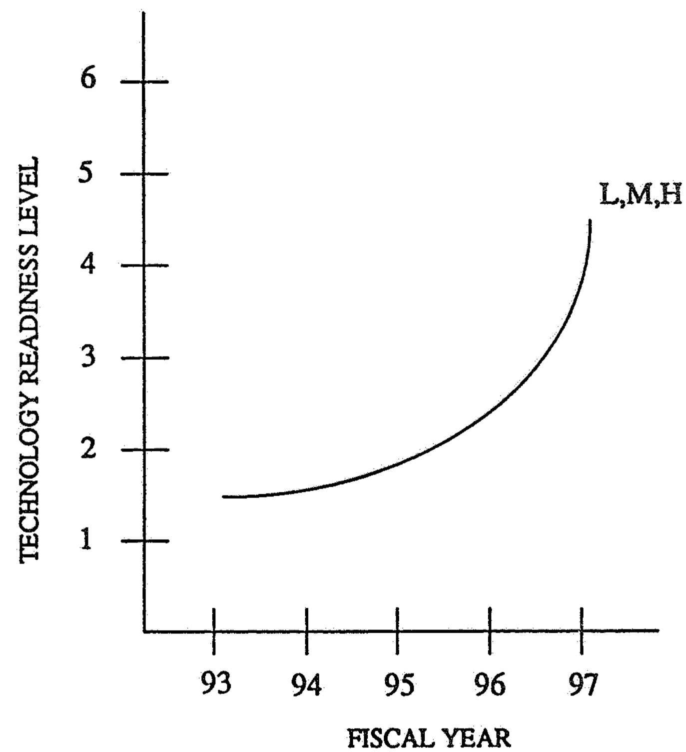
FLUID MANAGEMENT SYSTEM FLUID HANDLING

TECHNOLOGY ASSESSMENT

LOW-GRAVITY SLOSHING



DUMPING/VENTING/EMERGENCY RELIEF



FLUID MANAGEMENT SYSTEM — COMPONENTS AND INSTRUMENTATION

BACKGROUND

SCOPE: Certain components and instrumentation technology critical to both the current and the evolutionary Space Station Freedom fluid management system is not being addressed or requires funding augmentation.

OBJECTIVES:

To develop in-space technologies for the following:

1. Mass gaging of liquids in low-gravity environment
2. Fluid sampling/leak detection
3. Two-phase flow metering
4. Leak detection
5. Couplings/quick disconnects
6. In-space instrument calibration

REQUIREMENTS:

1. Mass Gaging: Accurate measurement (± 1% to 3% of the tank) the mass liquid contained in a vessel in low gravity is essential; no technique currently exists.
2. Fluid Sampling/Species Identification: Knowledge of what species are introduced into the fluid management system and in what quantities is required; could have safety implications.
3. Two-Phase Flow Metering: Will likely be required to assess performance of fluid systems operating in low gravity; no technique currently exists.
4. Leak Detection: All techniques currently being assessed require extensive EVA, alternatives should be evaluated which minimize EVA, identify location and magnitude of leak and isolate system.
5. Couplings/Quick Disconnects: No liquid loss, long life performance components are required.
6. In-space Instrument Calibration: No techniques currently being developed. Needed to assure accuracy of measurements in potentially safety critical systems.

FLUID MANAGEMENT SYSTEM — COMPONENTS AND INSTRUMENTATION

PROGRAM PLAN

APPROACH: INVESTIGATE PROMISING TECHNIQUES
- PERFORM LIMITED TESTING
- PREPARE DEVELOPMENT PLANS
- SELECT CANDIDATES FOR EXISTING FLIGHT EXPERIMENTS

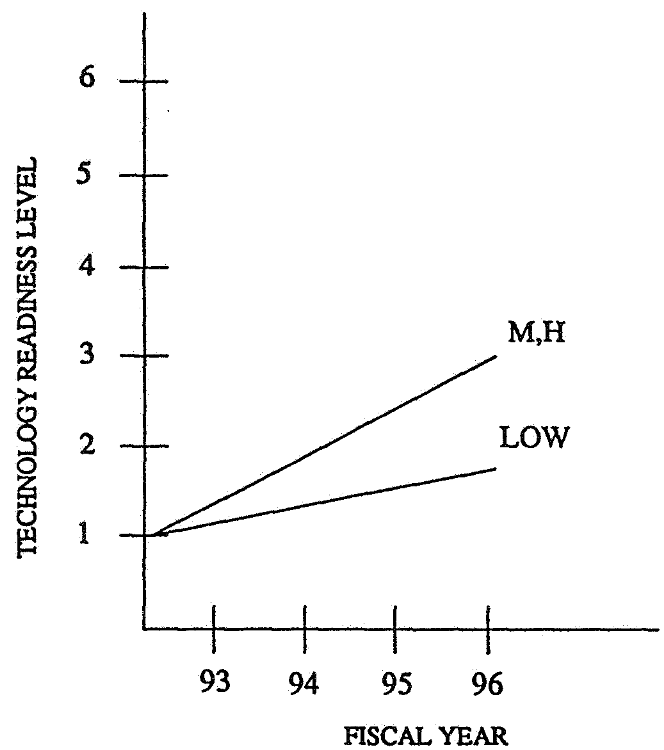
DELIVERABLES:

1. EXISTING TECHNOLOGY THAT CAN BE APPLIED TO ESSF
2. RECOMMENDED CHANGES TO ADAPT EXISTING TECHNOLOGY
3. INITIAL TEST RESULTS/PROOF OF CONCEPT
4. DEVELOPMENT PLANS

FLUID MANAGEMENT SYSTEM

COMPONENTS AND INSTRUMENTATION

TECHNOLOGY ASSESSMENT



FUNDING MAY NOT BE ADEQUATE
EVEN AT HIGHEST FUNDING LEVEL
PRIORITY GIVEN TO:

- FLUID SAMPLING/SPECIES IDENTIFICATION
- LEAK DETECTION
- ON-ORBIT CALIBRATION

FLUID MANAGEMENT SYSTEM

RECOMMENDATIONS

- IN-SPACE EXPERIMENTATION IS ESSENTIAL TO PROVIDE REQUIRED TECHNOLOGY
  - CRYOGENIC STORAGE AND TRANSFER
  - VENTING/DUMPING
  - SLOSH
- ON-GOING OAST, OSSA, AND OSF FLUID MANAGEMENT PROGRAMS <u>MUST</u> BE CONTINUED
- REFERENCE CONFIGURATIONS FOR EVOLUTIONARY STATION SHOULD BE MADE AVAILABLE ASAP
- ESTABLISH A REPOSITORY FOR IN-SPACE FLUID MANAGEMENT ACTIVITIES
  - POSSIBLY MANAGED/MAINTAINED BY AIAA/SAE/ASME COMMITTEES
  - UPDATED YEARLY

FLUID MANAGEMENT SYSTEM

ISSUES

FMS DESIGN

- IDENTIFICATION AND DISPOSAL OF USER-GENERATED WASTE LIQUIDS
- ADDITIONAL LINE(S) TO PROVIDE INERT GASES (E.G., He, Kr, & Ar)
- REDUNDANT ROUTING OF FLUID LINES
- CALIBRATION OF SYSTEM INSTRUMENTATION
- FMS INTERFACES FOR SERVICING MAN-TENDED FREE-FLYERS
- PROGRAM NEEDED FOR COMPONENT AND SYSTEM DEMONSTRATIONS (SPACE STATION ADVANCED DEVELOPMENT PROGRAM LACKING)

GENERAL

- IN-SPACE EXPERIMENTATION IS REQUIRED; CURRENT OAST, OSF, OSSA PROGRAMS LACK SUFFICIENT FUNDING
- POTENTIAL SAFETY ISSUES IDENTIFIED
  - RAPID TANK DEPRESSURIZATION MAY LEAD TO FORMATION OF FROZEN SOLIDS
  - SERVICING OF CO-ORBITING FREE-FLYER PROPULSION SYSTEMS (HYDRAZINE, BI-PROP)
  - SINGLE TRAY FOR ALL FLUID SERVICES

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

POWER SYSTEM TECHNOLOGY DISCIPLINE

JANUARY 19, 1990

DR. HENRY BRANDHORST, CHAIRMAN
LEWIS RESEARCH CENTER

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

<u>TECHNOLOGY DISCIPLINE SUMMARY FOR *POWER SYSTEM*</u>

- **SUBSTANTIAL BENEFITS IDENTIFIED FOR ADVANCED TECHNOLOGY**

  <u>GENERATION</u>

  - **PHOTOVOLTAIC PLANAR AND CONCENTRATOR ARRAYS**
    - REDUCED AREA (2x) AND REDUCED COSTS (RECURRING AND RESUPPLY)
    - 2x MASS REDUCTION WITH BETTER PACKING DENSITY AND PERFORMANCE
  - **NON-SOLAR OPTION**
    - NON-PLUTONIUM ISOTOPE DYNAMIC SYSTEM REDUCES ORIENTATION AND MISSION CONSTRAINTS

  <u>STORAGE</u>

  - **LONG LIVED NI/H_2 BATTERIES**
    - MORE THAN 2x INCREASE IN CYCLE LIFE REDUCES RESUPPLY COSTS
  - **TEST BED FOR HEI REGENERATIVE FUEL CELL WITH SYNERGISTIC SSF BENEFITS**
    - VALIDATES HEI TECHNOLOGY PLUS PROVIDING CONTINGENCY OR SAFE HAVEN POWER

  <u>DISTRIBUTION</u>

  - **AC FOR GROWTH**
    - HYBRID AC/DC SYSTEM
  - **INCREASED AUTONOMY**
    - FREES CREW TIME FOR OPERATIONS, INCREASES SAFETY AND RELIABILITY

- **SSF SYSTEM TRADES SHOULD BE CONDUCTED TO EVALUATE RISKS/BENEFITS OF TECHNOLOGY OPTIONS SOON**

ADVANCED PHOTOVOLTAIC ARRAY DEVELOPMENT

BACKGROUND

SCOPE - DEMONSTRATE ADVANCED SOLAR ARRAY LEVEL 5 TECHNOLOGY (PLANAR AND CONCENTRATOR) FOR SSF GROWTH.

OBJECTIVES - DEVELOP AND DEMONSTRATE ADVANCED SOLAR ARRAY OPTIONS WITH ≥50% IMPROVEMENT IN W/m^2 OVER BASELINE SOLAR ARRAY AND W/kg PERFORMANCE GREATER THAN BASELINE SOLAR ARRAY.

REQUIREMENTS/ RATIONALE - 100 kW NEEDED FOR EVOLUTIONARY SPACE STATION. SIGNIFICANT W/m^2 PERFORMANCE IMPROVEMENT REQUIRED TO REDUCE DRAG. CONCENTRATOR ARRAYS HAVE POTENTIAL FOR SUBSTANTIAL COST REDUCTIONS AND EFFICIENCY INCREASES. DOD INVESTMENT IN GaAs/Ge CAN BE USED TO PROVIDE HIGH PERFORMANCE PLANAR OPTION.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

ADVANCED PHOTOVOLTAIC ARRAY DEVELOPMENT

PROGRAM PLAN

APPROACH -

- FOR PLANAR ARRAY: PILOT PRODUCTION OF 19% 8x8 GaAs/Ge CELL TECHNOLOGY (OR TANDEM CELL), FAB, ASSEMBLE AND TEST PANEL COUPONS.
- FOR CONCENTRATOR ARRAY: DEVELOP LIGHTWEIGHT OPTICS, AND 25% CONCENTRATOR CELL. DESIGN, FAB, ASSEMBLE, AND TEST PANEL LEVEL HARDWARE.

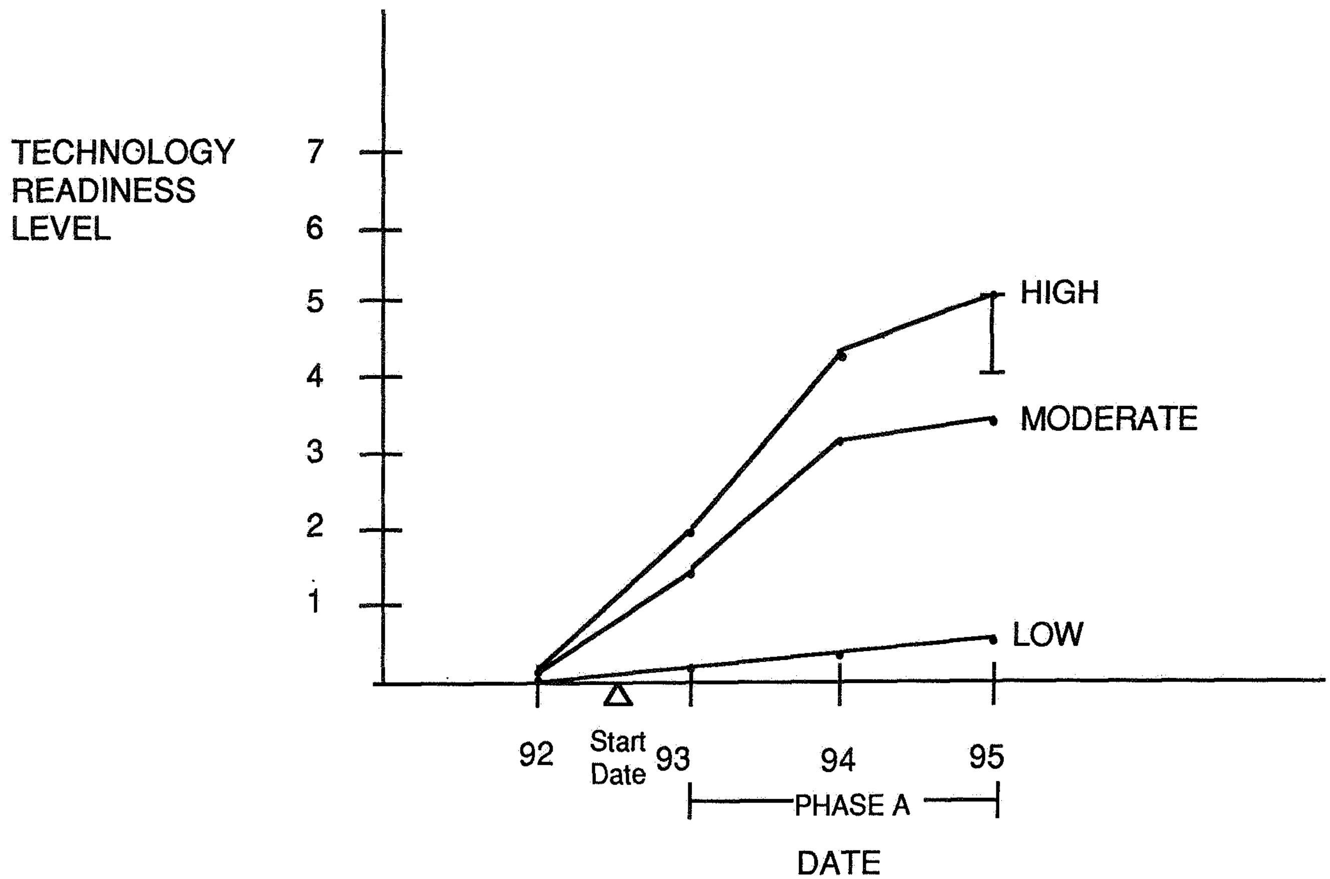
DELIVERABLES -

- PRODUCTION READY 19% GaAs/Ge CELLS (OR EQUIVALENT) FOR ADVANCED PLANAR CONCENTRATOR OPTICS/25% CELL, DEMONSTRATE PANEL.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

ADVANCED PHOTOVOLTAIC ARRAY DEVELOPMENT

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION
-A WORKSHOP

POWER SYSTEM *POWER GENERATION SUBSYSTEM*

SOLAR DYNAMIC TECHNOLOGY

BACKGROUND

SCOPE - PERFORM TECHNOLOGY DEMONSTRATIONS TO OBTAIN IMPROVEMENTS OVER CURRENT SSF DESIGN*

- LOWER WEIGHT
- LOWER LAUNCH VOLUME
- IMPROVED OPERATIONAL CAPABILITY
- IMPROVED RELIABILITY

OBJECTIVES - INCREASE SSF SOLAR DYNAMIC SPECIFIC POWER BY 100% (W/kg)

- 50% Wt REDUCTION IN HEAT RECEIVERS, CONCENTRATOR AND RADIATOR
- PCU PERFORMANCE IMPROVEMENTS

REQUIREMENTS/ RATIONALE - SUPPORT 175 kW HEI SSF WITH IMPROVED POWER SYSTEM

- LOWER WEIGHT, LAUNCH VOLUME AND COST

AN ALTERNATIVE, SUNLIGHT INDEPENDENT POWER OPTION WAS SURFACED THAT WILL REDUCE CONSTRAINTS ON SSF ORIENTATION AND FLIGHT HARDWARE

*IT IS ASSUMED THAT THE SSF PROGRAM OFFICE WILL IMPLEMENT THE SD DEVELOPMENT PROGRAM

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

POWER SYSTEM *POWER GENERATION SUBSYSTEM*

SOLAR DYNAMIC TECHNOLOGY

PROGRAM PLAN

APPROACH -

- DEFINE LIGHTWEIGHT SYSTEM DESIGN, PERFORM CONFIGURATION TRADE STUDIES
- FABRICATE AND TEST SUBSCALE SUBSYSTEM ELEMENTS- (CONCENTRATOR SEGMENT, RECEIVER, RADIATOR) TO ASSESS DESIGN VALIDITY AND POTENTIAL MASS SAVINGS, LONGEVITY
- INTEGRATE COMPONENTS TO DETERMINE SYSTEM SENSITIVITIES
- ASSESS FEASIBILITY/TECHNICAL/POLITICAL ISSUES IN NON-PLUTONIUM ISOTOPE/DYNAMIC/CONVERSION SYSTEM FOR SSF

DELIVERABLES -

- SUBSCALE CONCENTRATOR SEGMENTS, RECEIVER, RADIATOR TESTED AT APPROPRIATE SCALE
- LOWER LEVEL ASSEMBLIES
- FEASIBILITY STUDY OF NON-PLUTONIUM FUELED ISOTOPE/DYNAMIC CONVERSION SYSTEM

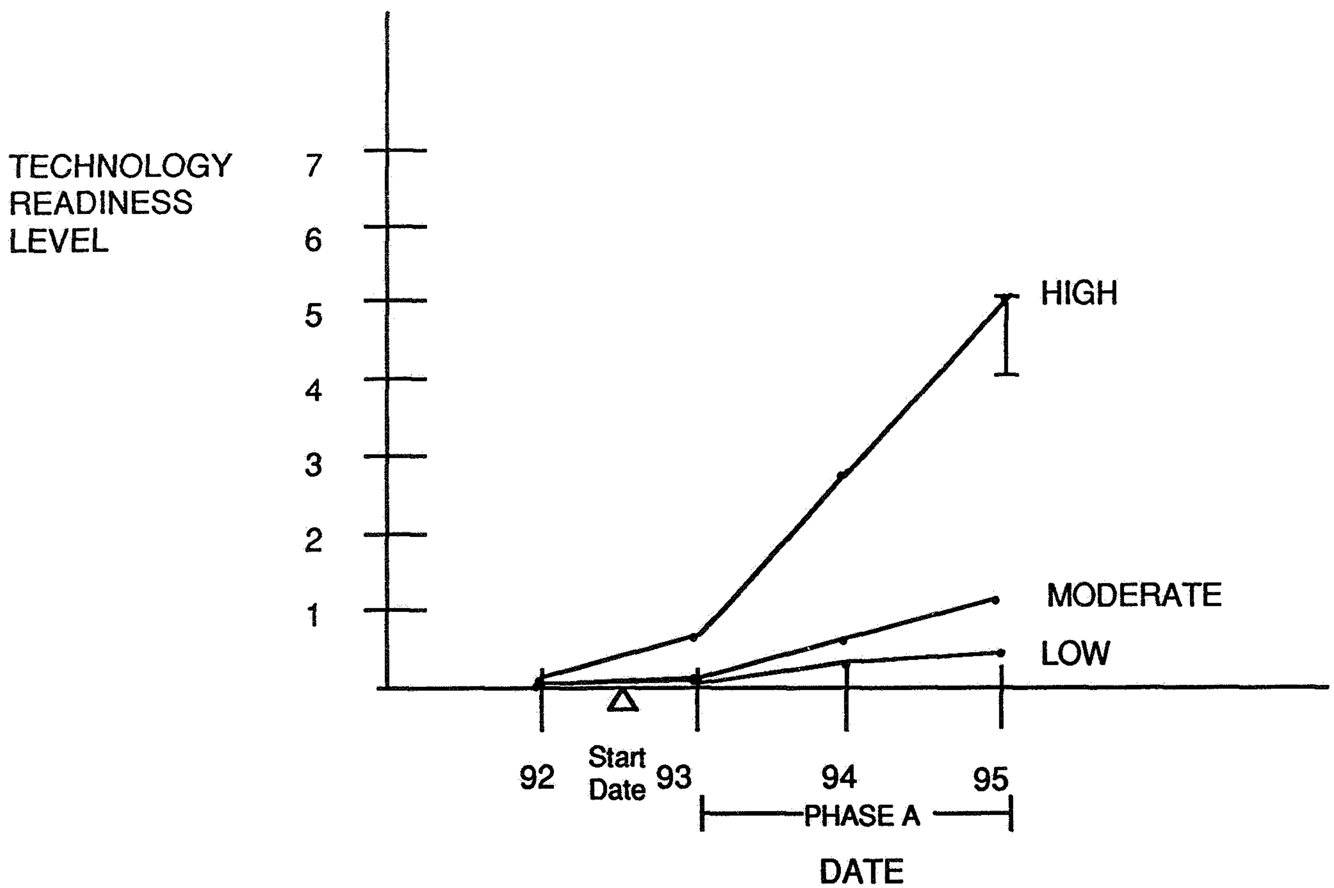
TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

POWER SYSTEM

POWER GENERATION SUBSYSTEM

SOLAR DYNAMIC TECHNOLOGY

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

POWER SYSTEM *ENERGY STORAGE SUBSYSTEM*

ADVANCED Ni/H_2 BATTERY TECHNOLOGY

<u>BACKGROUND</u>

SCOPE - VALIDATE Ni/H_2 BATTERY TECHNOLOGY FOR EXTENDED LIFE, IMPROVED ENERGY DENSITY

OBJECTIVES - REDUCE LIFE CYCLE COST BY INCREASING CYCLE LIFE BY AT LEAST 2X (10 yr 60,000 CYCLES), IMPROVE ENERGY DENSITY BY 20% AND INCREASE DoD CAPABILITY BY 150%

REQUIREMENTS/ RATIONALE - PRESENT Ni/H_2 BATTERIES ARE PLANNED FOR REPLACEMENT AFTER ABOUT 3.5+ YEARS, LIFE IMPROVEMENTS WOULD SUBSTANTICALLY REDUCE COSTS. INCREASING SSF POWER TO 100 kW BY 2000 AND 125 kW BY 2002 AND ULTIMATELY TO 175 kW WOULD BE ENHANCED BY LIGHTER WEIGHT LONGER LIVED BATTERIES

ADVANCED Ni/H_2 BATTERY TECHNOLOGY

<u>PROGRAM PLAN</u>

APPROACH -

- COMPONENT LEVEL TESTING OF ELECTRODE DESIGN, COMPOSITION AND PROCESSING
- FLIGHT TYPE CELL TESTING AND TECHNOLOGY VALIDATION
- BATTERY DESIGN IMPACT EVALUATION

DELIVERABLES -

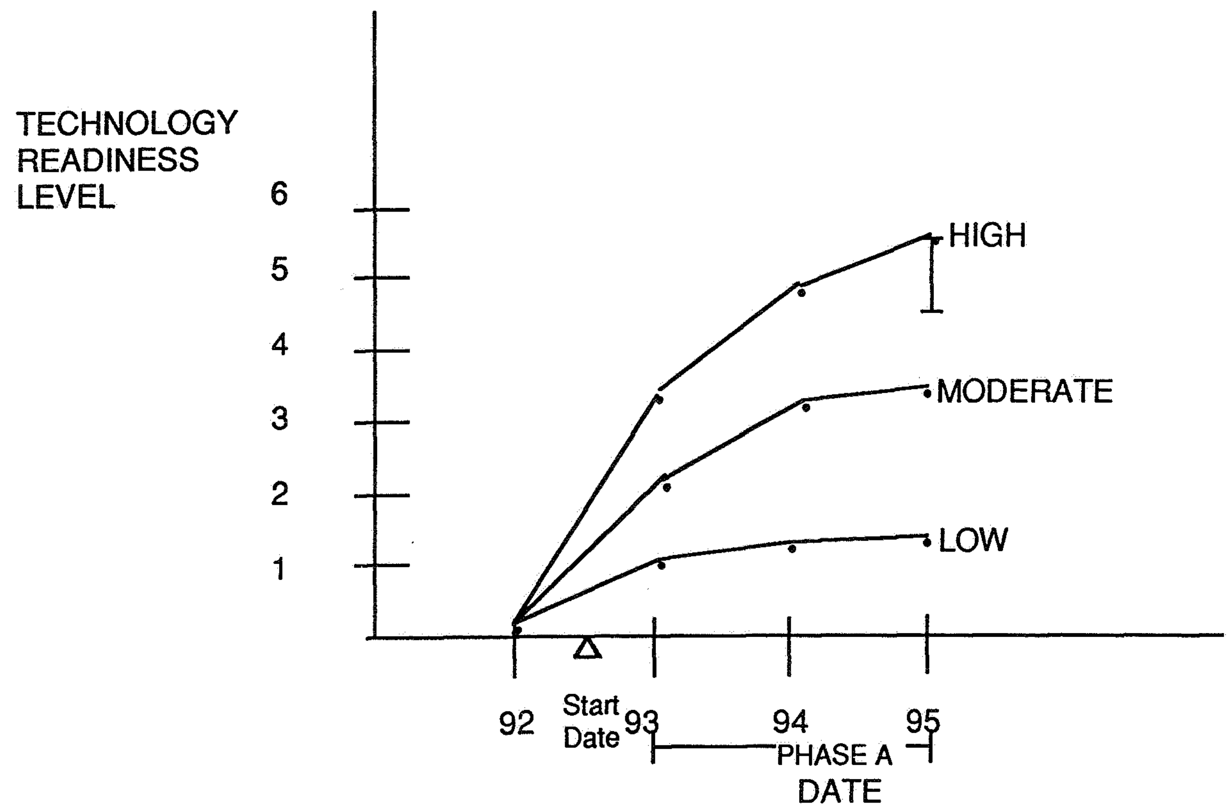
- 320 Ni/H_2 CELLS (81 AH)
- BATTERY DESIGN IMPACT EVALUATION
- TEST DOCUMENTATION

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

POWER SYSTEM *ENERGY STORAGE SUBSYSTEM*

ADVANCED Ni/H_2 BATTERY TECHNOLOGY

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

POWER SYSTEM *ENERGY STORAGE SUBSYSTEM*

REGENERATIVE FUEL CELL (RFC) DEMONSTRATION

<u>BACKGROUND</u>

SCOPE - DEMONSTRATE HEI RFC BREADBOARD AND ESTABLISH USEFULNESS FOR SSF.

OBJECTIVES -
- VALIDATE RFC TECHNOLOGY DEVELOPED FOR HUMAN EXPLORATION INITIATIVE (HEI),
- ALSO OFFERS SSF CONTINGENCY BY STORING UNUSED ENERGY,
- PROVIDES POTENTIAL INCREASE IN EMERGENCY, CONTINGENCY, PEAKING, OR SAFE HAVEN POWER.

REQUIREMENTS/ RATIONALE - SSF PROVIDES WORST CASE TESTING OF HEI RFC TECHNOLOGY; WILL PRCVIDE DESIGN CONFIRMATION REDUCING RISK TO HEI. TAPER CHARGING AND LOAD FACTOR ON SSF MAY PROVIDE UNUSED POWER FOR THIS TEST. MAY PROVIDE 200-1000 kW HRS FOR SAFE HAVEN, CONTINGENCY, PEAKING OR EMERGENCIES.

POWER SYSTEM *ENERGY STORAGE SUBSYSTEM*

REGENERATIVE FUEL CELL (RFC) DEMONSTRATION

PROGRAM PLAN

APPROACH -

- DEVELOP 10 kW LONG LIFE FUEL CELL (20,000 HRS)
- DEVELOP HIGH PRESSURE ZERO 'G' ELECTROLYSIS UNIT (20 kW, 20,000 HR LIFE)
- DEVELOP PASSIVE INTERACTION COMPONENTS (TANKS, CONTROLS . . . . .)
- DEMONSTRATE 2000 HOUR TEST OF SSF, LUNAR PROFILES

DELIVERABLES -

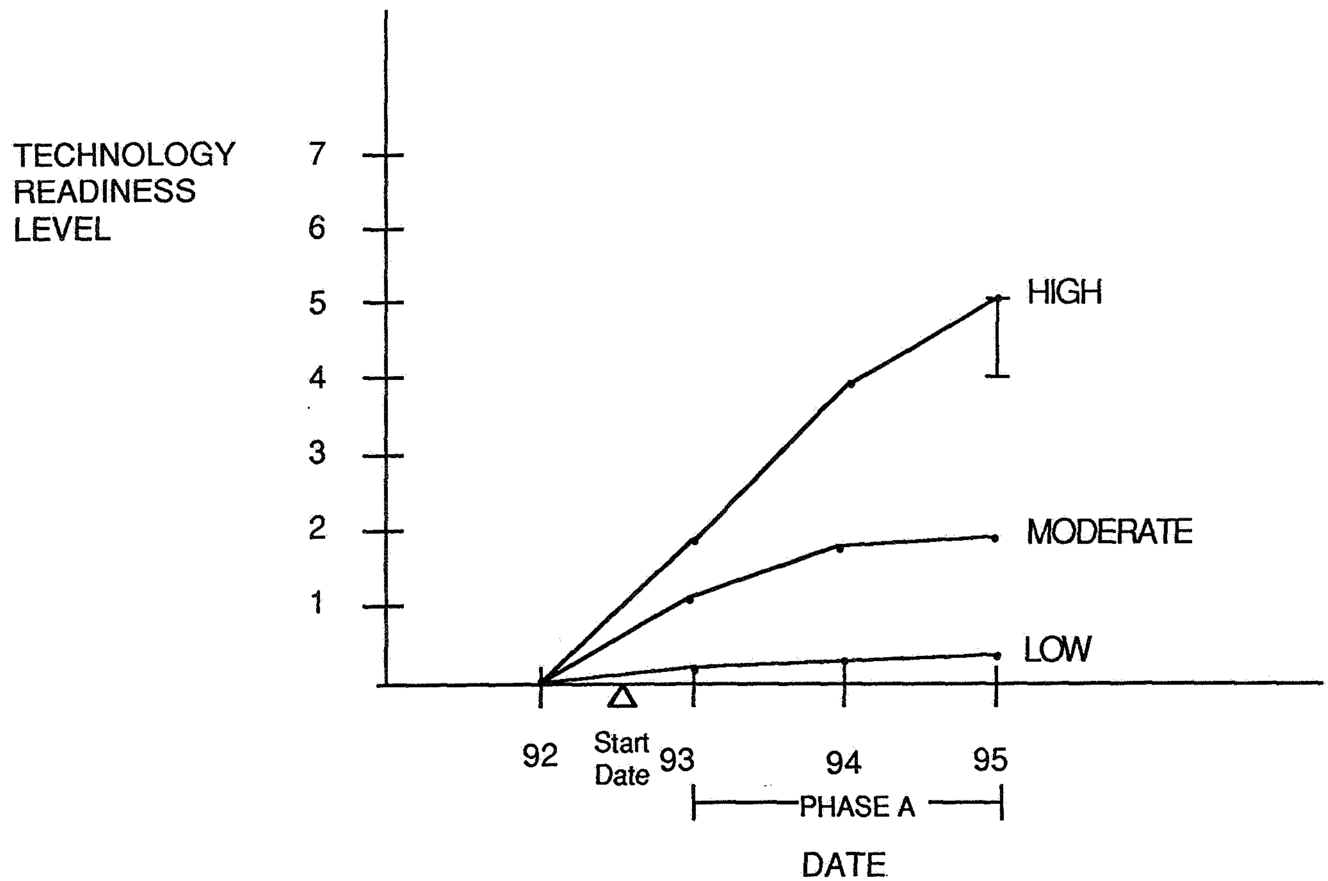
- BREADBOARD SYSTEM, LIFE TESTED READY FOR INTEGRATION INTO SSF EXPERIMENT
- TEST DATA

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

POWER SYSTEM *ENERGY STORAGE SUBSYSTEM*

REGENERATIVE FUEL CELL (RFC) DEMONSTRATION

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

POWER MANAGEMENT TECHNOLOGY

<u>BACKGROUND</u>

SCOPE - PROVIDE POWER MANAGEMENT SYSTEM TECHNOLOGIES FOR POWER NEEDED TO SUPPORT HEI & OTHER SSF NEEDS

OBJECTIVES - GROW PMAD CAPABILITY TO 175 kW WITH ALLOWANCE FOR FURTHER GROWTH AND AUGMENT IOC STATION POWER. USE STATION AS PROTOTYPE FOR HEI PMAD

REQUIREMENTS/RATIONALE -
- SAFETY/BUILT-IN TEST/AUTOMATED NDE
- MEET ALL HEI NEEDS
- AUTOMATE TO REDUCE CREW TIME & DOWN LINK TRAFFIC
- COMPATIBLE WITH IOC DC SYSTEM
- REDUCE LIFE CYCLE COSTS

POWER MANAGEMENT TECHNOLOGY

PROGRAM PLAN

APPROACH -

- PERFORM TRADE STUDY FOR SSF GROWTH AND REVELANCE TO HEI REQUIREMENTS
- ENSURE AUGMENTATION MEETS LUNAR BASE PMAD RQMTS
- DEVELOP CRITICAL COMPONENTS (AC & DC), SENSORS AND NON-DESTRUCTIVE DIAGNOSTICS
- DEMONSTRATE TECHNOLOGY & RESOLVE SYSTEMS ISSUES ON TEST BED(S)

DELIVERABLES -

- STUDY RESULTS AND RECOMMENDATIONS
- HOOKS & SCARS ON SSF (e.g., ROLL RING REQ.)
- FLIGHT PROTOTYPE COMPONENTS
- TEST BED DEMONSTRATION

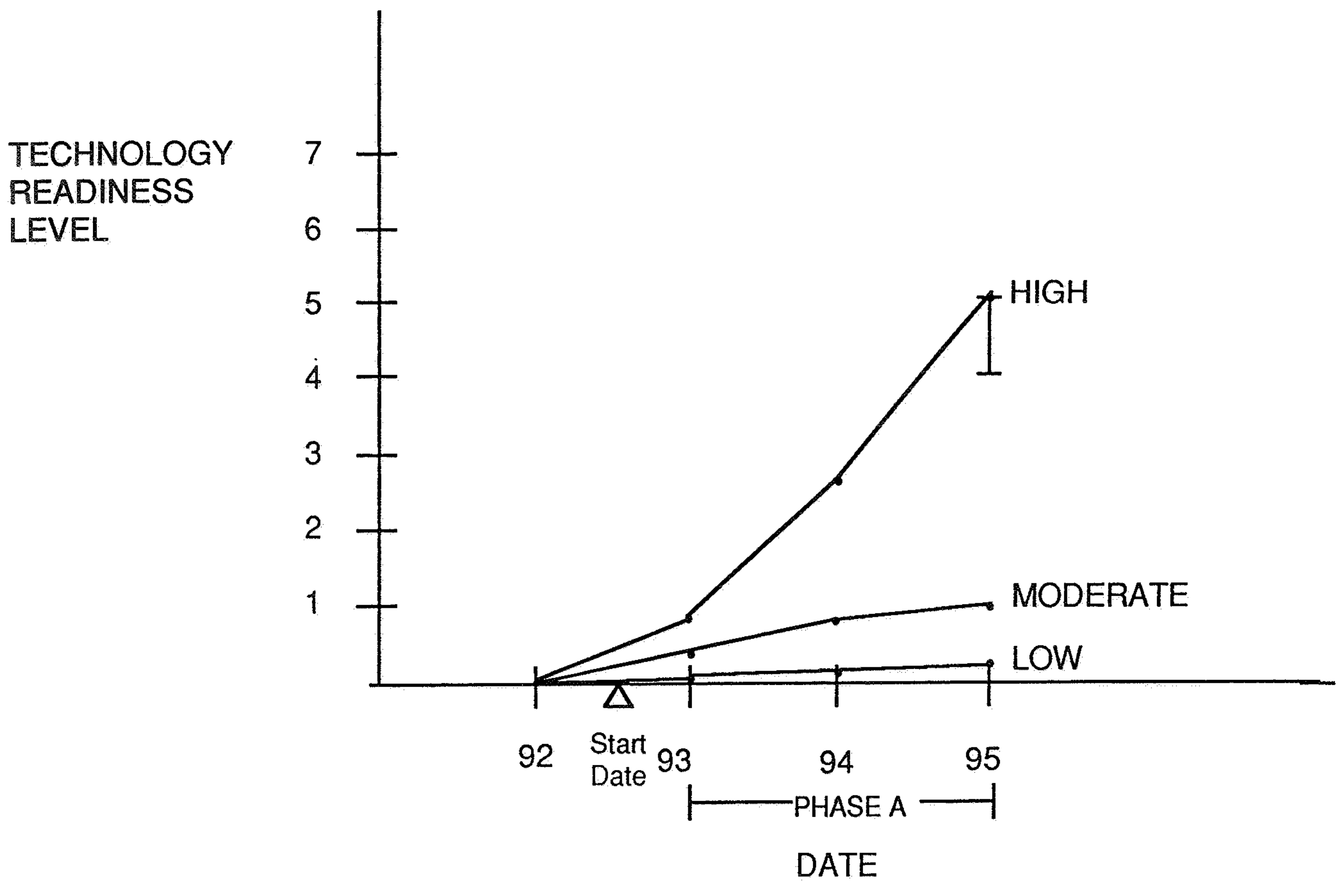
TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

POWER SYSTEM

POWER DISTRIBUTION

POWER MANAGEMENT TECHNOLOGY

TECHNOLOGY ASSESSMENT



POWER SYSTEM *POWER DISTRIBUTION*

ELECTRICAL POWER SYSTEM AUTOMATION

BACKGROUND

SCOPE - DEVELOP TECHNOLOGY FOR REAL-TIME PMAD AUTOMATION

OBJECTIVES - DEVELOP AI FOR EVENTUAL ONBOARD POWER OPS/MAINTENANCE INCLUDING FAULT IDENTIFICATION, ISOLATION AND POWER ALLOCATION

REQUIREMENTS/ RATIONALE -

- ENABLE SUFFICIENT CREW AVAILABILITY FOR TRANSPORT NODE OPERATIONS
- SIGNIFICANT INCREASE IN SAFETY & RELIABILITY
- IMPROVED RESOURCE UTILIZATION PROVIDING ADDITIONAL POWER FOR ONBOARD EXPERIMENTS
- PROOF-OF-CONCEPT DEMONSTRATION TEST BED

ELECTRICAL POWER SYSTEM AUTOMATION

PROGRAM PLAN

APPROACH -

- FORMAL REQUIREMENTS DEFINITION
- DEVELOP COOPERATING EXPERT SYSTEMS TECHNOLOGY
- MIGRATE INTELLIGENCE TO LOWER LEVELS
- DEVELOP NEEDED SMART SENSORS/SWITCHES
- CONFIRM PREDICTIVE FAULT MANAGEMENT
- LEVERAGE EXISTING SSF TEST BEDS
- DEVELOP V&V PROCEDURES FOR AI

DELIVERABLES -

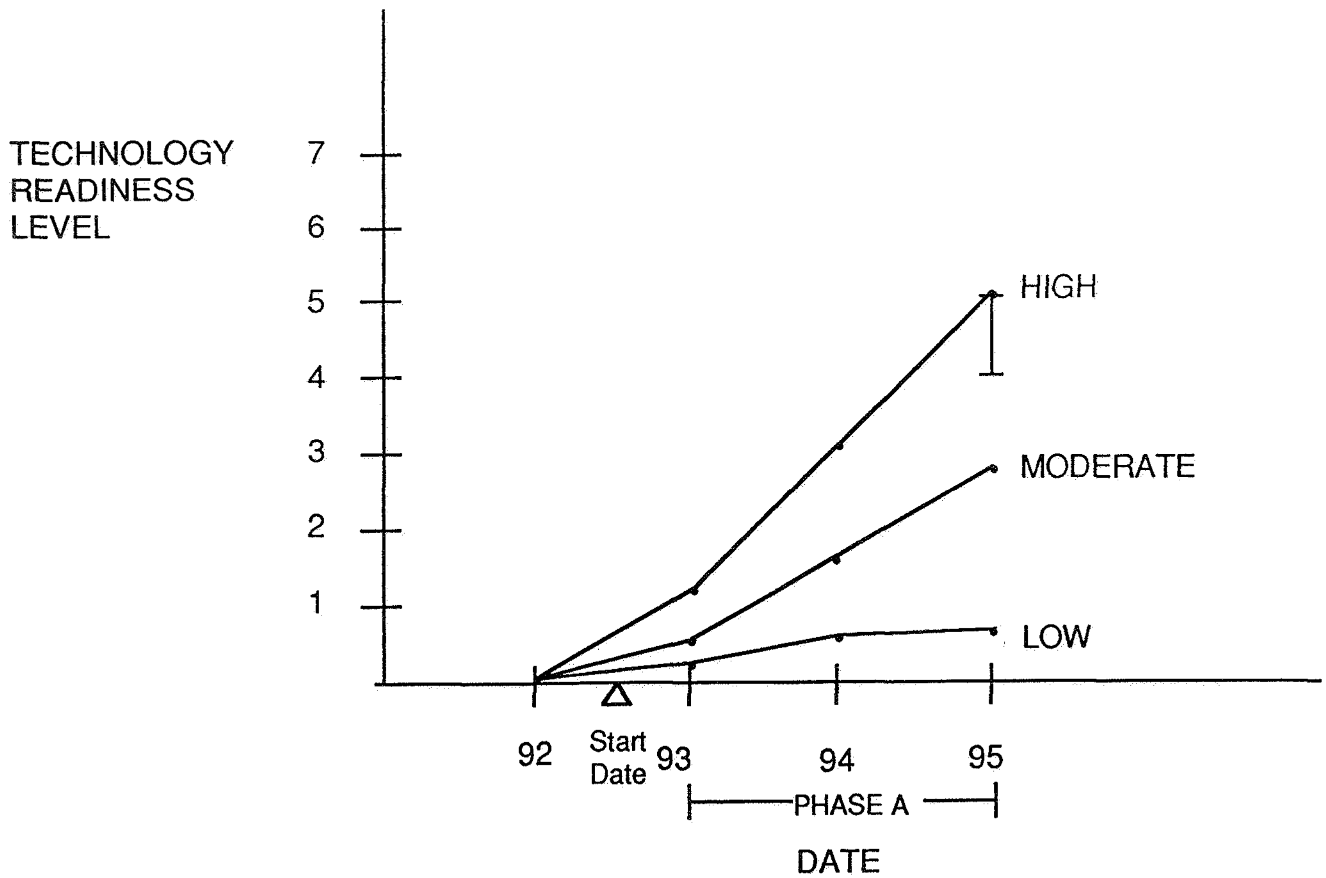
- SOFTWARE (HEURISTICS, RULES, ETC.)
- SENSOR/SWITCH HARDWARE
- PROOF-OF-CONCEPT DEMONSTRATION TEST BED

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

POWER SYSTEM *POWER DISTRIBUTION*

ELECTRICAL POWER SYSTEM AUTOMATION

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION
-A WORKSHOP

RECOMMENDATIONS/ISSUES FOR POWER SYSTEM

- **EXTENSIVE SSF SYSTEM TRADE-STUDIES TO QUANTIFY BENEFITS/RISKS OF TECHNOLOGY OPTIONS**
    - FIRM REQUIREMENTS NEEDED
    - CLEAR CUT CRITERIA FOR DECISION MAKING LCC vs INITIAL COST vs PROGRAMMATIC FUNDING PROFILE
    - ASSESS DESIRABILITY OF MULTIPLE POWER SOURCES
    - ASSESS ALL IDENTIFIED OPTIONS PLUS OTHERS
    - INCLUDE AC vs DC DISTRIBUTION ASSESSMENT FOR GROWTH
- **NEED MORE UNIFORM APPROACH TO AUTOMATION AND V & V ACROSS SSF**

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

SSF SUPPORT OF HEI - ISSUES/AC-DC POWER DISTRIBUTION

RECOMMENDATIONS/ISSUES FOR POWER SYSTEM

RECOMMENDATION: USE AC TO DISTRIBUTE 100 kW HEI POWER AUGMENTATION

BENEFITS:

- **HIGHER EFFICIENCY**
- **LOWER WEIGHT**
- **SAFER**
  - RELIABLE FAULT INTERRUPTION (HARDWARE PROTECTION)
  - EASIER SOFT FAULT DETECTION (FIRE & THERMAL DAMAGE)
  - PRACTICAL GROUND FAULT DETECTION (CREW SAFETY)
  - NO PERSISTENT ARCS
  - GREATER SYSTEM STABILITY (NO COUPLING OF MULTIPLE DC-DC CONVERTERS)
- **EASIER GROUNDING ISOLATION (GROUND POINTS CANNOT BE ISOLATED IN DC SYS)**
- **GREATER FLEXIBILITY & GROWTH CAPABILITY**
  - CHANNELIZATION NOT REQUIRED
  - EASY COMBINATION OF MULTIPLE GENERATORS
  - EASY MULTIPLE FEEDS TO LARGE OR CRITICAL LOADS
- **GREATER IMPROVED STATUS TO OPERATORS & CONTROL SYSTEM - BETTER SENSORS**

HEI REQUIREMENTS DIFFERENT THAN R&D STATION:

- **LOADS DIFFERENT - LARGER, MOTORS, ATTACHED VEHICLES, ETC.**
- **MORE PEAK LOADS, VARIABLE POINT OF DEMAND**
- **AC GENERATION (?) - SD**
- **TEST BED FOR HEI POWER SYSTEMS**

ISSUES:

- **FREQUENCY - SD GENERATION (1200 Hz), HIGH FREQUENCY (20 kHz), OTHER (400 Hz)**
- **CUT OVER POWER POINT - PMC (37.5 kW), AC (75 kW)**
- **AUGMENTATION OF EXISTING MODULE POWER**
- **DC vs AC SECONDARY DISTRIBUTION FOR NEW MODULES**

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

PROPULSION TECHNOLOGY DISCIPLINE

JANUARY 19, 1990

LEE W. JONES, CHAIRMAN
MARSHALL SPACE FLIGHT CENTER

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

TECHNOLOGY DISCIPLINE SUMMARY FOR PROPULSION

The SSF propulsion system has a dual function–not only does it provide propulsion for orbit maintenance, cancelling disturbance torques, and back-up attitude control, it also provides an acceptable (indeed, a useful) means of disposing waste fluids from the station. The current baseline for primary propulsion is a modular hydrazine system, and the multifluid resistojet system performs the waste fluid function and also provides for a portion of the orbit-raising propulsion requirements.

The evolution scenario that resulted from the MDSSC trade studies calls for the modular hydrazine system to be replaced or supplemented by an oxygen/hydrogen primary propulsion system after Assembly Complete. This is predicated upon station growth and sufficient power and water availability. In the event that insufficient power and water in the station fluid balance exist, the technology program defined in this plan includes work in hydrazine improvements and in storable bipropellants.

Because the life cycle costs of the SSF propulsion system would be significantly lower with the O2/H2 system, those technologies are ranked highest in priority. Hydrazine improvements are second priority, followed by the common technologies that must be addressed no matter which system is selected. The propellant resupply and bipropellant technologies are lowest priority.

A key point to be made is that several of these technologies are already ongoing, and require FY91 funding to avoid a hiatus in the work, which would drive up the eventual costs and threaten the schedule.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

Propulsion System — **Water Electrolysis 02/H2 System**

BACKGROUND

SCOPE - Demonstrate improved-life, high-pressure electrolysis units with simple, reliable, safe, on-orbit operating capability; on-orbit water cleanup capability; durable thrusters with improved igniters; light-weight, high pressure tankage; and high-pressure 02 and H2 compressors.

OBJECTIVES - To advance high pressure electrolysis technology in the areas of stack efficiency, dryers, phase separators, pressure control, sensors, and water pumps beyond the current capability that will be demonstrated in the JSC breadboard units to be delivered in the Spring of 1990. To understand the water cleanup requirements and then to advance the on-orbit water cleanup capability to meet these requirements. To build upon the 02/H2 thruster technology from the advanced development program in the areas of resonance igniters and extending the O/F ratio range. To develop and demonstrate light-weight graphite/epoxy tankage to a level that insures long life AND safe in-space operation. To build on the current JSC waste gas compressor technology to determine if high pressure compressors with low pressure electrolysis units is an attractive alternative to high-pressure electrolysis.

RATIONALE - Significant improvements in propellant resupply cost can be achieved by using O2/H2 propellant to perform Space Station reboost. There may also be some excess water available from the station water balance that would further reduce resupply costs. The effective specific impulse can be increased from 230 lb-sec/lbm for hydrazine to 370 lb-sec/lbm for O2/H2. Technology advancements have been made with this concept during the advanced development program and more recently in the JSC O2/H2 test bed and electrolysis breadboard contracts. The recent work has shown that the advancements mentioned above must be achieved in order for this attractive concept to be ready for operation post-AC. If this area is not funded we will not be any better off five years from now (when development should start) than we are today.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

Propulsion System **Water Electrolysis O2/H2 System**

PROGRAM PLAN

APPROACH:

1. High pressure electrolysis units--contract with suppliers to develop the needed technology in the areas of stack efficiency, phase separators, dryers, pressure control, sensors, and water pumps. Upgrade the current breadboard units with new components from these programs. Test complete electrolysis units to demonstrate 10,000 hours of operation and continue to upgrade areas that show problems.

2. Water cleanup--evaluate water cleanup requirements in subscale units and develop in-space cleanup techniques at the suppliers.

3. Thrusters---contract with suppliers to upgrade thrusters in the areas of life, ignition, and O/F range.

4. Tankage, mass flow control, and compressor--contract with suppliers to develop technology in these areas.

5. System test bed--demonstrate above improvements in JSC O2/H2 test bed as they become available. Develop database for extended-life, high-pressure H2 compatlbility. Demonstrate operating time data on flight type hardware.

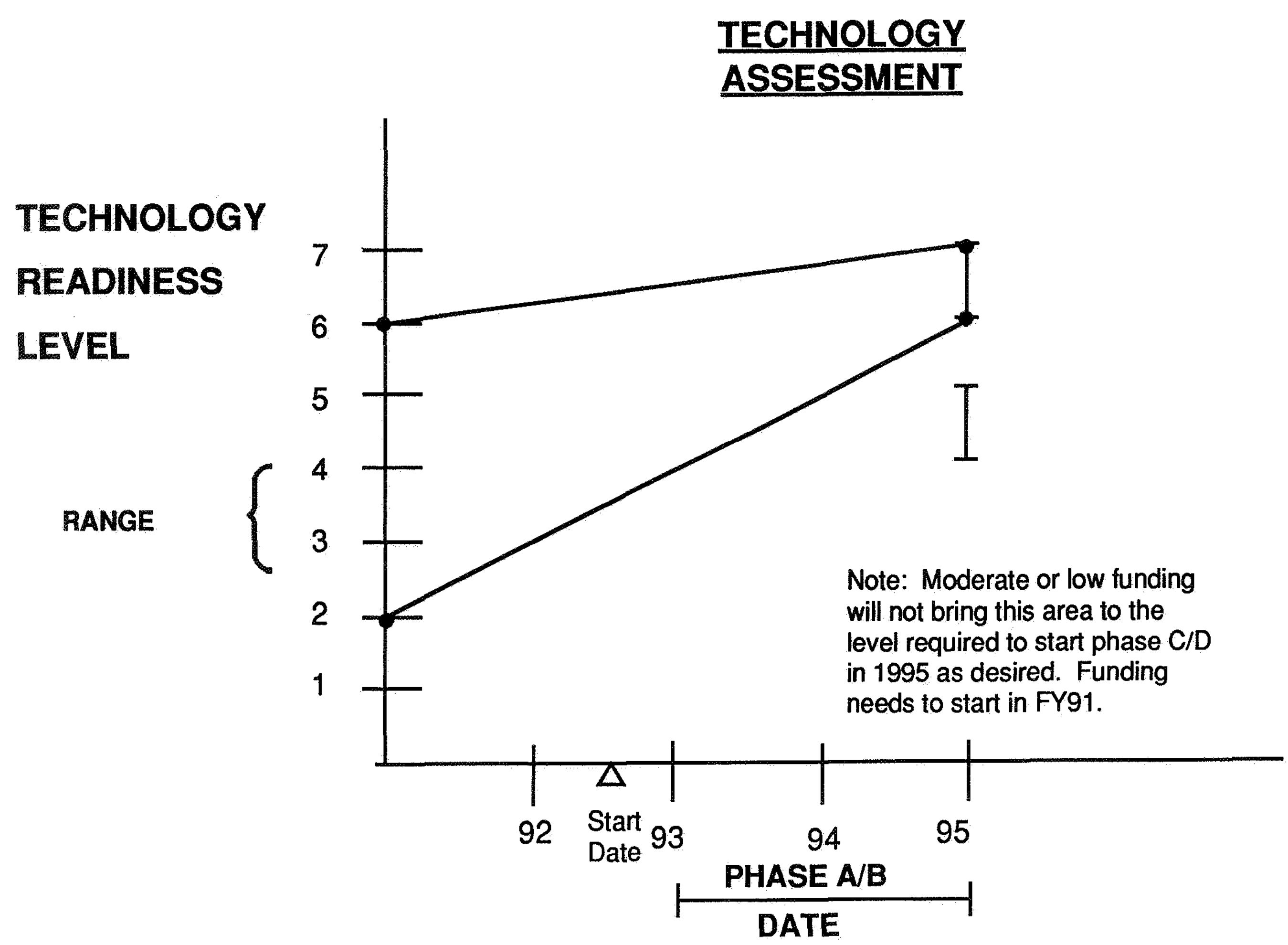
DELIVERABLES:

Prototype components and assemblies. Reports and test data from supplier programs and in-house testing. Flight demonstration hardware for the electrolysis phase separators.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

Propulsion System

Water Electrolysis O2/H2 System



TECHNOLOGY FOR SPACE STATION EVOLUTION - WORKSHOP

Propulsion System **Hydrazine System Advancements**

BACKGROUND

SCOPE - Improved-life resistojets and arcjets that will utilize the decomposition products of hydrazine to produce reboost thrust. Improved-life hydrazine thrusters and in-space propellant/pressurant resupply demonstration.

OBJECTIVES - To advance low-thrust hydrazine resistojet and arcjet technology beyond the current level of several hundred hours to a goal of 10,000 hours. To advance the life capability of moderate-thrust hydrazine thruster from the current level of 1,000,000 lb-secs to a goal of 10,000,000 lb-secs. To develop and demonstrate the technology to routinely and safety transfer hydrazine propellant and pressurants from a resupply tanker to the on-board storage tanks.

RATIONALE - Significant improvements in propellant resupply cost can be achieved by using low-thrust resistojets and arcjets to boost the specific impulse of hydrazine propellant. The effective specific impulse can be increased from about 230 lb-sec/lbm to the 400 lb-sec/bm range. These low thrust devices could then be used during long non-quiescent periods to supplement the reboost from moderate thrust devices and achieve significant propellant resupply savings. Also, improvements in the life of the moderate thrust reboost thrusters would save on logistics (spares and maintenance) costs, and on-orbit resupply via propellant transfer would save on transportation costs. Propellent transfer would require deomonstration of safe, zero leakage quick save on transportation costs. Propellent transfer would require demonstration of safe, zero leakage quick disconnects, zero-g venting, transfer pumps, and compressors for pressurant gas.

TECHNOLOGY FOR SPACE STATION EVOLUTION
-A WORKSHOP

Propulsion System **Hydrazine System Advancements**

PROGRAM PLAN

APPROACH -

1. Arcjets, resistojets; and long-life thrusters - Contract with suppliers to develop the needed technology advancements to achieve the life goals. Demonstrate life goals in sub-scale and full-scale testing.

2. In-space propellant/pressurant resupply - Contract with suppliers to develop the needed technology to demonstrate automated, safe propellant/pressurant resupply.

DELIVERABLES -

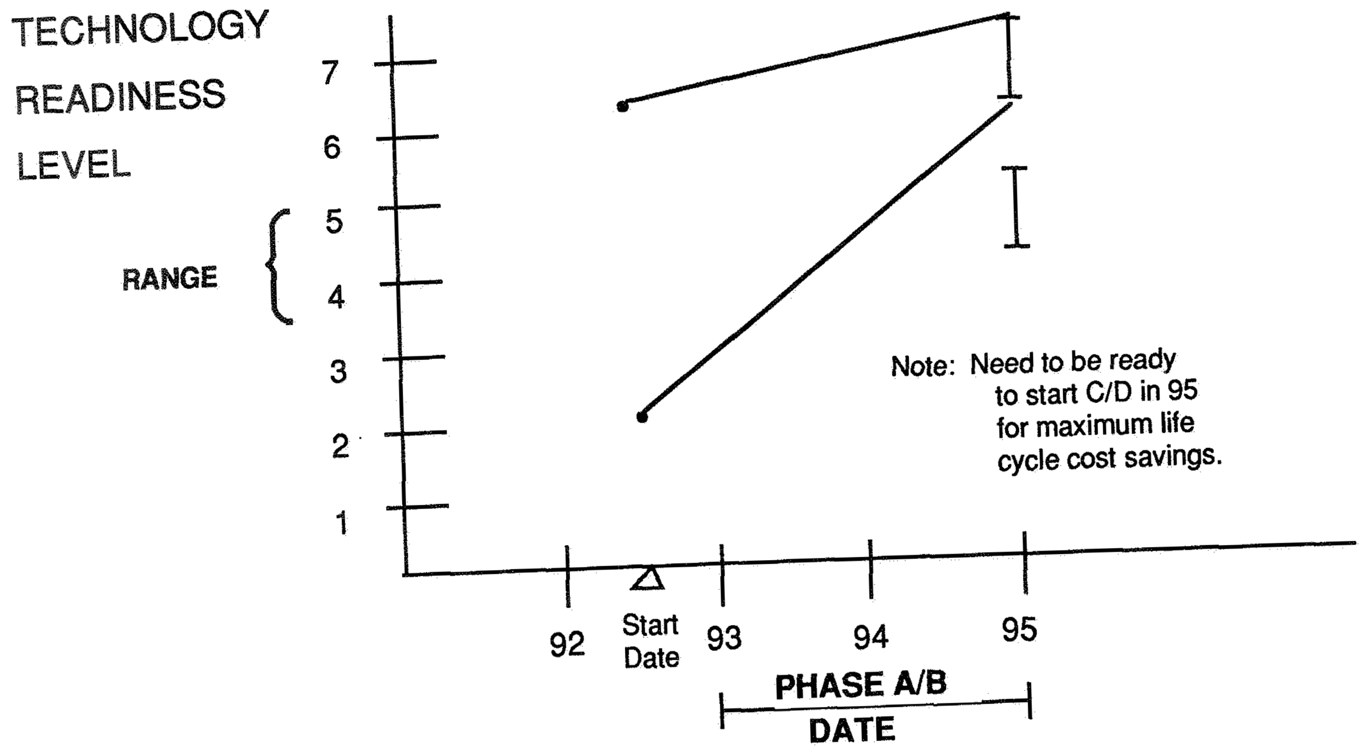
1. Test reports, final reports, and prototype units for in-house evaluation.

2. Test reports, final reports, prototype units for in-house evaluation, and flight demonstration hardware.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

Propulsion System **Hydrazine System Advancements**

TECHNOLOGY ASSESSMENT



Propulsion System **Common Technology**

BACKGROUND

SCOPE - Demonstrate those technologies that are considered by the panel to be "common" to all the propulsion options available to SSF. These technologies are critical to any of the options, and must be raised to at least technology level 5 in the advanced development program. The common technologies identified are: smart transducers, two-phase mass gaging, health monitoring and fault detection/isolation, cutting of liquid and gas lines without producing debris, "zero-leakage" components (including quick disconnects) and welding lines on-orbit.

OBJECTIVES - Conduct advanced development programs to produce: transducers that are capable of self-calibration while in active status; some means of propellant gaging in the space environment that can operate with both liquid and gas; a reliable, sophisticated health monitoring and fault detection/isolation system to provide the necessary long term reliability and safety that is essential to any SSF propulsion system; components and quick disconnects that will operate in space with near zero leakage; innovative ways to cut into propellant and pressurant lines without introducing debris that will contaminate the system with particles and cause valve seat leakage and other such undesirable effect; and an ability to perform welding operations on propellant and pressurant lines on orbit that is both safe and effective.

REQUIREMENTS - The technologies addressed are not new issues, but they are much more critical for very long-term, manned spacecraft than for current systems. They must be resolved for both SSF and Human Exploration Initiative missions to the moon and to Mars to be feasible. These technologies are also interdisciplinary; they do not benefit propulsion alone.

PROGRAM PLAN

APPROACH -

1. Smart transducers, two-phase mass gaging, and "zero leakage" components: Contract with suppliers to develop the hardware, and deliver to JSC for testing to demonstrate technology level 5.

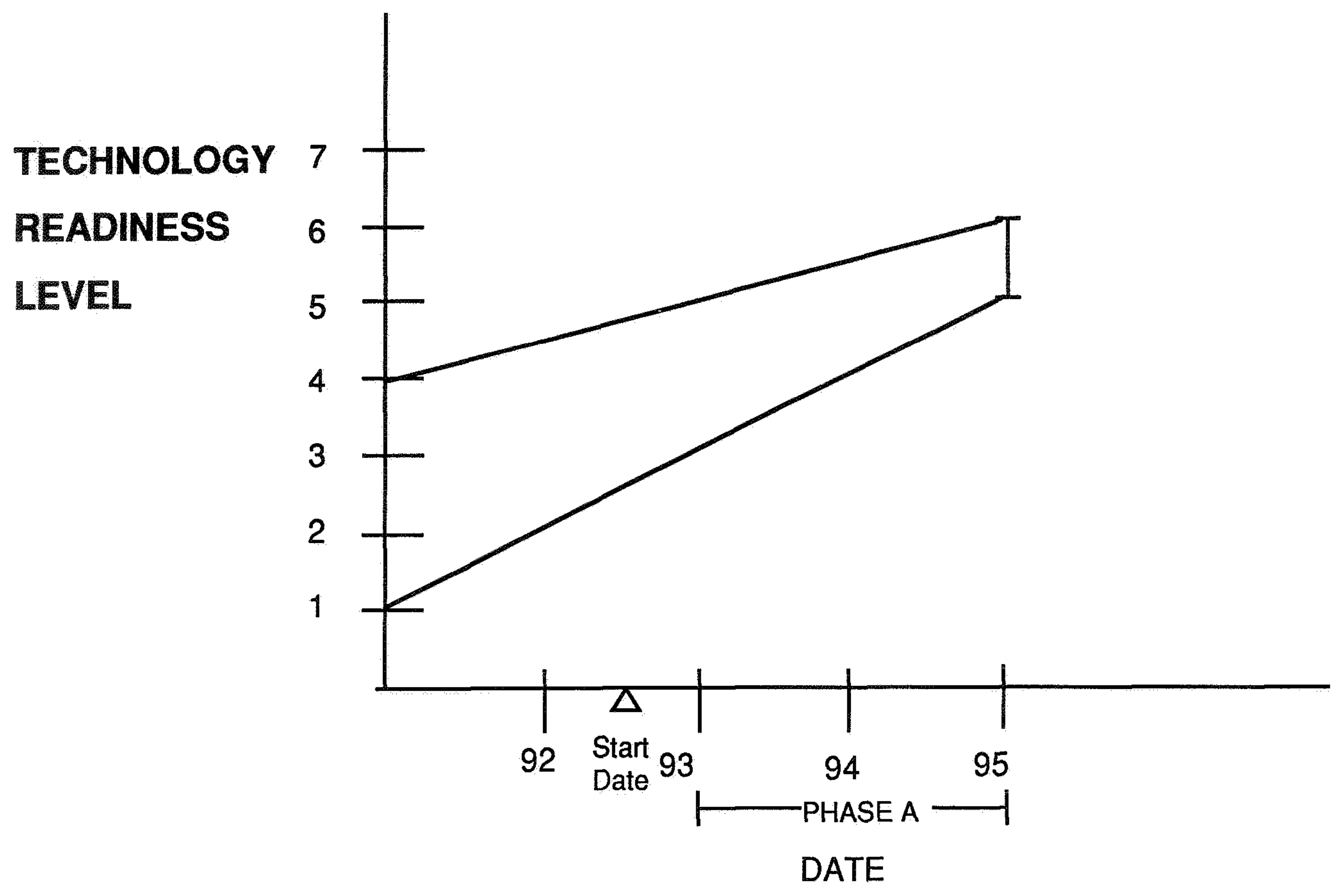
2. Health monitoring and fault detection/isolation: Task order contract with WPO2 contractor to define, consistent with philosophy to be used on the SSF; then contract with vendors to supply the appropriate instrumentation and systems.

3. Cutting and welding of lines in space: contract with suppliers to develop techniques and hardware to be subsequently tested to technology level 5 at JSC.

DELIVERABLES-

Prototype components and assemblies, supported by reports and test data where appropriate. In the case of health monitoring and fault detection/isolation, reports, test data, components and complete systems for integration into the SSF propulsion test bed at JSC.

TECHNOLOGY ASSESSMENT



BACKGROUND

SCOPE - Demonstrate those technologies that relate to the function of fluids disposal from the SSF and from the LTV / LEV. These systems may have the function of fluids disposal alone or both fluids disposal and orbit-raising propulsion, as in the case of the resistojets. The specific technologies to be demonstrated relate to: Vaporizers for liquids in microgravity (encompasses water/fluid purity determination and heat sources); Resistojets,including materials compatibility and higher performance and life; Arcjets, including materials compatibility and higher performance and life; and gas compressors.

OBJECTIVES - To conduct advanced development programs to bring the technology level of these selected systems up to at least level 5 or 6.

REQUIREMENTS - The issue of fluids disposal in the vicinity of the SSF has always been a critical one. Dumping of waste fluids is not acceptable, and means are sought which combine the functions of fluids disposal and propulsion. Resistojets and arcjets are two ways of accomplishing this. The technology for both is reasonably mature, but not yet at the requisite level. Vaporizer technology is judged to be at about level 3, and may be the basis of a flight experiment to adequately demonstrate its maturity for SSF. Compressors for such fluids as hydrogen are at about technology level 4, and require additional system level demonstration in addition to some more component level work.

PROGRAM PLAN

APPROACH -

1. Vaporizers : Contract with suppliers to develop the hardware and deliver to JSC for integration into the propulsion test bed.

2. Resistojets: Contract with suppliers to develop the hardware and deliver to JSC for integration into the propulsion test bed.

3. Arcjets: Contract with suppliers to bring the level up to that of the resistojet systems, then develop the hardware and deliver to JSC for integration into the propulsion test bed.

4. Gas compressors: Contract with suppliers to develop the hardware and deliver to JSC for integration into the propulsion test bed.

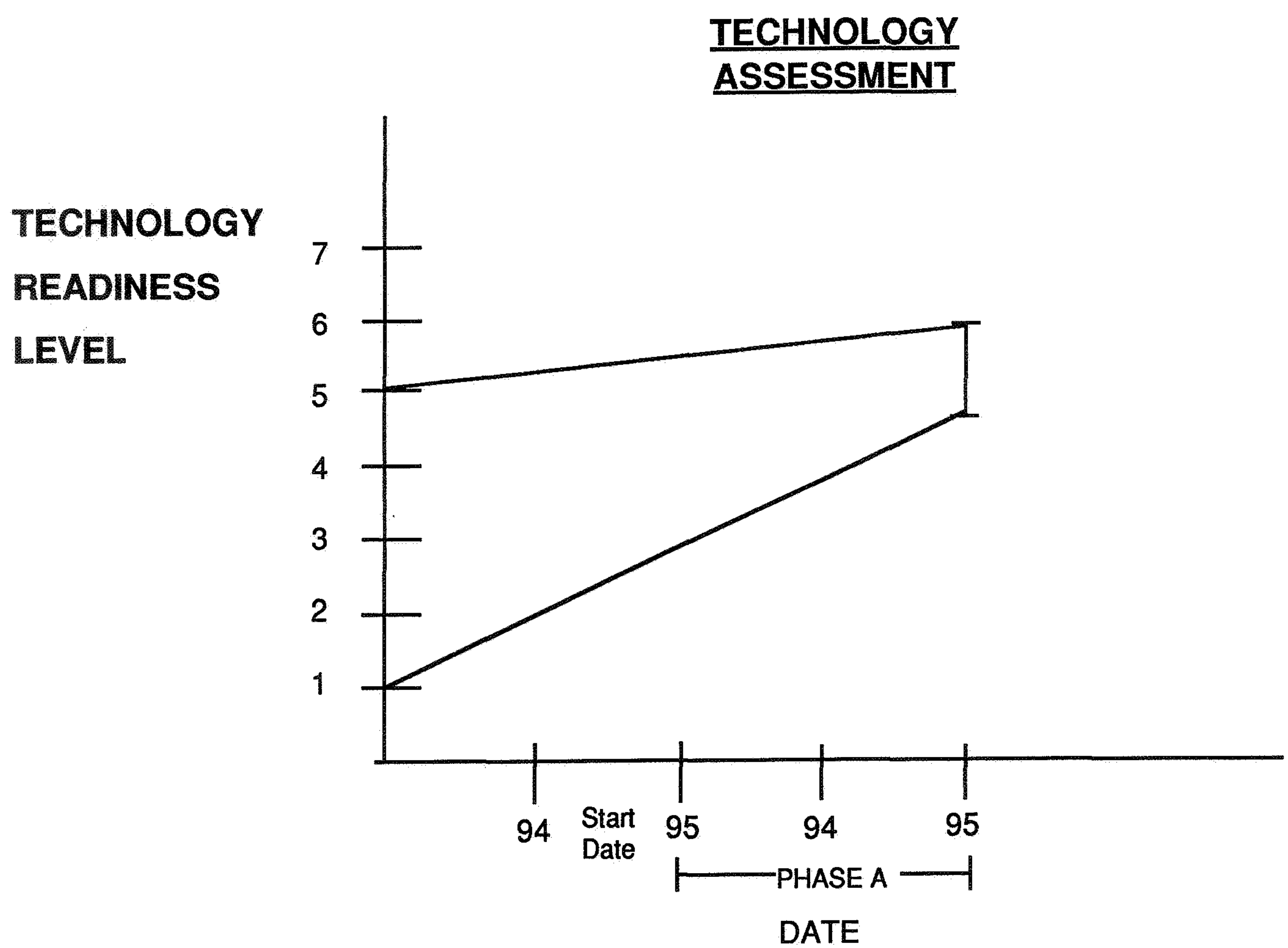
DELIVERABLES -

Prototype components and assemblies, supported by reports and test data where appropriate. As required, reports, test data, components and complete systems for integration into the SSF propulsion test bed at JSC.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

Propulsion

Fluids Disposal



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TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

Propulsion System | **Storable Bipropellant System**

BACKGROUND

SCOPE - Demonstrate life and combustion stability of N204/N2H4 bipropellant thrusters. Demonstrate in-space re-supply of these propellants.

OBJECTIVES - To advance the technology level of N204/N2H4 thrusters to a level which will provide confidence that this higher specific impulse propellant combination can be used for Space Station reboost.

Areas requiring demonstration include life, combustion stability, stage ignition, and plume contamination acceptability. To develop and demonstrate the technology to routinely and safely transfer these propellants and their pressurant gases from a resupply tanker to the on-board storage tanks.

RATIONALE - Significant improvements in propellant resupply cost can be achieved by using this propellant combination to perform Space Station reboost. The specific impulse of this propellant combination is about 310 lb-sec/1bm compared to 230 lb-sec/1bm for the baseline hydrazine system. The advantage of the N204/N2H4 combination over conventional N204/MMH is expected to be in much clearer plumes and the fact that the baseline N2H4 monopropellant system can still be retained for attitude control and reboost backup. New capability to handle MMH will not have to be added. Additional resupply costs savings can be achieved by implementing on-orbit resupply via propellant transfer rather than module change -out. This will require demonstration of safe, zero leakage quick disconnects, zero-g venting, transfer pumps, and compressors for the pressurant gas.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

PROGRAM PLAN

APPROACH:

1. N204/N2H4 bipropellant thrusters--contract with supplier(s) to develop needed technology advancements to achieve life, combustion stability, stage ignition, and plume contamination goals.
2. In-space propellant/pressurant resupply--contract with suppliers to develop the needed technology to demonstrate automated, safe propellant/pressurant resupply.

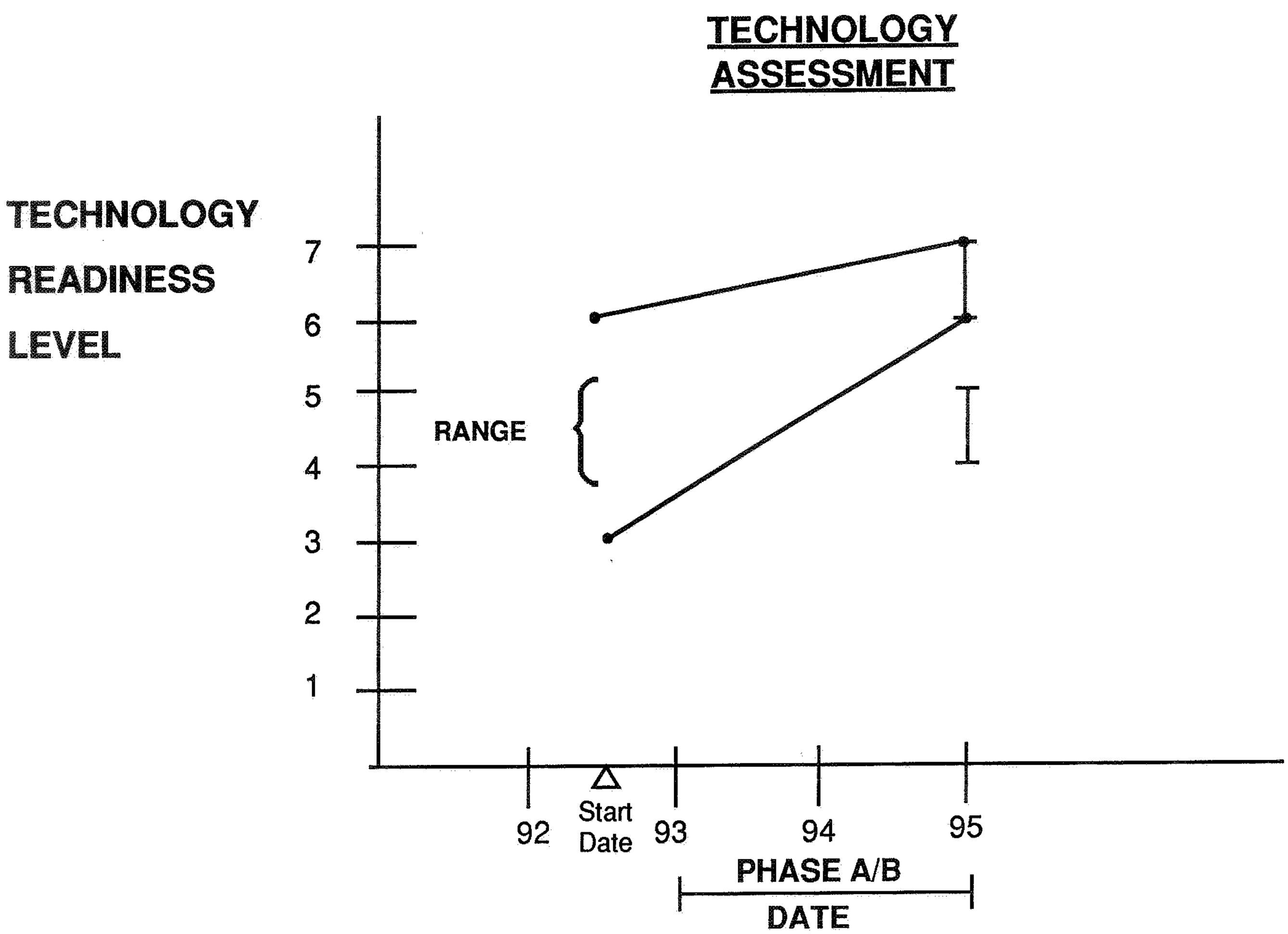
DELIVERABLES:

1. Test reports final reports, and prototype units for in-house evaluation.

2. Test reports final reports, prototype units for in-house evaluation and flight demonstration.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

Propulsion System | **Storable Bipropellant System**



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

RECOMMENDATIONS/ISSUES FOR PROPULSION

RECOMMENDATIONS: In this discipline area, the first priority for funding should be all those technologies that bear on the oxygen/hydrogen propulsion system. Second priority should be given to hydrazine system advancements. Third priority should be given to the common technology tasks and to the fluid disposal technologies. Those tasks that deal with the in-space resupply of propellants should be next in priority, followed by the storable bipropellant technology work.

This is based on the proposed evolution scenario, which would retain the hydrazine modules for attitude control and contingency reboost and add the O_2/H_2 for reboost after assembly complete. The hydrazine work would be done as an upgrade that could be made to the current hydrazine modules in case O_2/H_2 is never added and to provide additional options.

ISSUES: Funding for those technologies that are on-going should be continued without a break, to avoid a hiatus in the critical areas that are needed to meet the SSF schedule.

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TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

JANUARY 19, 1990

DR. MELVIN D. MONTEMERLO, CHAIRMAN
NASA HEADQUARTERS, CODE RC

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

- TECHNOLOGIES ARE USUALLY ASSESSED BY THE SAME AGENCIES THAT PROMOTE THEM.
- THE HIDDEN ASSUMPTION ALWAYS FAVORS THE STATUS QUO.
- TECHNOLOGY ASSESSMENTS RARELY RAISE THE IMPORTANT ISSUES.

FROM SULLIVAN, "PUBLIC INTEREST LAUNDRY LIST FOR TECHNOLOGY ASSESSMENT: TWO DOZEN ETERNAL TRUTHS ABOUT PEOPLE AND TECHNOLOGY," TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE, VOL. 8(4), 1975

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

TECHNOLOGY DISCIPLINE SUMMARY FOR ROBOTICS

FOUR TECHNOLOGY CATEGORIES

- **CROSS-CUTTING, SYSTEM WIDE**
  - SYSTEMS ENGINEERING PROCESSES FOR INTEGRATED ROBOTICS
  - MAN/MACHINE COOPERATIVE CONTROL
  - THREE-DIMENSIONAL REAL-TIME PERCEPTION
- **ADVANCED RESEARCH**
  - MULTIPLE-ARM REDUNDANCY CONTROL
  - MANIPULATOR CONTROL FROM A MOVABLE BASE
  - MULTIPLE-AGENT REASONING AND VERIFICATION OF AUTOMATED FUNCTIONS*
- **APPLICATION-SPECIFIC**
  - MECHANISMS
  - SENSORS
- **OTHER**
  - TECHNOLOGIES REVIEWED, MERGED, OR DROPPED
  - TECHNOLOGIES OVERLOOKED

***ALSO REPRESENTS AUTOMATION TRACK**

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS *MECHANISMS*

BACKGROUND

SCOPE:

- THE POSSIBILITY OF LOCAL CONTROL AND DISTRIBUTED PROCESSING ARCHITECTURES WILL DRIVE THE DESIGN OF COMPONENTS SUCH AS END EFFECTOR, JOINTS, ARM, ETC. INTEGRAL COOLING, LOCAL POWER SOURCES, POWER TO WEIGHT ARE TYPICAL AREAS REQUIRING EXTENSIVE INVESTIGATION. THE CONCERN FOR POWER CONSUMPTION, HEAT DISSIPATION, ETC., AFFECT THE DESIGN OF ROBOT MOTORS TO THE EXTENT THAT ENTIRE NEW TECHNOLOGIES MAY BE REQUIRED (E.G. SUPERCONDUCTORS).

OBJECTIVES:

- TO DEVELOP A RESEARCH INITIATIVE THAT DEALS WITH THE SPACE ROBOT AT A SYSTEM LEVEL IN THE AREA OF MECHANISMS

- TO EXAMINE AND ITEMIZE THE ENTIRE SPECTRUM OF PHYSICAL TASKS, NUMERICAL VALUES, FREQUENCY, AND LACK OF STRUCTURE ENVISIONED, AND DETERMINE THE AVAILABILITY OF EXISTING MECHANISMS TO MEET THESE NEEDS AND TO PROVIDE SOLUTIONS TO PROBLEM AREAS YET UNRESOLVED

- DEVELOP A UNIVERSAL MANUAL CONTROLLER WITH VERSATILE EMBEDDED DECISION MAKING SOFTWARE FOR HUMAN PERFORMANCE ENHANCEMENT AND THE OPERATION OF A FULL SPECTRUM OF SLAVE MANIPULATORS

- DEVELOP A SYSTEM HARDWARE AND SOFTWARE TECHNOLOGY TO PURSUE UNSTRUCTURED TASKS CONTAINING DISTURBANCES AND STILL REQUIRE PRECISION--A SOPHISTICATED MODELING-CONTROL OBJECTIVE

- DEVELOP ADVANCED MODULAR ROBOT ARCHITECTURES WHOSE STANDARDIZED MODULES CAN BE USED TO ASSEMBLE A FULL SERIES OF PROTOTYPES, i.e., A DESIGN INFRASTRUCTURE

BACKGROUND
CONTINUED

OBJECTIVES:

- DEVELOP A PRIME MOVER OF EXCEPTIONALLY LIGHTWEIGHT, HIGH RESOLUTION, AND HIGH STIFFNESS TO MAKE THE GENERALIZED ARCHITECTURE OF ROBOT MANIPULATORS FEASIBLE

- TO FURTHER PROVIDE DESIGNS COMPATIBLE WITH THE TOOLING USED FOR HUMAN EVA AND TO DEVELOP STANDARDIZED INTERFACES FOR BOTH MAN AND MACHINE WHERE APPLICABLE. THE KNOWLEDGE BASE PROVIDED BY THIS RESEARCH WILL DEFINE THE MATERIALS, MOTORS, TOOLING, THERMAL COMPONENTS, AND SYSTEMS CONCEPTS NEEDED IN THIS AREA.

- DEVELOP RECOGNIZED NUMERICAL REQUIREMENTS TO MEET SCENARIOS FOR UNEXPECTED EVENTS (PERHAPS 40% OF THE ACTUAL WORKLOAD).

REQUIREMENTS:

- CURRENT MECHANISM DESIGN DOES NOT ADEQUATELY SUPPORT THE DEVELOPMENT OF A ROBOT OPERATING IN THE 0-G AND VACUUM OF SPACE.

- THE POWER-TO-WEIGHT, POWER CONSUMPTION AND THERMAL RESTRICTIONS IMPOSED BY THE SPACE ENVIRONMENT ARE DRIVING FORCES IN THE DESIGN OF ANY MECHANISM IN SPACE, BUT THEY ARE MAGNIFIED WHEN APPLIED TO A ROBOT EXPECTED TO PERFORM A MYRIAD OF TASKS IN AN UNSTRUCTURED ENVIRONMENT.

- CURRENT MECHANISMS NEED TO BE ADAPTED FOR SPACE USE

  - LIGHTER MATERIAL
  - REDUCE OVERALL WEIGHT
  - REDUCE SIZE
  - INTERFACES ADAPTED FOR ROBOTICS USE

BACKGROUND
CONTINUED

REQUIREMENTS (CONTINUED):

- NEW MECHANISMS ARE REQUIRED FOR TASKS THAT MAN CANNOT DO IN SPACE.
- EVA TOOLS NEED TO BE MODIFIED FOR ROBOTIC INTERFACE.
- PNEUMATIC TOOLS ARE NEEDED.
- LATCHING DEVICES CAPABLE OF HOLDING LARGE COMPONENTS, STRUCTURES OR APPENDAGES ARE NEEDED.
- POWER TOOLS FOR ROBOTICS USE
    - DRILL
    - WRENCHES
    - WINCH/HOIST (SPACE CRANE)
- PRECISION LIGHT SOURCES ARE NEEDED.
- DUAL GRASPING TOOLS ARE NEEDED.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE *MECHANISMS*

PROGRAM PLAN

APPROACH:

- NASA AND THE AEROSPACE COMMUNITY HAVE ONGOING RESEARCH EFFORTS IN THE AREA OF SPACE MATERIALS, STRUCTURES AND MECHANISMS. HOWEVER, THIS INITIATIVE WOULD PROVIDE A FOCUS OF THESE EFFORTS IN THE AREA OF ROBOTICS. IT WOULD DEVELOP A FOCAL POINT FOR THE INTEGRATION OF THE LATEST TECHNICAL ADVANCES IN MECHANISMS AS THEY APPLY TO SPACE ROBOTICS. THE INITIATIVE WOULD DETERMINE THE AREAS REQUIRING MORE CONCENTRATED RESEARCH AND ATTACK THESE PROBLEMS IN AN AGGRESSIVE MANNER TO PROVIDE TIMELY SOLUTIONS FOR SPACE STATION FREEDOM.

DELIVERABLES:

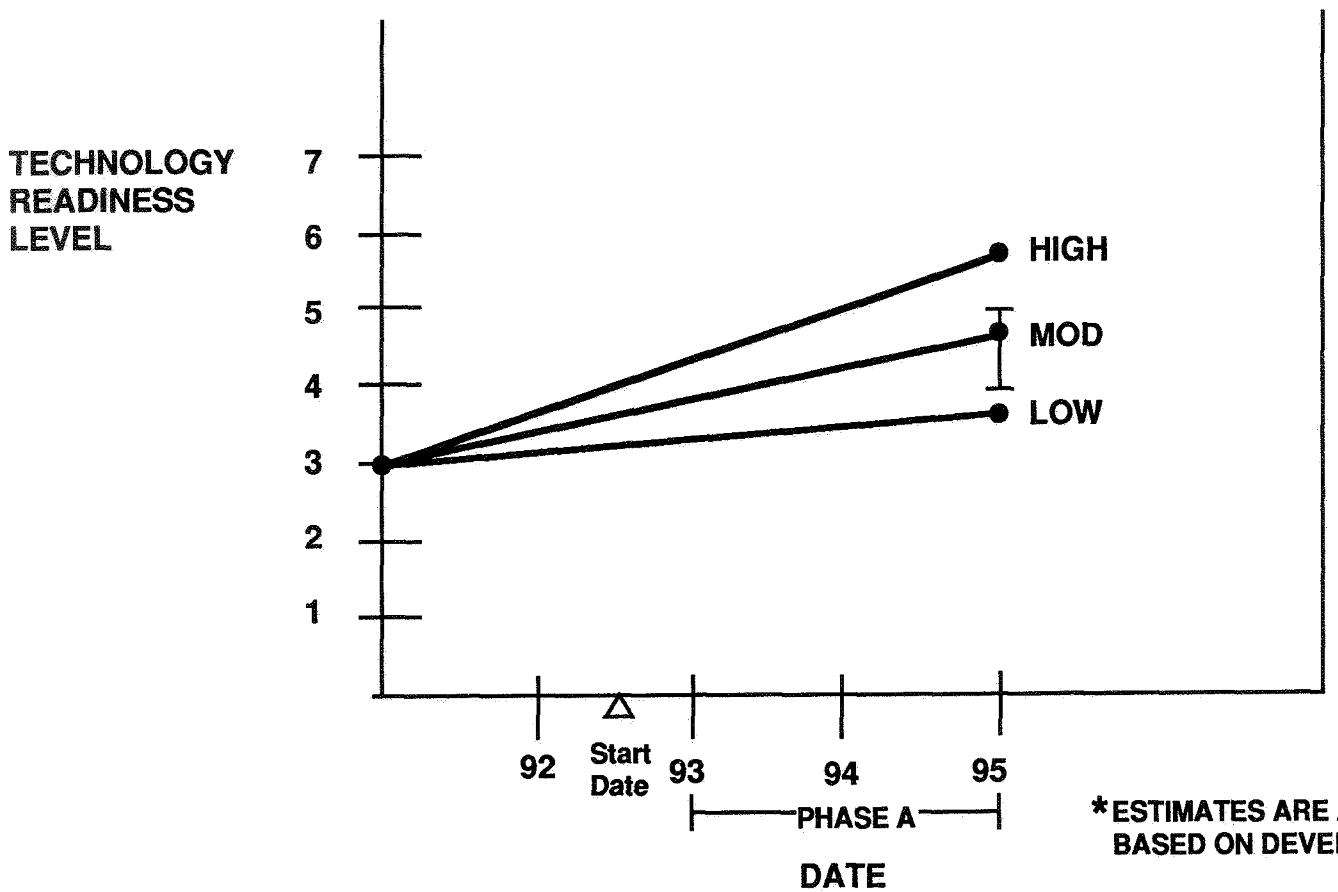
- A ROBOT SYSTEMS DEFINITION INCORPORATING THE DESIGN CRITERIA DETERMINED TO BE THE LATEST AVAILABLE, AND A FORECAST OF TECHNICAL IMPROVEMENTS ON THE HORIZON WITH THEIR PROJECTED AVAILABILITY
- A DEMONSTRATION ROBOT SYSTEM INCORPORATING THE MECHANISM CURRENTLY UNDER DEVELOPMENT AND ASSESSMENT CRITERIA FOR THE COMPONENT TEST EVALUATION
- INTERFACE DEFINITION FOR ELECTRICAL AND MECHANICAL COMPONENTS IN THIS ARENA

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

MECHANISMS

TECHNOLOGY ASSESSMENT*



*ESTIMATES ARE APPROXIMATE AND BASED ON DEVELOPMENT PLAN

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE *SENSORS*

BACKGROUND

SCOPE:

- ENHANCEMENT IN SENSOR TECHNOLOGY IS REQUIRED TO IMPROVE THE CAPABILITIES FOR SAFE AND EFFECTIVE TELEROBOTIC OPERATION IN THE SPACE STATION ENVIRONMENT. THIS AREA INCLUDES ALL THE MEANS, PASSIVE AND ACTIVE, BY WHICH THE HUMAN TELEOPERATOR, OR LATER, THE SEMI-AUTONOMOUS ROBOT, COLLECTS INFORMATION ABOUT THE ENVIRONMENT.

OBJECTIVES:

- IT IS NECESSARY TO DEVELOP A SENSOR PACKAGE THAT WOULD FACILITATE THE SAFE AND SUCCESSFUL OPERATION OF A ROBOTIC SYSTEM IN THE SPACE STATION ENVIRONMENT. TO ACCOMPLISH THIS THE SENSORS MUST PROVIDE NAVIGATION, COLLISION, AND OBJECT MAINTENANCE GUIDANCE. THESE SENSORS SHALL PROVIDE MACHINE VISION WITH HIGH RESOLUTION CAPABILITY; LASERS FOR CLOSE PROXIMITY RANGING; FORCE/TORQUE AND CONTACT SENSING; AND SPECIALIZED SENSORS SUCH AS ULTRASONIC SENSORS.

REQUIREMENTS:

- PRESENT SENSOR TECHNOLOGIES PLACE LIMITS ON THE CAPABILITIES OF SPACE TELEOPERATION AND ON THE DEVELOPMENT OF ROBOTS WITH INCREASING AUTONOMY. SENSORS MUST BE IMPROVED TO SUPPORT SAFE OPERATIONS IN MORE CHALLENGING, UNSTRUCTURED ENVIRONMENTS AND TO ALLOW TELEROBOTIC SYSTEMS TO ACCOMPLISH A WIDER VARIETY OF TASKS TO REPLACE, AND EVENTUALLY EXCEED, EVA CAPABILITIES. SPECIALIZED SENSORS MUST BE DEVELOPED FOR THE MICROGRAVITY IVA AND VACUUM SPACE ENVIRONMENTS TO ENABLE SPECIFIC INSPECTION, DIAGNOSIS AND REPAIR TASKS.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE *SENSORS*

PROGRAM PLAN

APPROACH:

- IN CONJUNCTION WITH OTHER AREAS, DEVELOP A DATABASE OF TELEROBOTIC ACTIVITIES AND TASKS REQUIRED FOR SPACE STATION AND HUMAN EXPLORATION MISSIONS, AND REFINE THE INFORMATION TO FOCUS ON SENSOR REQUIREMENTS. IDENTIFY SPECIFIC TASKS THAT MAY REQUIRE SPECIALIZED SENSORS.
- CONTINUE THE DEVELOPMENT OF MACHINE VISION TECHNOLOGIES FOR A VARIETY OF SPACE TELEROBOTIC OPERATIONS.
- CONTINUE THE DEVELOPMENT OF FORCE/TORQUE AND CONTACT SENSORS FOR A VARIETY OF SPACE TELEROBOTIC OPERATIONS.
- DEVELOP SENSOR PACKAGES TO ENABLE SAFE PROXIMITY OPERATIONS, GRAPPLING, TRANSLATION, COLLISION AVOIDANCE, AND WORKSPACE OPERATIONS IN COMPLEX UNSTRUCTURED ENVIRONMENTS.
- DEVELOP SPECIALIZED SENSORS FOR EXTERNAL ROBOTS FOR THE INSPECTION, DIAGNOSIS, AND REPAIR OF MALFUNCTIONING EQUIPMENT IN THE SPACE ENVIRONMENT INCLUDING LEAK DETECTORS, INTERROGATION, ULTRASONIC, AND OTHER NDT INSPECTION SENSORS.
- DEVELOP SPECIALIZED SENSORS FOR IVA ROBOTS INCLUDING ATMOSPHERIC SAMPLERS AND AUDIO SENSORS.

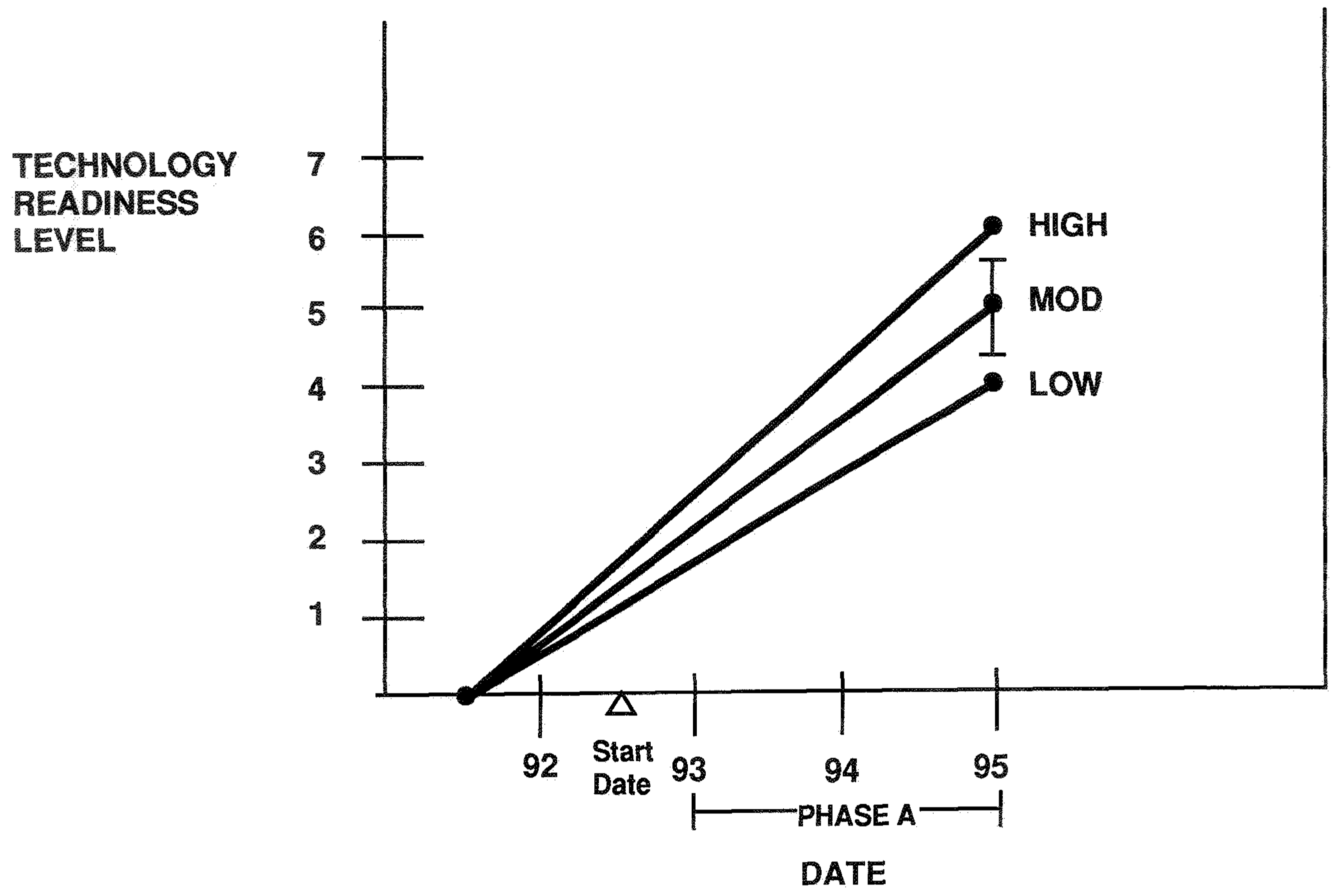
DELIVERABLES:

- A GROUND TEST/DEMONSTRATION WHICH SHOWS THE FUNCTIONAL ASPECTS OF THE TRADE STUDY SELECTED SENSORS FOR ROBOTIC NAVIGATION, COLLISION AVOIDANCE, AND OBJECT MAINTENANCE. OBJECT MAINTENANCE SENSORS WILL BE CHOSEN BASED ON NEEDS AT THE TIME.
- FLIGHT DEMONSTRATION SAME AS NUMBER 1. THIS CAN BE ACCOMPLISHED USING AN EXISTING PROGRAM, SUCH AS S^3, WITHOUT HINDERING THE PROGRAM.
- FLIGHT SENSORS SHOULD BE AVAILABLE FOR INTEGRATION BY THE FIRST SPACE STATION FREEDOM FLIGHT.
- OTHER FUNCTIONS MAY BE REQUIRED.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE *SENSORS*

TECHNOLOGY ASSESSMENT



ROBOTICS TECHNOLOGY DISCIPLINE

SYSTEMS ENGINEERING PROCESSES FOR INTEGRATED ROBOTICS

BACKGROUND

SCOPE:

- DEVELOP AN ON-GOING PROGRAM FOR THE SYSTEMS-LEVEL ENGINEERING OF SPACE ROBOTICS, ENCOMPASSING THE INTERNAL ARCHITECTURE, INTERACTION WITH THE EXTERNAL TASK AND ENVIRONMENT, AND WITH PARTICULAR EMPHASIS ON THE INTERACTION WITH HUMANS, BOTH CONTROLLING AND AT THE WORK SITE

OBJECTIVES:

- UNDERSTAND THE INTERRELATIONSHIPS BETWEEN COMPONENT TECHNOLOGIES AND TELEROBOT CAPABILITIES.
- IDENTIFY THE KEY TASKS IN THE INTEGRATION OF COMPONENT TECHNOLOGIES INTO FULLY CAPABLE TELEROBOTIC SYSTEMS.
- DEVELOP A QUANTITATIVE DATA BASE ON TELEROBOTIC CAPABILITIES OVER A VARIETY OF TYPICAL SPACE TASKS.
- DEVELOP LABORATORIES CAPABLE OF QUICKLY TESTING NEW CONCEPTS IN SPACE HARDWARE TO EVALUATE COMPATIBILITY WITH TELEROBOTIC OPERATIONS.
- HAVE A QUANTITATIVE BASIS FOR CRITICAL TRADE STUDIES BETWEEN TELEROBOTIC CAPABILITIES AND PROGRAM REQUIREMENTS.
- HAVE A PATHWAY FOR DEVELOPMENT OF INNOVATIVE TECHNOLOGIES.
- BETTER UNDERSTAND INTERFACES (PARTICULARLY TOOLS AND END EFFECTORS) BETWEEN TELEROBOTICS AND TASKS.
- STUDY THE POTENTIAL INTERACTIONS BETWEEN TELEROBOTS AND HUMANS IN SPACE (BOTH EVA AND IVA), AIMED AT DEVELOPING AND REVIEWING STANDARDS FOR THE DESIGN OF JOINT HUMAN/TELEROBOTIC WORKSITES.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

SYSTEMS ENGINEERING PROCESSES FOR INTEGRATED ROBOTICS

BACKGROUND (CONTINUED)

RATIONALE:

- IT IS NOT SUFFICIENT TO STUDY TELEROBOTIC TECHNOLOGIES WITHOUT UNDERSTANDING HOW THESE TECHNOLOGIES COME TOGETHER TO FORM A ROBOT SYSTEM, OR HOW THE TELEROBOT INTERACTS WITH CURRENTLY PLANNED OR POTENTIAL FUTURE SPACE APPLICATIONS

REQUIREMENT:

- A PRELIMINARY REQUIREMENTS DEFINITION IS REQUIRED TO REDUCE LIFE-CYCLE COST.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

SYSTEMS ENGINEERING PROCESSES FOR INTEGRATED ROBOTICS

PROGRAM PLAN

APPROACH:

- NASA SHOULD CONTINUE THE ESTABLISHMENT OF MULTI-PURPOSE TEST BEDS TO USE FOR DEVELOPING NECESSARY DATA BASES FOR TELEROBOTICS SYSTEMS ANALYSIS. THIS SHOULD INCLUDE BOTH TESTBEDS FOR DEVELOPING SYSTEMS INTEGRATION OF TECHNOLOGIES INTO TELEROBOT SYSTEMS, AND SYSTEMS STUDIES OF THE APPLICATIONS OF TELEROBOTICS TO CURRENT AND FUTURE TASKS, INCLUDING APPROPRIATE SIMULATION OF THE SPACE ENVIRONMENT. ATTENTION MUST BE PAID TO RECONFIGURABLE ARCHITECTURES, RAPID PROTOTYPING, AND TASK APPLICATIONS DRAWN FROM THE SPECTRUM OF CURRENT AND POTENTIAL FUTURE TELEROBOTIC REQUIREMENTS IN SPACE.

DELIVERABLES:

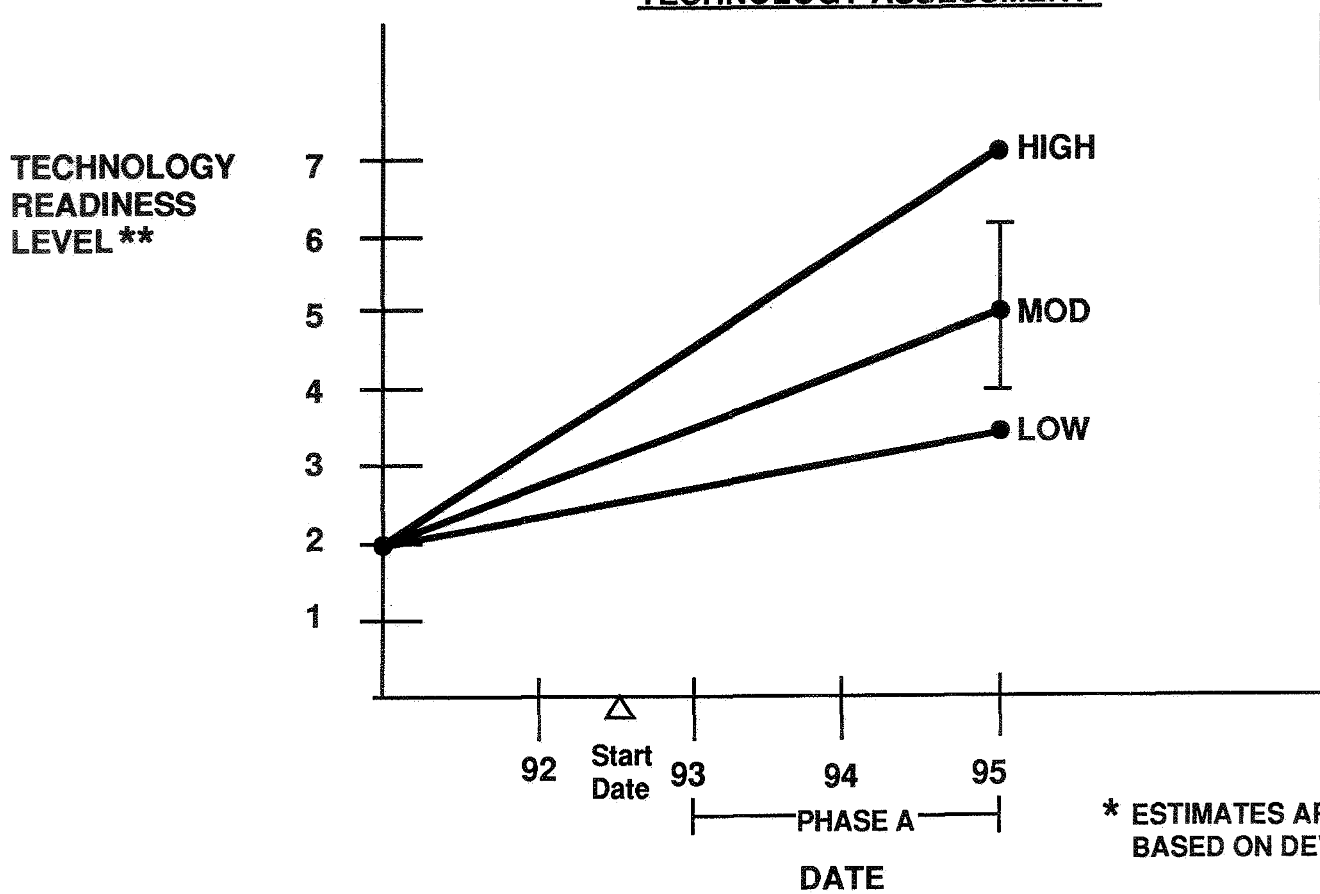
- QUANTITATIVE DATA BASE ON TELEROBOTIC CAPABILITIES AND LIMITATIONS, CROSS-INDEXED AGAINST ROBOTIC COMPONENT TECHNOLOGIES
- DEVELOPMENT OF A REFERENCE STANDARD FOR SPACECRAFT DESIGNERS FOR EVA/TELEROBOTIC INTERFACES FOR SERVICING
- DESIGN OF A STANDARD TOOL AND INTERFACE SET, WITH EMPHASIS ON TOOL SYSTEMS COMPATIBLE WITH BOTH EVA AND TELEROBOTIC SYSTEMS
- SIMULATION FACILITIES FOR USE IN ASSESSING TELEROBOTIC CAPABILITIES AS PART OF THE DEVELOPMENT PROCESS FOR FUTURE SPACECRAFT
- DEVELOPMENT OF A KNOWLEDGE BASE ON THE INTEGRATION OF COMPONENT TECHNOLOGIES INTO FUNCTIONAL, ROBUST TELEROBOTIC SYSTEMS

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

SYSTEMS ENGINEERING PROCESSES FOR INTEGRATED ROBOTICS

TECHNOLOGY ASSESSMENT*



* ESTIMATES ARE APPROXIMATE AND BASED ON DEVELOPMENT PLAN

** FOR UNBUILT SYSTEMS

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

MAN/MACHINE COOPERATIVE CONTROL

BACKGROUND

SCOPE:

- MAN-MACHINE COOPERATIVE CONTROL REFERS TO THE DEVELOPMENT, IMPLEMENTATION, AND VALIDATION OF METHODOLOGIES BY WHICH MAN AND ROBOT(S) CAN PERFORM REQUIRED TASKS IN CONCERT. SUCH TASKS CAN BE PERFORMED DIRECTLY BY MAN, REMOTELY BY MAN (TELEOPERATION), DIRECTLY BY MACHINE UNDER OPERATOR SUPERVISION, AND JOINTLY BY MAN AND MACHINE (SHARED CONTROL). HUMAN FACTORS TASK ALLOCATION AND SYSTEM PERFORMANCE CONSIDERATIONS ARE EXPLICITLY INCLUDED AS WELL AS CONSISTENT UPDATE OF WORLD MODELS, PERFORMANCE MONITORING, AND SAFETY.

OBJECTIVES:

- ULTIMATELY OFF-LOAD AS MUCH WORK AS POSSIBLE TO THE ROBOT.
- USE THE RESOURCES OF ALL SYSTEM AGENTS APPROPRIATELY.
- BE ABLE TO FLUIDLY TRANSITION BACK AND FORTH AMONG AGENTS (TRADED CONTROL).

RATIONALE:

- DIRECT TELEOPERATED CONTROL OF IMPORTED ROBOTIC FUNCTIONS (E.G., ORU CHANGEOUT VIA GROUND CONTROL) IS SLOW, TEDIOUS, AND PRONE TO ERROR. DIFFICULTIES ABOUND IN COMPREHENSIVELY OBSERVING THE WORK SPACE; DERIVING A SUITABLE 3-D SENSE OF POSITION, FORCE, AND ORIENTATION; AND DEALING WITH TIME DELAYS. FULL AUTONOMY FOR HIGHLY COMPLEX INTERACTIONS WILL BE SLOW IN FORTHCOMING. THEREFORE, THE FULL COOPERATION BETWEEN MAN AND ROBOT (PERFORMING SPECIFIC AUTONOMOUS OPERATIONS) IS ESSENTIAL FOR FEASIBILITY, EFFICIENCY, AND FAIL-SAFE ASSURANCE OF THE COMPLETE OPERATION.

REQUIREMENT:

- A PRELIMINARY REQUIREMENTS DEFINITION IS NEEDED FOR PRODUCTIVITY ENHANCEMENT.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

MAN/MACHINE
COOPERATIVE CONTROL

PROGRAM PLAN

APPROACH:

- ESTABLISH TESTBED AND ASSOCIATED SPACE RELATED SCENARIOS OF INTEREST.
- DEVELOP CAPABILITY TO PERFORM REQUIRED PRIMITIVE OPERATIONS (E.G., MOVE, GRASP, INSERT, FIND, ETC.) BOTH THROUGH TELEOPERATION, AUTONOMOUS OPERATION, SHARED OPERATION, ETC. THIS IS A MAJOR SYSTEMS INTEGRATION ACTIVITY.
- BASED ON PERFORMANCE INDICATORS, DETERMINE APPROPRIATE MIX OF RESOURCE UTILIZATION FOR A VARIETY OF SCENARIOS WHICH SPAN THE RANGE OF ROBOTIC OPERATIONS OF INTEREST.

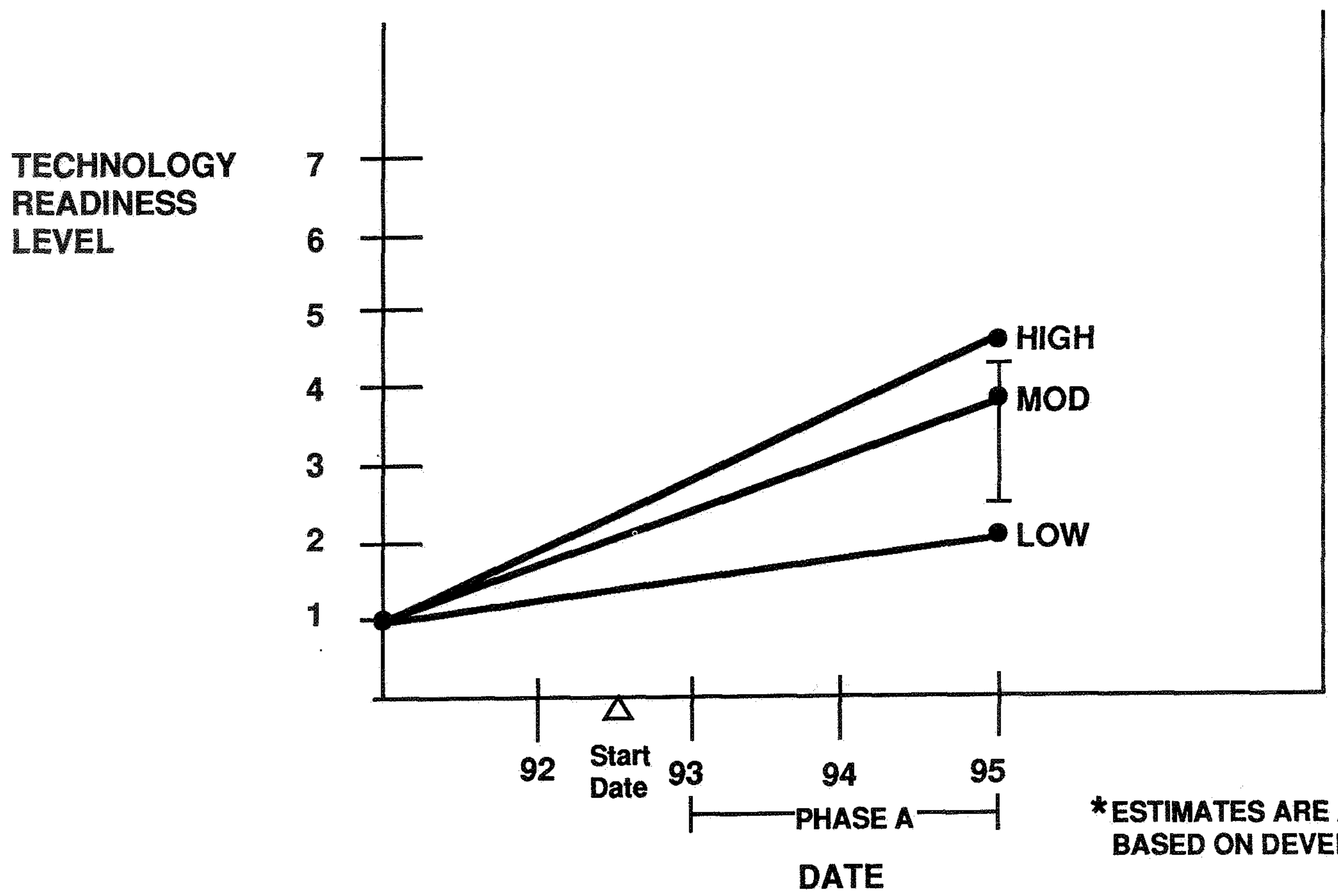
DELIVERABLES:

- A DEMONSTRATED CAPABILITY TO SMOOTHLY TRANSITION TASKS BETWEEN DIRECT OPERATOR CONTROL AND AUTONOMOUS OPERATION
- A DATA BASE WHICH GUIDES THE SUITABILITY OF TASK ALLOCATION FOR A VARIETY OF FUNCTIONS

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE *MAN/MACHINE COOPERATIVE CONTROL*

TECHNOLOGY ASSESSMENT*



*ESTIMATES ARE APPROXIMATE AND BASED ON DEVELOPMENT PLAN

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

3D - REAL-TIME MACHINE PERCEPTION

BACKGROUND

SCOPE:

- 3D-REAL-TIME MACHINE PERCEPTION REFERS TO MACHINE COGNITIVE PROCESSES WHICH CAN EXTRACT SENSORY DATA FROM VARIABLE ENVIRONMENTS IN REAL-TIME TO PROVIDE KNOWLEDGE ENABLING REAL-TIME INTERACTION WITH THE ENVIRONMENT, AND PLANNING AND REASONING ABOUT FUTURE ACTIVITIES.

OBJECTIVES:

- DEVELOP MEANS OF PROCESSING AND MANAGING THE ACQUISITION OF DATA FROM MULTIPLE SENSOR TYPES, USING CONVENTIONAL AND ALTERNATIVE PROCESSOR TECHNOLOGIES SUCH AS PARALLEL PROCESSORS AND NEURAL NETWORKS AS REQUIRED; INTEGRATING THE DATA TO BUILD AND VERIFY REPRESENTATIONS OF THE ROBOT'S ENVIRONMENT CONSISTING, NOT ONLY OF SPATIAL, BUT ALSO TEMPORAL, PROCEDURAL, FUNCTIONAL, AND OTHER INFORMATION; TO SUGGEST ROBOT INTERACTION WITH THE ENVIRONMENT BOTH FOR PURPOSES OF CLOSED LOOP CONTROL AND REASONING ABOUT CURRENT AND FUTURE ACTIVITIES.

RATIONALE:

- PRESENT MACHINE COGNITION SYSTEMS ARE LIMITED IN CAPABILITY TO PERFORMING SPECIALIZED FUNCTIONS IN CAREFULLY CONTROLLED ENVIRONMENTS. PROCESSING CAPABILITIES REQUIRED TO PERFORM THESE FUNCTIONS GENERALLY FAR EXCEED THOSE AVAILABLE TO IMPLEMENT REAL-TIME UTILIZATION OF SENSED DATA.

REQUIREMENT:

- OPERATIONAL CONSTRAINTS FOR PROXIMITY OPERATIONS, LIFE-CYCLE COST REDUCTIONS AND PRODUCTIVITY ENHANCEMENT DUE TO IMPROVED ROBOT PERFORMANCE

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

3D - REAL-TIME MACHINE PERCEPTION

PROGRAM PLAN

APPROACH:

- DEVELOP ALGORITHMS AND PROCESSING ARCHITECTURE WHICH ENABLE THE EXTRACTION OF INFORMATION FROM SENSED DATA AND THE INTEGRATION OF INFORMATION FROM DIFFERENT DATA TYPES.
- DEVELOP MEANS OF REPRESENTING ENVIRONMENTAL INFORMATION IN A STRUCTURED MANNER, INCLUDING SPATIAL, FUNCTIONAL, PROCEDURAL, TEMPORAL, AND OTHER INFORMATION TYPES AND PROCESSES BY WHICH NEW INFORMATION CAN BE INTEGRATED INTO EXISTING MODELS AND CONFLICTING INFORMATION RATIONALIZED.
- INTEGRATE COGNITION PROCESSES WITH REASONING PROCESSES TO ENABLE DIRECTED ACQUISITION OF SENSORY INFORMATION ABOUT UNKNOWN ASPECTS OF THE ENVIRONMENT.

DELIVERABLES:

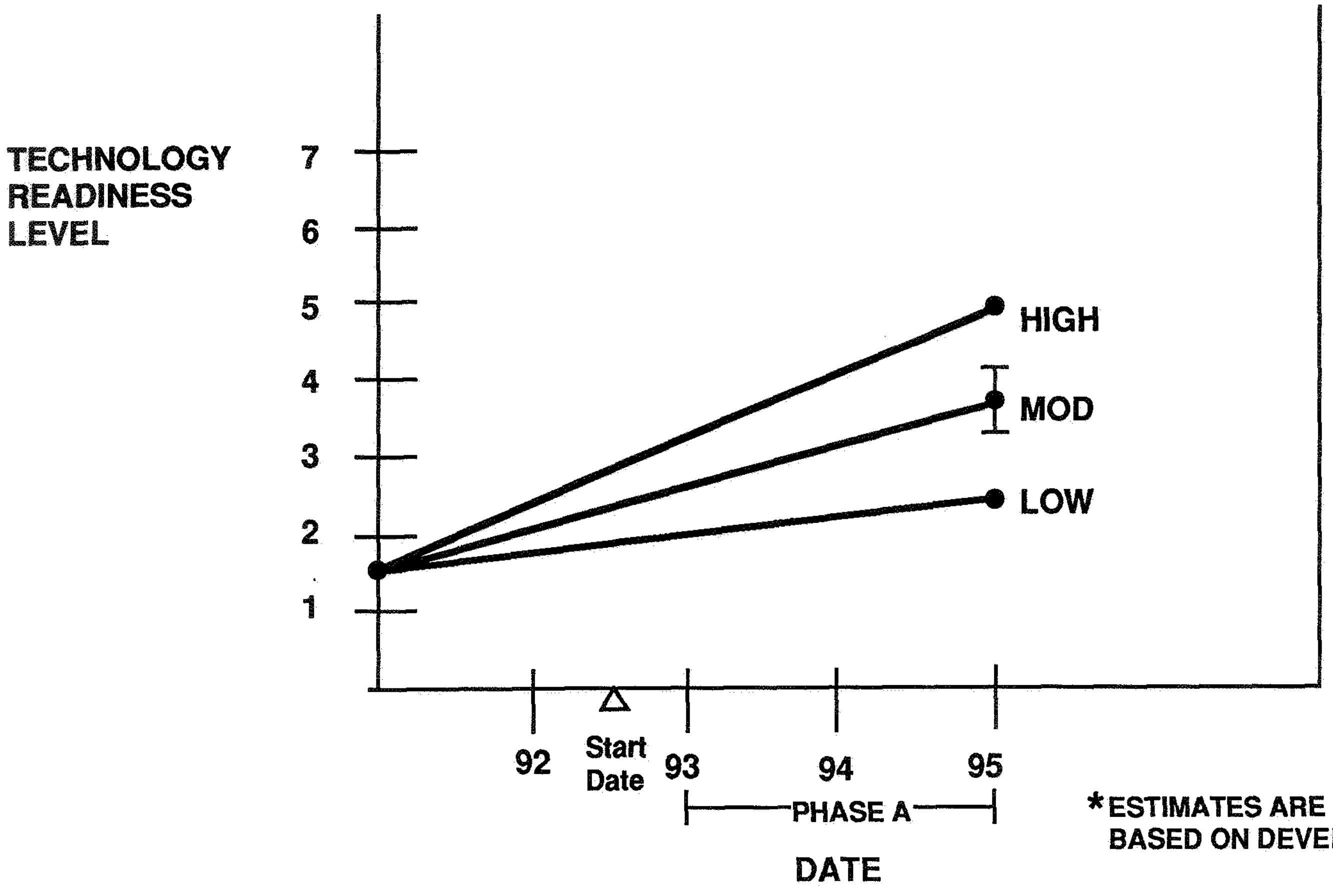
- A SELF-CONTAINED COGNITIVE PROCESSING SYSTEM UTILIZING DATA FROM GENERAL SENSORS CAPABLE OF DEVELOPING ENVIRONMENTAL MODELS, WHICH INTERFACES WITH CONVENTIONAL COMPUTING SYSTEMS
- A DEMONSTRATION SYSTEM USING TWO OR MORE SENSOR TYPES TO BUILD ENVIRONMENTAL MODELS UTILIZED BY REAL-TIME CONTROL AND PLANNING SYSTEMS TO PERFORM A COMPLEX TASK IN A FLEXIBLE ENVIRONMENT

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

3D - REAL-TIME MACHINE PERCEPTION

TECHNOLOGY ASSESSMENT*



*ESTIMATES ARE APPROXIMATE AND BASED ON DEVELOPMENT PLAN

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

MULTIPLE ARM REDUNDANCY CONTROL

BACKGROUND

SCOPE:

- MULTIPLE ARM REDUNDANCY CONTROL IS A METHOD OF EFFECTIVELY PLANNING AND CONTROLLING THE POSITIONING AND MOTION OF MULTIPLE MANIPULATOR ARMS TO SATISFY MULTIPLE OBJECTIVES BEYOND SIMPLE POSITIONING OF THE END-EFFECTORS.

OBJECTIVES:

- DEVELOP ROBUST AND COMPUTATIONALLY EFFICIENT ALGORITHMS FOR PLANNING AND CONTROLLING ADDITIONAL DEGREES-OF-FREEDOM TO SATISFY CERTAIN CRITERIA SUCH AS OBSTACLE AVOIDANCE, LIGHTING AND CAMERA-VIEWING POSITIONING; AND THE OPTIMIZATION OF OBJECTIVE FUNCTIONS INCLUDING JOINT VELOCITIES, POWER DISSIPATION, ACTUATOR TORQUES, CONTACT FORCES AND TORQUES, IMPEDANCE, SYSTEM MOMENTUM, AND DEXTERITY.

REQUIREMENTS:

- ADDITIONAL DEGREES-OF-FREEDOM ARE INHERENT TO MULTIPLE ARM ROBOTS AND MUST BE CONTROLLED IN SOME MANNER. THEY ARE ALSO EXTREMELY USEFUL IN OBTAINING OTHER GOALS THAT CAN CONFLICT WITH THE DESIRED POSITIONING OF THE END-EFFECTORS (SUCH AS COLLISION AVOIDANCE). FURTHERMORE, COORDINATION BETWEEN THE MULTIPLE ARMS MUST PROGRESS BEYOND THE CURRENT METHOD OF INDEPENDENTLY CONTROLLING EACH ARM (RMS W/FTS ATTACHED).

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

MULTIPLE ARM REDUNDANCY CONTROL

PROGRAM PLAN

APPROACH:

- STUDY AND SELECT MANIPULATION OBJECTIVES TO BE HANDLED BY REDUNDANT DEGREES-OF-FREEDOM.
- DEVELOP ALGORITHMS TO SATISFY THESE MANIPULATION OBJECTIVES.
- SELECT AN EXPERIMENTAL SYSTEM ON WHICH TO IMPLEMENT THESE ALGORITHMS. TUNE AND OPTIMIZE THE ALRGORITHMS FOR THIS SPECIFIC SYSTEM.

DELIVERABLES:

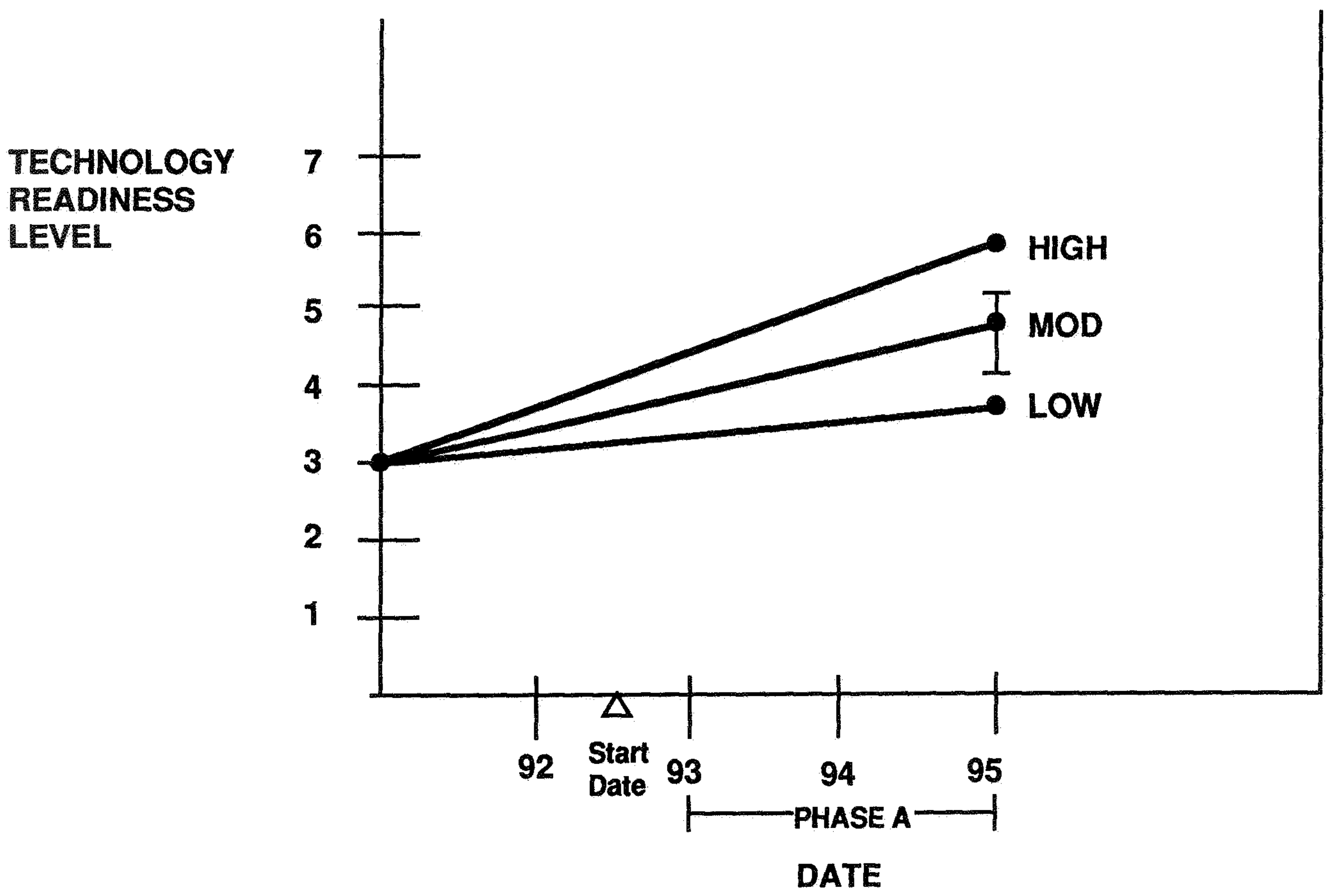
- COMPREHENSIVE STUDY OF WHAT OBJECTIVES TO HANDLE AND HOW TO IMPLEMENT THEM
- MULTIPLE ARM REDUNDANCY CONTROL ALGORITHMS
- DEMONSTRATION OF ORU CHANGE-OUT USING MULTIPLE ARMS WHILE SATISFYING OBSTACLE AVOIDANCE, CONTACT FORCE MINIMIZATION, ETC., USING FTS OR SPDM-CLASS ROBOT

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

MULTIPLE-ARM REDUNDANCY CONTROL

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

MANIPULATOR CONTROL FROM A MOVABLE BASE

BACKGROUND

SCOPE:

- MANIPULATOR CONTROL FROM A MOVABLE BASE REFERS TO AN ADAPTIVE MANIPULATOR/VEHICLE SYSTEM THAT IS ABLE TO ACTIVELY ACCOMMODATE CHANGING TASK-BASE RELATIONSHIPS IN REAL-TIME WHILE AVOIDING COLLISIONS AND INSURING A STABLE COUPLED FREE-FLYER/TASK SYSTEM.

OBJECTIVE:

- DEVELOP TECHNOLOGY ALLOWING MANIPULATION PERFORMED FROM A FREE-FLYING BASE WHICH IS SAFE AND WITHOUT ADVERSE EFFECT ON THE TASK PLATFORM.

RATIONALE:

- FREE-FLYING MANIPULATION WILL ALLOW ORU EXCHANGE AND REPAIR FUNCTIONS TO BE PERFORMED ON DELICATE STRUCTURES OR LOW-MASS SATELLITES WITHOUT DAMAGE OR EFFECTS TO THEIR ORBIT OR ATTITUDE. BY ALLOWING TASK-INDUCED FORCES TO BE REACTED THROUGH A HOLDING ARM WHILE SIMULTANEOUSLY AVOIDING INDUCING FORCES DUE TO TASK-BASE MOTION AND COMPENSATING FOR COUPLED TASK-BASE SYSTEM DYNAMICS, A FREE FLYER OF REAL MASS CAN PERFORM OPERATIONS WITHOUT ADVERSE AFFECT TO THE PLATFORM.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

MANIPULATOR CONTROL FROM A MOVABLE BASE

PROGRAM PLAN

APPROACH - MOVING BASE MANIPULATION WILL REQUIRE TECHNOLOGY THRUSTS IN THREE AREAS: (1) SENSING, (2) CONTROLS, AND (3) MECHANISM.

1. IN THE SENSING AREA, INVESTIGATION INTO REAL-TIME OBJECT TRACKING IN BOTH POSITION AND ORIENTATION WILL BE ESSENTIAL TO SUCCESS. THE QUESTION OF WHAT "REAL-TIME" IS MUST ALSO BE ADDRESSED. VIDEO RATES OF 30 Hz ARE NOT SUFFICIENT EXCEPT FOR SLOW REACTING TASKS (< 3 Hz).

2. IN THE CONTROLS ARENA, INVESTIGATION OF ADAPTIVE CONTROLS FOR A COMPLETE FREE FLYER (i.e., 2 MANIPULATORS AND VEHICLE) SHOULD BE STUDIED. OTHERWISE JOINT FRICTION AND OTHER NONLINEAR EFFECTS WILL RESULT IN UNEXPECTED MOTIONS. DYNAMIC EFFECTS BOTH DURING STATION KEEPING AND AT TASK CONTACT (A VERY NONLINEAR PROBLEM) WILL NEED TO BE INVESTIGATED AND MODELLED. TASK-MANIPULATOR CONTACT FORCES GENERATE TORQUES WHICH CAN EASILY CAUSE PERTURBATION OSCILLATIONS WHICH WILL NEED TO BE REACTED BY EITHER THE VEHICLE CONTROLS OR COUNTERING FF MOTIONS. COLLISION AVOIDANCE WILL NEED TO BE EXPANDED TO REAL-TIME REACTION RATES SINCE COUNTERACTING FORCES CAN EASILY LEAD TO COUPLED SYSTEM DYNAMICS AND MOTIONS WHICH ARE PHYSICALLY COLLIDED.

3. IN THE MECHANISM ARENA, COMPLIANT ARMS WITH HIGH-SPEED REACTION/ RESPONSE WILL BE NECESSARY UNDER WORST CASE SCENARIOS TO PREVENT STATION AND/OR FF DAMAGE.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

MANIPULATOR CONTROL FROM A MOVABLE BASE

PROGRAM PLAN (CONTINUED)

DELIVERABLES:

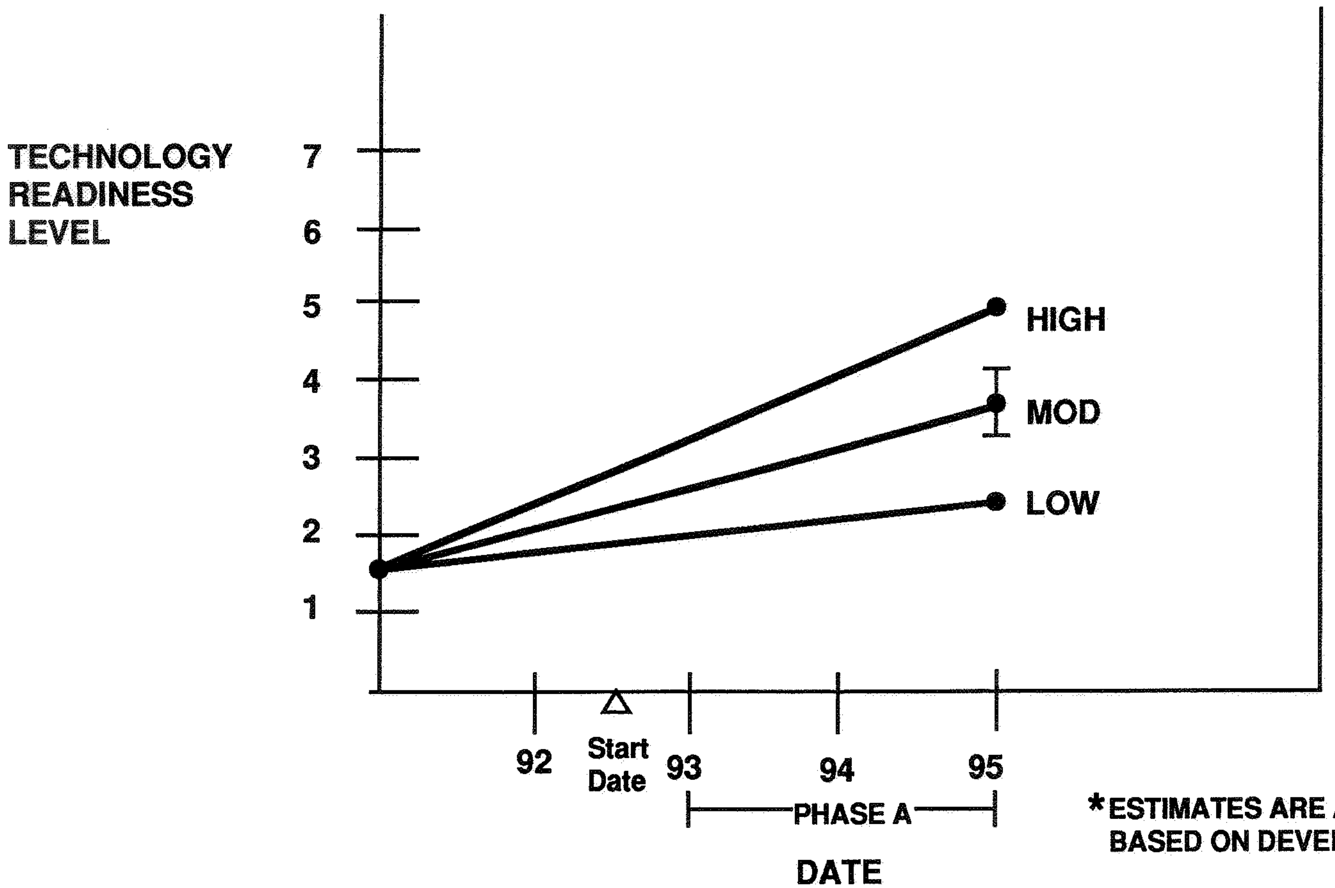
- FREE-FLYING TECHNOLOGY DEVELOPMENT IN THE AREAS OF SENSING, CONTROLS AND MECHANISMS. SPECIFICALLY:
    - REAL-TIME TASK-BASE RELATIONSHIP SENSOR SYSTEM
    - CONTROL ALGORITHMS FOR DYNAMIC COMPENSATION OF TASK-BASE MOTION
    - HIGH-SPEED COMPLIANT MECHANISMS FOR MANIPULATION
- A DEMONSTRATION OF FREE-FLYING MANIPULATION USING PENDULUM-LIKE TASKS AND ROBOTS
- A DEMONSTRATION OF FREE-FLYING MANIPULATION IN THE WET TANK AT MARSHALL USING BOTH ZERO BUOYANCY TASKS AND ROBOTS
- ACTIVE ACCOMMODATION OF FTS "FOOT" AS A DEMONSTRATION TEST FLIGHT

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE

MANIPULATOR CONTROL FROM A MOVABLE BASE

TECHNOLOGY ASSESSMENT*



*ESTIMATES ARE APPROXIMATE AND BASED ON DEVELOPMENT PLAN

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

BACKGROUND

SCOPE:

- MULTI-AGENT REASONING REFERS TO AN ENVIRONMENT FOR ROBOTIC SYSTEMS PERFORMING UNDER VARYING DEGREES OF AUTONOMY TO ENGAGE IN INTERACTIVE AND COOPERATIVE ACTIVITIES.

OBJECTIVE:

- DEVELOP SYSTEMS AND METHODOLOGIES TO REASON ABOUT THE COOPERATIVE INTERACTION OF HETEROGENEOUS AGENTS, INCLUDING REASONING ABOUT EACH AGENT'S LOCAL ACTIVITY AS WELL AS THE INTEGRATED COMPOSITE ACTIVITY OF THE WHOLE ENVIRONMENT.

REQUIREMENTS:

- AGENTS OPERATING AUTONOMOUSLY, OR UNDER PARTIAL AUTONOMY, MUST PERFORM SOME LEVEL OF REASONING ABOUT THEIR ENVIRONMENT TO SYNTHESIZE DECISIONS ABOUT THEIR FUNCTIONS, AND HENCE WILL DRAW UPON A VARIETY OF INPUTS AND REASONING SCHEMES TO SYNTHESIZE THESE DECISIONS. IN ADDITION, MULTIPLE INTERACTIVE AGENTS REQUIRE REASONING WHICH CONSIDERS ACTIVITY ON A GLOBAL SCALE. THE DEGREE OF AUTONOMY EMPLOYED WILL VARY FROM SYSTEM TO SYSTEM, RESULTING IN THE INTERACTION OF MULTIPLE HETEROGENEOUS AGENTS. FOR COOPERATIVE MAN-MACHINE INTERACTION, THE REASONING RATIONALE USED BY AUTONOMOUS AGENTS MUST BE VERIFIED TO THE SATISFACTION OF HUMAN AGENTS DEPENDING ON THE AUTONOMY. THEREFORE, TECHNOLOGY MUST BE DEVELOPED TO REASON ABOUT ACTIVITIES FOR COOPERATING AGENTS OF VARYING LEVELS OF CAPABILITIES, AND TO VERIFY THE ASSOCIATED RATIONALE.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE | *MULTI-AGENT REASONING*

PROGRAM PLAN

APPROACH:

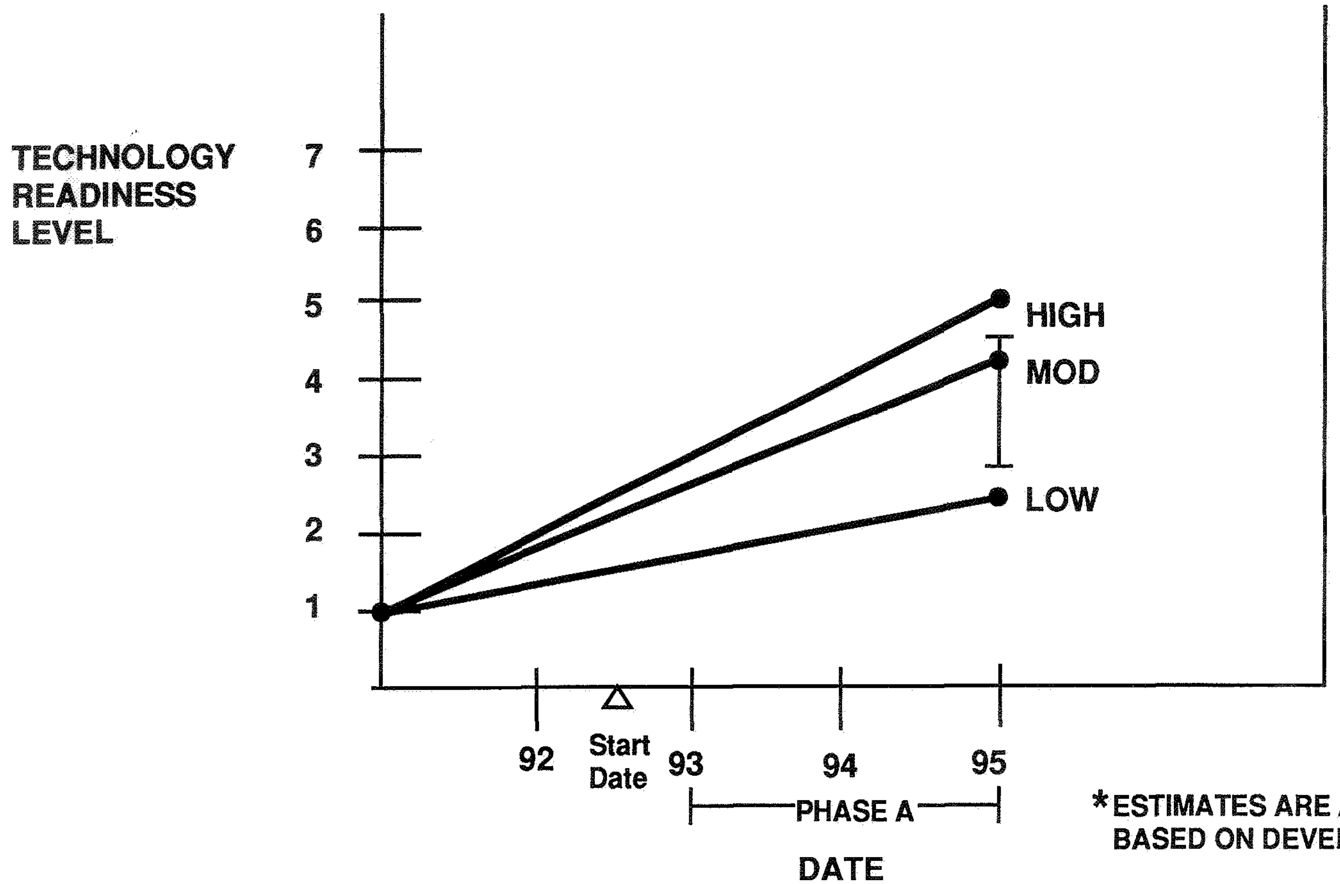
- DEVELOP PLANNING PROCESSES FOR SINGLE AGENTS AND MULTIPLE COOPERATIVE AGENTS AT BOTH TASK-SEQUENCE AND TASK-EXECUTION LEVELS
- DEVELOP METHODS FOR VERIFICATION OF PLANNING RATIONALE EMPLOYING MULTIPLE REASONING SCHEMES
- DEVELOP EXPLANATION FACILITIES FOR JUSTIFICATION OF PLANNING RATIONALE TO HUMAN AGENTS
- DEVELOP METHODS FOR DISTRIBUTING WORLD KNOWLEDGE AMONG MULTIPLE AGENTS, AND COOPERATIVELY SHARING THESE RESOURCES WHILE MAINTAINING INTEGRITY IN THE KNOWLEDGE
- DEVELOP TECHNIQUES FOR ACCOMMODATING UNCERTAINTIES AND ANOMALIES IN THE PLANNING ENVIRONMENT

DELIVERABLES:

- ROBOTIC AGENTS WHICH CAN SEMI-AUTONOMOUSLY PLAN THEIR ACTIONS IN A RELATIVELY UNSTRUCTURED ENVIRONMENT, EXPLAIN/JUSTIFY RATIONALE USED IN DERIVING PLANS, AND COOPERATIVELY SHARE THOSE PLANS WITH OTHER AGENTS
- TECHNOLOGY DEMONSTRATIONS FOR DISTRIBUTED REASONING AND REPRESENTATION OF WORLD KNOWLEDGE

ROBOTICS TECHNOLOGY DISCIPLINE *MULTI-AGENT REASONING*

TECHNOLOGY ASSESSMENT*



*ESTIMATES ARE APPROXIMATE AND BASED ON DEVELOPMENT PLAN

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ROBOTICS TECHNOLOGY DISCIPLINE — *SURFACING EVOLUTION TECHNOLOGIES*

GOAL: TO PERFORM AUTONOMOUSLY, FAIL-SAFE TO HUMAN OPERATOR

REQUIREMENT: ROBUSTNESS

TASK: ORU CHANGEOUT FROM THE GROUND

SURVEY OF TASK REQUIREMENTS VERSUS TIME

1995-1999 ASSEMBLY COMPLETE	1996-2002 LUNAR MISSION	2006-2016 MARS MISSION

- ASSEMBLY
  - TRUSS
  - UTIL TRAYS
  - SIAS, PMADS
- ORU CHANGEOUT
- INSPECTION ASSEMBLY
- TRANSLATION
- MAINTENANCE
- EVA SUPPORT

- SOLAR DYNAMICS ASSEMBLY
- VEHICLE SERVICING AND REPAIR
- SATELLITE SERVICING
- PAYLOAD INTEGRATION
- IVA SUPPORT

- ASSEMBLY
  - SPACECRAFT
  - AEROBRAKE
- LARGE CRYO TANK CHANGEOUT
- INSPECTION
- AUTONOMOUS BERTHING

ORU CHANGEOUT FROM THE GROUND

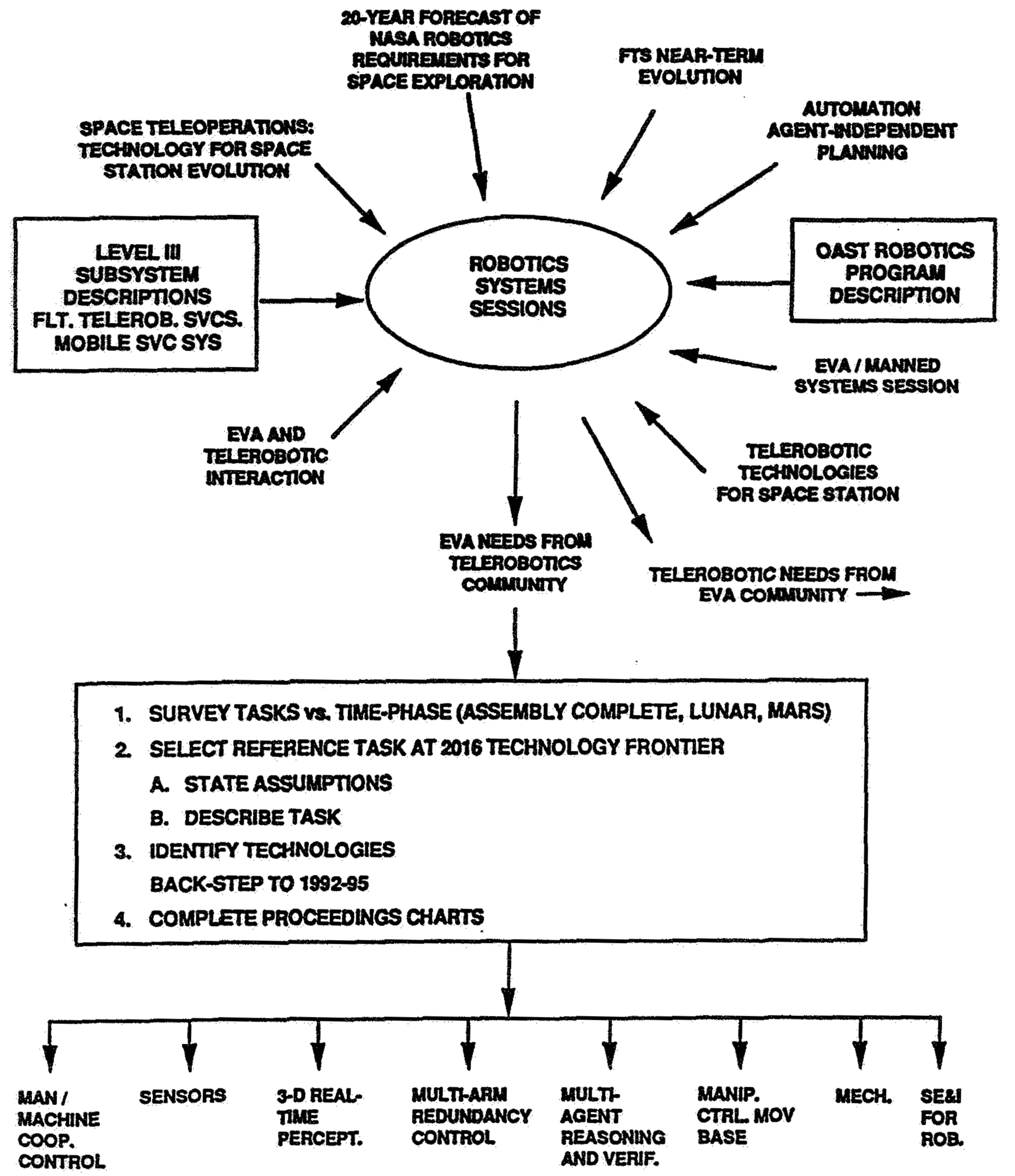
ASSUMPTIONS

- 2016+ TIME FRAME
- 3 SECOND VARIABLE TIME DELAY
- SSF ORU
- POSSIBLY UNKNOWN LOCATION OF FAILED ORU
- UNSTRUCTURED WORK ENVIRONMENT
- GROUND OPERATED SUPERVISORY CONTROL

TECHNOLOGY FOR SPACE STATION EVOLUTION - *A WORKSHOP*

ROBOTICS TECHNOLOGY DISCIPLINE

PROCESS DEFINITION FOR SURFACING TECHNOLOGY REQUIREMENTS



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

RECOMMENDATIONS/ISSUES FOR ROBOTICS

- PROGRAM VS. TECHNOLOGY REQUIREMENTS
  E.G., DO THIS → "REDUCE EVA BY 10% AND PERFORM THE SAME TASKS" (TECHNICAL)
  NOT THIS → "GIVE ME THE REQUIREMENTS" (ORGANIZATIONAL)
- MORE INTERACTION BETWEEN EVA, ROBOTICS, AND SSF DESIGN COMMUNITIES
- IDENTIFY BENCHMARK TASKS AND MEASURES OF PRODUCTIVITY
- ALLOCATE SOME CONTINUING PORTION OF STS, MFTS, AND SPDM TO RESEARCH/TESTING
- TO OBTAIN SOME DEGREE OF GROUND CONTROL OR REMOTE MANIPULATION FOR SSF SUPPORT OF LUNAR AND MARS ACTIVITIES, THE FOLLOWING TECHNOLOGY AREAS REQUIRED DURING 1992-1995 AS A BRIDGE TO SUCH ACTIVITIES

  - SYSTEMS ENGINERING PROCESSES FOR ROBOT INTEGRATION
  - MAN/MACHINE COOPERATIVE CONTROL
  - 3-D REAL-TIME PERCEPTION
  - MULTIPLE-ARM REDUNDANCY CONTROL
  - MULTI-AGENT REASONING AND VERIFICATION*
  - MANIPULATOR CONTROL FROM MOVEABLE BASE
  - MECHANISMS
  - SENSORS

* ALSO APPLIES TO AUTOMATION

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

RECOMMENDATIONS/ISSUES (Cont'd)

- MANY TECHNOLOGIES IN THE ROBOTICS DISCIPLINE ARE LEVERAGED WITH OTHER SUPPORT. THE FUNDING SCENARIOS DEVELOPED HEREIN ARE BASED ON CONTINUED EQUIVALENT OF GREATER SUPPORT IN THOSE NON-OAST FUNDED PROGRAMS.
- THE RESULTS OF THIS SESSION SHOULD BE WEIGHED AGAINST EXISTING PROGRAMS AND PRIORITIES PRIOR TO ADOPTION OF SPECIFIC TECHNOLOGY RECOMMENDATIONS.

MULTIPLE-ARM REDUNDANCY CONTROL:

- R&D HAS SHOWN THAT THIS TECHNOLOGY IS MATURE ENOUGH TO BE DEVELOPED FOR "MID-TERM" (1995--2000) SPACE ROBOTIC SYSTEMS.
- INCREASING DEGREES-OF-FREEDOM CAN BE ADDED (IF DESIRED AND NECESSARY) TO MEET MANIPULATION OBJECTIVES OTHER THAN END-EFFECTOR POSITIONING. AT LEAST SEVEN DOF ARE NEEDED FOR COLLISION AVOIDANCE WHILE IN CONTACT.
- COST OF ADDING EXTRA ARMS AND EXTRA DEGREES-OF-FREEDOM MUST BE TRADED OFF AGAINST ADDITIONAL CAPABILITY.

SENSORS:

- THIS AREA INCLUDES ALL THE MEANS, PASSIVE AND ACTIVE, BY WHICH THE HUMAN TELEOPERATOR, OR (LATER) THE SEMI-AUTONOMOUS ROBOT COLLECTS INFORMATION ABOUT THE ENVIRONMENT.
- ADVANCES IN SENSORS ARE REQUIRED TO IMPROVE THE CAPABILITIES FOR SAFE AND EFFECTIVE TELEROBOTIC OPERATION IN THE SPACE STATION ENVIRONMENT.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

RECOMMENDATIONS/ISSUES (Cont'd)

SENSORS:

- SENSOR TECHNOLOGIES INCLUDE:
  - MACHINE VISION, INCORPORATING SUCH AREAS AS VARIABLE RESOLUTION AND ZOOM; STEREO VISION, SCANNERS, INTEGRATED LIGHTING CONTROL, AND INFRARED DETECTORS
  - DATA BASE OF ROBOT ACTIVITIES AND TASKS
  - LASERS AND OTHER RANGING DEVICES FOR USE IN PROXIMITY OPERATIONS, GRAPPLING, AND WORKSPACE OPERATIONS
  - SPECIALIZED SENSORS FOR EXTERNAL ROBOTS INCLUDING LEAK DETECTORS, INTEGRATION, ULTRASONIC, OR OTHER NDT INSPECTION SENSORS TO SUPPORT THE DIAGNOSIS OF MALFUNCTIONING EQUIPMENT OR OTHER TASKS
  - FORCE/TORQUE SENSORS AND CONTACT SENSORS
  - SENSORS FOR POTENTIAL IVA ROBOTS INCLUDING ATMOSPHERIC SAMPLERS AND AUDIO SENSORS
- THE ROBOTIC SYSTEMS MUST INTERACT WITH PHYSICAL OBJECTS IN ITS ENVIRONMENT. IT MUST BE ABLE TO NAVIGATE FROM A KNOWN POSITION TO A NEW LOCATION WHILE AVOIDING ANY CONTACT WITH OBJECTS ENROUTE. TO ACCOMPLISH THIS, COLLISION AVOIDANCE AND NAVIGATION TECHNOLOGY REQUIRE DEVELOPMENT. THEREFORE, SENSORS ARE REQUIRED WHICH ARE ABLE TO ACQUIRE HIGH-RESOLUTION DATA DESCRIBING THE ROBOT'S PHYSICAL SURROUNDINGS WHILE FUNCTIONING WITHIN COMPUTATIONAL RESOURCES OF THE SYSTEM.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

ISSUES RAISED IN PLENARY SESSION
(R. KOHRS, 1/16/90)

ISSUE:

- THERE EXISTS A NEED FOR USEFUL, HARD REQUIREMENTS FOR FTS AND MSC AND A NEED TO ASSIGN JOBS TO EACH (THERE ARE NO SPECIFIC REQUIREMENTS IN CURRENT DOCUMENTATION).

RESPONSE:

- A TASK IS UNDERWAY ENTITLED "EXTERNAL MAINTENCE AUDIT" TO ALLOCATE TASKS BETWEEN ROBOTICS AND EVA. TASK MANAGERS ARE C. PRICE AND W. FISHER.

ISSUE:

- THERE EXISTS A NEED FOR COMMONALITY AMONG HAND CONTROLLERS; THERE ARE CURRENTLY SIX TYPES.

RESPONSE:

- AN INFORMAL TASK (i.e. NO ALLOCATED FUNDS) IS UNDERWAY BETWEEN BEN BARKER (SE&I LEVEL II) AND DEAN JENSEN, (JSC MANNED SYSTEMS) ENTITLED "JOINT LEVEL 2 - JSC STUDY: HAND CONTROLLER COMMONALITY PROCESS." THE OBJECTIVE OF THE TASK IS "TO RECOMMEND THE NUMBER AND TYPE OF HAND CONTROLLER CONFIGURATIONS THAT CAN MEET SPACE STATION REQUIREMENTS."

- A TASK, CONDUCTED BY W. HANKINS, IS UNDERWAY AT LaRC TO EVALUATE 4 TYPES OF HAND CONTROLLERS WITH AND WITHOUT FORCE-FEEDBACK.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

STRUCTURES AND MATERIALS TECHNOLOGY DISCIPLINE

JANUARY 19, 1990

ROBERT J. HAYDUK, CHAIRMAN
NASA HEADQUARTERS, CODE RM

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

STRUCTURES AND MATERIALS *MATERIALS*

BACKGROUND

SCOPE — To provide the materials, processes and data base to permit the design, fabrication, maintenance and inspection of a manned, on-orbit space station and its supporting subsystems that will withstand prolonged usage and provide durability in a space environment.

OBJECTIVES — To develop environmentally tolerant materials and material systems for space application; to develop on-orbit repair processes; and to explore the science for on-orbit Non-Destructive Evaluation (NDE).

RATIONALE — Current non-metallic materials available for space station design cannot withstand the prolonged exposure to various elements of space environment without severe degradation in their mechanical and/or physical properties. Increased survivability, durability, and performance are needed. In addition, knowledge is lacking of on-orbit repair, construction and inspection techniques needed to permit maintenance and system integrity of a manned space station.

PROGRAM PLAN

APPROACH -

1. Conduct basic materials development and characterization to (1) improve the environmental resistance of polymeric basic materials and (2) obtain high-performance materials capable of increasing structure efficiencies.
2. Expose advanced materials to space environments to acquire a reliable and verified design database. Establish for these materials a set of failure criteria and design allowables. Develop ground-based test methods and facilities that permit ground simulation of space environments, and correlate this data with actual space exposure.
3. Develop procedures, acceptance criteria, and inspection techniques for conducting in-space repair, refubishment, and certification.
4. Develop processes and NDE certification for in-space construction of evolutionary structural concepts.

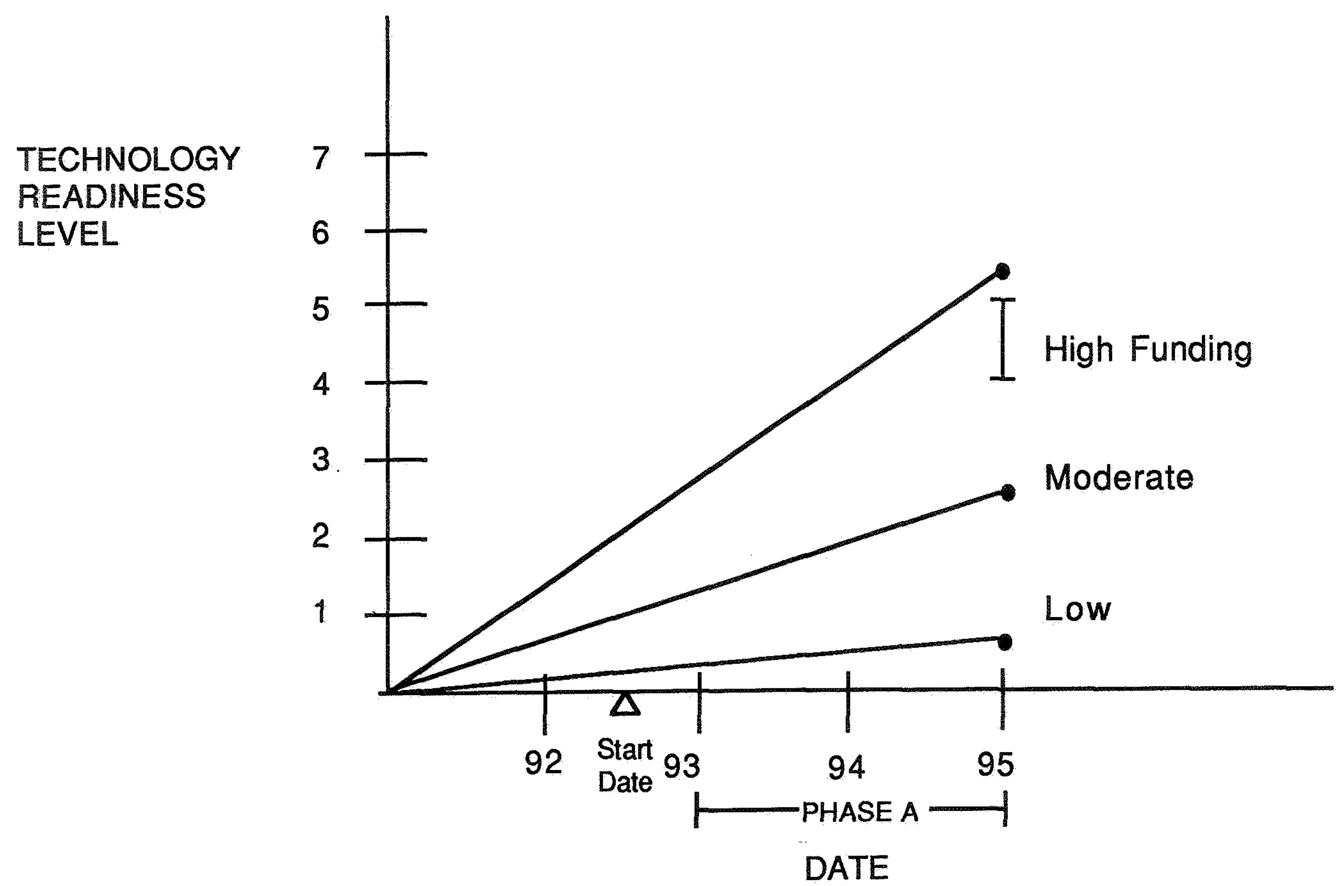
DELIVERABLES -

1. An approved materials list for space system application and a supporting data base.
2. A demonstration of ground-based space environment simulation and correlation.
3. Recommended NDE procedures and structural certification criteria.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

STRUCTURES AND MATERIALS *MATERIALS*

TECHNOLOGY ASSESSMENT



BACKGROUND

SCOPE - Ground and flight demonstrations of a series of large space structures aimed at significantly reducing or eliminating EVA requirements for construction on future NASA missions.

OBJECTIVES - 1) Develop automated assembly methods and associated tools for constructing a wide variety of advanced space structures. Demonstrate the feasibility of automated assembly on a full-scale testbed. 2) Develop advanced erectable structures including mechanical and welded joints and associated assembly aids. Establish accurate EVA timelines through the use of full-scale ground tests and a demonstration flight test. 3) Develop deployable linear and area truss structures for advanced mission applications. Demonstrate the reliability of deployable structures through full-scale deployment tests and analysis.

RATIONALE - The limiting consideration for many new missions is the ability to build large structures at a reasonable cost. Because of the lack of experience with large space structures, mission studies tend to be limited to small spacecraft. The development and demonstration of large space structures would open up mission design ranges as well as improve the agency's ability to predict mission costs.

PROGRAM PLAN

APPROACH -

1. Develop a large robotic arm (space crane) and associated end effectors for assembling large spacecraft. Demonstrate the operation of the arm and develop assembly timelines using a full-scale ground testbed.
2. Develop lightweight composite mechanical joint and welded joints for exploration vehicles, hangars, and reflectors. Demonstrate these new structures through EVA ground tests and through one selected flight test.
3. Develop large-scale deployable truss structures. Demonstrate the viability of deployables through a ground demonstration of a large truss platform.

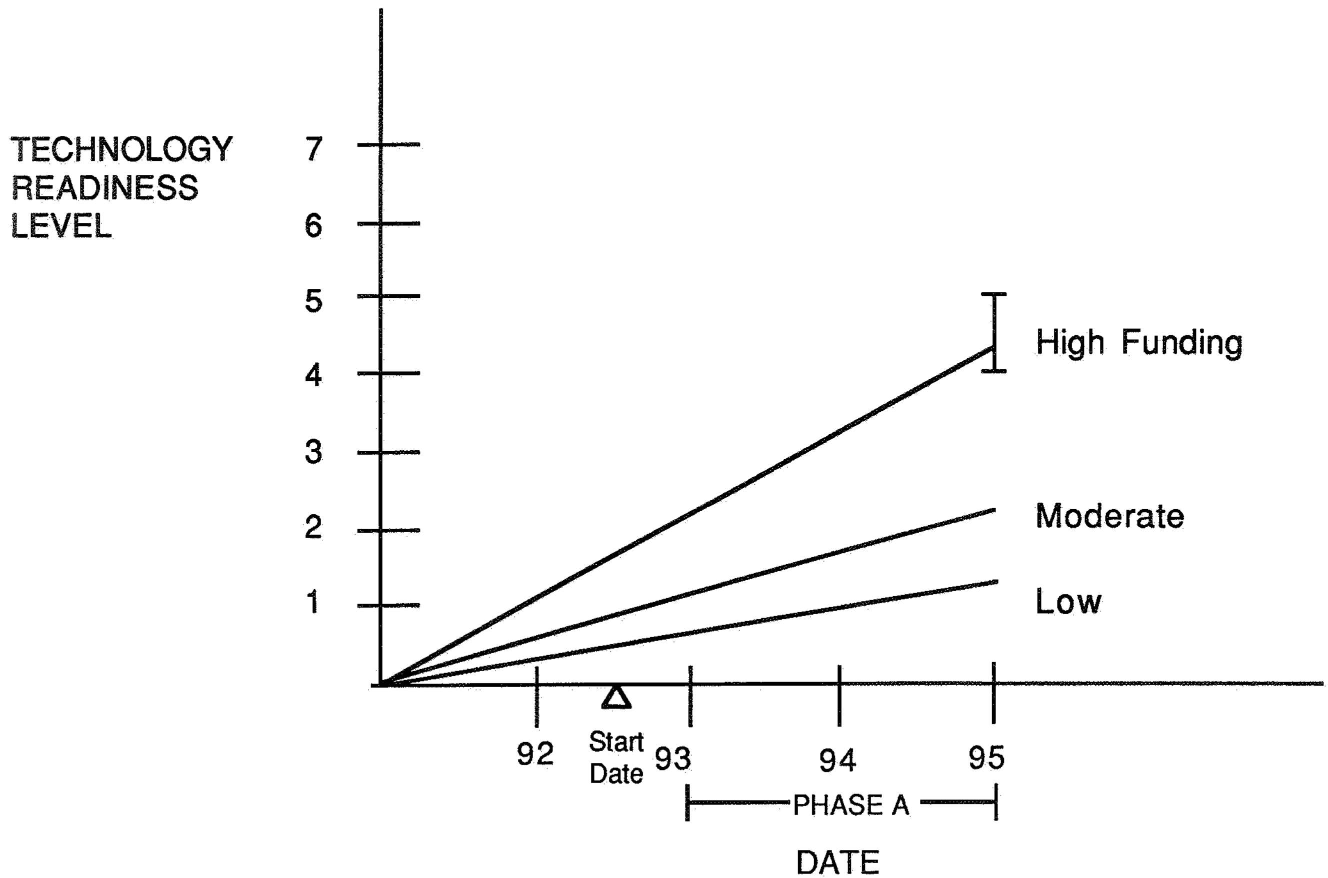
DELIVERABLES -

1. Demonstrated space crane and end effectors. Automated assembly scenarios and timelines.
2. Demonstrated lightweight composite joints and welding techniques. EVA timelines validated by ground and flight tests.
3. Large-scale validated deployable structural concepts. Validated deployment analysis.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

STRUCTURES AND MATERIALS *SPACE CONSTRUCTION*

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

STRUCTURES & MATERIALS *SPACE CONSTRUCTION*

ISSUES

- Minimum availability of EVA to do construction.
- Reliability of robotic assembly.
- Demonstrations are needed to accrue confidence in space construction methods and timelines.
- Piece-by-piece manual construction is EVA-intensive.

RECOMMENDATIONS

- Develop automated assembly testbed.
- Develop integrated deployable and/or modular structural components.
- Develop rapid EVA-erectable assembly scenarios. Advocate In-Space Construction Flight Experiments.
- Continue to develop new space suit to extend EVA time and astronaut efficiency.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

BACKGROUND

SCOPE — The dynamics of the Space Station Freedom in its Assembly Complete and evolutionary growth versions, including the characterization of the dynamics of the Station and attached manipulators, payloads, fueling systems and vehicles, and the interaction of the control systems of these components with the Station structural dynamics and attitude control system.

OBJECTIVES — To develop a well-verified dynamic model of the Assembly Complete Station and the analytical and experimental modeling tools to confidently extend the dynamic model to evolutionary configurations. Assured stability, improved performance and reduced dynamic loads will be achieved through application of the dynamic model.

RATIONALE — Even in its Assembly Complete configuration, the Space Station Freedom represents a complex structural dynamic environment. In its evolution of configurations, with the addition of larger power systems, manipulators, fuel storage and transfer systems, and berthed vehicles, the dynamics of the Station will become extremely complex. Uncertainties in modeling can lead to conservatism in dynamic loads analysis, unexpected interaction of control systems of the station and flexible manipulator and appendages, and potential failure to maintain fuels in configuration for transfer. Because of the size and flexibility of the Station, it is impossible to ground test in full scale. Therefore, a well-coordinated program of component and scale model ground tests, on-orbit tests, and analysis is necessary.

PROGRAM PLAN

APPROACH:

1. Develop the instrumentation and algorithms to characterize the dynamics of the Station during assembly and at Assembly Complete, in order to establish a well-understood benchmark for evolution and to provide a system for structural health monitoring for extended life.
2. Develop a comprehensive ability to model the dynamic structure control interactions, not only of the Station dynamics and attitude control system, but of the attached interacting manipulators and active payloads. This includes ground and flight CSI experimentation and analytical development.
3. Develop approaches to dynamic load limiting and alleviation, so as to extend the structural envelope into the range necessary for evolution. This includes schemes for reduction and alleviation of loads due to proximity operations; station reboost and maneuver; EVA and manipulator motion; docking; and berthing. Microgravity management approaches will be explored for conflicting demands of evolving Station.
4. Develop a comprehensive model of the dynamics of the station, including multibody and large-angle behavior of various sub-assemblies and appendages, and their respective controllers, which includes potentially geometric nonlinear and chaotic motion, for use in final verification of load alleviation and control schemes.
5. Develop simplified yet nonlinear model of fluid dynamic behavior and slosh, for the purposes of modeling cryogenic on-board fuels, and the fuel of berthed vehicles.

DELIVERABLES :

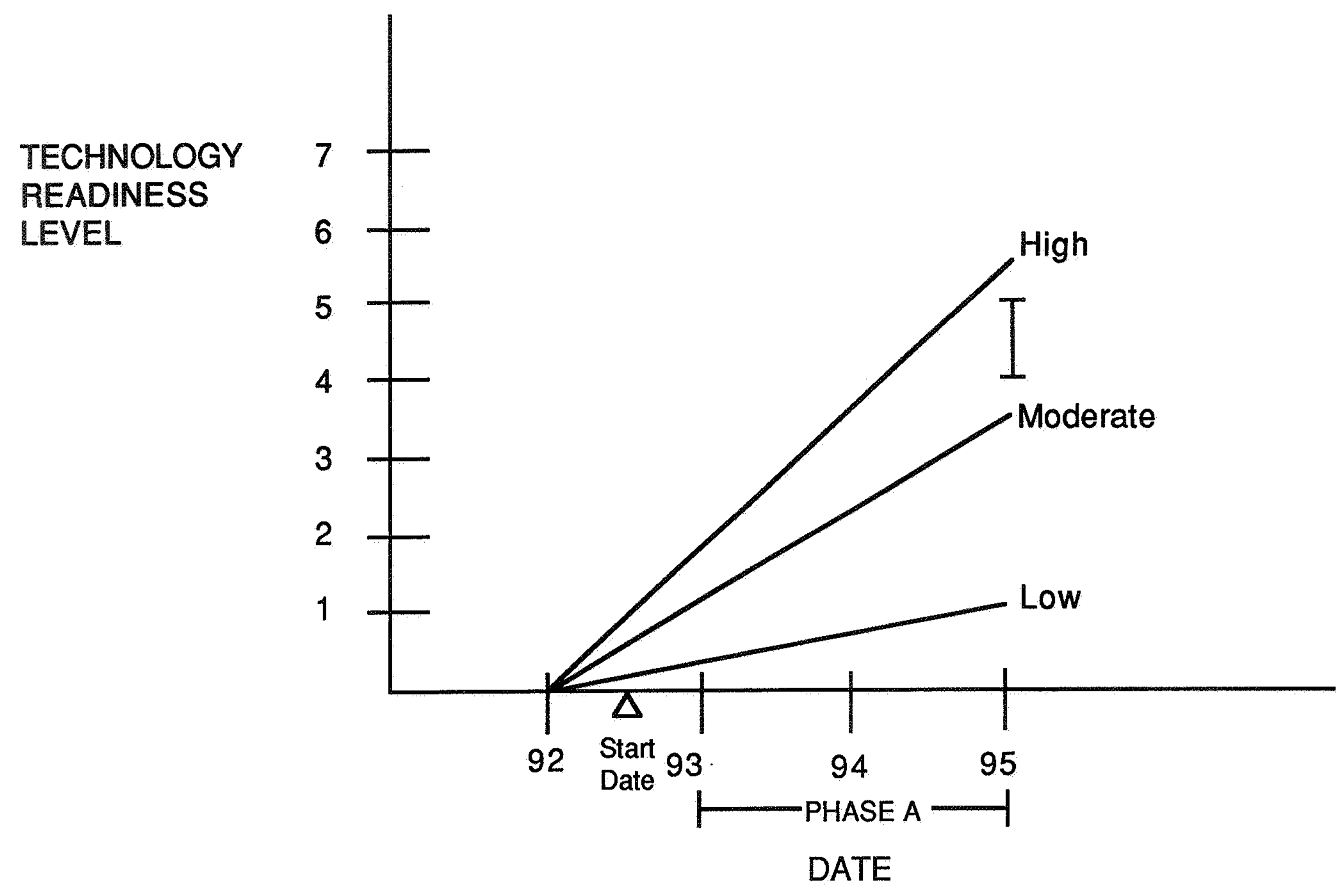
1. A thoroughly documented linear dynamic model of the Assembly Complete Station and the instrumentaiton system for health monitoring.
2. An analysis capability for design and assessment of multiple interacting control systems on a flexible vehicle.
3. Design approaches and prototype hardware for load alleviation and isolation (for microgravity management).
4. A comprehensive, nonlinear structural dynamic model of the Assembly Complete and evolutionary station configurations.
5. An analysis capability for nonlinear slosh of fluids in low gravity.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

STRUCTURES AND MATERIALS

STRUCTURAL DYNAMICS / CSI

TECHNOLOGY ASSESSMENT



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TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL SYSTEM TECHNOLOGY DISCIPLINE

JANUARY 19, 1990

DR. WILBERT E. ELLIS, CHAIRMAN
JOHNSON SPACE CENTER

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

TECHNOLOGY DISCIPLINE SUMMARY FOR *THERMAL CONTROL*

To support the required evolutionary Space Station capabililites, *the thermal* control system must accommodate up to a fourfold increase (300 KW) of heat loads. Utilization of the baseline technology to accommodate the growth requirement will significantly impact:

- Radiator deployed area and associated sweeping volume,
- EVA assembly time,
- Orbiter manifesting penalties,
- Orbital and ground operational support, and
- Maintenance and repair operations.

Cost effective growth of the evolutionary thermal control system requires the:

- Heat rejection system size increase be reduced,
- Capability of the heat acquisitions and transport systems be increased,
- System assembly, monitoring and controls be *more* automated,
- Passive heat rejection techniques be improved, and
- Essential analytical tools be developed.

A comprehensive technology program, which will enable the necessary thermal technologies to meet the Space Station evolution need has been defined with development plans for *three different (High, Moderate,* and Low) funding levels.

BACKGROUND

SCOPE: A high capacity and long life heat rejection subsystem that will be used to minimize required increase of radiator area, to decrease or eliminate EVA radiator assembly/maintenance time and to reduce radiator launch penalties.

OBJECTIVES: To develop a high capacity and long life heat rejection subsystem which will utilize (1) elevated radiator operating temperature and stable coating properties to maximize the heat flux capability of the radiator, (2) thermal storage to accommodate peak load without additional radiator area, (3) long life and robotic assembly compatible radiator panels to reduce EVA time, and (4) decreased radiator weight and stowage volume to reduce launch penalties.

JUSTIFICATION: The evolutionary heat rejection subsystem must increase its capacity to match increased Station power levels. Utilization of the baseline technology to accommodate the increaed capacity will require a very large radiator area increase which not only will generate significant launch weignt, stowage and EVA assembly time penalties but also result in orbiter docking approach constraints, structural interference with power and/or habitat modules and thermal interference with attached payloads. Furthermore, current coating and insulation materials will degrade with time by atomic oxygen depletion, solar radiation, ionizing radiation and micrometeoroid and debris impacts. With the increased number of radiator panels, maintenance (change out) of the radiator panels will become a major drain of the crew time and productivity. A heat rejection with higher heat flux, longer life and lower weight must be developed to mitigate all these impacts.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL *HEAT REJECTION*

PROGRAM PLAN

APPROACHES:

1. Develop a high density heat storage subsystem for heat loads leveling.
2. Develop a extended-life surface coating to allow for radiator design with begining of life properties.
3. Develop high thermal conductance between thermal bus and radiator panels.
4. Develop a high efficiency heat pump which will significantly increase radiator temperature without incurring a substantial power penalty.
5. Develop a high temperature and high capacity heat pipe to accommodate high temperature radiator operation.
6. Develop higher micrometeoroid/debris tolerant radiator panels to reduce maintenance and repair.
7. Develop robotic radiator assembly techniques with closer tolerance to reduce EVA.
8. Develop a light-weight, high-conductivity and high-strength materials for radiator fin and heat pipe.

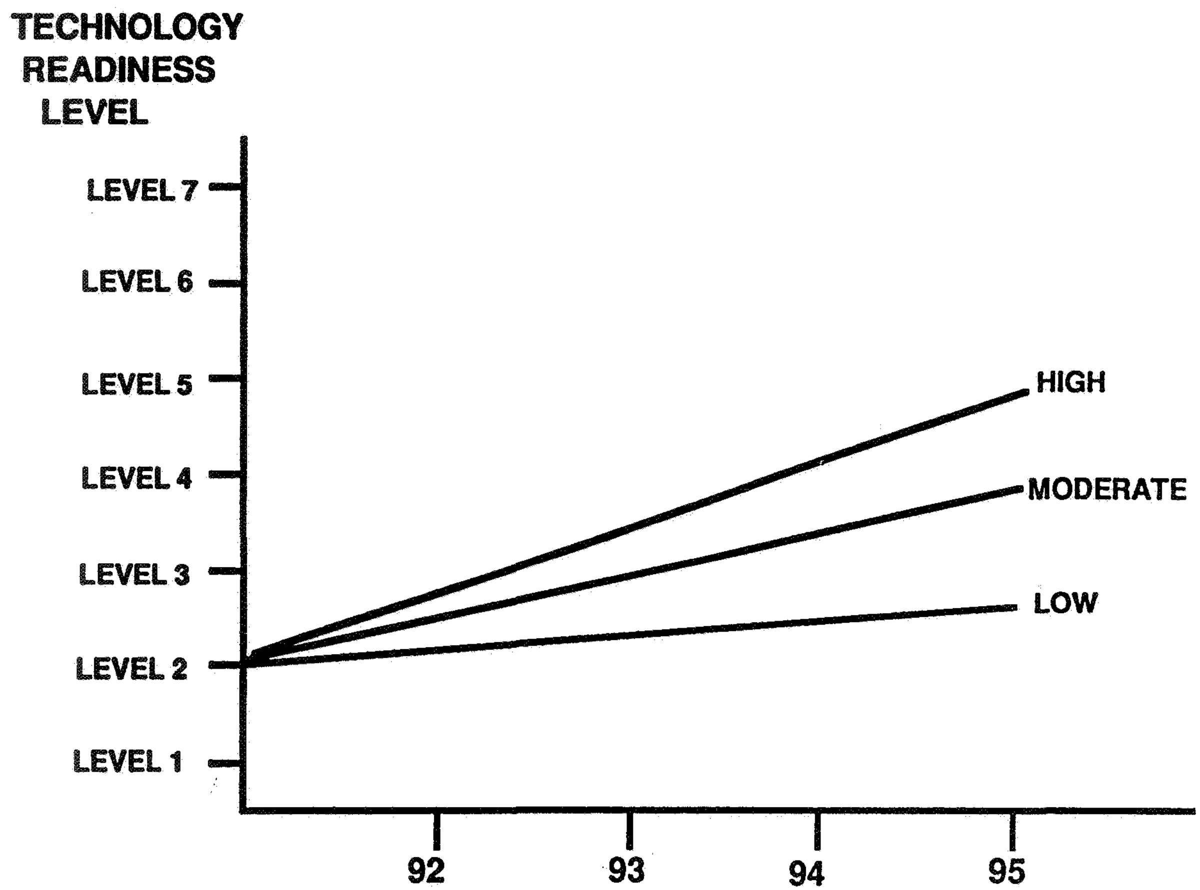
DELIVERABLES:

1. Heat rejection technologies that will enable a high capacity (up to 300KW) Space Station heat rejection subsystem with required increase of radiator area minimized, EVA radiator asembly/maintenance time decreased or eliminated and radiator launch penalties reduced.
2. A technology demonstration preprototype which will be used to support DDT&E of the evolutionary Space Station heat rejection subsystem.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL *HEAT REJECTION*

<u>TECHNOLOGY ASSESSMENT</u>



A WORKSHOP

BACKGROUND

SCOPE: A highly efficient and robust 2-phase heat acquisition and transport subsystem which will accommodate incremental growth to a total capacity of 175 KW and/or 300 KW, and will provide active thermal control to attached payloads and service facilities.

OBJECTIVES: To develop a high efficient (in weight, power, EVA assembly time and cost) and robust two-phase flow heat acquisition and transport subsystem which will utilize (1) high heat flux capacity, long life heat exchage devices, (2) efficient active thermal control for attached payloads and service facilities, (3) very low leakage quick disconnects and transport lines, (4) robotic compatible ORU's, and (5) pumps with lower power consumption and longer life.

JUSTIFICATION: The evolutionary heat acquisition and transport subsystem requires a significant increase of the heat exchange devices and complex extensions of the transport lines to provide active thermal control to additinal modules, attached payloads and service facilities. Utilization of the baseline technology to accommodate the growth requirement will impose a very large increase in weight, power and EVA assembly time penalties, as well as potential for intolerable environmental contamination due to ammonia leakage from the increased line length and complexity of plumbing network. A heat acquisition and transport system with higher heat flux, longer life heat exchangers, less leakage lines and quick disconnects must be developed to provide efficient active thermal control to the growth Space Station equipment and payloads.

PROGRAM PLAN

APPROACHES:

1. Develop high heat flux, low pressure drop heat exchange devices for the two-phase thermal bus evaporators and condensers.
2. Improve materials compatibility of NH3 and H2O heat exchangers.
3. Continue development of payload thermal bus for active cooling of attached payloads and/or service facilities.
4. Develop very low leakage quick disconnects and non-permeating ammonia lines whcih are compatible with robotic assembly.
5. Develop automation and robotics compatibility for other thermal bus ORU's.
6. Develop two-phase flow thermal bus pumps with a lower power consumption and a longer mean time between failures.

DELIVERABLES:

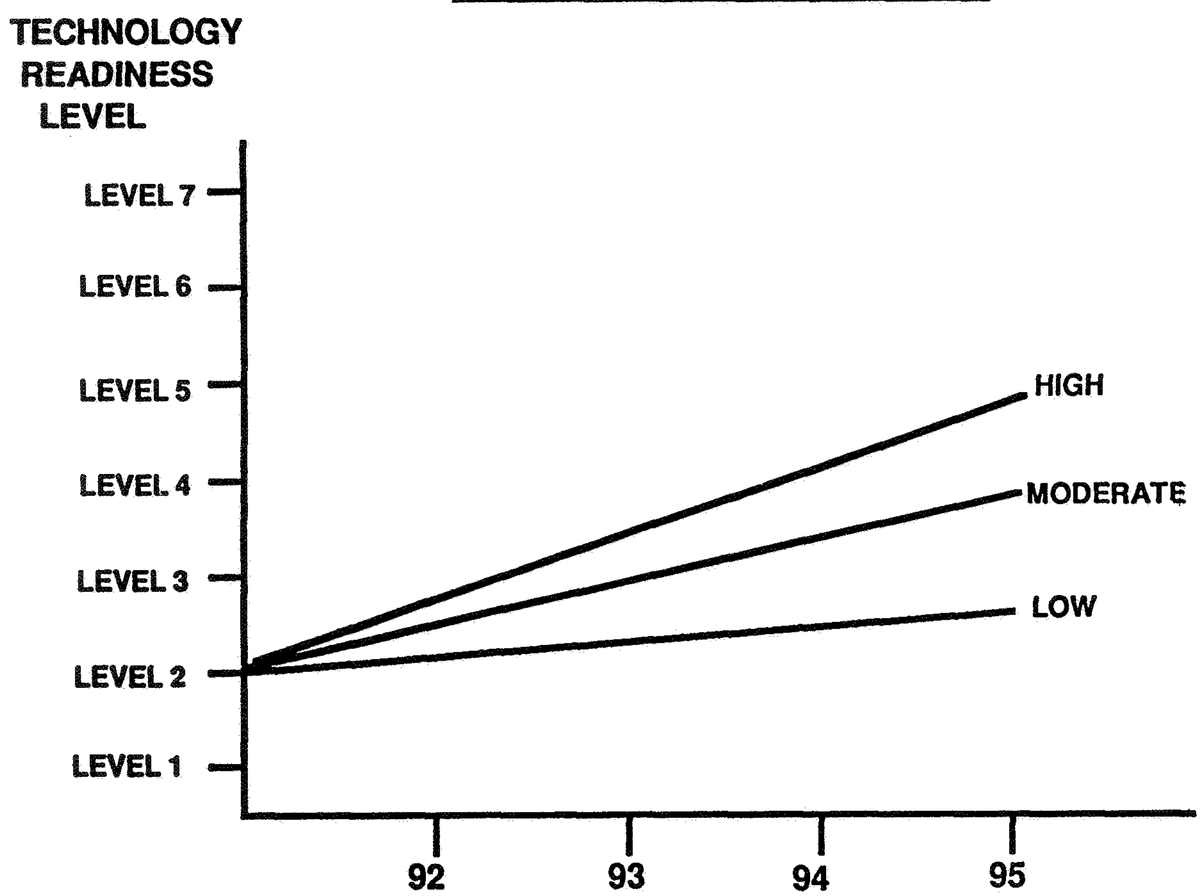
1. Heat acquisition and transport technologies that will enable a highly efficient and robust Space Station therrmal bus.
2. A technology demonstration preprototype which will be used to support DDT&E of the evolutionary Space Station heat acquisition and transport subsystem.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL

HEAT ACQUISITION AND TRANSPORT

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

BACKGROUND

SCOPE: A fully automated monitoring and control subsystem which will reduce crew and ground support needed for the operation and failure detection, isolation and recovery (FDIR) of the thermal control system.

OBJECTIVES: To develop a fully automated monitoring control subsystem which will incorporate AI/Expert System technology to perform normal operation control, failure detection, isolation and recovery, system performance trend analysis and predicion of unscheduled maintenance for the thermal system. The monitoring and control subsystem will interface with the crew and ground support through the Space Station Data Management and Operation Management Systems.

JUSTIFICATION: The evolutionary Station thermal control system will have increased complexity with growth in the quantity of hardware components and complexity in system architecture. Utilization of the baseline automatic control techniques to accommodate the growth requirements will result in a significant increase of crew and ground support required for operation and FDIR of the thermal control system. A fully automated thermal control system incorporating AI/Expert System technology will alleviate the required crew and ground support, thus increse productivity and reduce the operational cost of the evolutionary Space Station. Furthermore, the monitoring and control subsystem based on AI/Expert System will be able to perform system trend analysis and predict unscheduled maintenance to prevent failure of aging equipment to increase crew productivity and safety.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL *MONITORING & CONTROL*

PROGRAM PLAN

APPROACHES:

1. Incorporate AI/Expert System technology into monitoring and control of the thermal control system. The thermal control technology community will work hand-in-hand with the AI technology community in this development.
2. Improve instrumentation for measurements of two-phase flow rate and quality and for accurate remote sensing of surface temperatures.
3. Develop reliable automatic leak detection and position identification and isolation techniques.

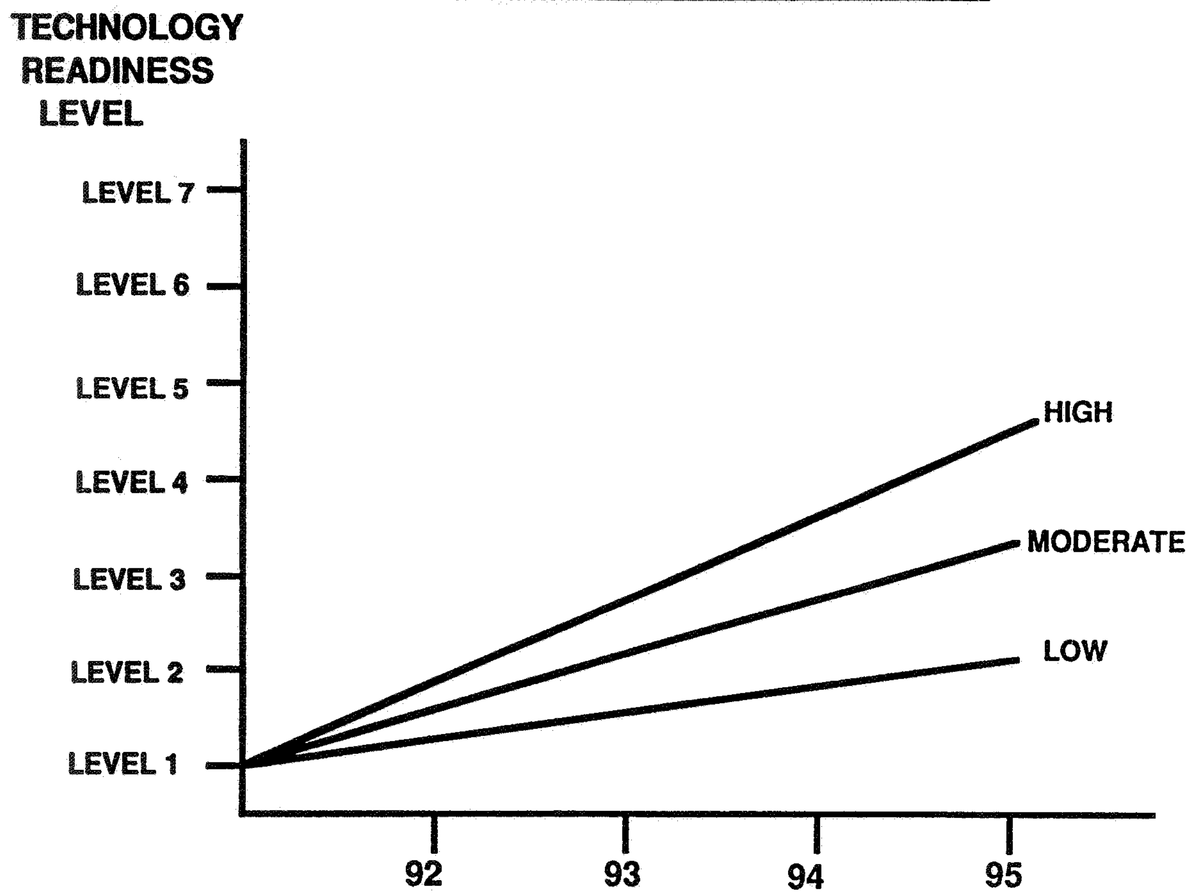
DELIVERABLES:

1. AI/Expert System based monitoring and control technology which will enable a fully automated monitoring and control subsystem for the evolutionary Space Station thermal control system.
2. A technology demonstration preprototype which will be used to support DDT&E of the monitoring and control subsystem for the evolutionary Space Station thermal control system.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL *MONITORING & CONTROL*

TECHNOLOGY ASSESSMENT



BACKGROUND

SCOPE: Passive thermal control devices to accommodate higher passive heat loads and to reduce maintenance and electrical heater requirements.

OBJECTIVES: To develop high capacity passive thermal control techniques such as long-life and high performance surface coating and insulation materials to accommodate higher passive heat loads, and flexible heat pipes for load sharing to reduce heater power consumption.

JUSTIFICATION: The evolutionary Station passive thermal control system must accommodate higher heat loads associated with growth of attached payload requirements. Utilization of the baseline passive control techniques to meet the growth requirements will result in a significant increase of passive radiator area. The increase in area may not be allowed due to interference with the required views to space of the attached payloads. Furthermore, the baseline coating and insulation materials will degrade with time by atomic oxygen depletion, solar radiation, ionizing radiation and micrometeroid/debris impact, longer-life materials are required to reduce the EVA time for refurbishment of passive thermal control components.

PROGRAM PLAN

APPROACHES:

1. Develop coating and insulation materials less sensitive to space environment.
2. Improve surface properties of the coating materials.
3. Develop passive load-sharing techniques , such as flexible, variable conductance heat pipes, for reduction of heater power requirements.

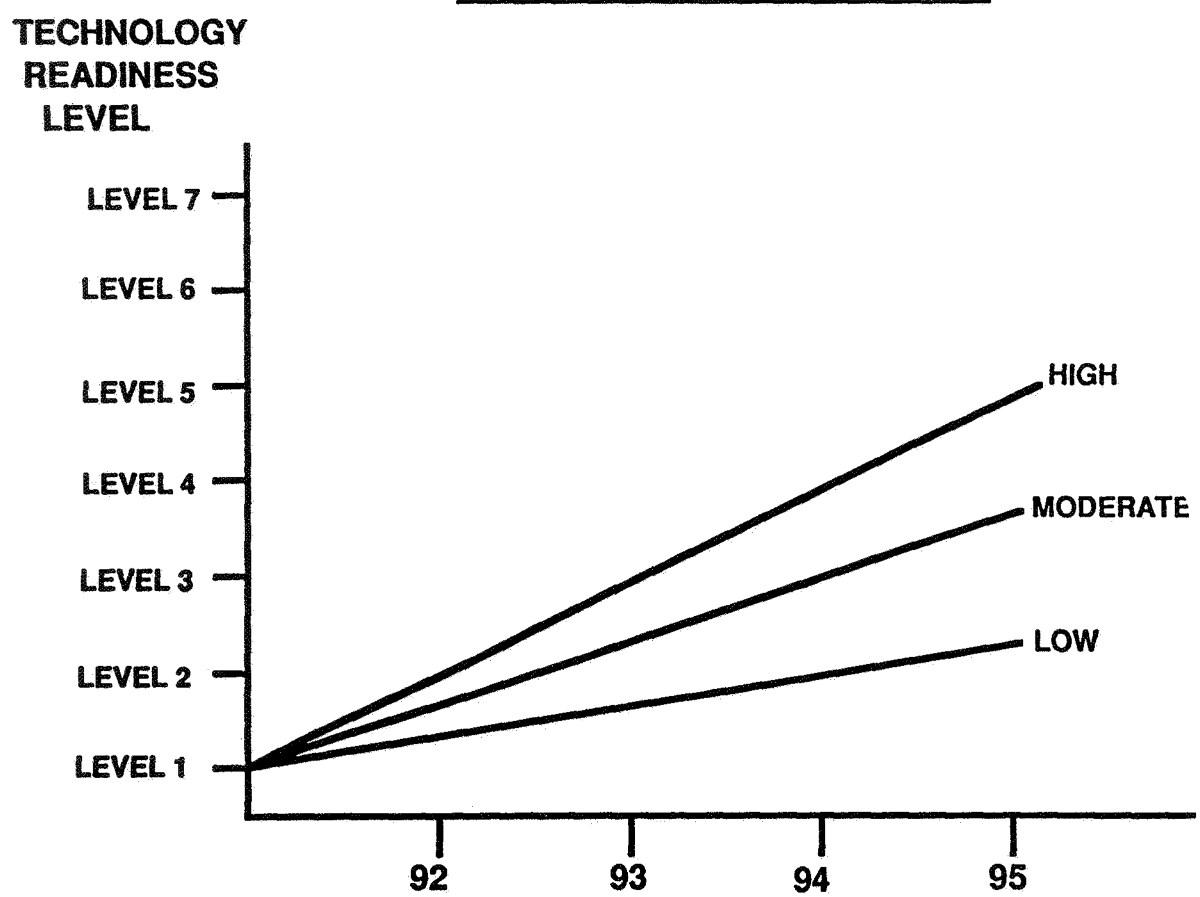
DELIVERABLES:

1. Passive thermal techniques which will accommodate higher heat loads with minimized increase of radiator area, and longer material durability.
2. A technology demonstration preprototype which will be used to support DDT&E of the evolutionary Space Station passsive thermal control.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL *PASSIVE THERMAL CONTROL*

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

BACKGROUND

SCOPE: A capability to accurately predict performance of growth Space Station thermal control components and system, with analytical tools which have been verified with test data.

OBJECTIVES: To develop fully verified theoretical models and design algorithms which are based on fundamental understanding of two-phase fluid behaviors and heat transfer in microgravity obtained through ground and flight testing. The analysis tools to be developed, enhanced and verified include empirical tools for component/system designs, two-phase flow dynamic simulation tools and integrated system analysis tools.

JUSTIFICATION: Fully verified theoretical models and design algorithms do not exist for two phase fluid flow and associated thermal processes in microgravity, resulting in overly conservative designs for the baseline Space Station thermal control system. Application of the existing analysis tools for the evolutionary thermal control system will incur significant unnecessary weight, power and cost penalties. Development/enhancement of the analytical tools and test verifications of the tools and advanced technology will be the most cost effective way to minimize the conservatism in the design process of the thermal control system.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL *ANALYSIS AND TEST VERIFICATION*

PROGRAM PLAN

APPROACHES:

1. Establish fundmental understanding of two-phase fluid flow behaviors and heat transfer in zero-gravity through ground and flight experiments.
2. Develop new/enhance existing empirical design tools to increase design confidence. Incoporate AI technology into the design tools.
3. Generate a 3-D analytical simuation tool for two-phase flows in microgravity.
4. Improve existing integrated system analysis tools for design conservatism reduction, DDT&E support and flight techniques development.
5. Create central database by compiling data from a wide range of sources to facilitate accuracy and completeness of analytical process.
6. Integrate evolutionary technology hardware into the existing test beds to minimize testing costs.

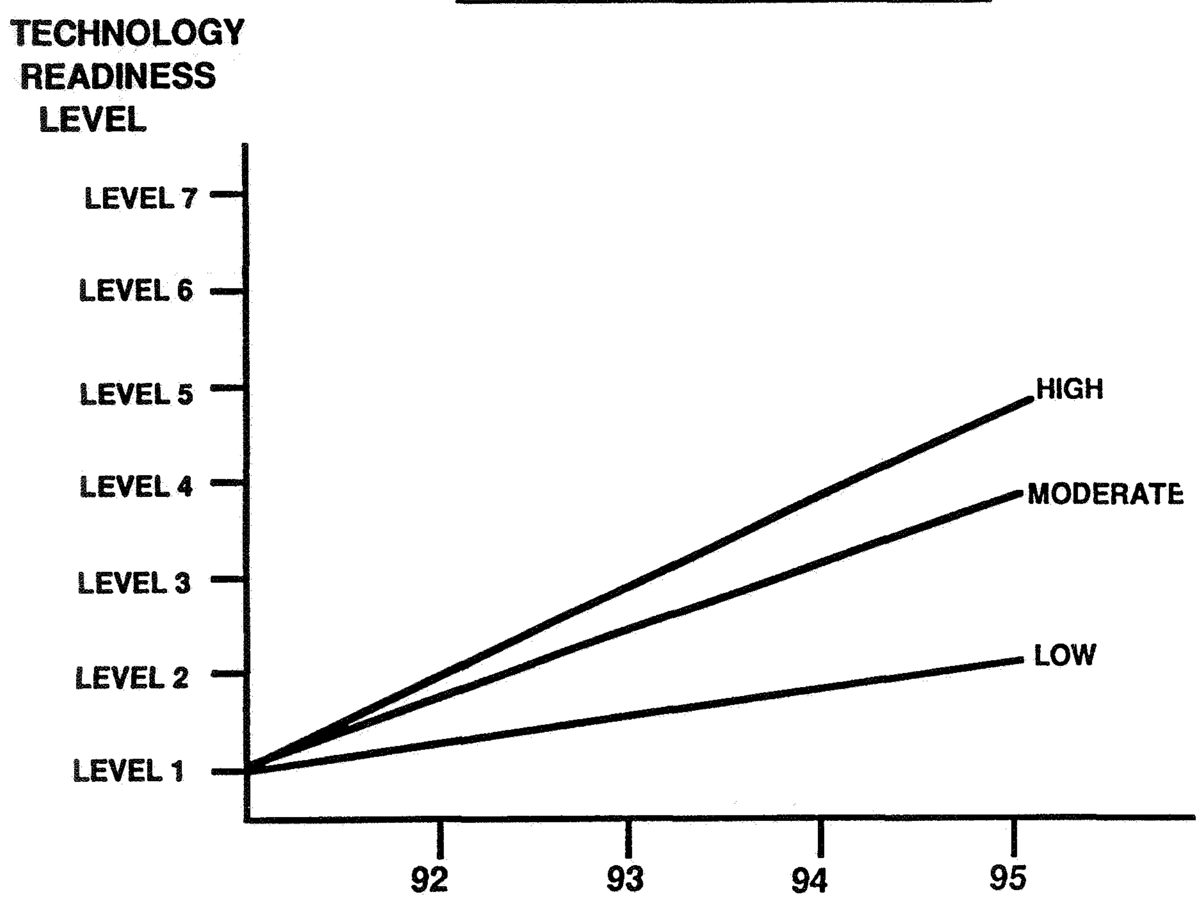
DELIVERABLES:

1. A comprehensive set of test verified analytical tools required to enable efficient design, development, test and evaluation of Space Station evolutionary thermal control system.
2. Testing evaluation of evolutionary thermal control technology.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL *ANALYSIS AND TEST VERIFICATION*

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL

RECOMMENDATIONS

o REDUCE SIZE AND INCREASE LIFE OF GROWTH RADIATOR SYSTEM TO AVOID COSTLY INCREASES ASSOCIATED WITH THE UTILIZATION OF BASELINE TECHNOLOGY

o INCORPORATE AI ROBOTICS TECHNOLOGY INTO THE TCS TO:

- MINIMIZE ORBITAL AND GROUND OPERATION SUPPORT
- INCREASE THE EFFICIENCY OF MAINTENANCE AND REPAIR (E.G., FDIR)
- REDUCE EVA TIME

o DEVELOP ACTIVE THERMAL CONTROL ALTERNATIVES TO ENABLE

- ACTIVE EXTERNAL EQUIPMENT COOLING
- MORE EFFICIENT AND LESS COSTLY HEAT ACQUISITION DEVICES

o INITIATE A MAJOR EFFORT TO DEVELOP AND VALIDATE A COMPREHENSIVE SET OF ANALYTICAL TOOLS TO ENABLE EFFICIENT DESIGN AND EVALUATION OF THE GROWTH THERMAL SYSTEM.

THERMAL CONTROL

ISSUES

- o UTILIZATION OF BASELINE TECHNOLOGY TO MEET GROWTH STATION REQUIREMENTS WILL RESULT IN COSTLY INCREASES OF:
  - DEPLOYED RADIATOR AREA AND ASSOCIATED SWEEP VOLUME
  - EVA ASSEMBLY TIME
  - ORBITER MANIFESTING PENALTIES (WEIGHT & VOLUME)
  - ORBITAL AND GROUND OPERATIONAL SUPPORT
  - MAINTENANCE AND REPAIR OPERATIONS
- o EXISTING ANALYTICAL TOOLS RESULT IN OVERLY CONSERVATIVE DESIGN (I.E., UNNECESSARY WEIGHT, VOLUME AND POWER PENALTIES)
- o DEPENDENCE ON <u>ONLY</u> PASSIVE COOLING OF ALL EXTERNAL EQUIPMENT WILL NOT BE ADEQUATE FOR GROWTH STATION

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TECHNOLOGY FOR SPACE STATION EVOLUTION

A WORKSHOP

KEYNOTE ADDRESS

DR. W. B. LENOIR
ASSOCIATE ADMINISTRATOR
OFFICE OF SPACE STATION
JANUARY 16, 1990

PRESENTATION BY WILLIAM B. LENOIR

TO "TECHNOLOGY FOR SPACE STATION EVOLUTION"

DALLAS, TEXAS

JANUARY 16, 1990

*1 o <u>Starting Point</u> - Assembly Complete - Crucial First step to Evolution
- 8 crew; 75 kw; full distributed systems; International
- Users; materials, life sciences, attached Payloads servicing
- Support; transportation → shuttle, maintenance
- Balanced system

o Reasons for Growth
- More power, better micro-gravity, different staging
- Cheaper, quicker, safer ....

o <u>Current Growth Concepts</u>

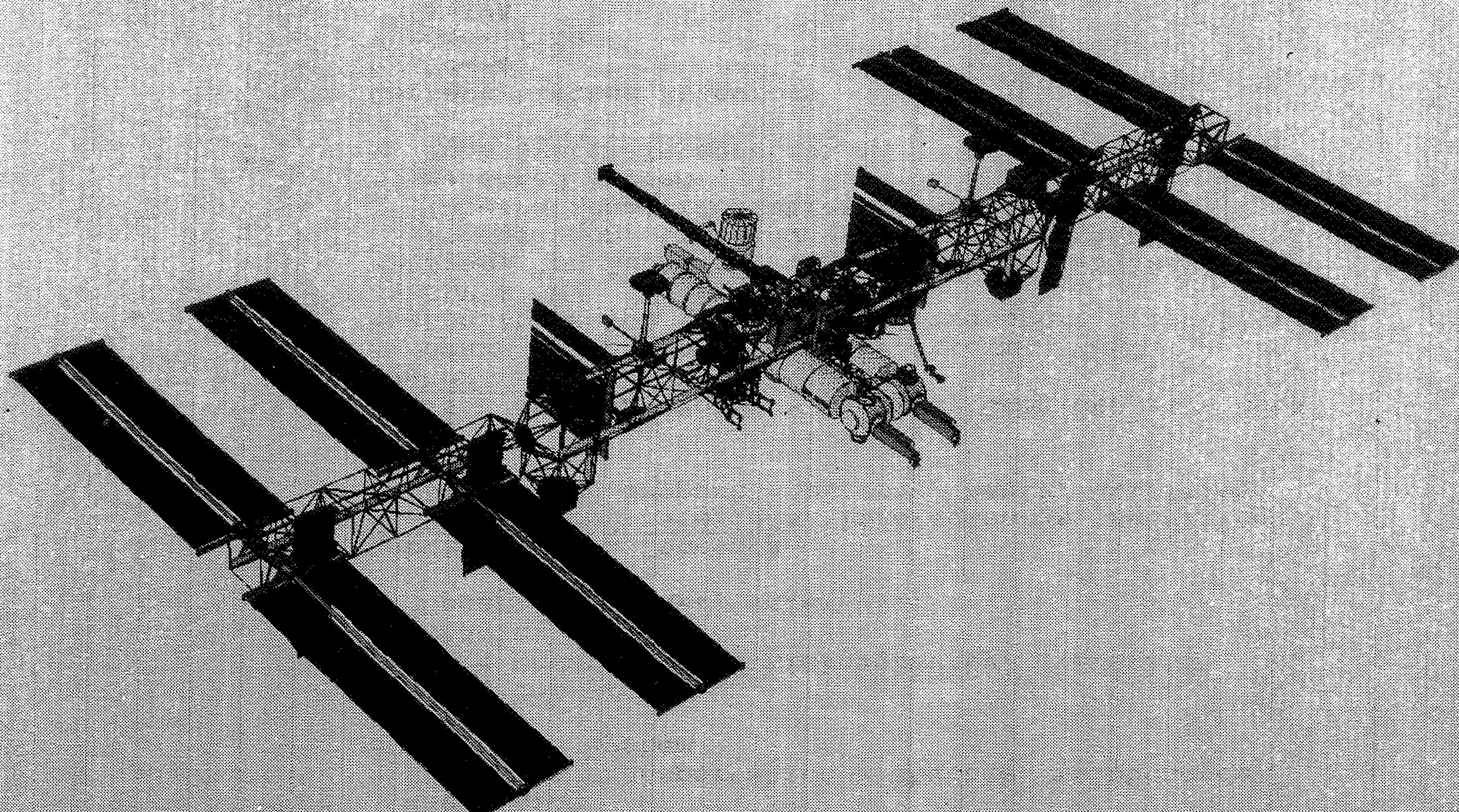
*2 - R&D Station materials, life sciences, servicing
*3 - Lunar/Mars Support - 12 crew, keels, utilities, bays

*4 o <u>Revisit Starting Point</u> - Assembly Complete as a total system
- Space Ops - <u>Manned Base</u>, Platforms, TDRS
- Logistics Ops - Processing, Transport - Shuttle, ELV's OMV
- Space Ops Support - Control Center, Payload Ops integration, training - Systems & Payloads, International facilities, users facilities
- Balanced System

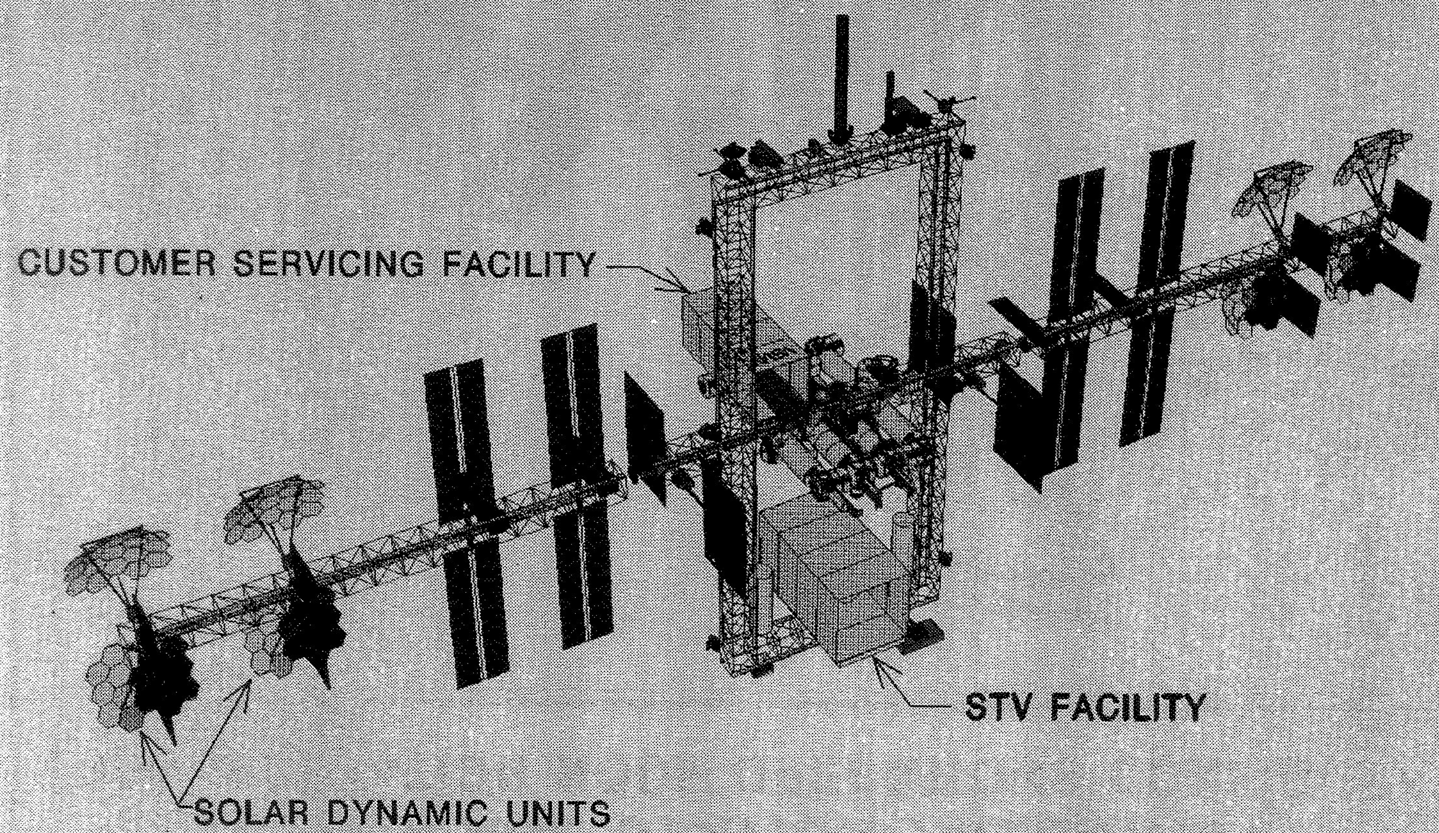
*5 - <u>Full System Integration</u>

o Current Limited Resources
- Power
- Crew Time
  - IVA
    -- Habitation
    -- Training
  - EVA
- Transportation
- Communication and Data
- Personnel
  - Management
  - Engineering
  - Operations Support
- Logistics
- Inter-user Interferences
- Funding

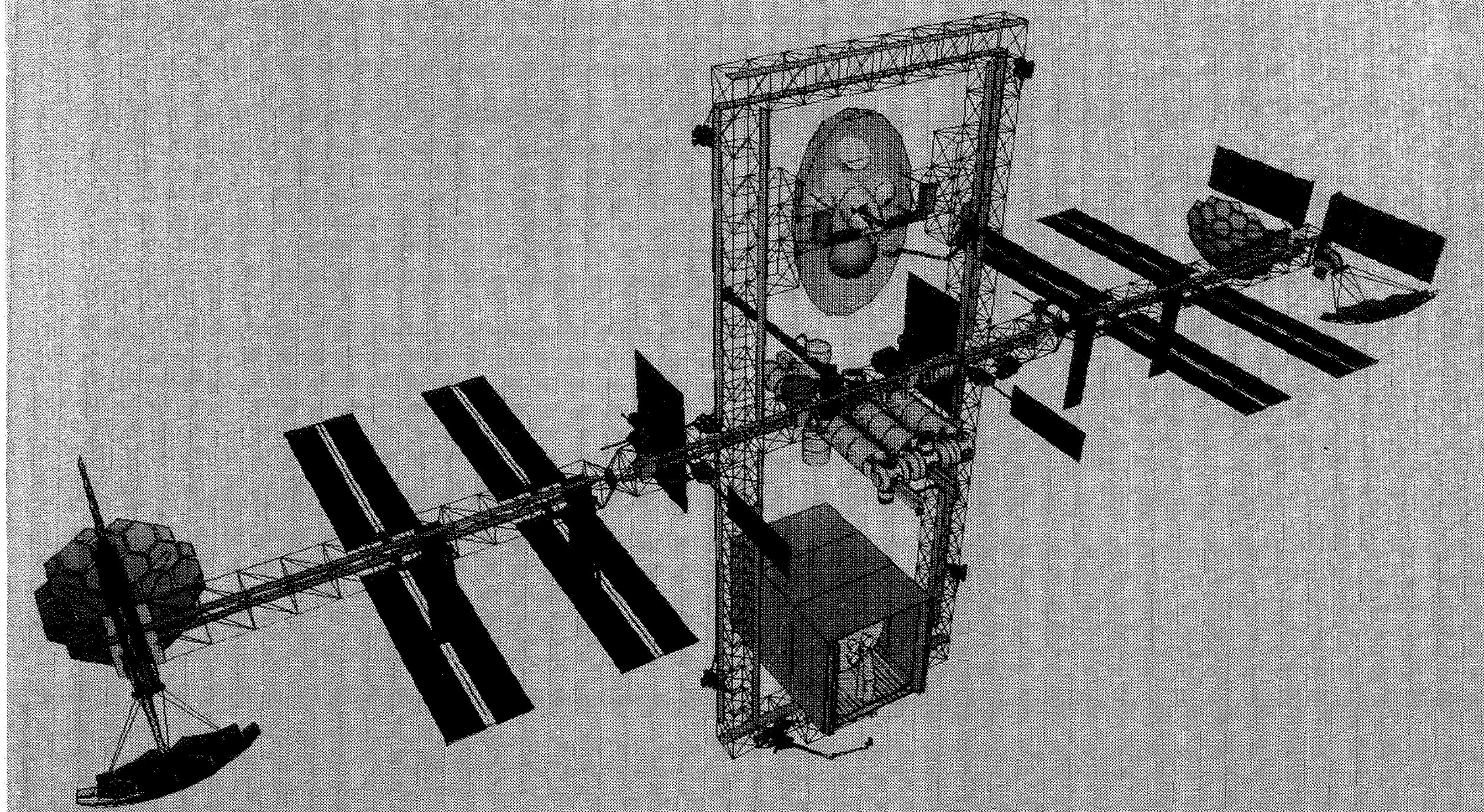
SPACE STATION FREEDOM ASSEMBLY COMPLETE



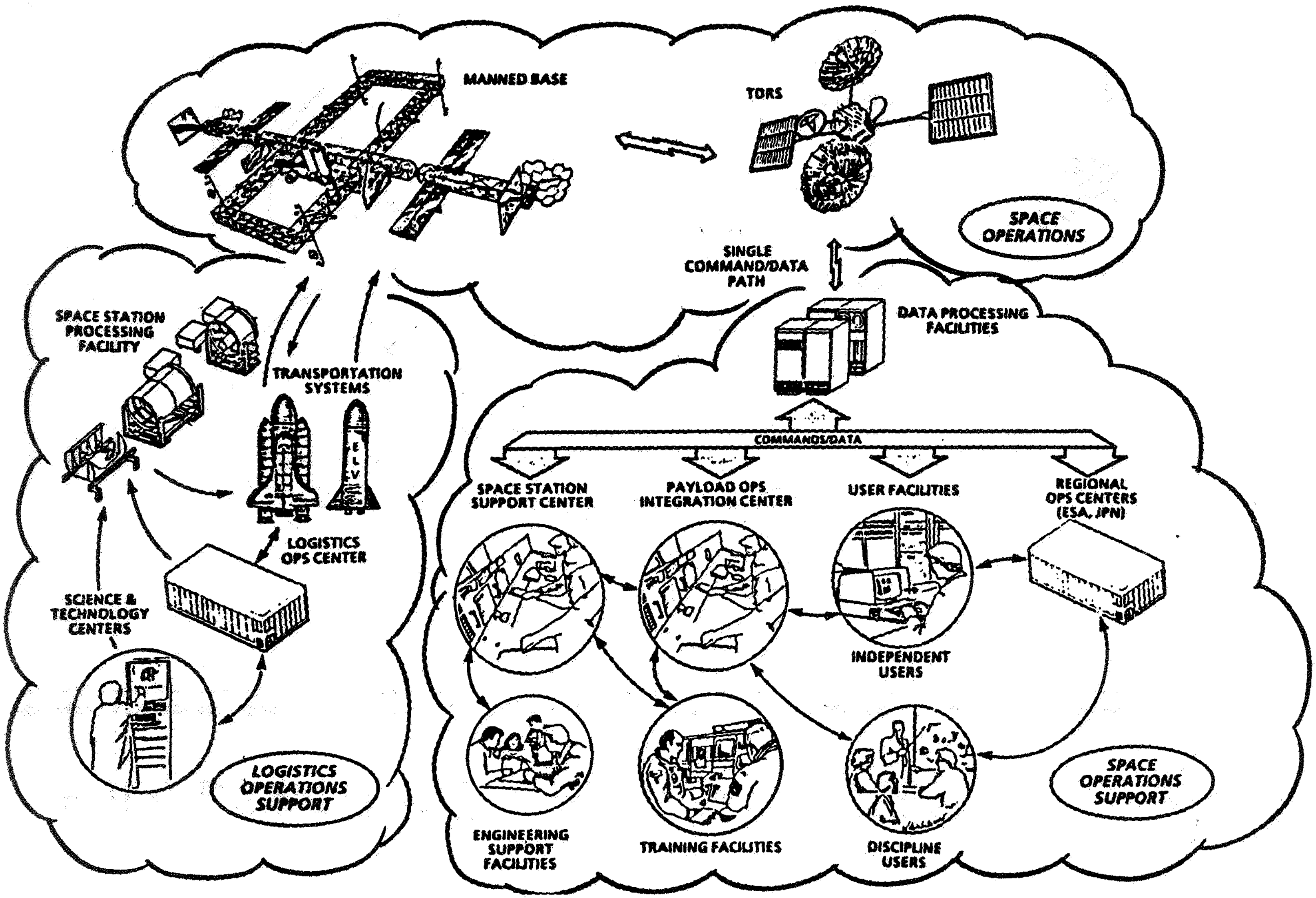
SPACE STATION FREEDOM RESEARCH AND DEVELOPMENT CONFIGURATION



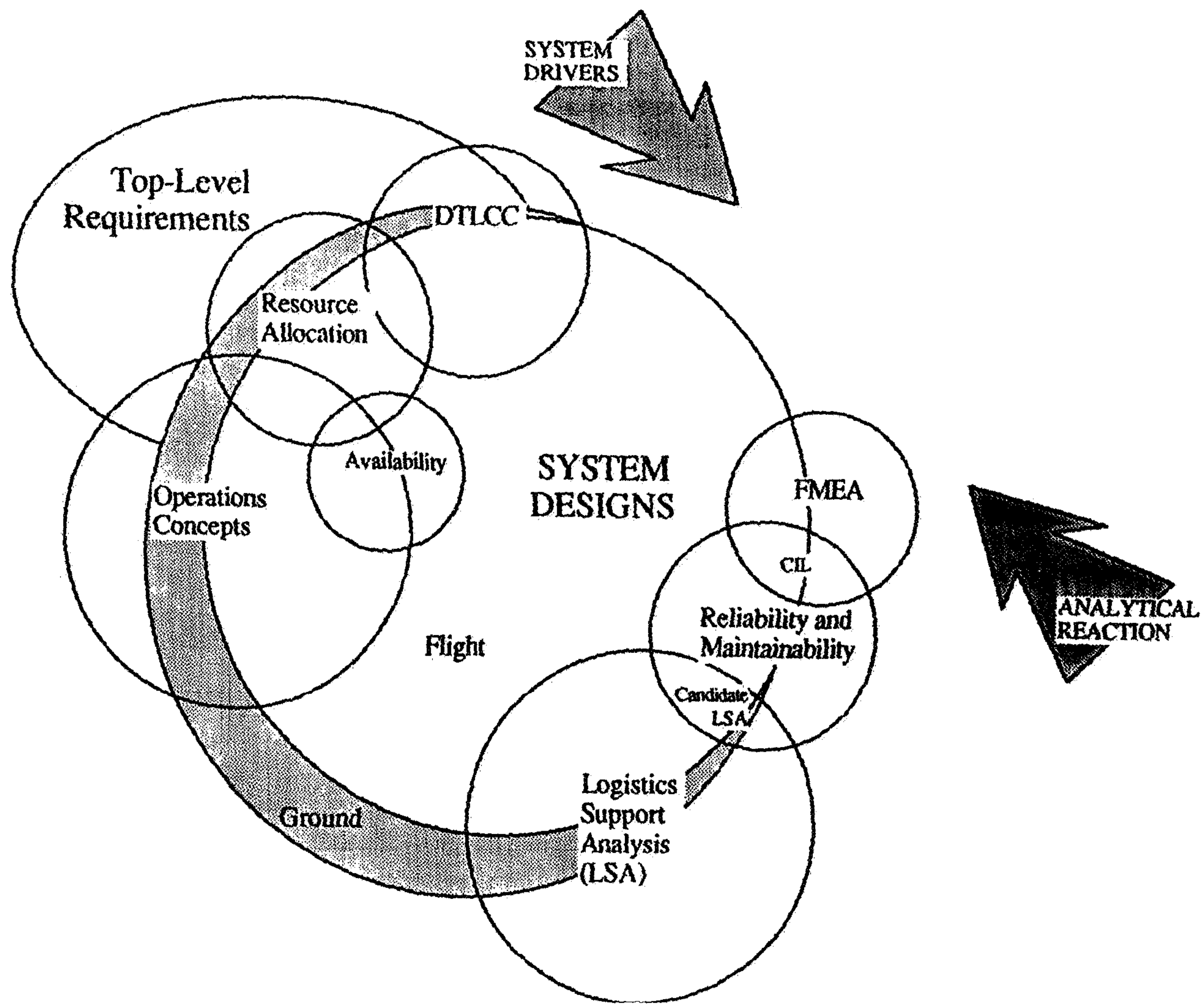
SPACE STATION FREEDOM
TRANSPORTATION NODE OPERATIONS CONFIGURATION



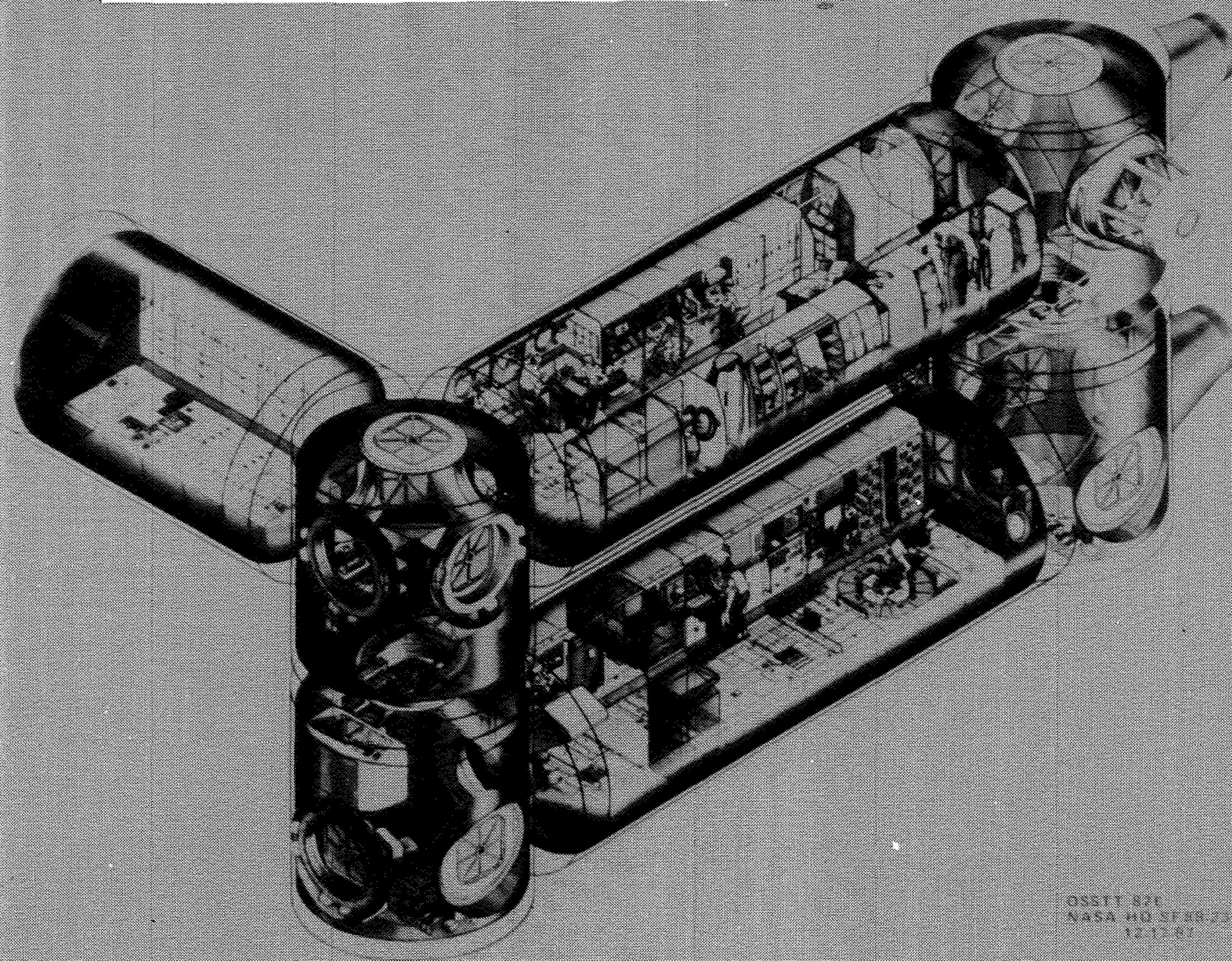
MANNED BASED OPERATIONS INFRASTRUCTURE



FULL DESIGN INTEGRATION CONCEPTS



U.S. SPACE STATION PRESSURIZED MODULES



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National Aeronautics and Space Administration

FREEDOM

SPACE STATION EVOLUTION

• MISSION REQUIREMENTS AND EVOLUTION SCENARIOS •

Presented at the

TECHNOLOGY FOR SPACE STATION EVOLUTION
- A WORKSHOP -

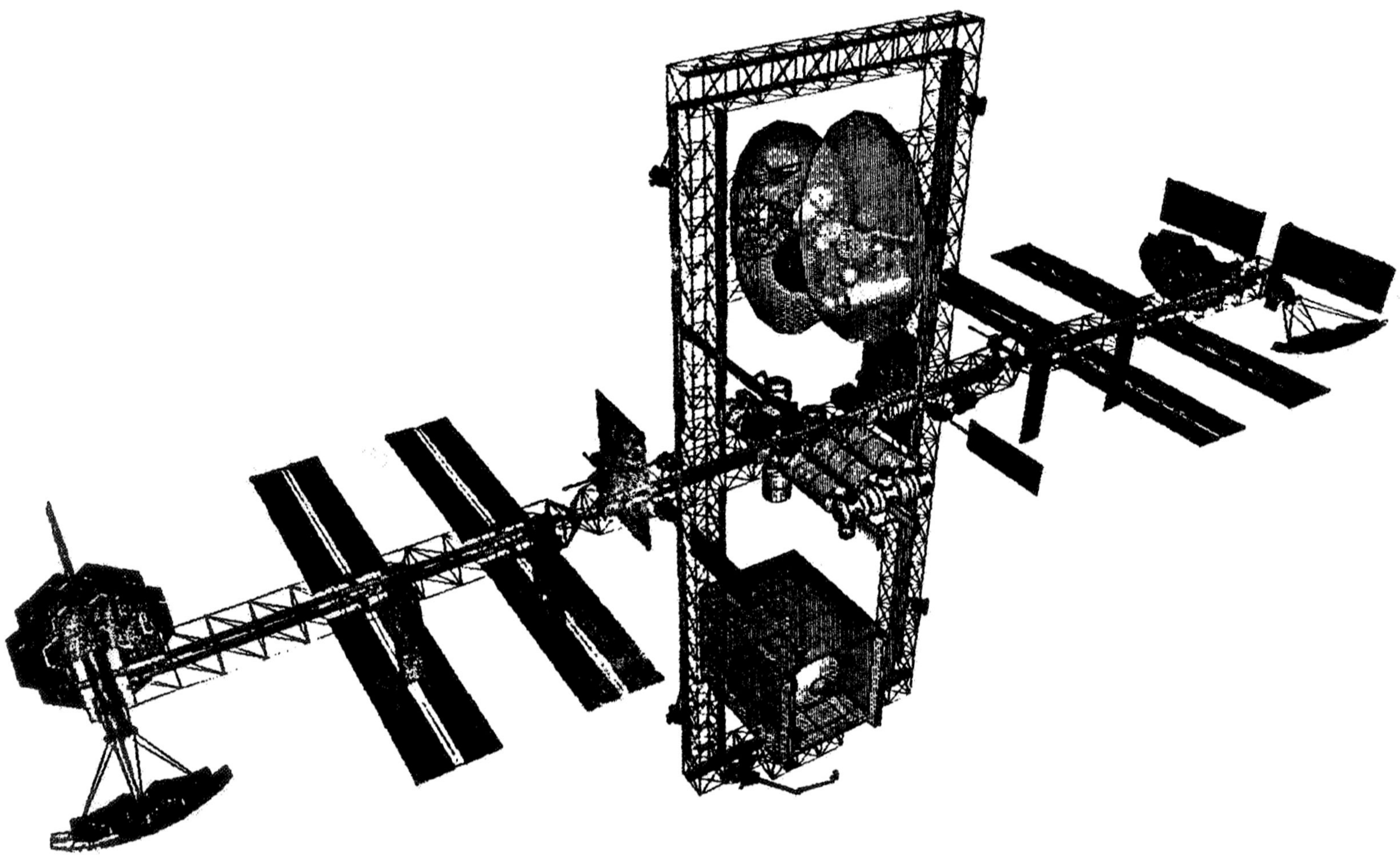
JANUARY 16, 1990

DR. EARLE K. HUCKINS III
Director
Strategic Plans and
Programs Division
Office of Space Station

274

LTV & MTV OPERATIONS CONFIGURATION

FREEDOM



LaRC SSFO EDO

TOPICS

- Space Station Evolution
- Evolution of User Needs
- Evolution Scenarios
- Reference Evolution Configuration

SPACE STATION EVOLUTION

- Space Station is designed to be a permanent facility
- During the long operational lifetime of the Station
  - -- User needs will change
  - -- Technology will evolve/systems will become obsolete
- Space Station configuration, operations, and utilization <u>will</u> be evolved
- Evolution should be a key design consideration
  - -- To meet user needs
  - -- To avoid obsolescence
  - -- To improve productivity/efficiency

DIMENSIONS OF SPACE STATION EVOLUTION

- Technology improvements/ obsolescence avoidance

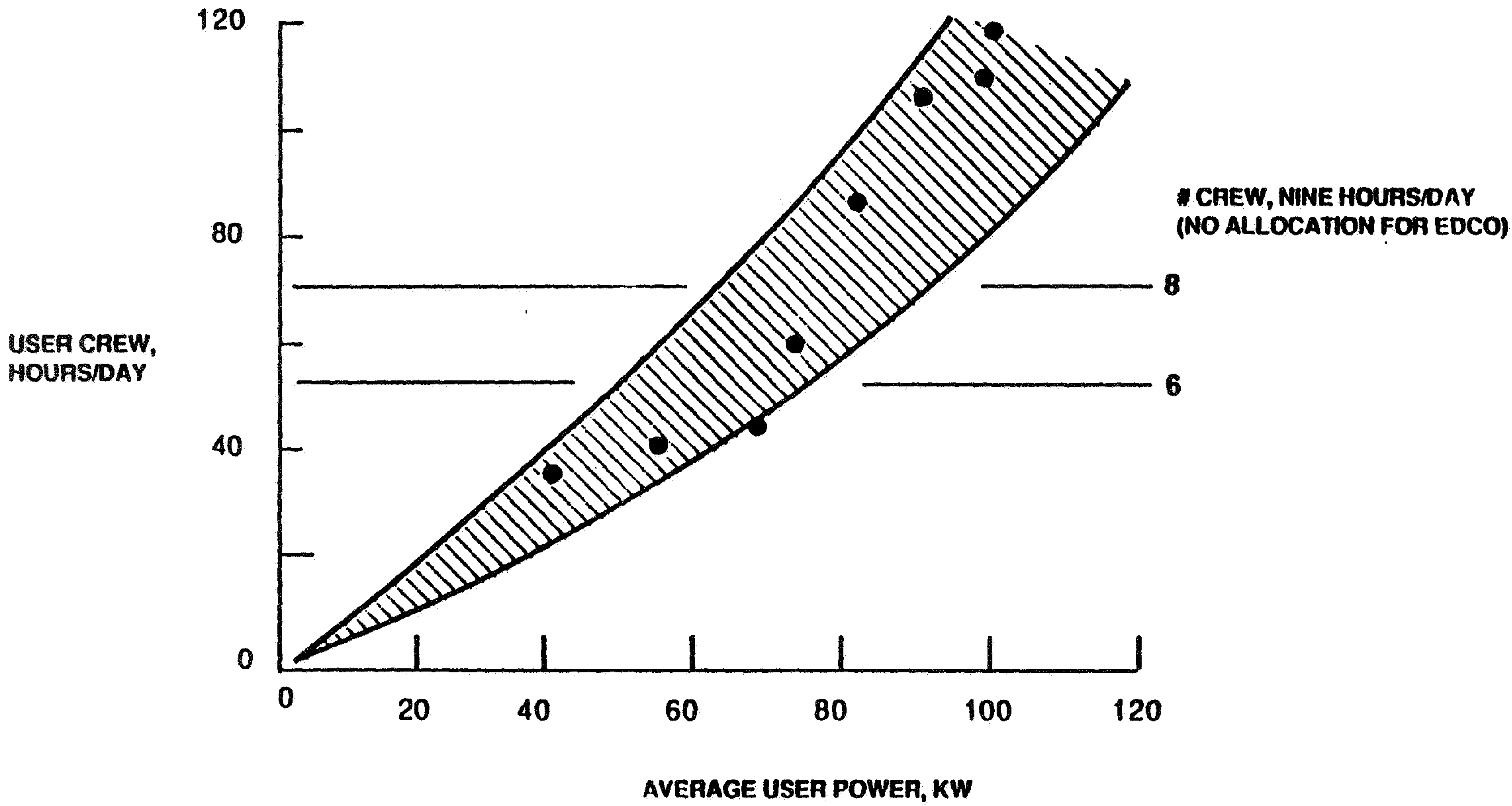
- Expanding existing capabilities

  -- Power
  -- Pressurized volume
  -- Crew time
  -- Attach points
  -- (Etc.)

- Adding new capabilities

  -- Servicing
  -- Assembly

POWER-CREW RELATIONSHIP

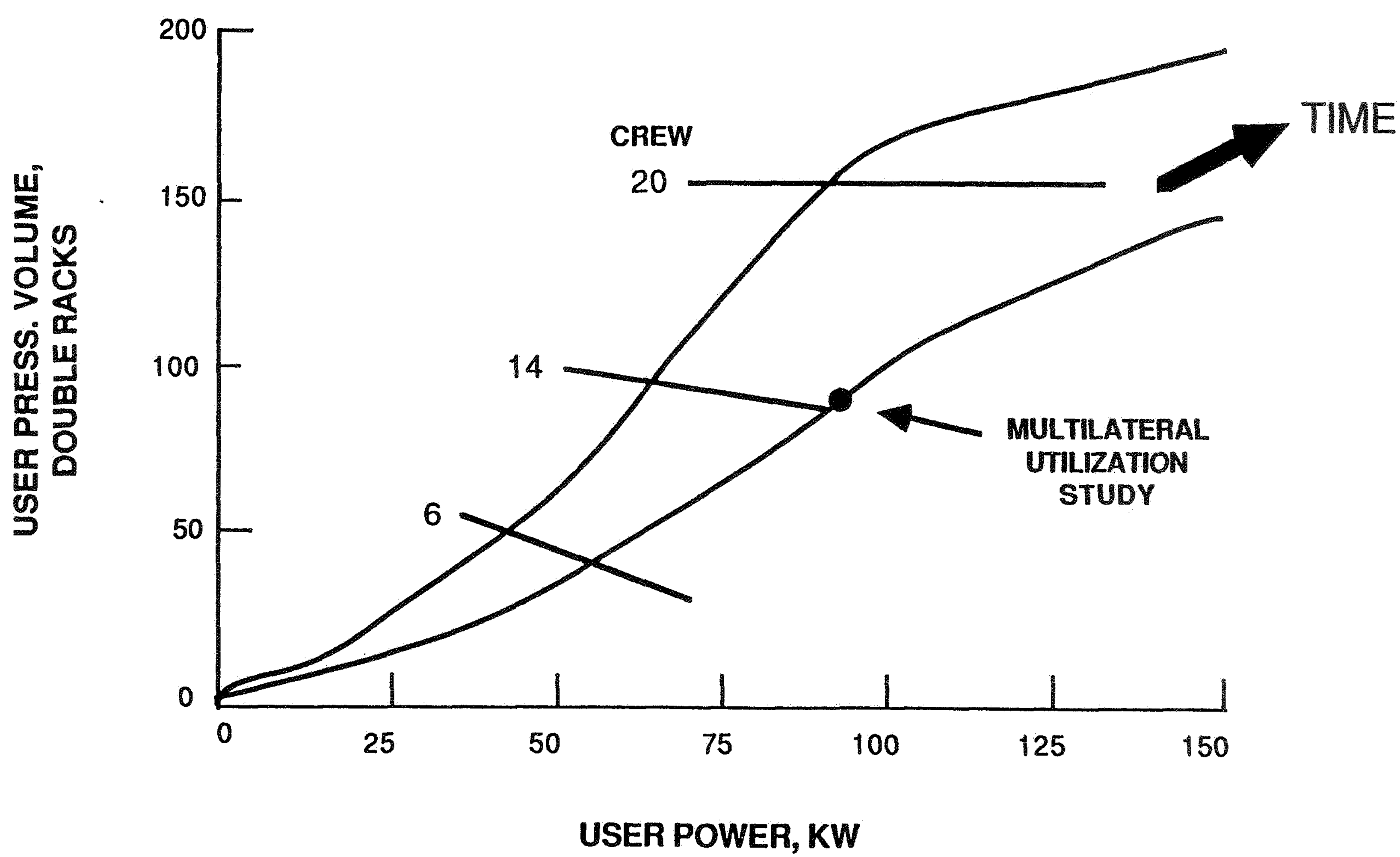


DATA FROM MULTILATERAL UTILIZATION STUDY

"CHINESE MENU" APPROACH

USER POWER, PRESS. VOL. AND CREW

(EVOLUTION MISSION MODEL)



USER NEEDS ASSESSMENT POWER/CREW/PRESSURIZED VOLUME SUMMARY

- USER DEMANDS FOR POWER, CREW AND PRESSURIZED VOLUME CANNOT BE COMPLETELY DECOUPLED
  - BASELINE USER PRESSURIZED VOLUME APPEARS ADEQUATE
  - USER EQUIPMENT OPERATED AT REQUESTED LEVELS AND FREQUENCY RESULTS IN A DEMAND FOR INCREASED POWER (UP TO 100 KW) AND CREW (UP TO 14)
  - BASELINE CREW SIZE APPEARS ADEQUATE FOR USER POWER LEVELS UP TO ABOUT 60 KW
  - LONG TERM EVOLUTION USER NEEDS ARE:
    - 200 DOUBLE RACKS
    - 150 KW
    - 22 CREW

SPACE STATION R&D EVOLUTION SCENARIOS

- Initialization Point is the Phase I Station
- Based on assumed utilization emphasis
  - e.g., Microgravity Research and Commercial Materials Production
- Major goal of the scenario is to accommodate all missions in the emphasis area on schedule
- Fits in other mission areas (e.g., Life Sciences) as resources become available
- Scenario is constrained by Earth to Leo transportation support model

SPACE STATION R&D EVOLUTION SCENARIOS

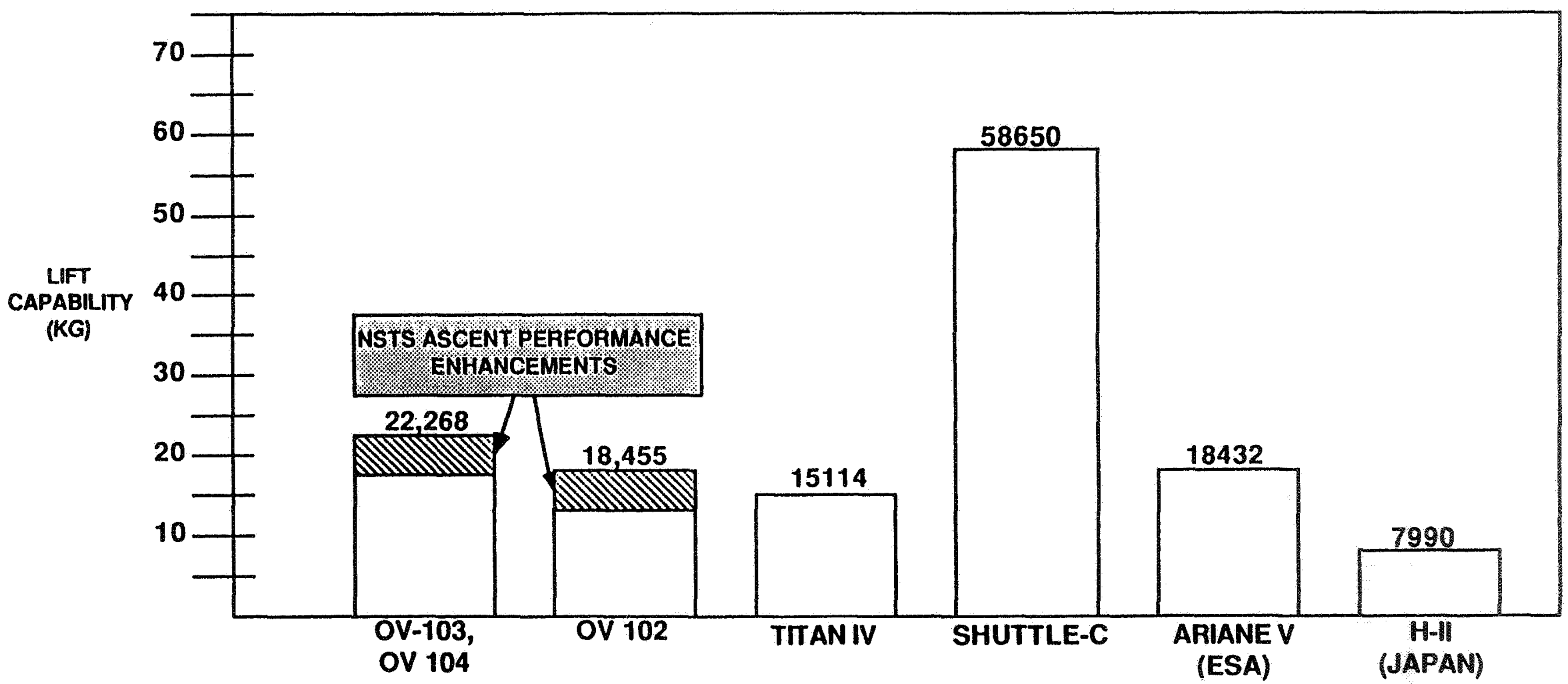
FREEDOM

Scenario	Utilization Emphasis	Transportation Support
1	Microgravity Research	Aggressive
2	Microgravity Research & Materials Production	5 NSTS/yr only
3	" " " "	Moderate
4	" " " "	Aggressive
5	Life Sciences Research	5 NSTS/yr only
6	" " "	Moderate
7	" " "	Aggressive
8	Observational Science	5 NSTS/yr only
9	" "	Moderate
10	" "	Aggressive

EXPLORATION MISSIONS

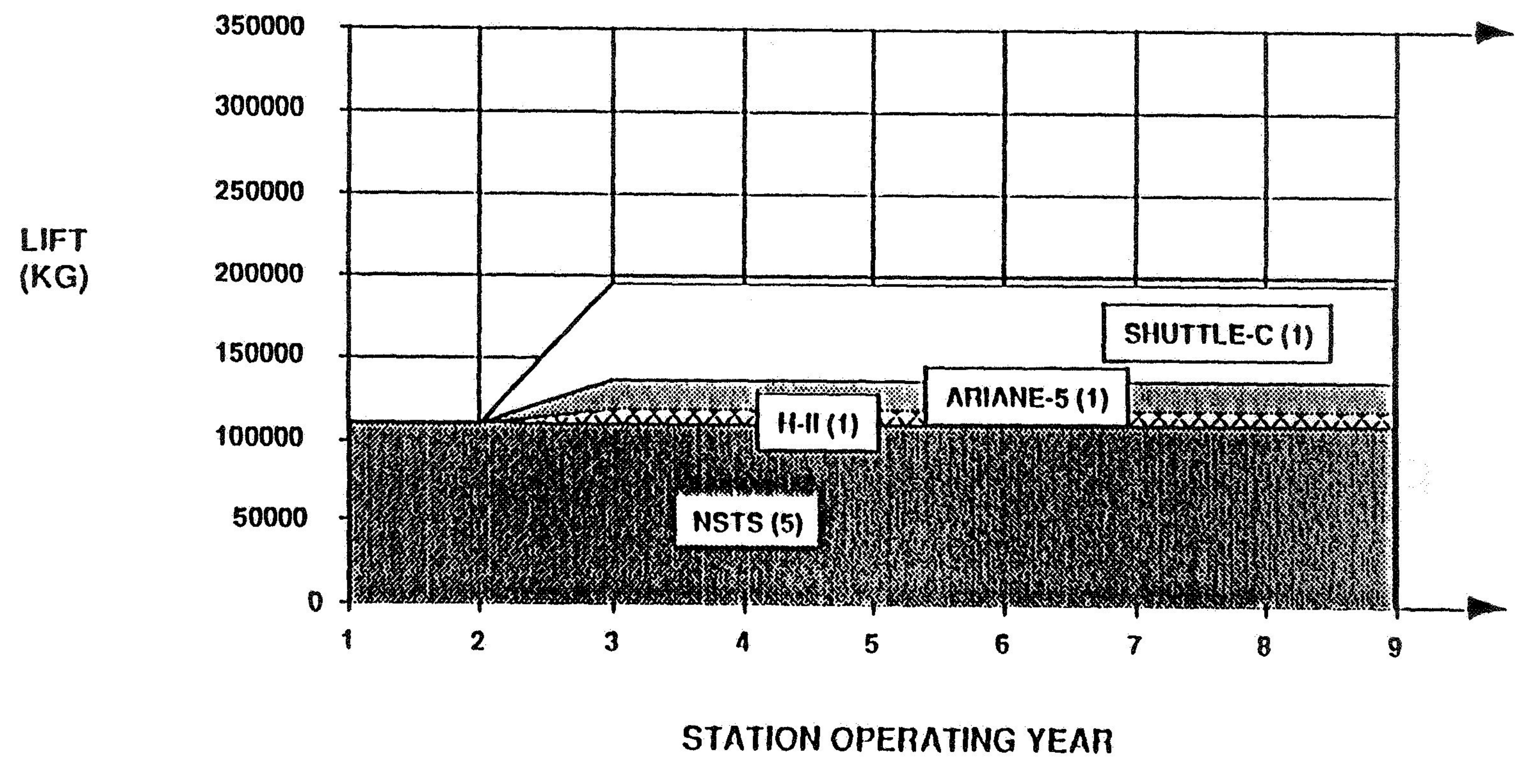
- Precursors
  - Life Science R&D
  - On-orbit processing technology development
  - Vehicle technology development/verification
- Lunar/Mars missions
  - On-orbit processing

TRANSPORTATION SYSTEMS CAPABILITY TO SPACE STATION



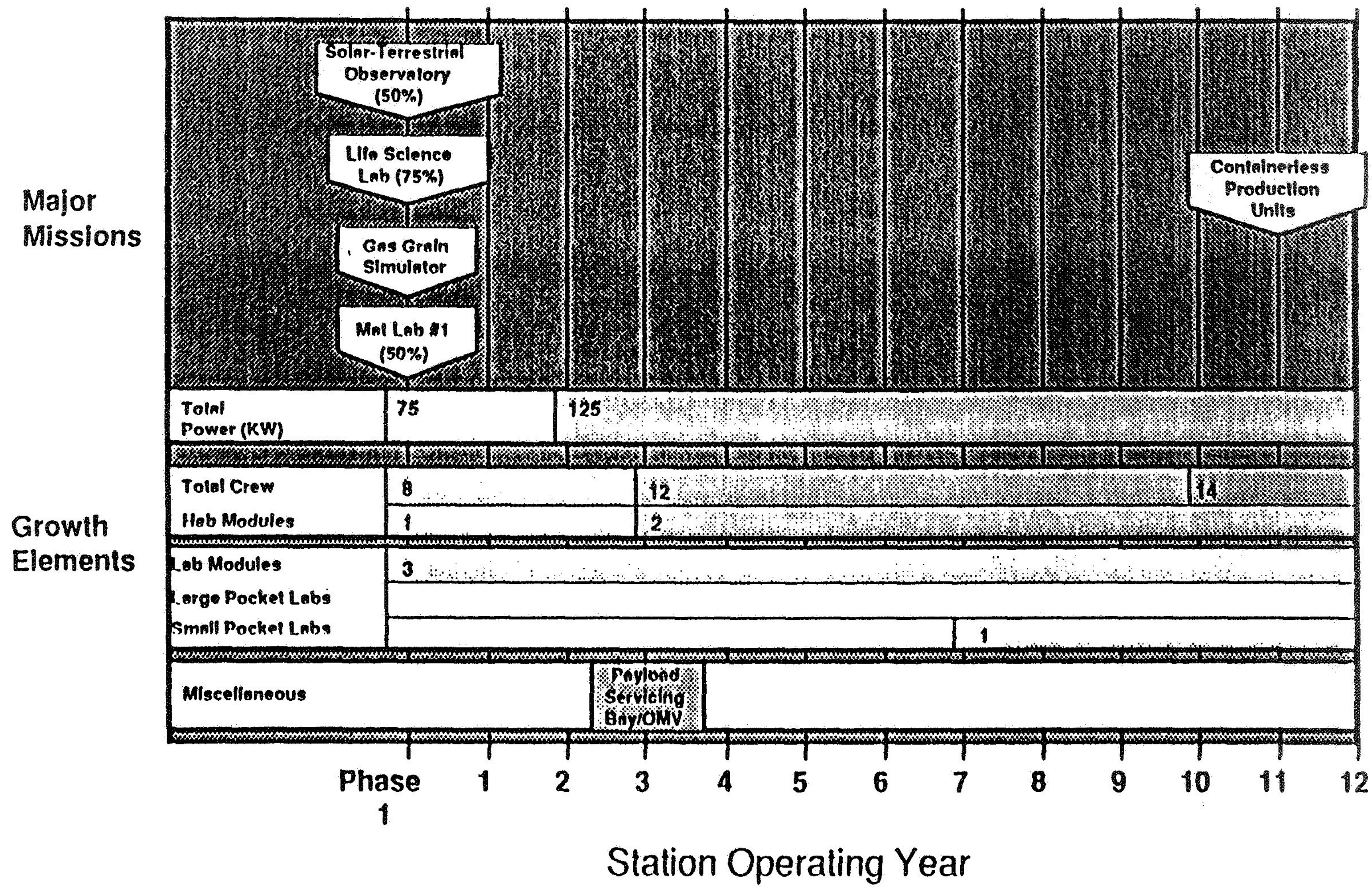
STUDY APPROACH
TRANSPORTATION MODEL
CONTINUED

ModerateTransportation Support



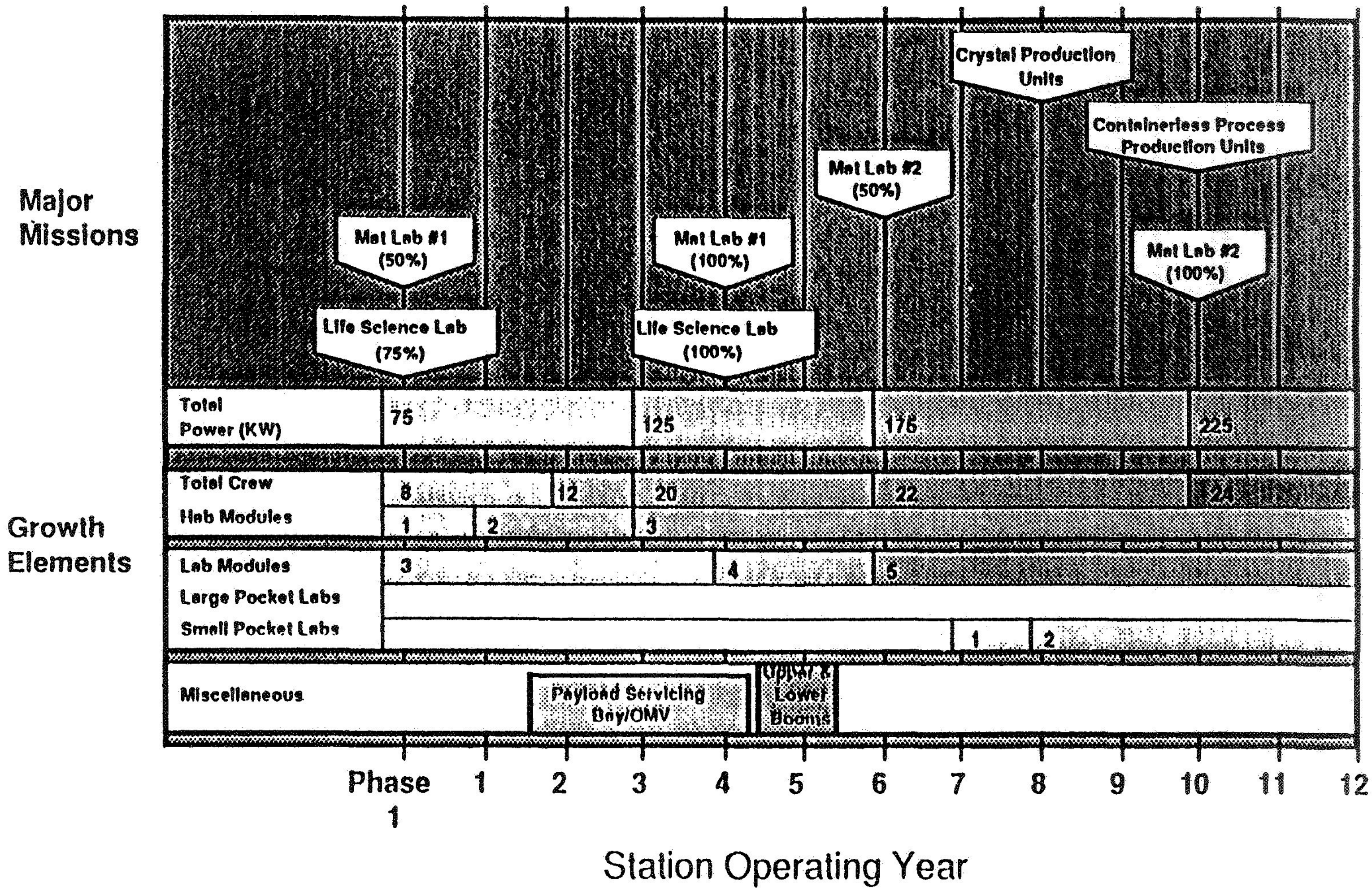
GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



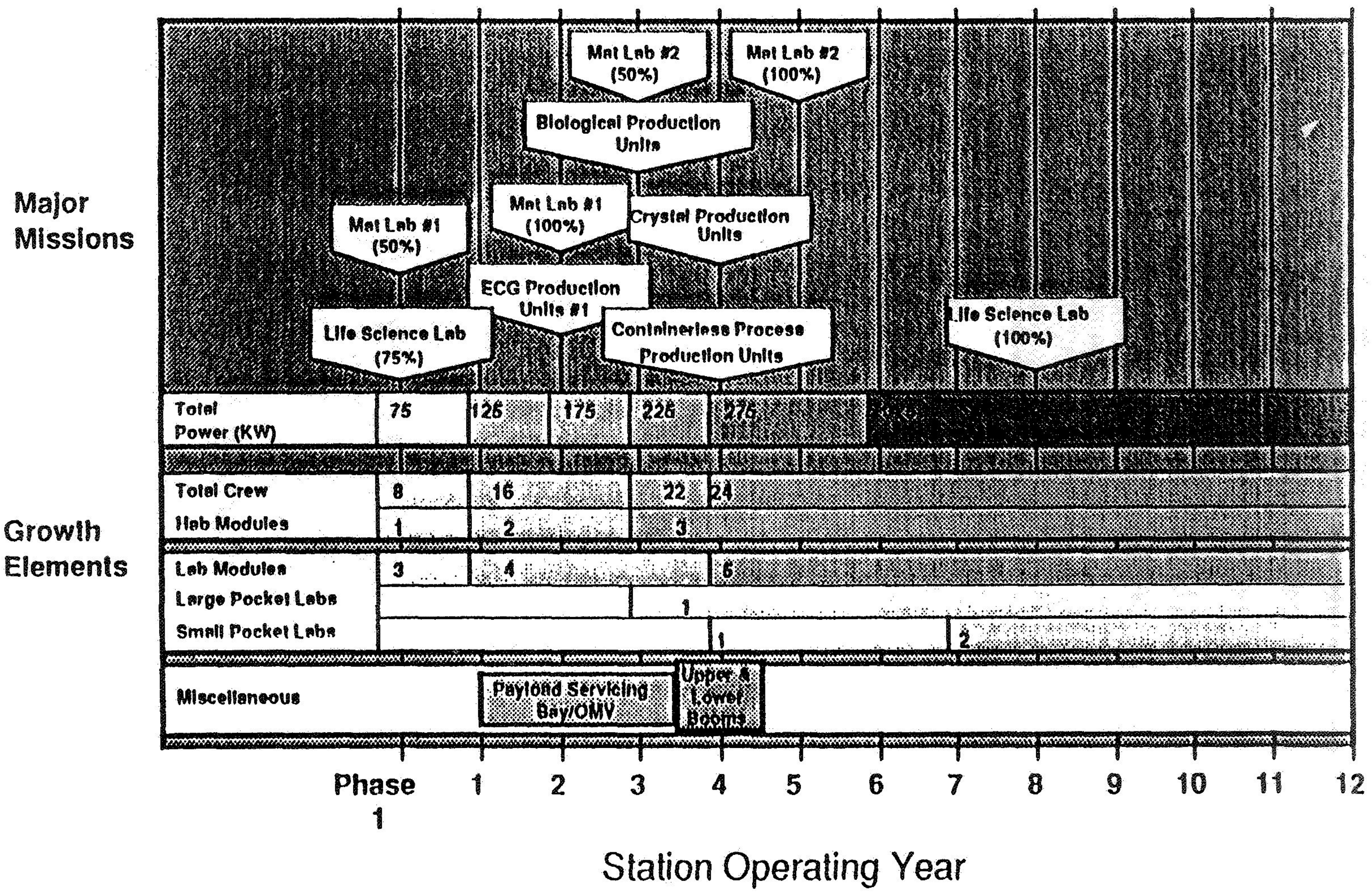
GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



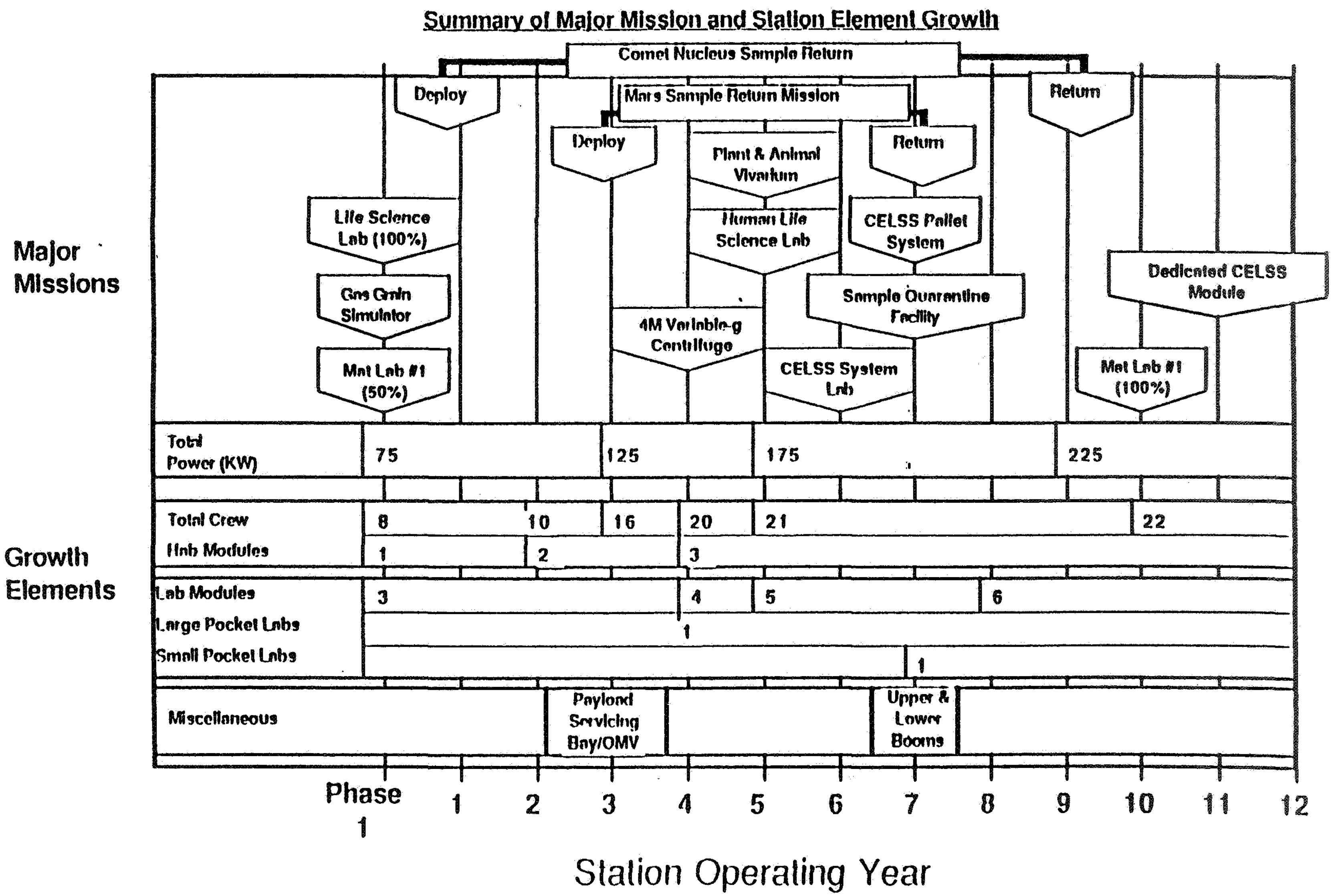
GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



EVOLUTION SCENARIO RESULTS

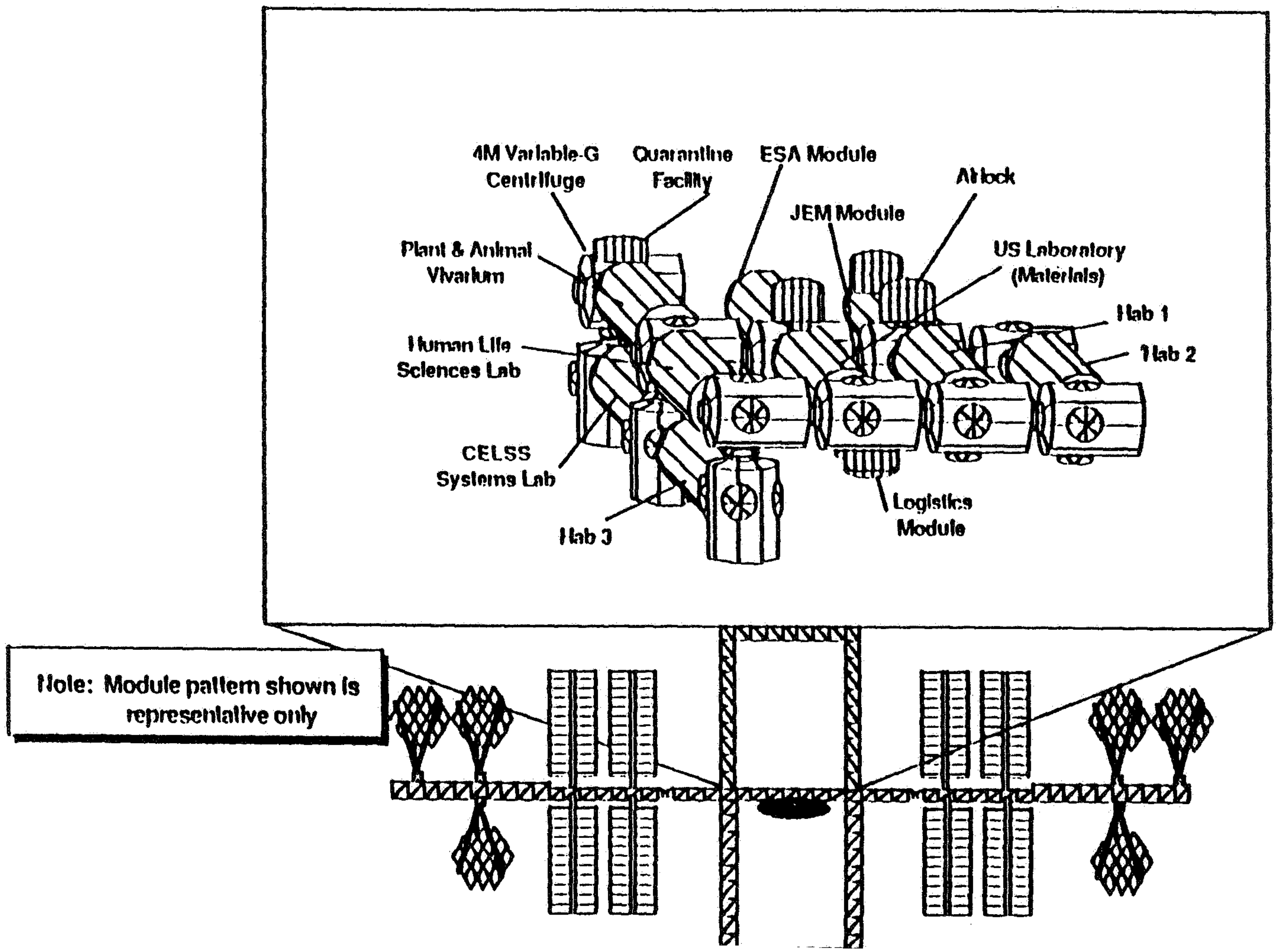
LIFE SCIENCES EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED



EVOLUTION SCENARIO RESULTS

LIFE SCIENCES EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

<u>Final Station Configuration</u>



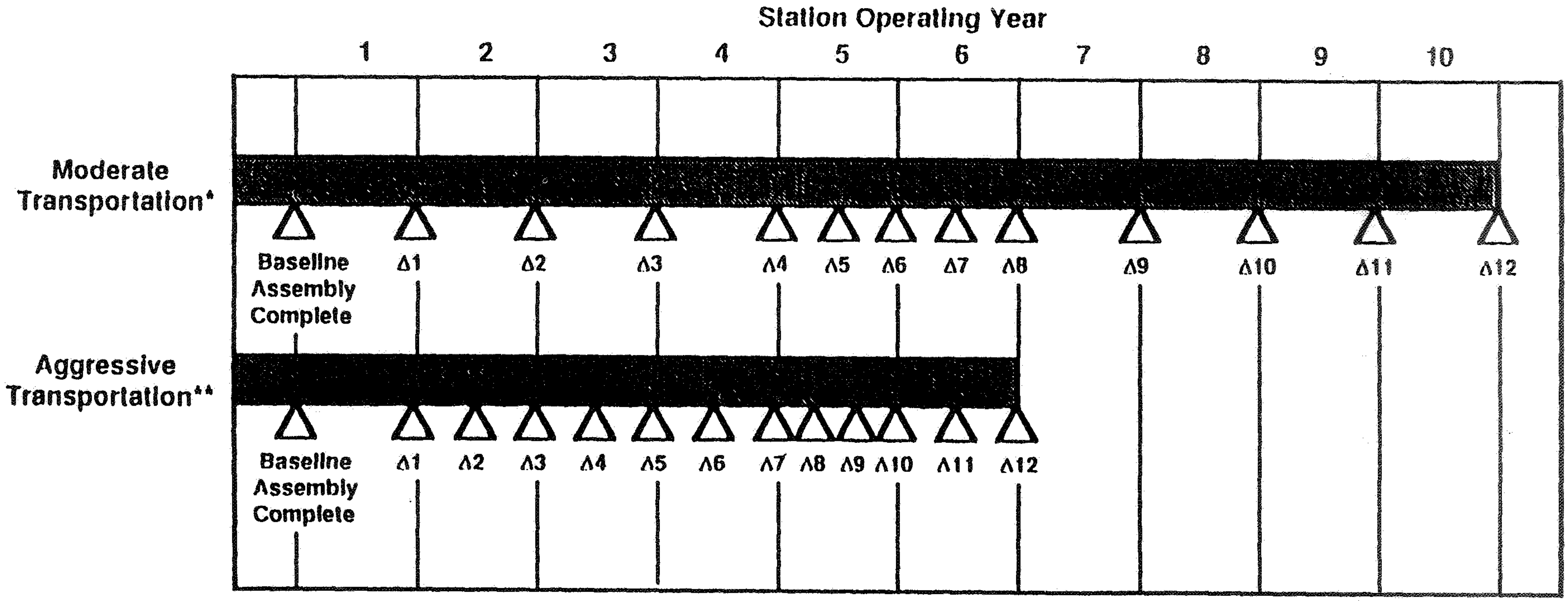
TIME-PHASED SPACE STATION GROWTH
GROWTH DELTAS

Δ 1	- Solar Dynamic Module Pair; 2 - 25m Transverse Boom Extension, Space Based OMV & Space Based OMV accommodations
Δ 2	- Upper/Lower Keels & Booms
Δ 3	- 1 Hab Module; 2 Resource Nodes
Δ 4	- 1 Solar Dynamic Module Pair; Servicing Facility Phase 1
Δ 5	- 1 Large Pocket Lab; 1 Lab Module; 2 Resource Nodes; Servicing Facility Phase 2
Δ 6	- STV/STV Hangar; Assembly Platform; Servicing Facility Phase 3 (Competed Servicing Facility)
Δ 7	- 1 Lab Module; Back Porch (if needed); 1 Resource Node (if needed)
Δ 8	- 1 Solar Dynamic Module Pair; 2 - 25m Transverse Boom Ext.
Δ 9	- 1 Hab Module; 1 Resource Node (if needed)
Δ 10	- 1 Small Pocket Lab
Δ 11	- 1 Solar Dynamic Module Pair
Δ 12	- 1 Large Pocket Lab

Increasing accommodation facilities for unpressurized storage will be required throughout growth and particularly in Delta's 1 and 2. The extent of these facilities is in part dependant upon facilities present at assembly complete and details are TBD.

TIME-PHASED SPACE STATION GROWTH
GROWTH DELTAS
CONTINUED

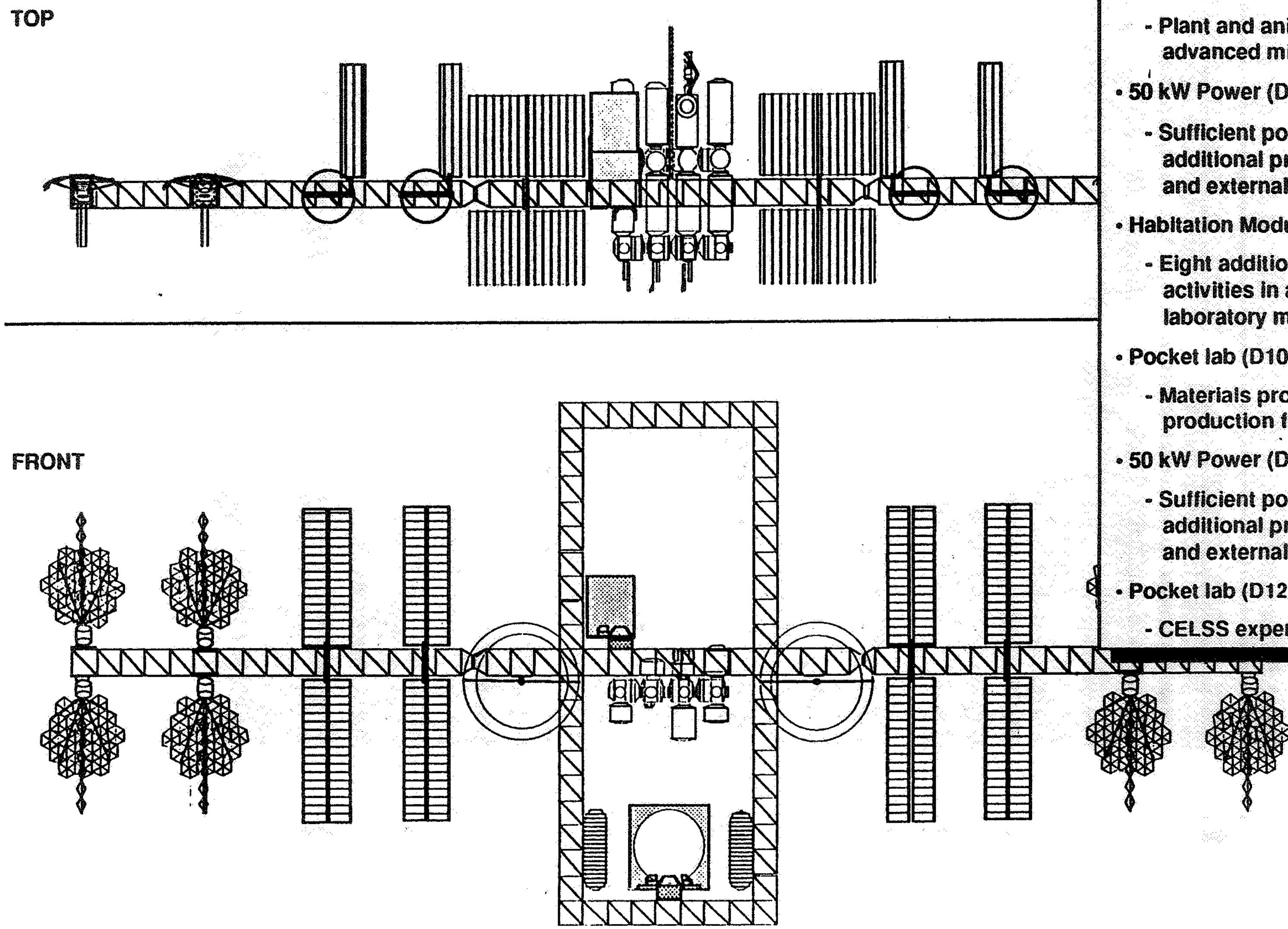
TIME PHASING OF THE DELTA GROWTH INCREMENTS IS DEPENDANT UPON THE AMOUNT OF TRANSPORTATION SUPPORT TO THE SPACE STATION



* Moderate transportation support represents a build up to 6 NSTS flights per year supplemented with the equivalent of 3 NSTS flights worth of expendable launch vehicle

** Aggressive transportation support represents a build up to 8 NSTS flights per year supplemented with the equivalent of 5 NSTS flights worth of expendable launch vehicle

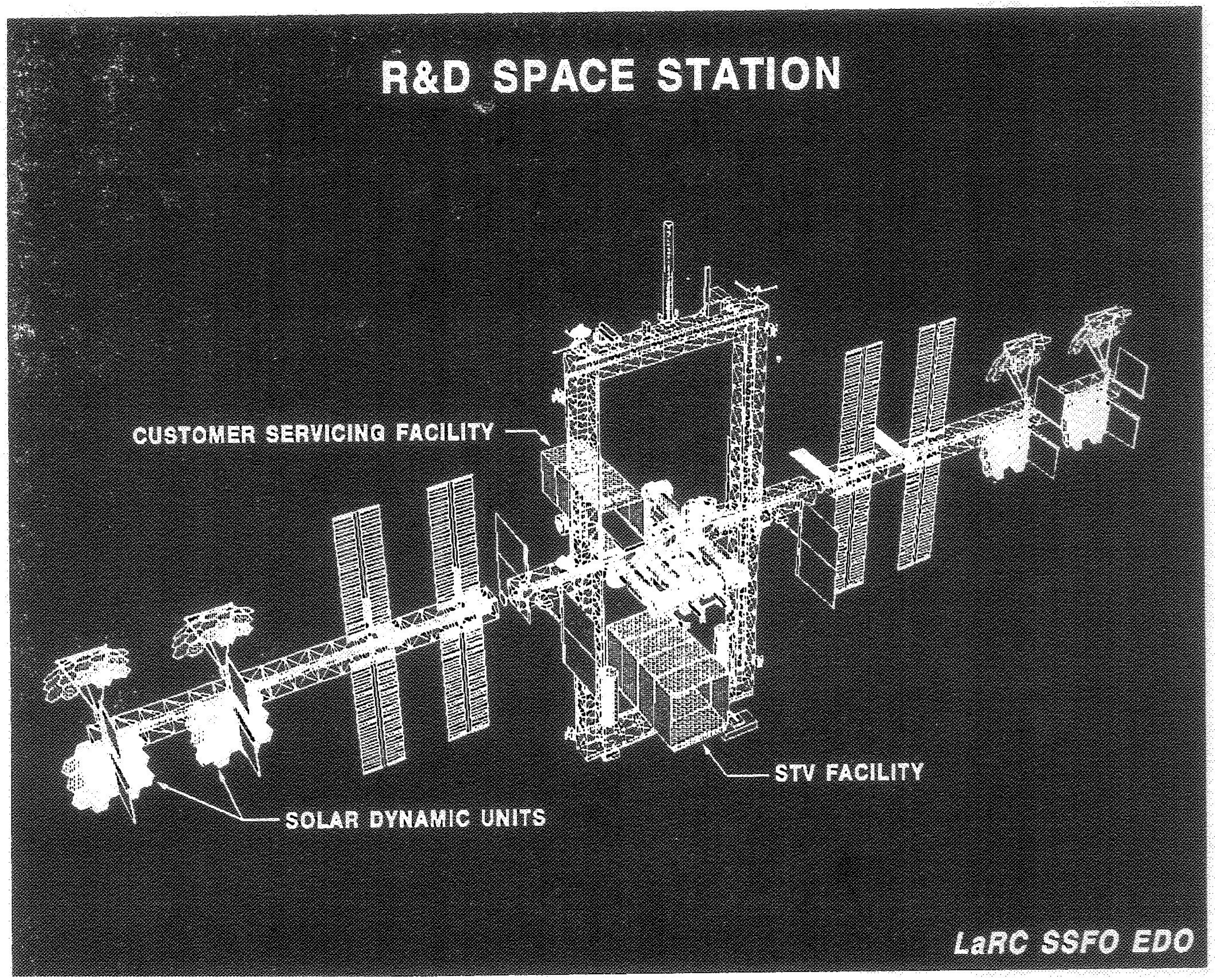
TIME-PHASED SPACE STATION GROWTH
DELTA 12



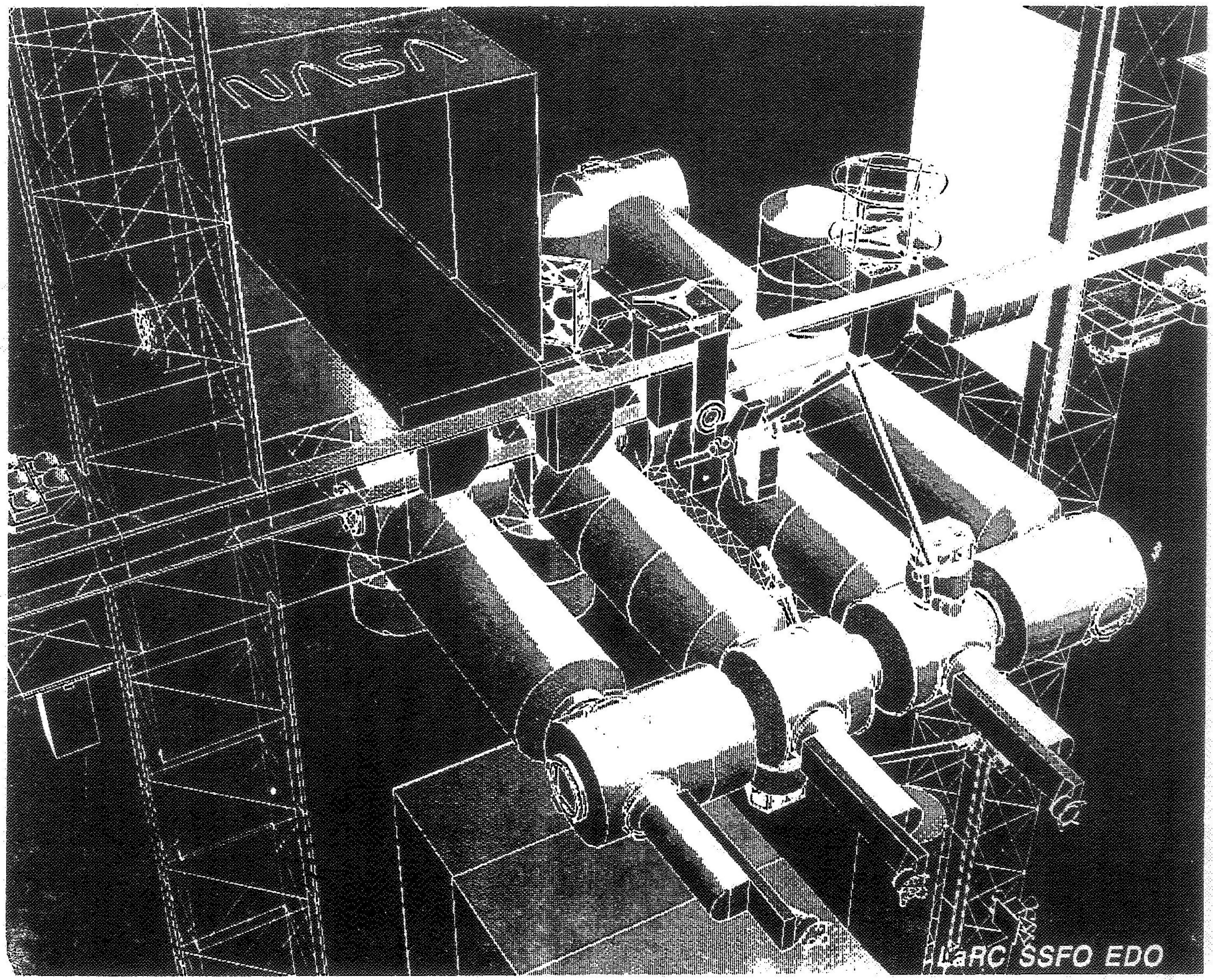
Additional Capability

- Laboratory Module (D7)
  - Plant and animal vivarium or advanced microgravity research
- 50 kW Power (D8)
  - Sufficient power to support additional pressurized modules and external facilities
- Habitation Module (D9)
  - Eight additional crew to support activities in additional laboratory modules
- Pocket lab (D10)
  - Materials processing pilot production facility
- 50 kW Power (D11)
  - Sufficient power to support additional pressurized modules and external facilities
- Pocket lab (D12)
  - CELSS experimentation

R&D SPACE STATION
(PRELIMINARY)



R&D SPACE STATION GROWTH MODULE PATTERN



ADDITIONAL SPACE STATION R&D EVOLUTION ELEMENTS

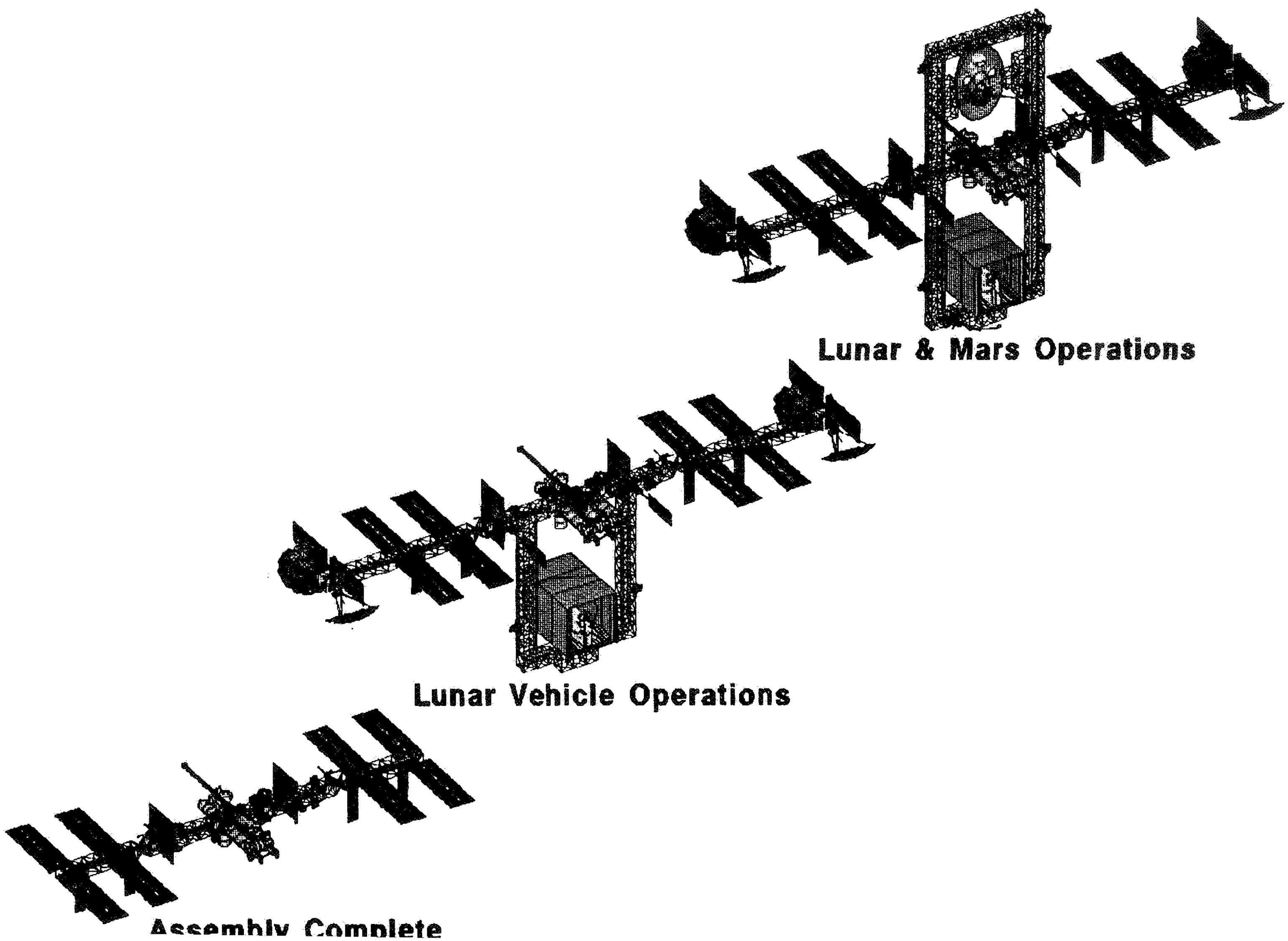
FREEDOM

Components	Number	Mass (kg)
Habitats	2	47,000
Laboratory Modules	2	68,900
Extended Resource Nodes	6	44,600
Pocket Labs	3	30,700
Truss Bays	64	5,700
Utility Trays	64	11,300
Solar Dynamic Units	8	55,200
Customer Servicing Facility	1	27,100
STV Propellant Tanks (Wet)	2	40,600
Attached Payloads	2	15,100
Thermal Radiators	4	11,000
Total		368,700

SPACE STATION FREEDOM
EVOLUTION FOR HUMAN EXPLORATION

Space Station Freedom Elements	Assembly Complete	Lunar Vehicle Operations (Expendable-Reusable)	Lunar & Mars Operations
Modules	3 Laboratory (1 U.S., 1 European, 1 Japanese) 1 Habitation	3 Laboratory (1 U.S., 1 European, 1 Japanese) 2 Habitation	Same
Truss Structure	Transverse Boom	Transverse Boom, Lower Keels & Lower Boom	Transverse Boom, Dual Keel, and Mars Vehicle Support Structure
Power & Thermal	75 kW	125-175 kW	175 kW
Crew	8 Permanent	10-12 Permanent, 4 Transient Lunar	12 Permanent, 4 Transient Lunar or Mars
Vehicle Processing	None	Enclosed Lunar Vehicle Hangar	Enclosed Lunar Vehicle Hanger, Mars Vehicle Assembly Facility
Remote Manipulator, (Canadian), Mobile Transporter	1 Remote Manipulator, 1 Mobile Transporter	1-2 Remote Manipulators, 1 Mobile Transporter	2 Remote Manipulators 2 Mobile Manipulators

SPACE STATION FREEDOM
EVOLUTION FOR HUMAN EXPLORATION



Space Station as a Transportation Node

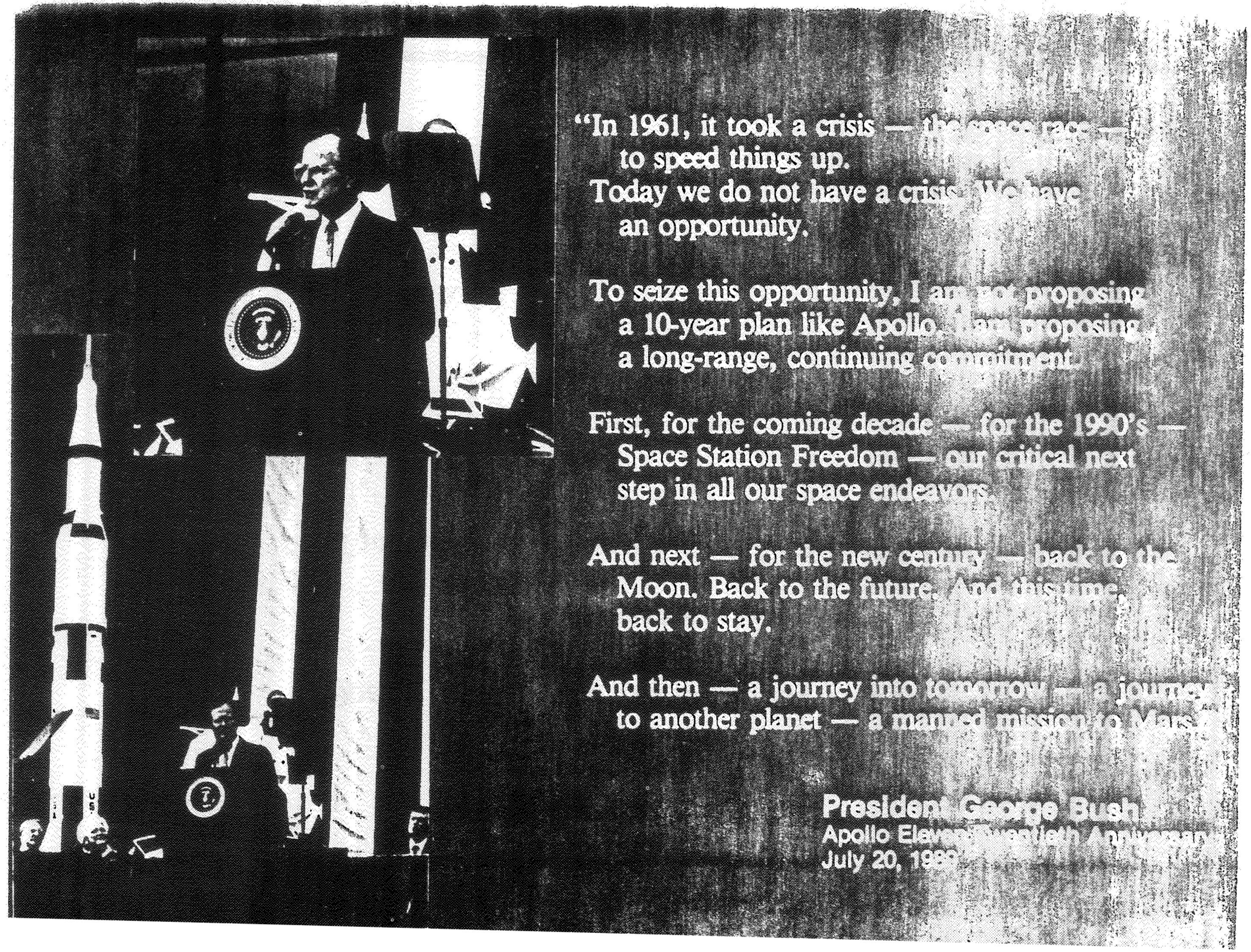
presented at

Technology for Space Station Evolution -
A Workshop

January 16, 1990
Dallas, Texas

Jeffrey D. Rosendhal
Special Assistant for Policy
Office of Exploration

Office of Exploration


"In 1961, it took a crisis — the space race — to speed things up.
Today we do not have a crisis. We have an opportunity.
To seize this opportunity, I am not proposing a 10-year plan like Apollo. I am proposing a long-range, continuing commitment.
First, for the coming decade — for the 1990's — Space Station Freedom — our critical next step in all our space endeavors.
And next — for the new century — back to the Moon. Back to the future. And this time, back to stay.
And then — a journey into tomorrow — a journey to another planet — a manned mission to Mars."
President George Bush
Apollo Eleven Twentieth Anniversary
July 20, 1989

NASA'S 90-DAY STUDY

In response to the President's speech, the NASA Administrator created a task force, headed by Aaron Cohen, director of the Johnson Space Center, to conduct a 90-day study of the main elements of an Exploration Initiative

The study provides reference material in support of the Vice President and the National Space Council, and enables NASA to better understand technical parameters

The study examined

- technical scenarios
- science opportunities
- required technologies
- international considerations
- institutional strengths and needs
- cost/resource estimates

NASA's study consists of analysis, not recommendations

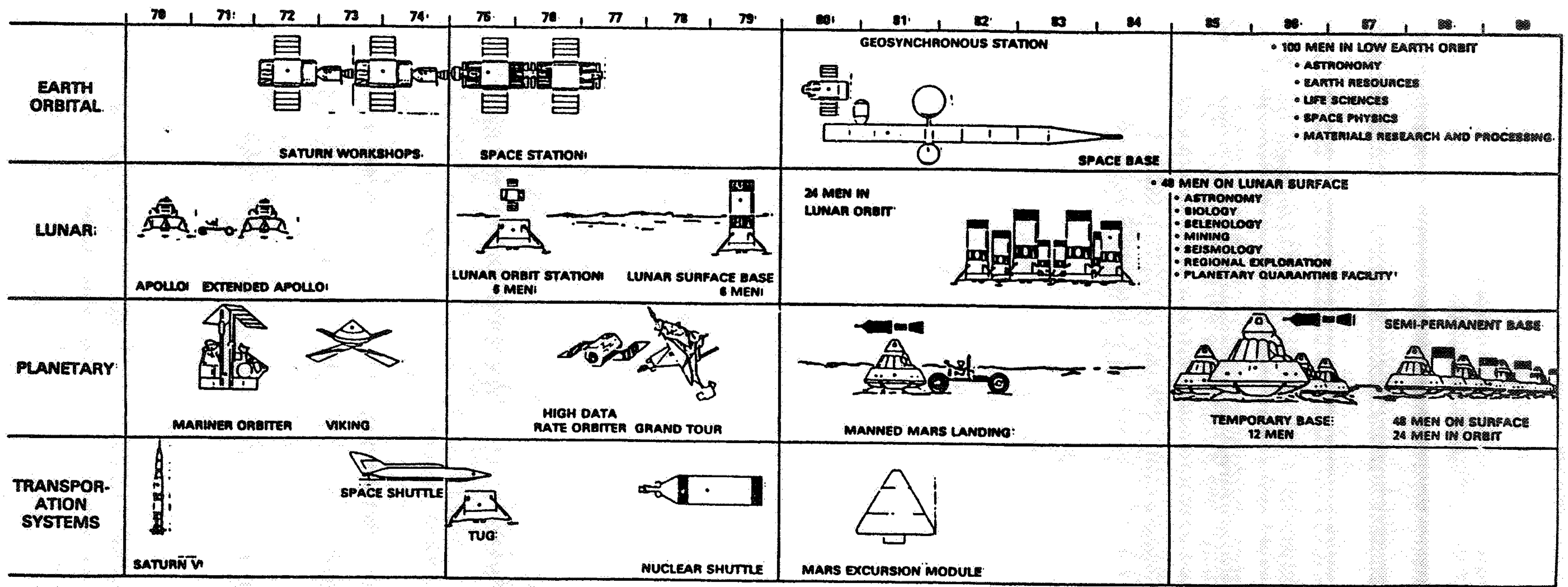
NASA

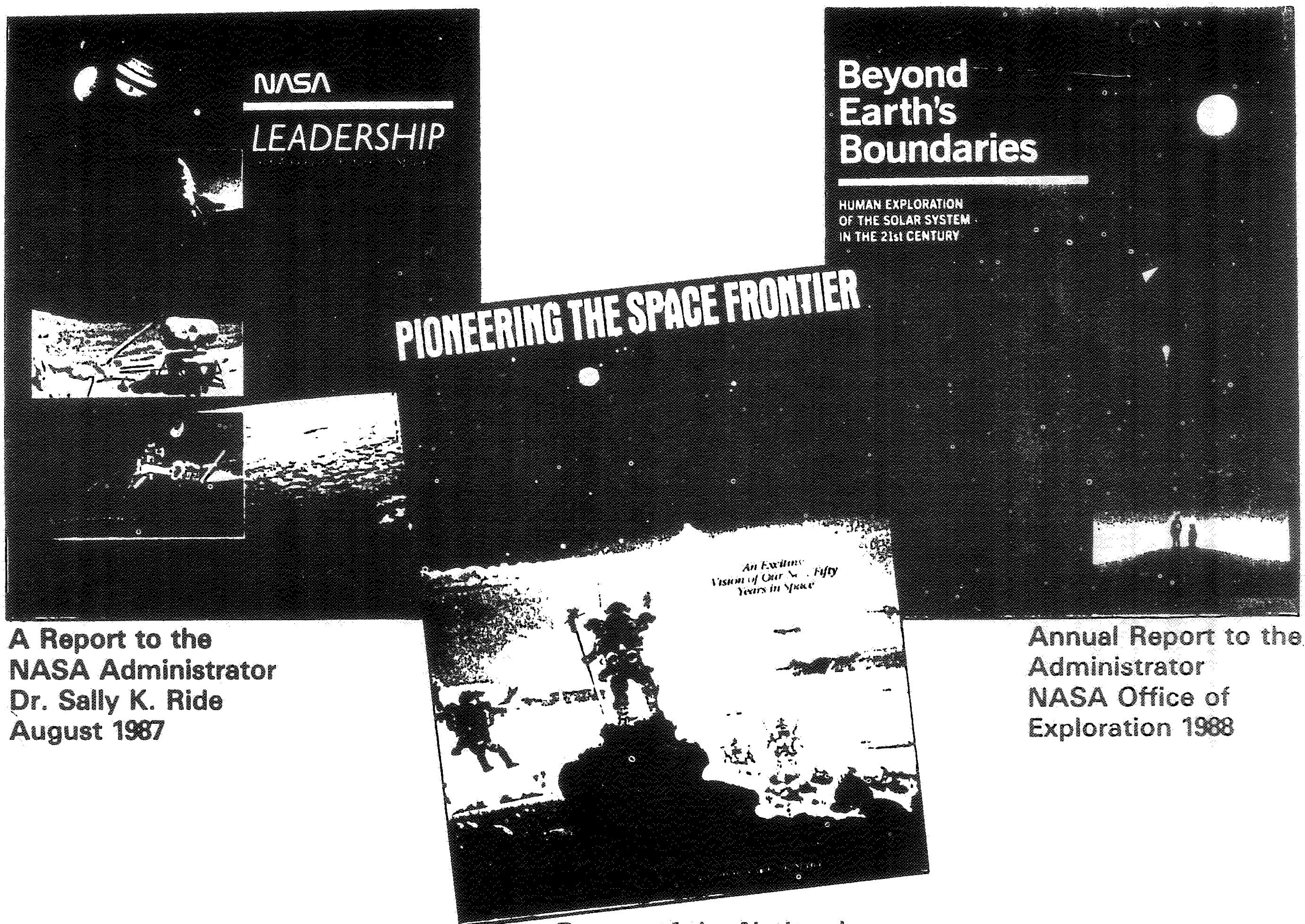
KEY TECHNICAL VARIABLES STUDIED

- Launch vehicle size
- In-space assembly or direct to surface
- Space Station Freedom, new spaceport, or direct assembly
- Chemical, electric, nuclear, or unconventional propulsion
- Aerobraking or all-propulsive vehicles
- Expendable or reusable spacecraft
- Propellant or tank transfer
- Open or closed life support
- Zero-gravity or artificial-gravity Mars vehicle
- In situ or Earth-supplied resources

Office of Exploration

VON BRAUN INTEGRATED SPACE PROGRAM
1970 - 1990





A Report to the
NASA Administrator
Dr. Sally K. Ride
August 1987

Report of the National
Commission on Space

Annual Report to the
Administrator
NASA Office of
Exploration 1988

EXPLORATION APPROACH

Build upon past and present investments in space

- Apollo, Viking, etc.
- Space Shuttle
- Space Station Freedom

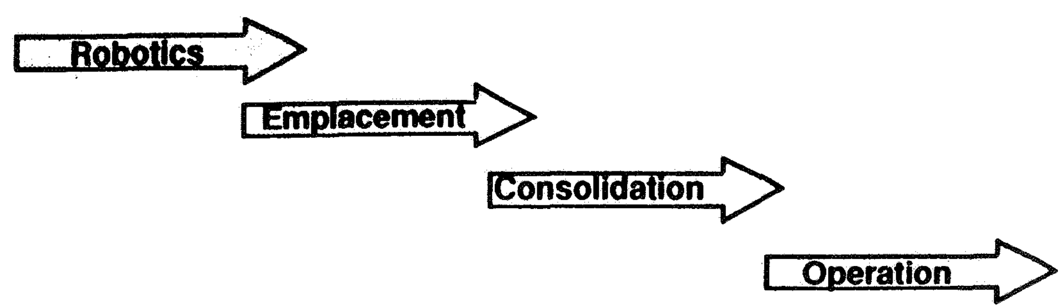
Employ robotic craft along with manned systems

Emphasize science along the way

Build a lunar outpost first

- Research base for science and technology
- Test-bed for humans to Mars

Explore Moon and Mars in phases



NASA

WHY GO TO THE MOON FIRST?

Learn to build, live and work on planetary surface close to home

Nearby — a 3-day trip and near instantaneous communications

Human experience in partial gravity leads to Mars

New science opportunities

Significant achievement by early next century

An evolutionary approach to "expanding human presence and activity"

Office of Exploration

EXPLORATION STRATEGY

Lunar Outpost

Robotics

- Outpost site is selected and verified

Emplacement

- Initial surface habitat is established
- Lunar excursion vehicle servicing capability is developed
- Initial science instruments are emplaced

Consolidation

- Habitation facilities are enhanced
- Science is expanded
- Mars systems and operations support are simulated
- In situ resource use begins

Operation

- Steady-state operations begin
- Lunar science is further expanded

Mars Outpost

Robotics

- Outpost site is selected and verified
- Engineering data are gathered to support development of human vehicles and systems

Emplacement

- First Human lnading on and return from Mars
- Initial surface habitat is established
- Water production and extraction techniques are demonstrated
- Local science and exploration are conducted

Consolidation

- First extended stay times on Mars occur
- Habitation facilities are enhanced
- Regional science and exploration are conducted

Operation

- Steady-state operations begin
- Lunar science is further expanded

NASA

DEVELOPMENT OF REFERENCE APPROACHES

All reference approaches assume technology successes

Approaches differ according to study variables

- Schedule of major events
- Lunar mission content
- Mars mission content

- Elements can be used to construct other reference approaches

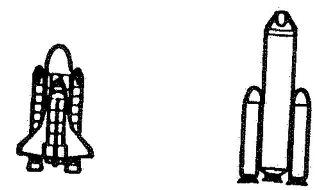
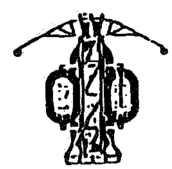
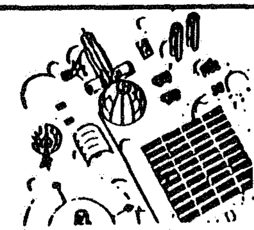
Reference Approaches				
A	B	C	D	E
Earliest Moon			No Space Station Disruption	
Earliest Lunar Outpost	Earliest Mars	Later Mars	Permanently Manned Lunar Outpost	Man-Tended Lunar Outpost

CHARACTERISTICS OF REFERENCE APPROACHES

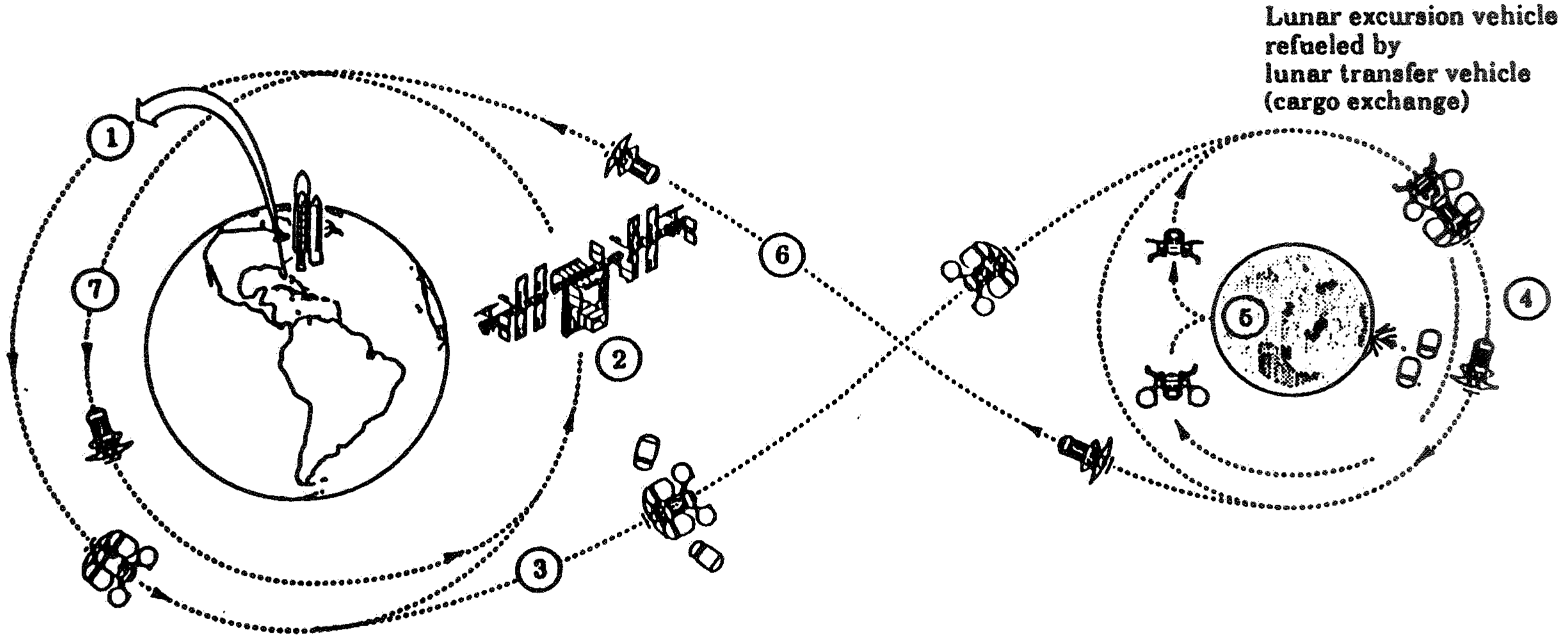
	Reference Approaches				
	A	B	C	D	E
	Earliest Moon			No Space Station Disruption	
	Earliest Lunar Outpost	Earliest Mars	Later Mars	Permanently Manned Lunar Outpost	Man-Tended Lunar Outpost
Lunar Emplacement	1999-2004	1999-2004	1999-2004	2002-2007	2002-2007
Lunar Consolidation	2004-2009	2004-2007	2004-2008	2007-2012	2008-2013
Lunar Operation	2010→	2005→	2005→	2013→	2014→
Humans on the Moon	2001	2001	2001	2004	2004
Permanent Habitation	2002	2002	2002	2005	→
Constructible Habitat	2005	2006	2007	2008	2011
Eight Crew	2006	2007	2007	2009	—
Lunar Oxygen Use	2010	2005	2005	2013	—
Lunar Farside Sortie	2012	2008	2008	2015	2022
Lunar Steady State Mode	2012	2008	2012	2015	→
Mars Emplacement	2015-2019	2010-2015	2015-2019	2017-2022	2024→
Mars Consolidation	2020-2022	2015-2018	2020-2022	2022	→
Mars Operation	2022→	2018→	2022→	→	→
Humans on Mars	2016	2011	2016	2018	2016
Extended Mars Stay	2018	2014	2018	2023	2027

NASA

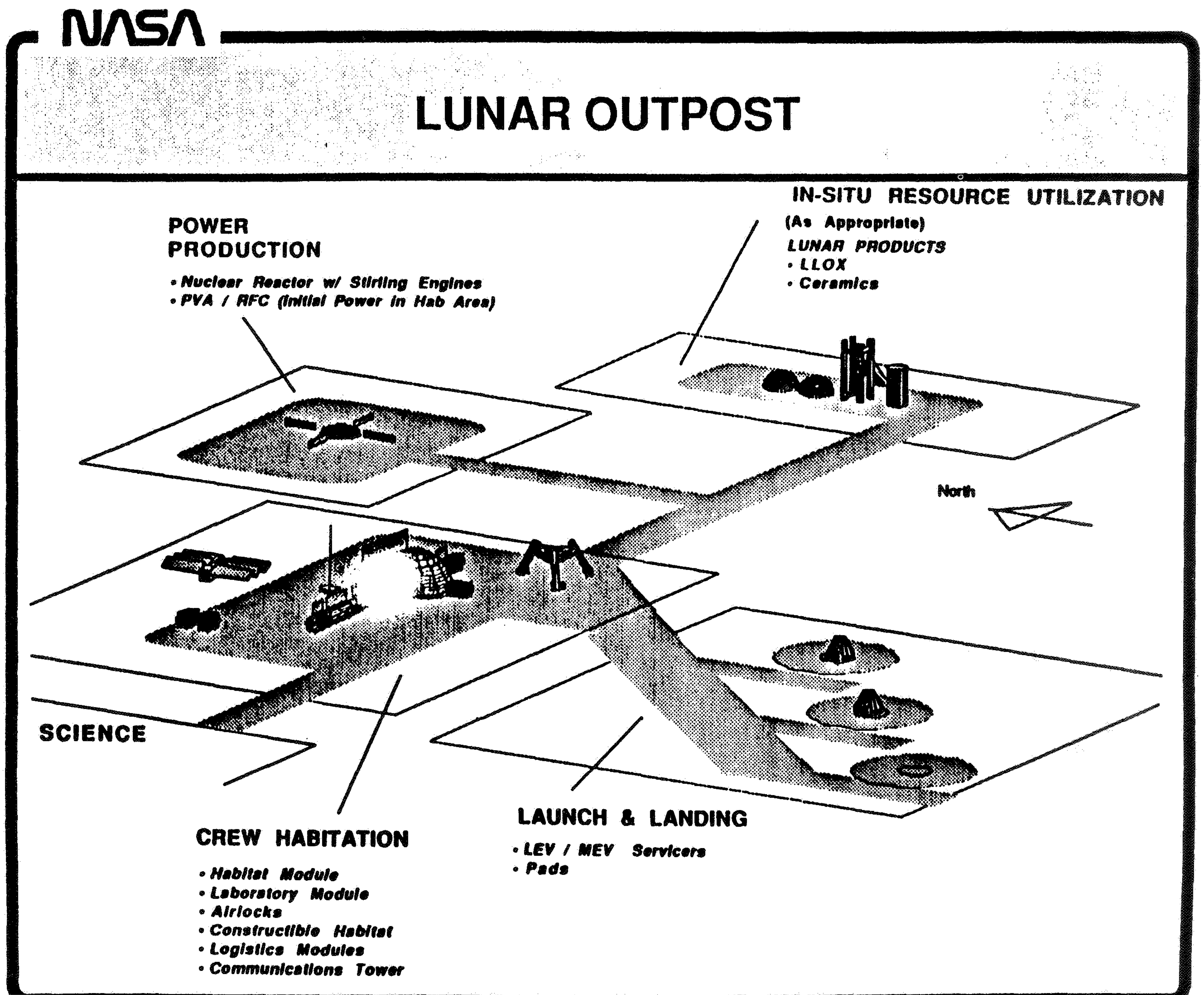
LUNAR OUTPOST EXPLORATION ELEMENTS

Segment		System
Earth-to-Orbit Transportation		Crew: Space Shuttle Cargo: Heavy-lift Launch Vehicle
Low-Earth Orbit		Space Station Freedom (Growth Version)
Transfer to and from Lunar Orbit		Crew and Cargo: Lunar Transportation Vehicle
Transfer to and from Lunar Surface		Crew and Cargo: Lunar Excursion Vehicle
Lunar Outpost		Surface Systems (Habitat, Power, etc.)

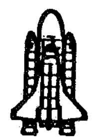
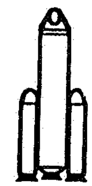
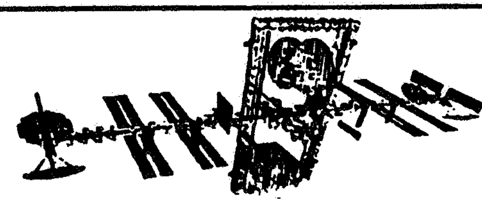
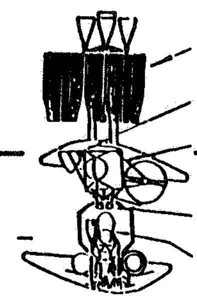
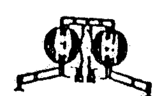
LUNAR MISSION PROFILE



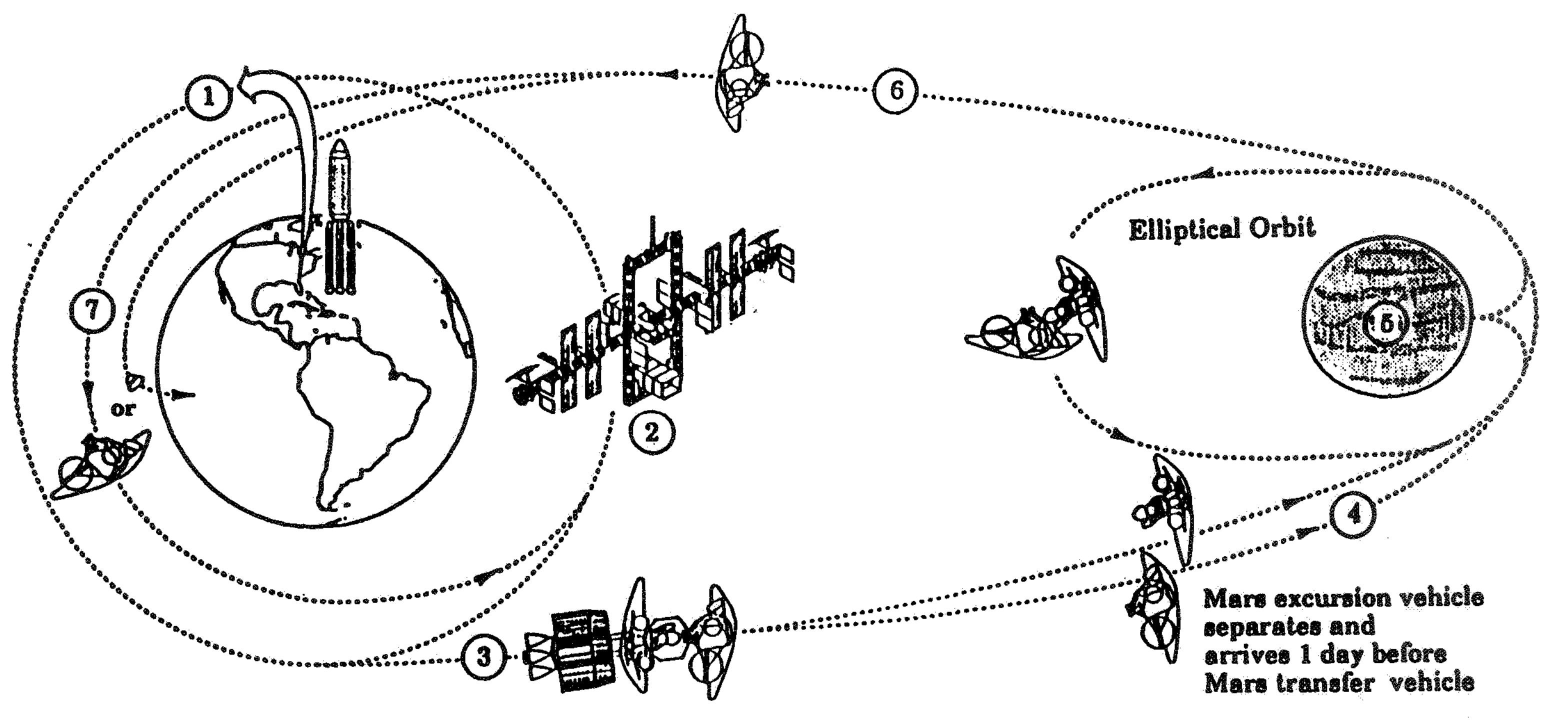
1. Payload Delivered to Space Station Freedom
2. Lunar Transfer Vehicle Mated with Payload at Freedom
3. Trans-Lunar Phase with Lunar Transfer Vehicle
4. Lunar Transfer Vehicle Rendezvous with Lunar Excursion Vehicle from Moon
5. Excursion Vehicle Returns to Moon with Payload
6. Trans-Earth Phase with Transfer Vehicle
7. Transfer Vehicle Aerobrake Maneuver and Return to Freedom


NASA
LUNAR OUTPOST
POWER PRODUCTION
• Nuclear Reactor w/ Stirling Engines
• PVA / RFC (Initial Power in Hab Area)
IN-SITU RESOURCE UTILIZATION
(As Appropriate)
LUNAR PRODUCTS
• LLOX
• Ceramics
North
SCIENCE
CREW HABITATION
• Habitat Module
• Laboratory Module
• Airlocks
• Constructible Habitat
• Logistics Modules
• Communications Tower
LAUNCH & LANDING
• LEV / MEV Servicers
• Pads

MARS EXPEDITION ELEMENTS

Segment		System
Earth-to-Orbit Transportation	 	Crew: Space Shuttle Cargo: Advanced Heavy-lift Launch Vehicle
Low-Earth Orbit Transportation Node		Space Station Freedom (Evolved to Support Mars Expedition and Lunar Outpost)
Transfer to and from Mars Orbit		Crew and Cargo: Mars Transfer Vehicle
Transfer to and from Martian Surface		Crew and Cargo: Mars Excursion Vehicle
Humans on Mars		Lander and Exploration Tools

MARS MISSION PROFILE



1. Payload delivered to Space Station Freedom
2. Mars transfer vehicle mated with payload at Freedom
3. Trans-Mars phase with Mars transfer vehicle
4. Mars transfer vehicle remains in Mars orbit; Mars excursion vehicle descends to surface
5. Excursion vehicle to/from Mars surface
6. Trans-Earth phase with transfer vehicle
7. Transfer vehicle aerobrake maneuver and return

SPACE STATION FREEDOM

A permanently manned, international research laboratory and, later, a staging base for the Moon and Mars

Need for:

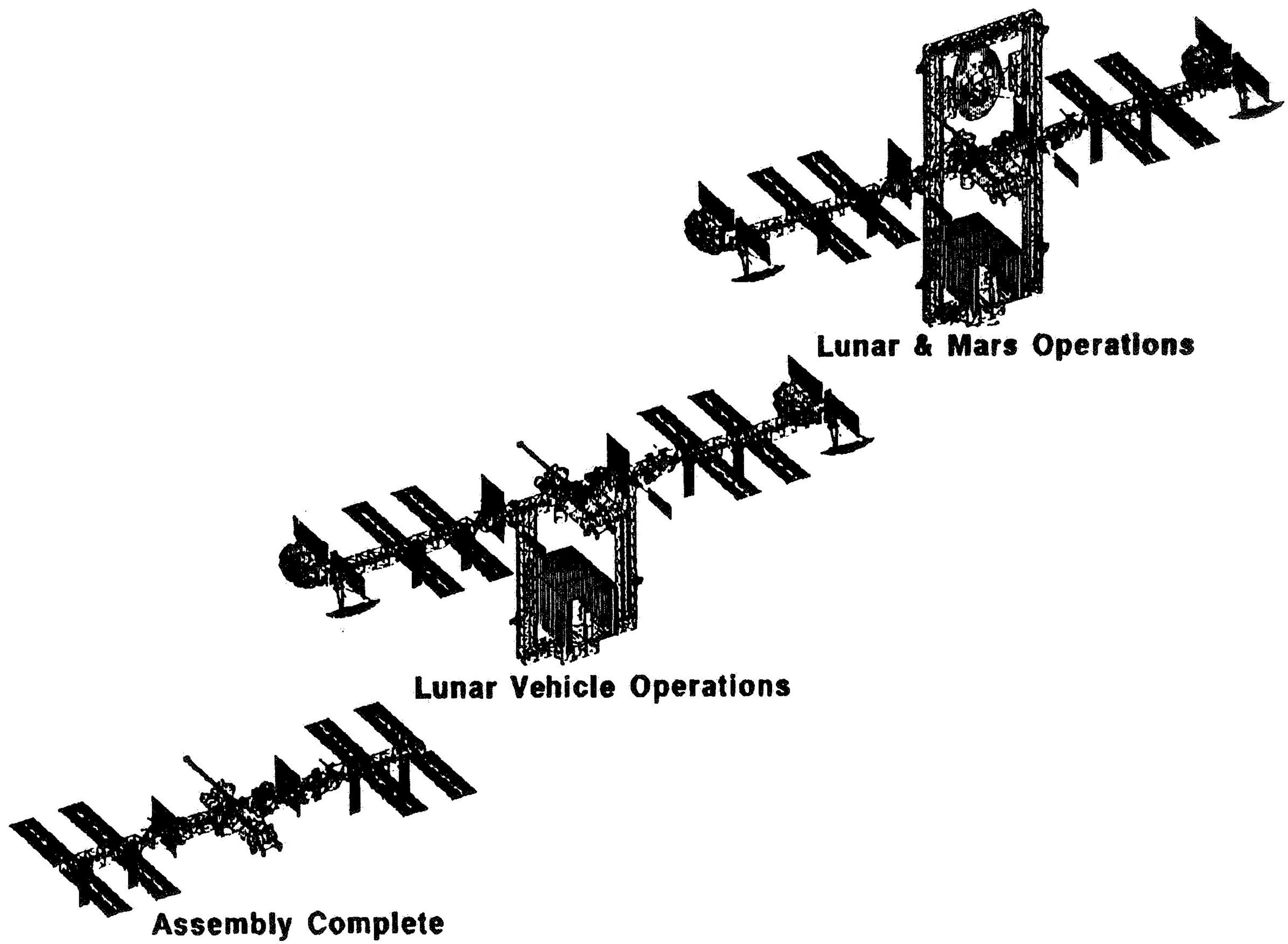
- Life sciences research and microgravity countermeasures
- Technology development and validation
- Development of operational procedures
- Assembly, test, launch, recovery, turnaround of space vehicles

Current design can evolve to the more capable configuration essential for a return to the Moon and human exploration of Mars

President Bush called Space Station Freedom: "our critical next step in all our space endeavors"

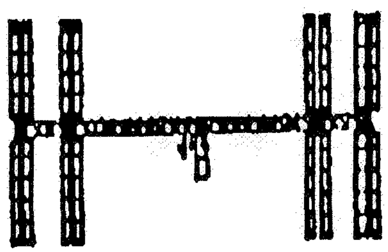
NASA

SPACE STATION FREEDOM
EVOLUTION FOR HUMAN EXPLORATION



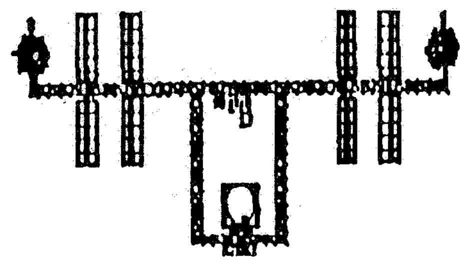
SPACE STATION FREEDOM EVOLUTION

Assembly Complete
199X



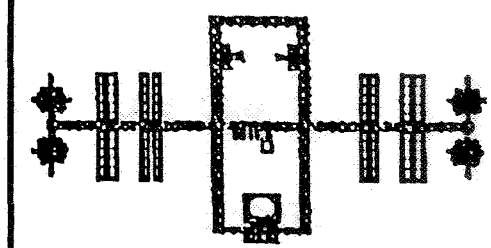
Crew: 8
Power: 75 kW
Volume: 1 habitat
3 laboratories

Lunar Mission Node
200X



Crew: 10 (plus 4 transient)
Power: 125 kW
Volume: 2 habitats
4 laboratories

Lunar/Mars Mission Node
20XX



Crew: 12 (plus 4 transient)
Power: 175 kW
Volume: 2 habitats
4 laboratories

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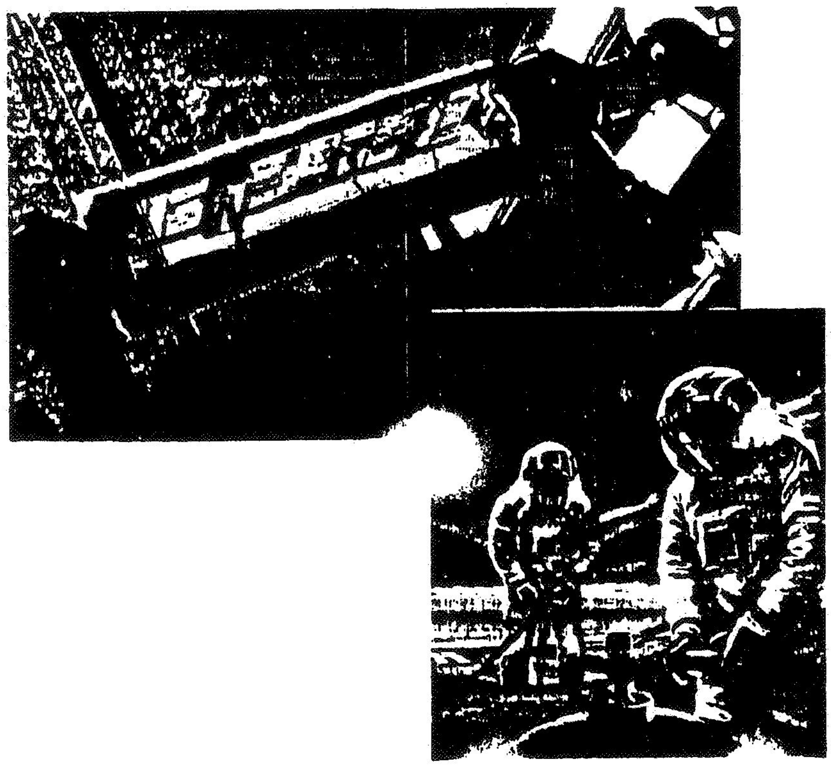
EXPLORATION LIFE SCIENCES



- Radiation Protection
- Reduced Gravity Countermeasures
- Medical Care
- Life Support in Habitats and Space Vehicles
- Extravehicular Activity
- Behavior and Performance

Earth → Freedom → Lunar Outpost → Mars

ARTIFICIAL GRAVITY?

Microgravity exposure causes major physiological change

- Bone mineral loss
- Muscle atrophy
- Cardiac deconditioning

Current countermeasures (exercise) may be insufficient for the lengthy voyage to Mars

Strategy to test and evaluate necessary zero-g countermeasures will utilize

- Space Shuttle extended duration orbiter
- Space Station Freedom

  and eventually

- The lunar outpost itself

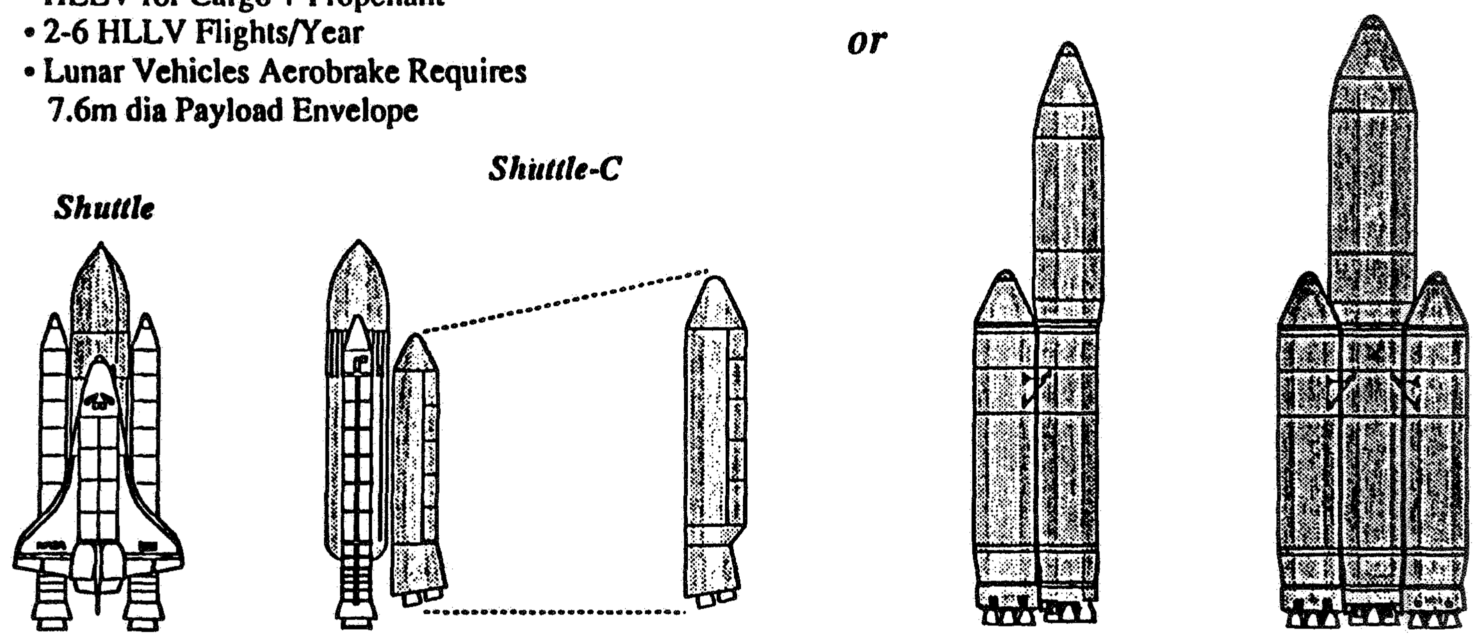
Current approach: plan a zero-g Mars transfer vehicle, but begin low level definition of an artificial gravity system just in case

Humans must be certified for journey to Mars

LAUNCH VEHICLES FOR LUNAR MISSIONS

- **Requirements**
  - Shuttle for Manned Launches
  - HLLV for Cargo + Propellant
  - 2-6 HLLV Flights/Year
  - Lunar Vehicles Aerobrake Requires 7.6m dia Payload Envelope

Shuttle ***Shuttle-C*** ***or*** ***ALS.***

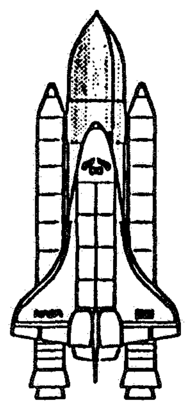


Shuttle	Shuttle-C	Shuttle-C	ALS	ALS
• 2 ASRMs • Std ET • 3 x 104% SSMEs • 22t P/L Capability to SSF • 4.6m x 18.2m P/L Envelope	• 2 ASRMs • Std ET • 3 x 104% SSMEs • 71t P/L Capability to SSF • 4.6m x 25m P/L Envelope	• 2 ASRMs • Mod. ET • 3 x 104% SSMEs • 61t P/L Capability to SSF • 7.6m x 25m P/L Envelope	• 1 LOX/LH_2 Booster w/6 STMEs • LOX/LH_2 Core w/3 STMEs • 52.3t P/L Capability to SSF • 7.6m D x 30m L P/L Envelope	• 2 LOX/LH_2 Booster w/6 STMEs • LOX/LH_2 Core w/3 STMEs • 98.2t P/L Capability to SSF • 10m D x 30m L P/L Envelope

LAUNCH VEHICLES FOR MARS MISSIONS

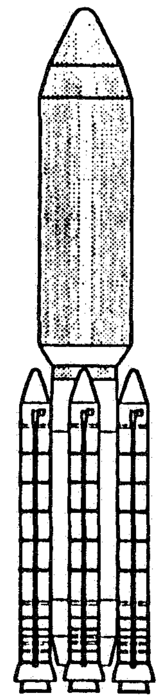
- **Requirements**
  - Shuttle for Manned Launches
  - Large HLLV for Cargo and Propellant (140t to LEO)
  - 5 to 7 HLLV Launches Per Mission
  - Mars Vehicle Aerobrake Requires Payload Envelope of 12.5 m Dia

Shuttle



- 2 ASRMs
- Std ET
- 3 x 104% SSMEs
- 22t P/L Capability to SSF
- 4.6m x 18.2m Payload Envelope

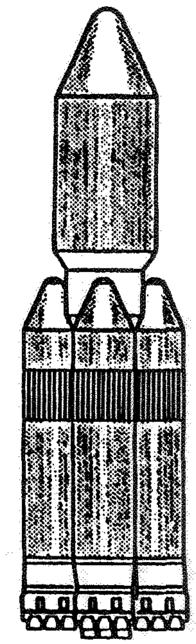
Shuttle Derived HLLV



- 4 ASRMs
- 4 x SSMEs on 10m Dia Core
- Recoverable P/A Module
- 12.5m D x 30m L Payload Envelope

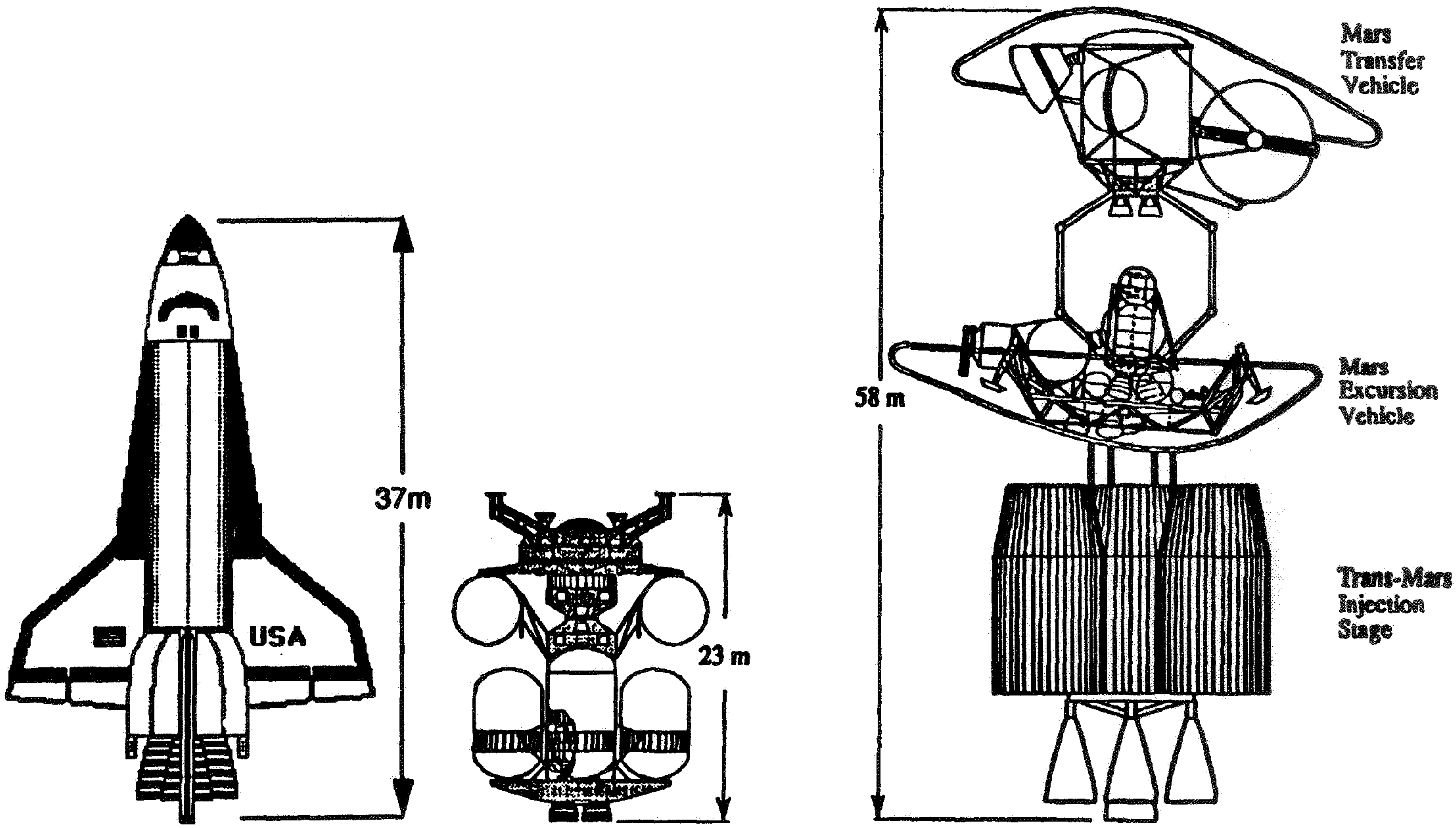
or

Growth ALS



- 3 LOX/LH_2 Boosters w/6 STMEs ea.
- LOX/LH_2 Core w/3 STMEs
- 12.5m D x 21m L Payload Envelope

SHUTTLE AND LUNAR/MARS TRANSFER VEHICLES

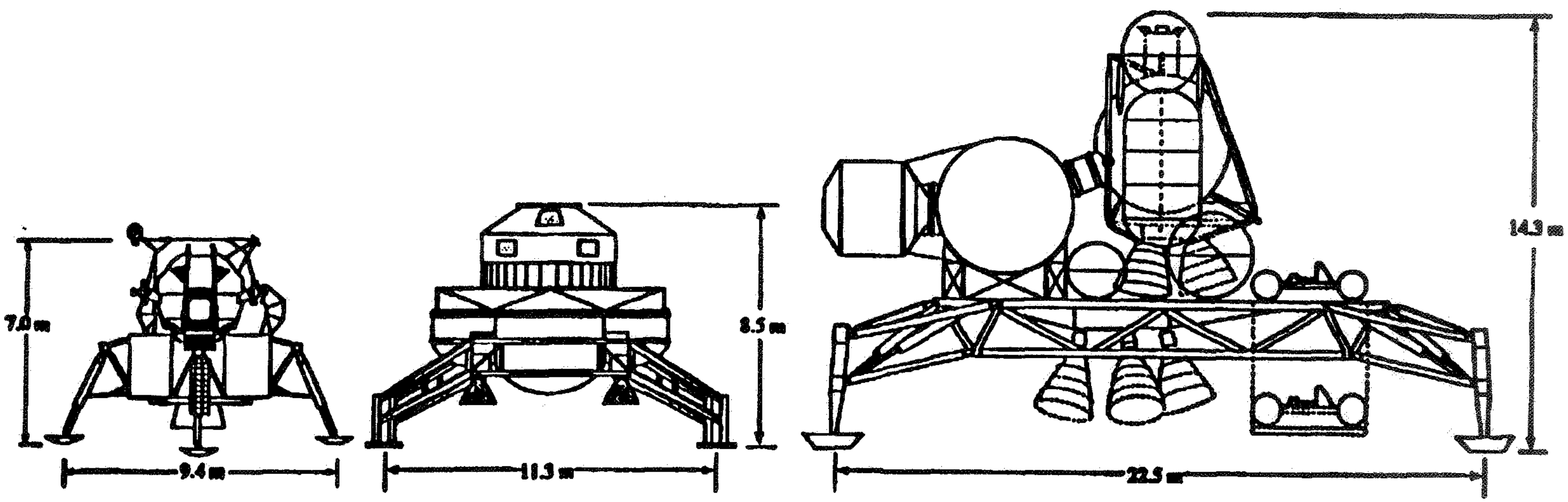


Space Shuttle
Mass = 92 metric tons
(Payload = 22 metric tons)

Lunar Transportation System
Mass = 200 metric tons

Mars Transportation System
Mass = 800 metric tons

APOLLO LUNAR MODULE AND LUNAR/MARS EXCURSION VEHICLES



Apollo Lunar Module
Payload Mass = 0.7 metric tons

Lunar Excursion Vehicle
Payload Mass = 15 metric tons

Mars Excursion Vehicle
Payload Mass = 25 metric tons

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CRITICAL TECHNOLOGY CHALLENGES

Technology Areas	Benefits
• Regenerative Life Support Systems	• Enables strategic self-sufficiency goals • Annual mass savings of 45 metric tons
• Aerobraking	• Essential for cost-effective space transportation • Annual mass savings of 60 metric tons
• Advanced Space En[illegible]	• Essential for cost-effective space transportation • Annual mass savings of 30 metric tons
• Surface Nuclear Power	• Enables strategic self-sufficiency goal • Mass savings of 315 metric tons
• In Situ Resource Utilization	• Enables strategic self-sufficiency goal • Annual mass savings of 315 metric tons
• Radiation Protection	• Essential for strategic Mars goal

CONCLUSIONS OF THE 90-DAY STUDY

- Major investments in challenging technologies are required
- Scientific opportunities are considerable
- Robotic spacecraft will be needed
- Current launch capabilities are inadequate
- Space Station Freedom is essential
- Program alternatives do exist
- Opportunities for international cooperation exist
- A long-range commitment and significant resources will be required

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SCIENCE ON MARS

Planet most like Earth

- Has an atmosphere, evidence of warmer past
- Mars has intrigued humans for generations

Search for life on Mars

- Life may have existed long ago
- It may still exist in protected underground environments
- Answers will provide clues about evolution of life

Global climate change on Mars

- Created geologically fascinating planet
- May enhance our understanding of changes on Earth

Human and robotic exploration

- Both important for complex field studies

Human presence key to advancing understanding

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SCIENCE: SIGNIFICANT OPPORTUNITIES

Excellent science to be done on both Moon and Mars

- Robotic science
- Human interactive science

Fundamental scientific themes

- Origin and history of Earth and Moon
- The origin of life/life on Mars
- Global climate change
- Search for other solar systems
- Fate of the Universe

Research opportunities cover many disciplines

- Solar Physics
- Geology
- Biology
- Astrophysics
- Chemistry
- Space Physics

Exciting and productive opportunities for space science

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INTERNATIONAL COOPERATION

Japan

- Limited experience
- Ambitious aspirations
- Growing capabilities: H-II vehicle and Space Station module
- Interested in lunar resource utilization?

Europe

- Technically expert
- Seeking autonomous capabilities in manned space flight
- Partner in Space Station, and designing Hermes space plane
- Would seek equality in any future initiative

U.S.S.R.

- Returned lunar samples robotically in 1970s
- Active planetary program, had focused on Venus
- Interest in Mars, but limited success
- Proposed a manned Mars project with the U.S.

Canada

- Built Canadarm for Shuttle
- Building Mobile Servicing System for Space Station Freedom
- Significant robotic capabilities
- Would probably welcome a role in this area

Other Nations

- China, India and Brazil have small space programs
- Desire to participate?
- Role for nations with small or no space experience?

INTERNATIONAL COOPERATION

Advantages are significant

- Access to first-rate technical personnel and facilities
- Reduction in cost
- Foreign policy benefits

Civil Space Program has extensive experience

- NASA has concluded over 1000 agreements with more than 100 countries
- Scientific exchanges, foreign instruments and major hardware contributions
- Space Station, Spacelab, Apollo-Soyuz

Negotiations will be complex

- Protection of important U.S. interests
- Protection against unwarranted technology transfer
- Satisfaction of foreign interests
- Assurances regarding funding continuity

NASA

COST DRIVERS

Mass carried to low-Earth orbit

Heavy-lift launch vehicles

Scope of technology program
- Parallel development
- Push/pull
- Automation and robotics

Extent of Space Station mods

Approach to risk

Operations philosophy

Extent of robotic precursor missions
- Number and sophistication

Scale of lunar activity
- Crew size
- Stay time
- Surface systems

Scale of Mars activity
- Trip time
- Same as lunar activities

Nature of international participation

Program stability
- Funding
- Milestones

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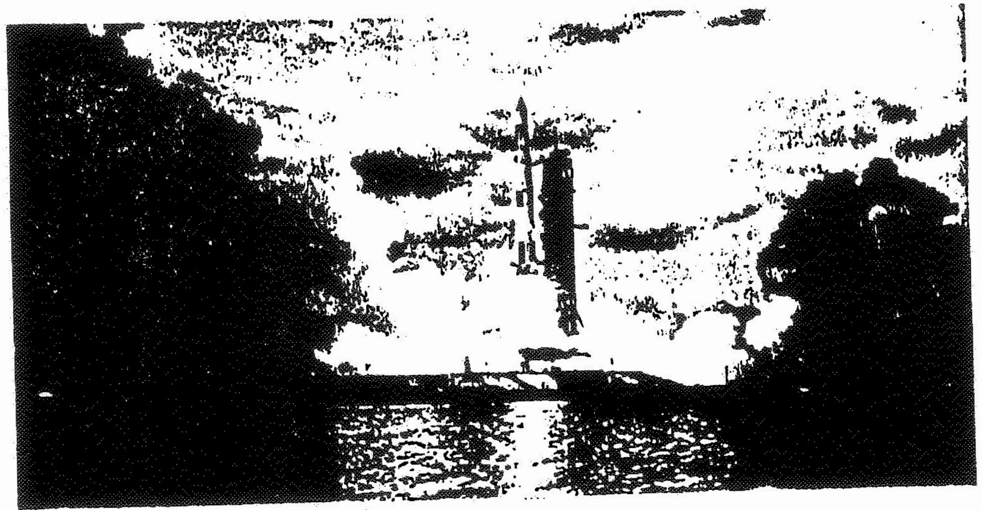
THE EXPLORATION INITIATIVE

Definition of key parameters and approaches has just begun

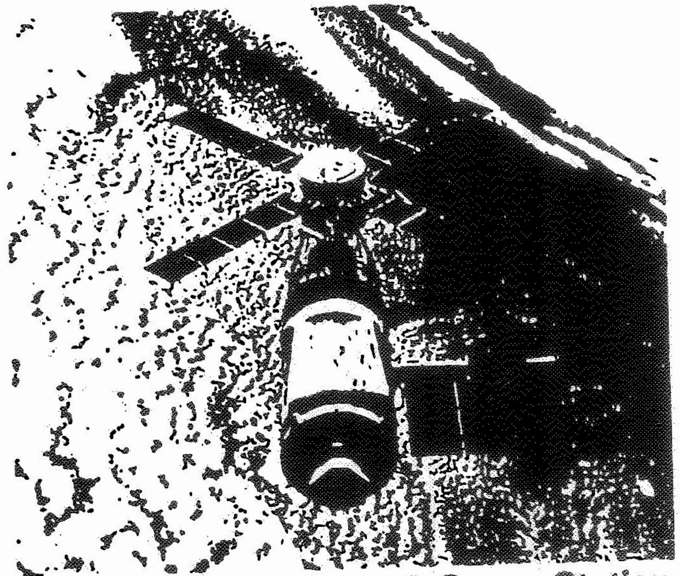
- Program scope
- Technology
- Science
- Mission scenarios
- Alternative concepts/innovative approaches
- International cooperation
- Management

NASA continues to look at program options
and welcomes new concepts

WHAT WE ONCE HAD

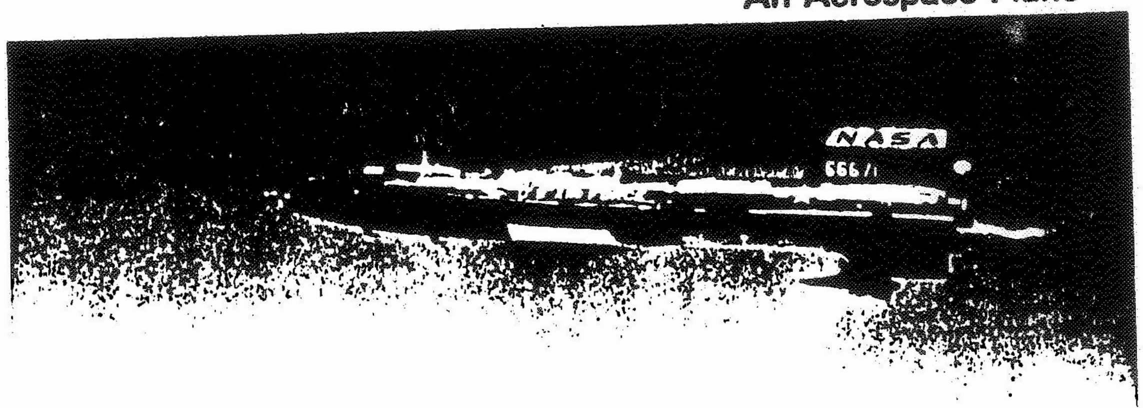


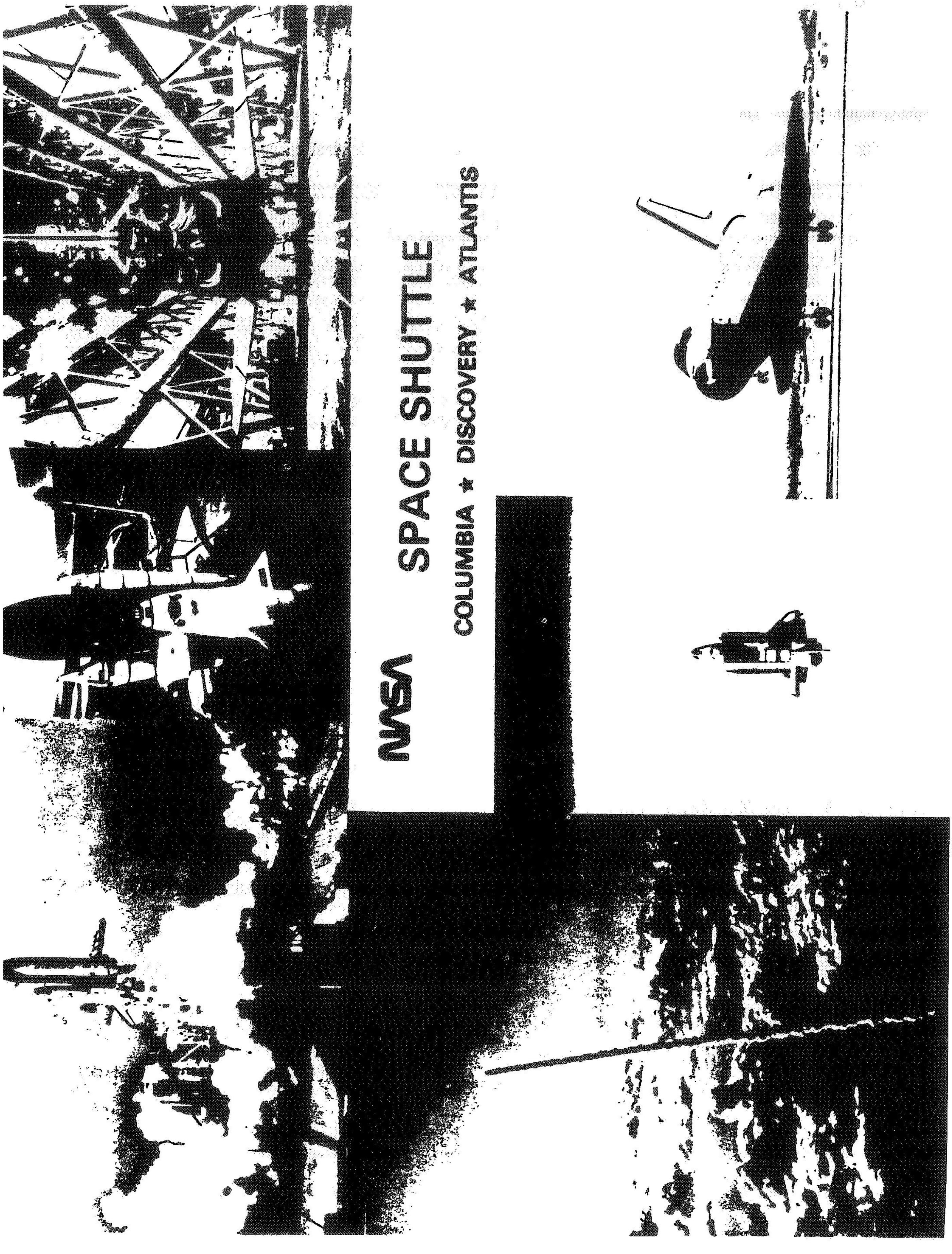
A Heavy-lift Launch Vehicle

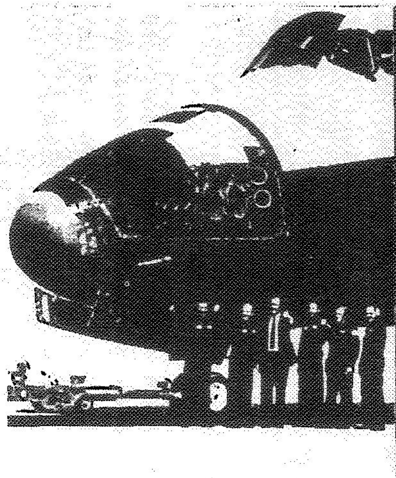


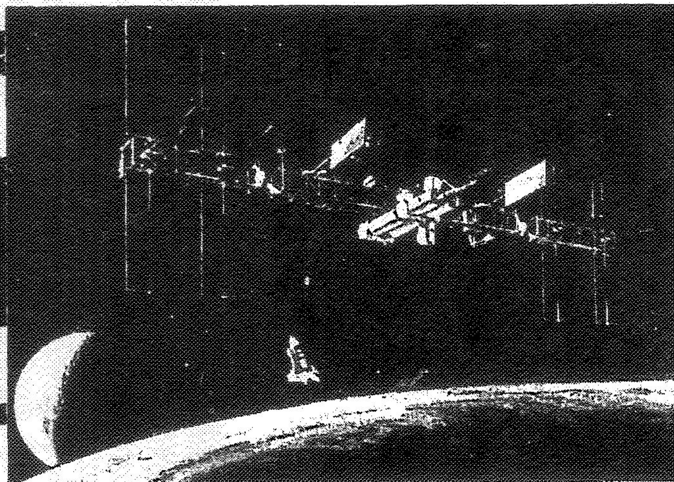
A Space Station

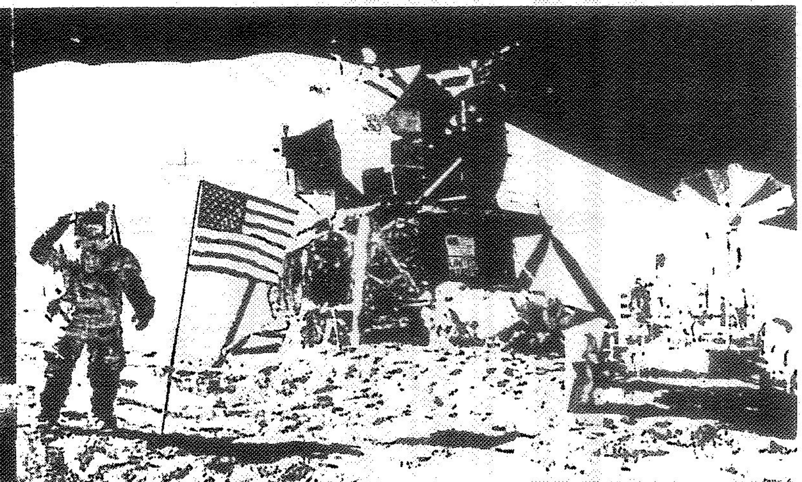
An Aerospace Plane



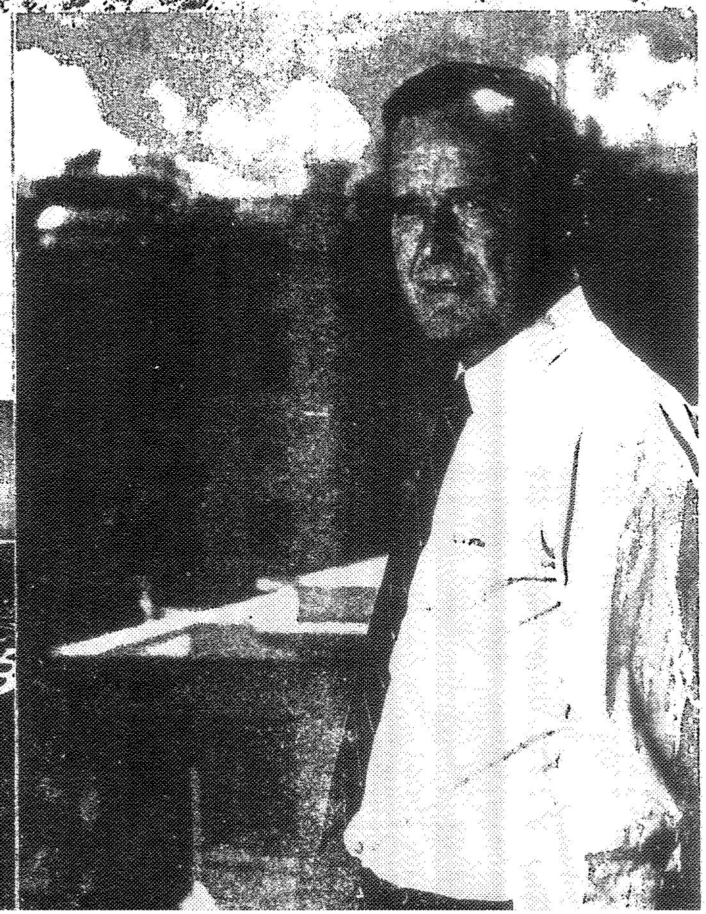

NASA
SPACE SHUTTLE
COLUMBIA ★ DISCOVERY ★ ATLANTIS



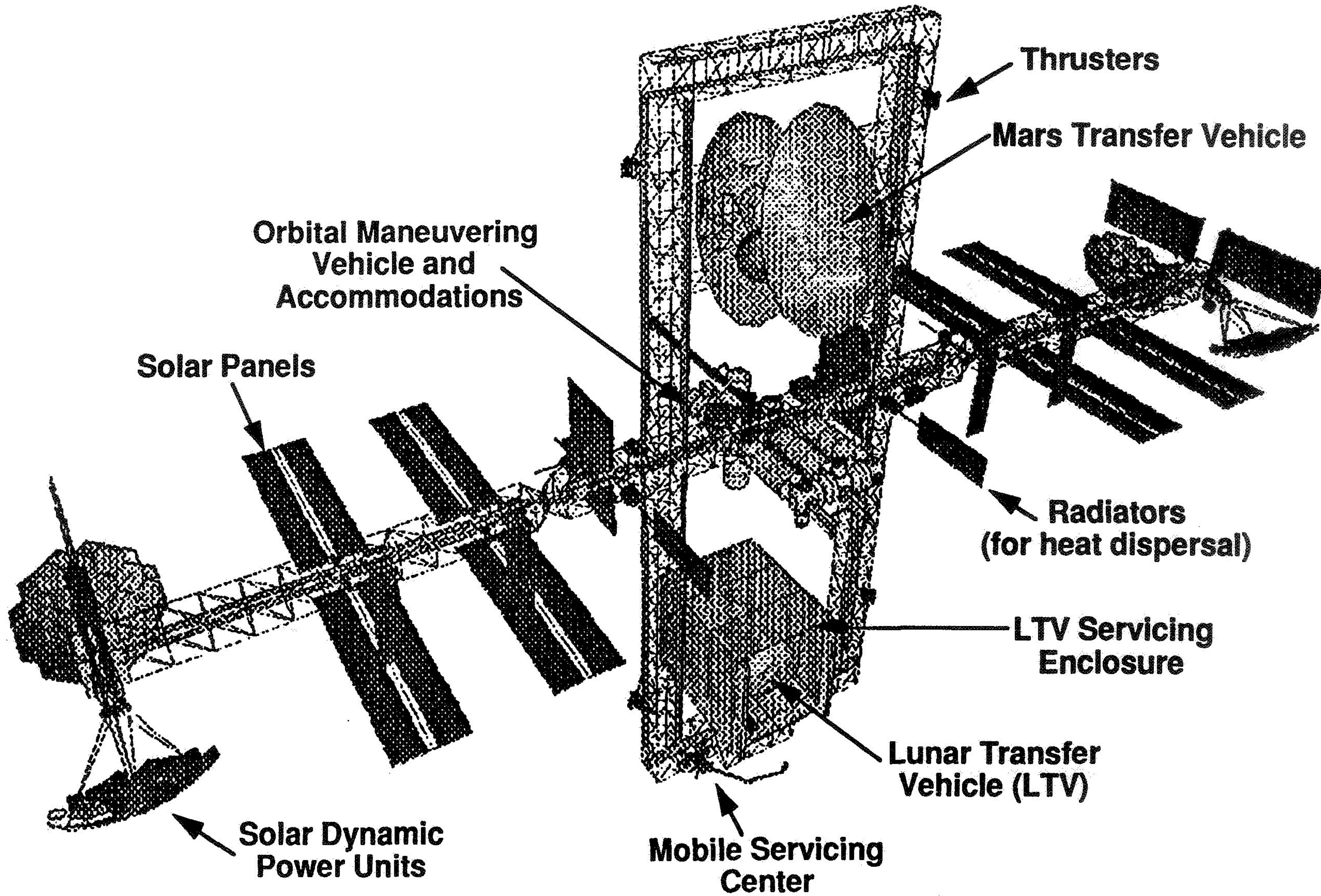




"I am proposing a long-range, continuing commitment. First, for the coming decade -- for the 1990's -- Space Station Freedom -- our critical next step in all our space endeavors. And next -- for the new century -- back to the Moon. Back to the future. And this time, back to stay. And then -- a journey into tomorrow -- a journey to another planet -- a manned mission to Mars."



MARS/LUNAR TRANSPORTATION NODE



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EFFECT ON AMERICA

Science and Technology

- Increase knowledge
- Develop new and more efficient systems

Competitiveness

- Spur America's competitiveness in the 21st century

Education

- Stimulate young people to pursue careers in mathematics, science, and engineering

International Cooperation

- Bring nations together to achieve peaceful exploration

Pride

- Provide our citizens with a visible symbol of America's strength and vision

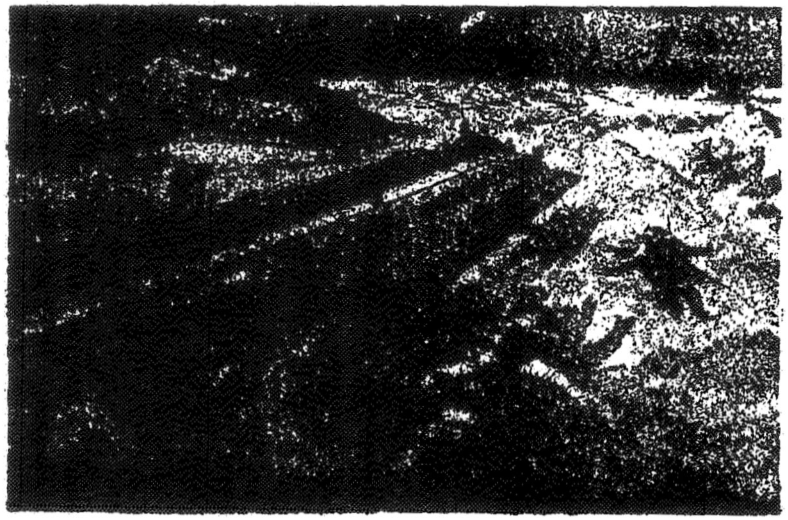
Technology for Space Station Evolution
A Workshop

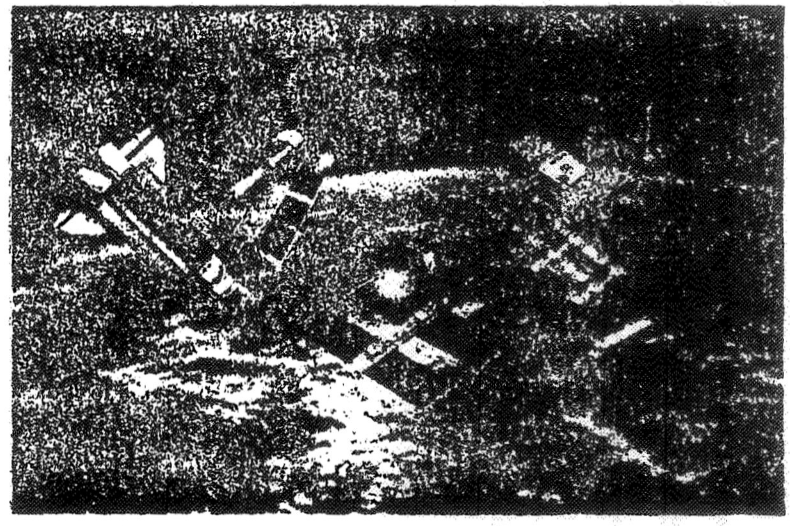
Importance of Automation

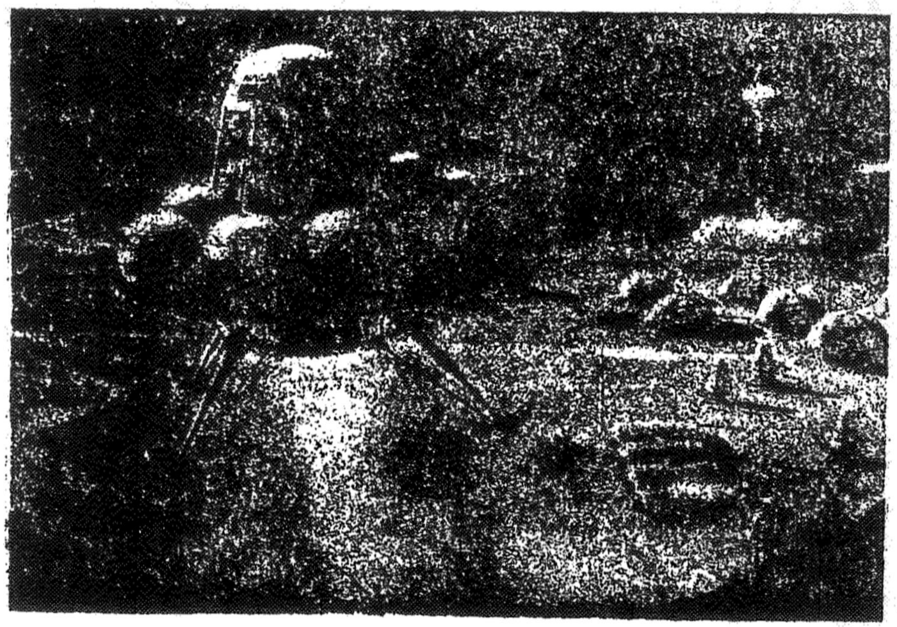
January 16, 1990

Dr. Henry Lum
NASA Ames Research Center

THE NATIONAL SPACE CHALLENGES


LUNAR OUTPOST


PERMANENT PRESENCE IN SPACE



Importance of Automation

Topics for Discussion

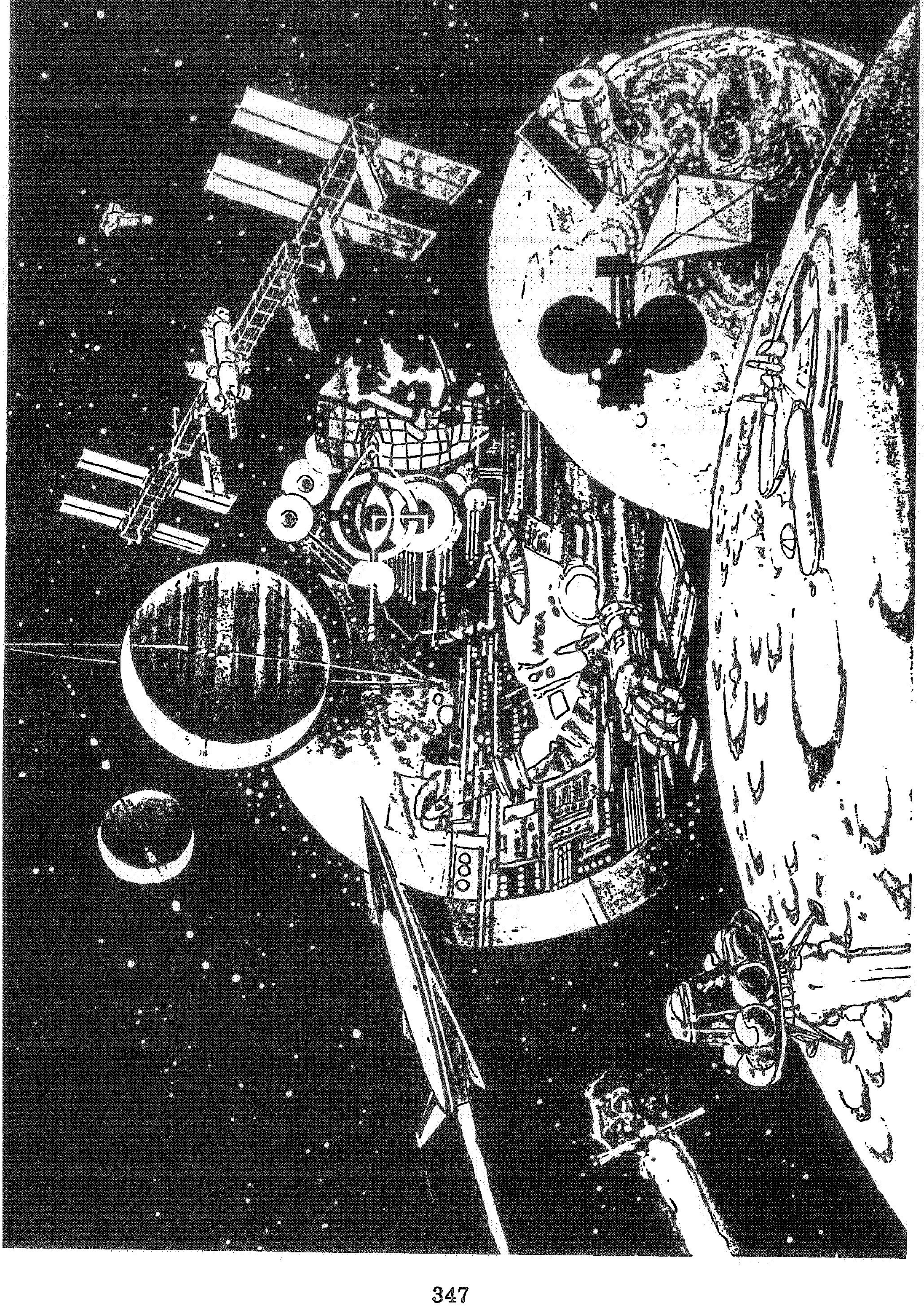
- What is Automation?
- How can it be successfully used?
- Technology Challenges
- Cultural barriers to Implementation and Utilization
- Summary

Advanced Automation

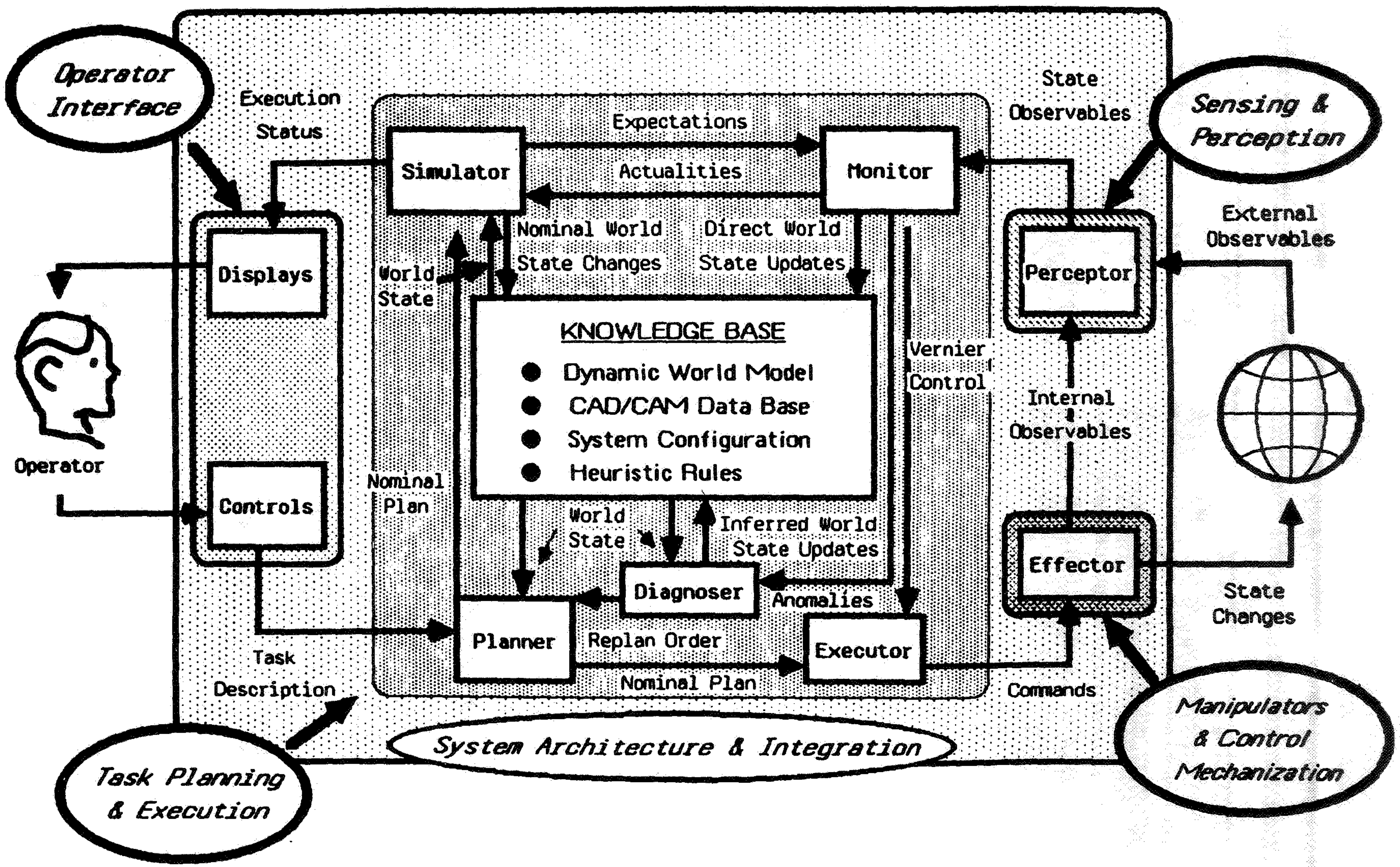
System Integration of AI Technologies with "Conventional" Technologies

Resulting in

"Intelligent" (Advanced Automation) Systems



Architecture of an Autonomous Intelligent System



Automation

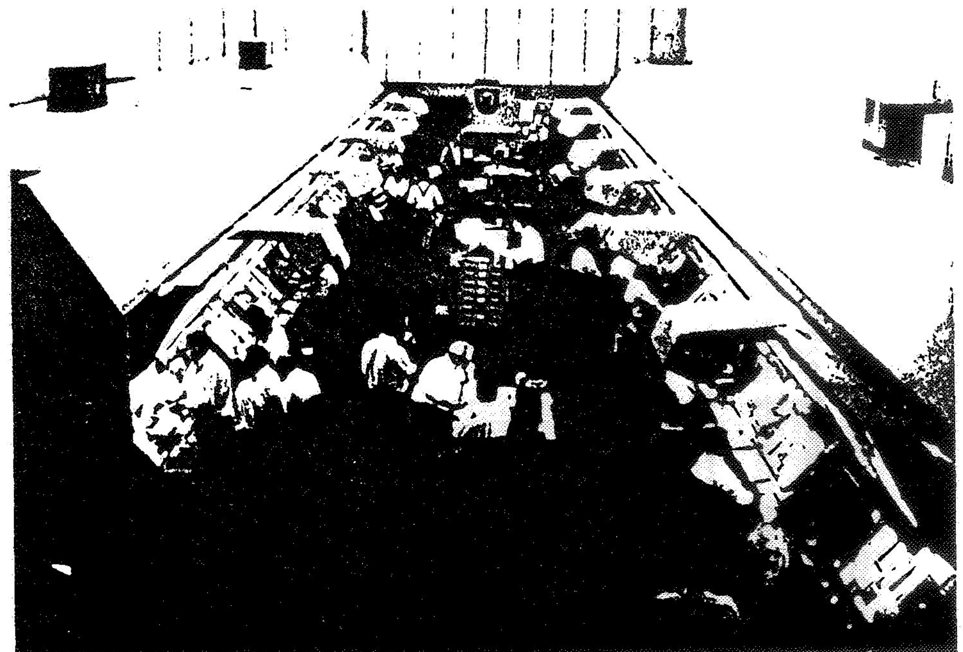
DOES NOT

Solve All Problems!

Beneficial Use of Automation is Driven by Applications Focused in Five Areas:

- Space and Aeronautical Operations
- Management and Analysis of Science and Engineering Data
- Onboard Monitoring, Diagnosis, and Control
- Preservation and Utilization of Program Life-Cycle Knowledge
- High-Fidelity Simulation and Training

SPACE AND AERONAUTICAL OPERATIONS



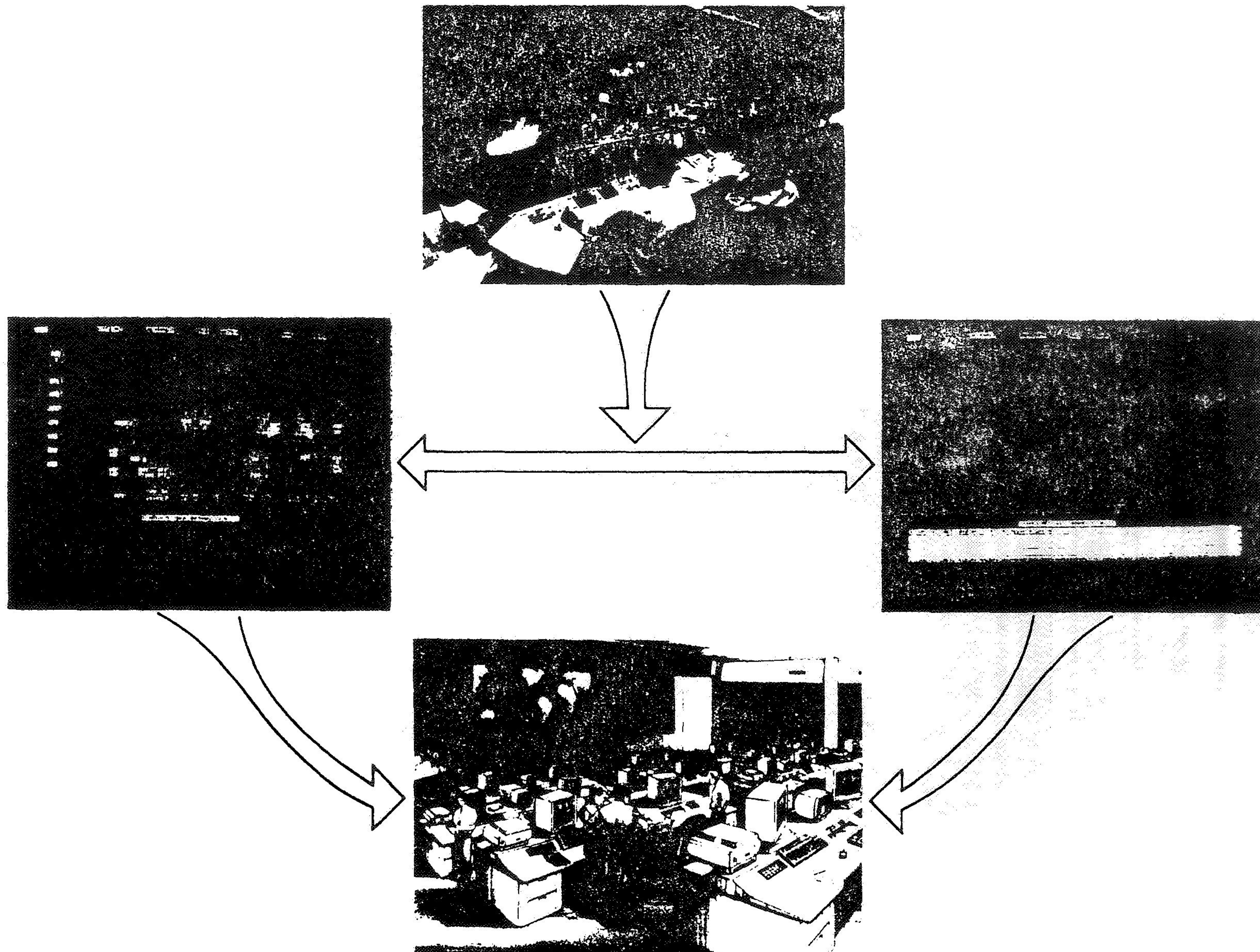
GOALS

- Reduce Manpower Needs
- Reduce Training Time
- Improve Critical Decision Making

CURRENT APPLICATION PROJECTS

- Computer Decision Aids for Air Traffic Controllers (Descent Advisor)
  - Safely Increase Traffic Volume in Terminal Areas
- Proximity Operations
  - Effective Planning Aid, Based on Human Factors, Control Theory, and Operational Experience for Maneuvers in Complex Orbital Environments
- Space Station Freedom Crew Station Design
  - Flexible, Mobile, Wearable Information Displays for IVA
- Superfluid Helium On-Orbit Transfer (SHOOT)
  - Software Systems to Allow Ground-Based Experimenters and STS Crew to Monitor and Control In-Space Cryogen Transfers
- Principal Investigator (PI)-In-A-Box
  - Capability for Crew to Better Conduct "Reactive" Science

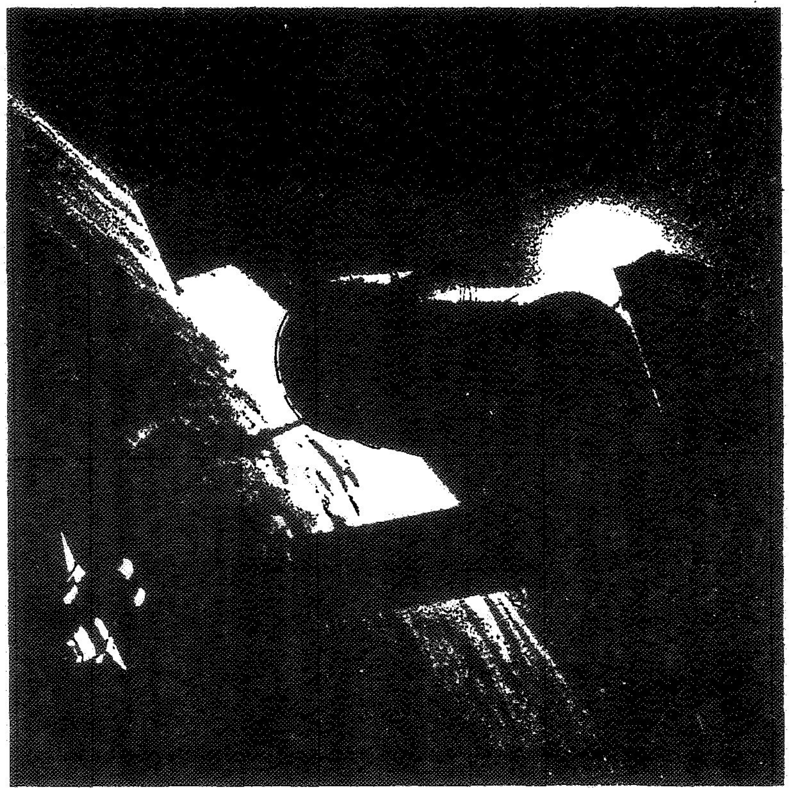
AUTOMATED SYSTEMS FOR IN-FLIGHT MISSION OPERATIONS
EVOLUTION OF AUTOMATION TECHNOLOGY



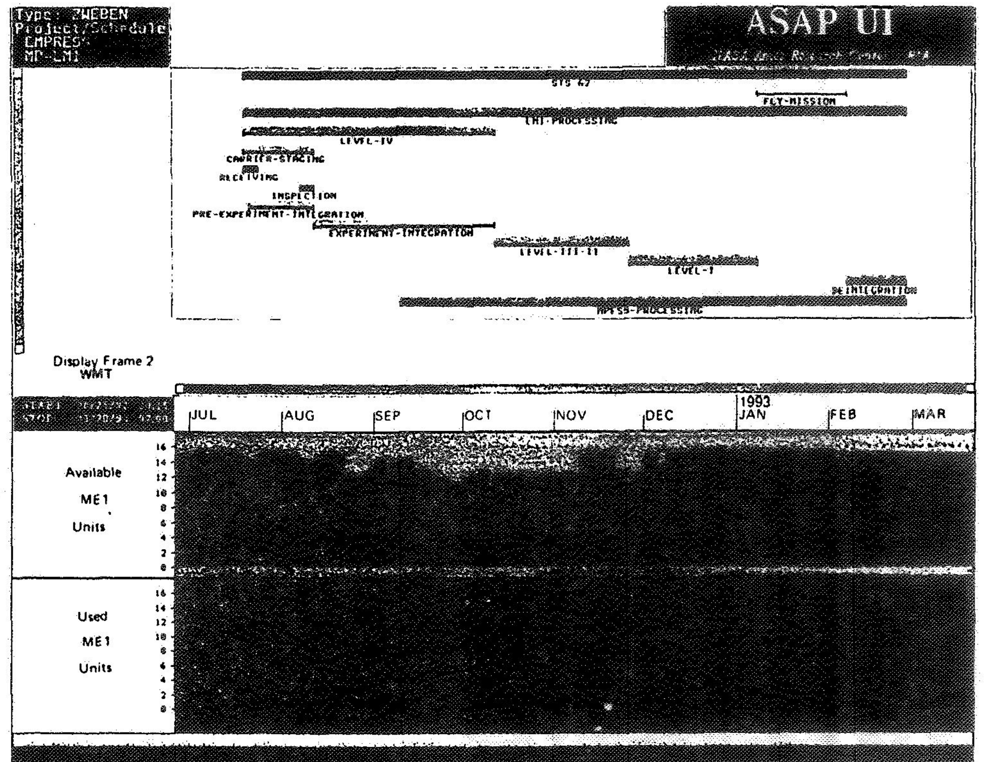
NASA AMES RESEARCH CENTER

KNOWLEDGE-BASED SCHEDULING AND RESOURCE ALLOCATION

- Automatic Scheduling
  - The placement of tasks in time given complex resource requirements subject to domain constraints
- Reactive Rescheduling
  - Meeting the exigencies of developments during the course of the schedule
- Constraint-based Representation
  - Provides system modularity and extensibility

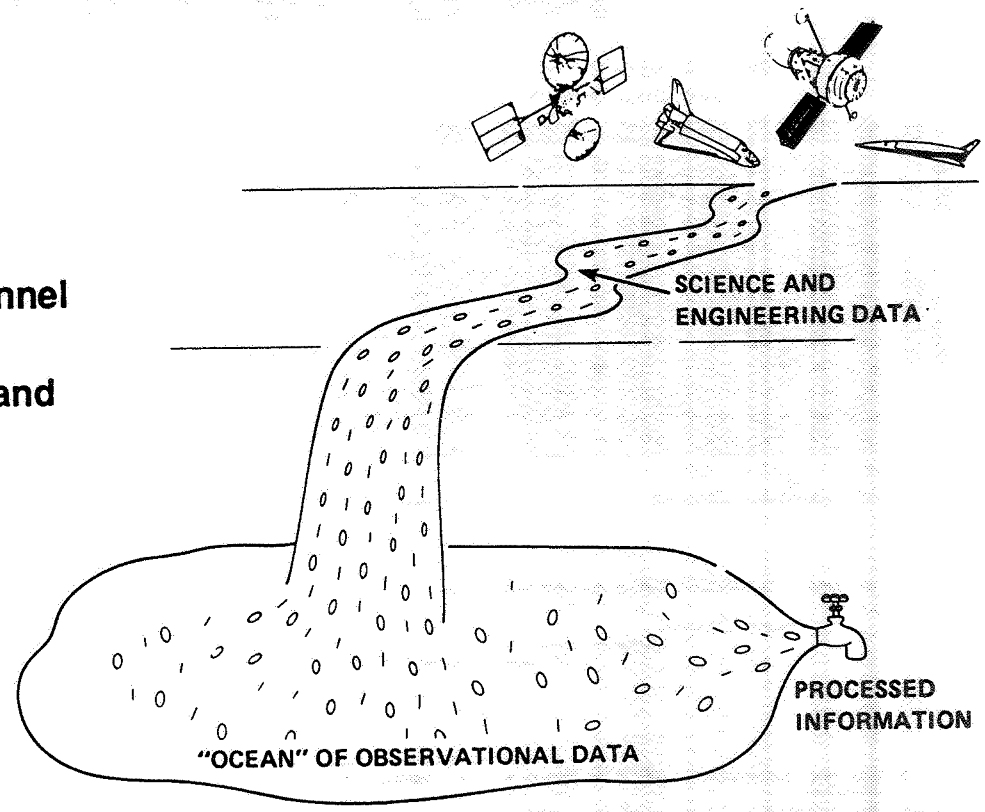


Science Scheduling
Hubble Space Telescope



Ground Operations Management
KSC Space Shuttle Payload Processing

MANAGEMENT AND ANALYSIS OF SCIENCE AND ENGINEERING DATA



GOALS

- Increase Science Return from Under-Analyzed Observational Data
- Improve Effective Utilization of Channel Bandwidth Capacity
- Conduct In-Situ Analysis on Lunar and Planetary Surfaces

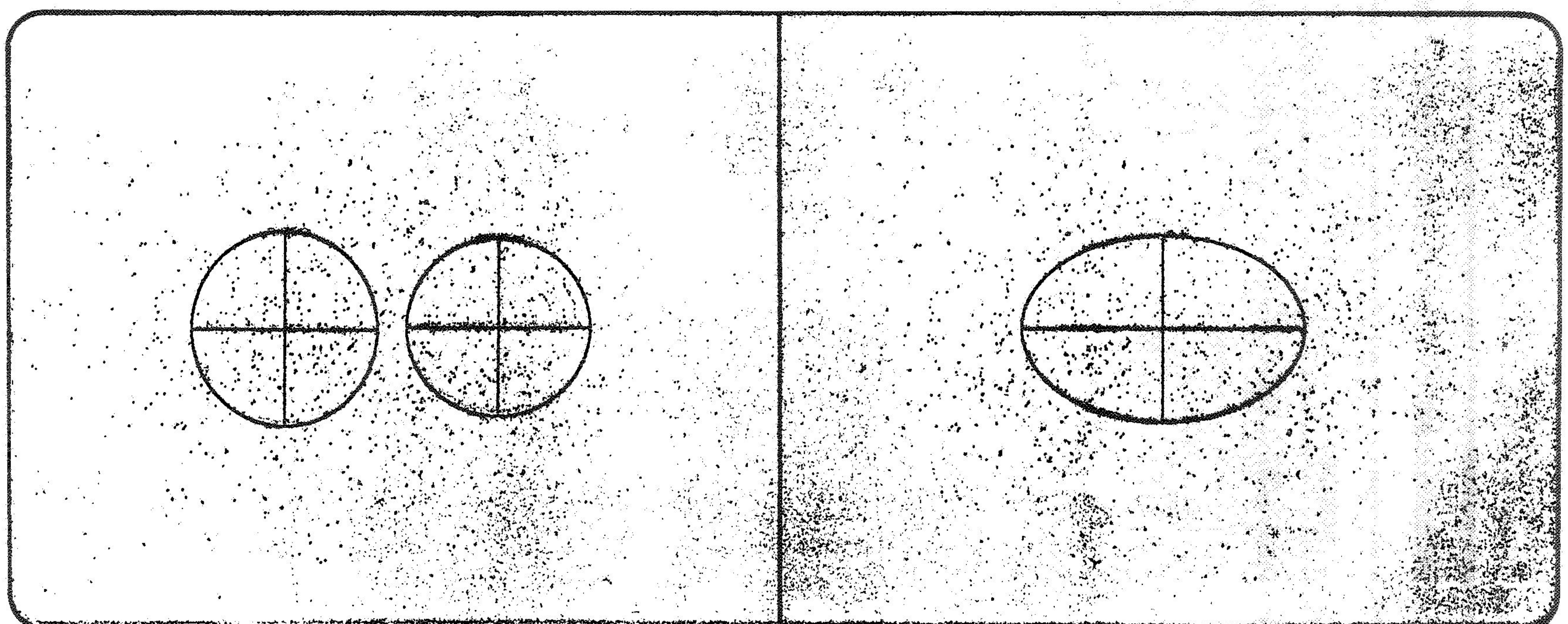
CURRENT APPLICATION PROJECTS

- Virtual Environment Workstation (VIEWS)
    - Full Information Display of Integrated Time-Varying Data in a Virtual Environment Format
- Autoclass
    - Use of Advanced Reasoning Technology for Classification of Large Data Sets
- Automation of Differential Thermal Analyzer/Gas Chromatograph (DTA/GC)
    - Software for Fault Diagnosis and Correction, and In-Situ Analysis

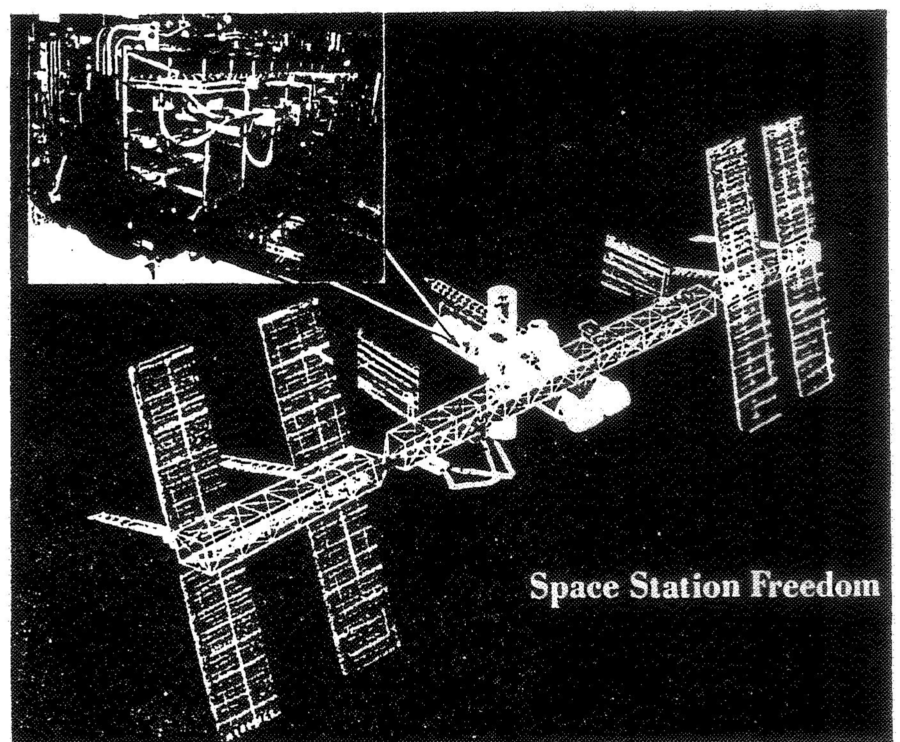
BAYESIAN LEARNING - AUTOCLASS

[illegible]

ONE CLASS OR TWO?



ONBOARD MONITORING, DIAGNOSIS & CONTROL



GOALS

- Enhance Mission Safety by Early Discovery of Incipient Failures
- Free Crew to Conduct Mission Tasks
- Provide Real-Time Capabilities Beyond Human Performance Levels

CURRENT APPLICATION PROJECTS

- Intelligent System for Real-Time Control of Space Station Freedom Thermal Control System
  - Rule and Model-Based System for Control, Fault Detection, Fault Isolation and Recovery
- Real-Time Science and Navigation Planner for Planetary Rovers
  - Reactive Science Planner Integrated with Navigation Planning
- Planetary Rover Vision System
  - 2-D Image Velocities from Image Sequences and 3-D Motions from 2-D Velocities
- Datalink Human Factors
  - Quantitative Measures and Evaluations of Pilots' Information Requirements
- Computer Vision/Guidance Aids for Rotorcraft NOE Flight

SYSTEMS AUTONOMY DEMONSTRATION PROJECT

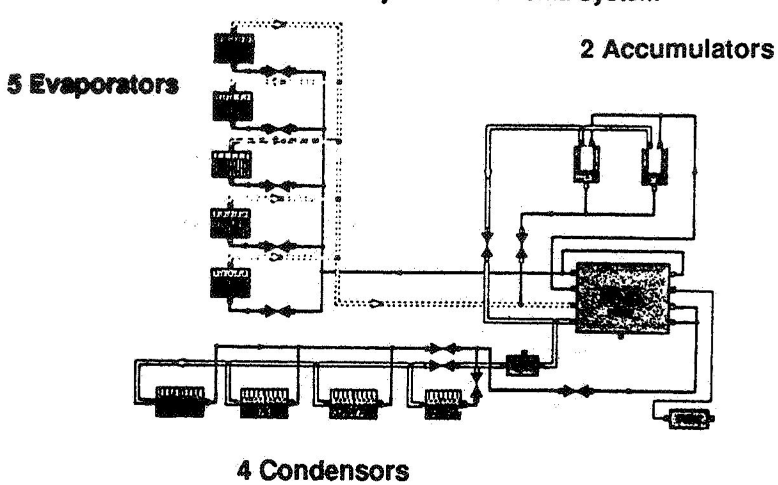
ADVANCED AUTOMATION DEMONSTRATION OF SPACE STATION FREEDOM THERMAL CONTROL SYSTEM

TECHNOLOGY CHALLENGE

EXPERT SYSTEM REALTIME CONTROL OF A COMPLEX ELECTRO-MECHANICAL SYSTEM

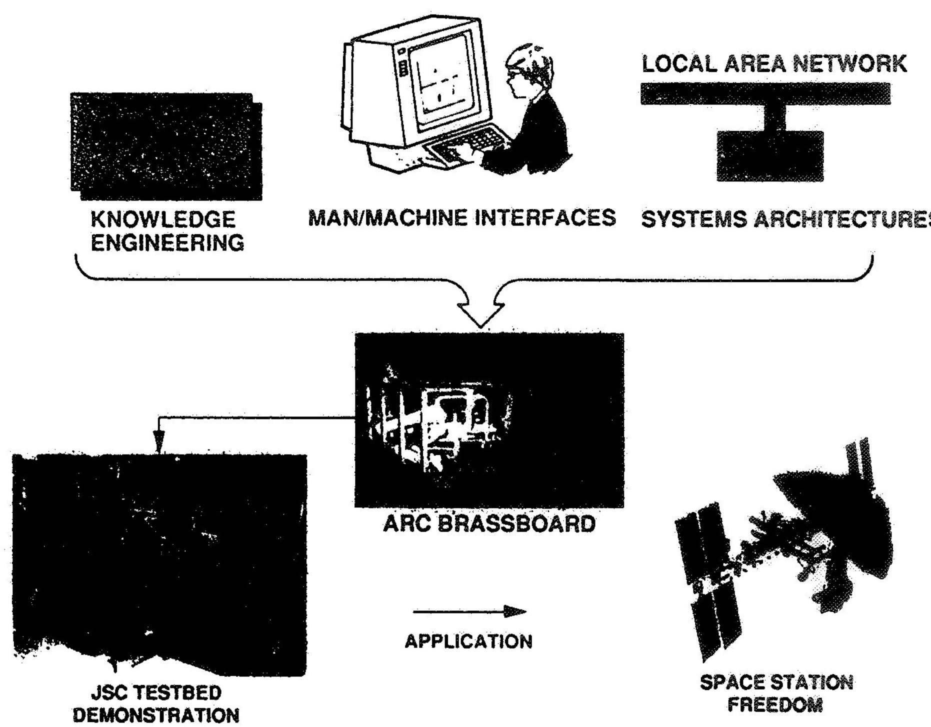
- *Advanced Thermal Technology*
- *Complex Physical System*

THERMAL CONTROL SYSTEM (TCS)
Two-Phase Anhydrous Ammonia System



TECHNOLOGY IMPLEMENTATION

JOINT ARC/JSC DEMONSTRATION



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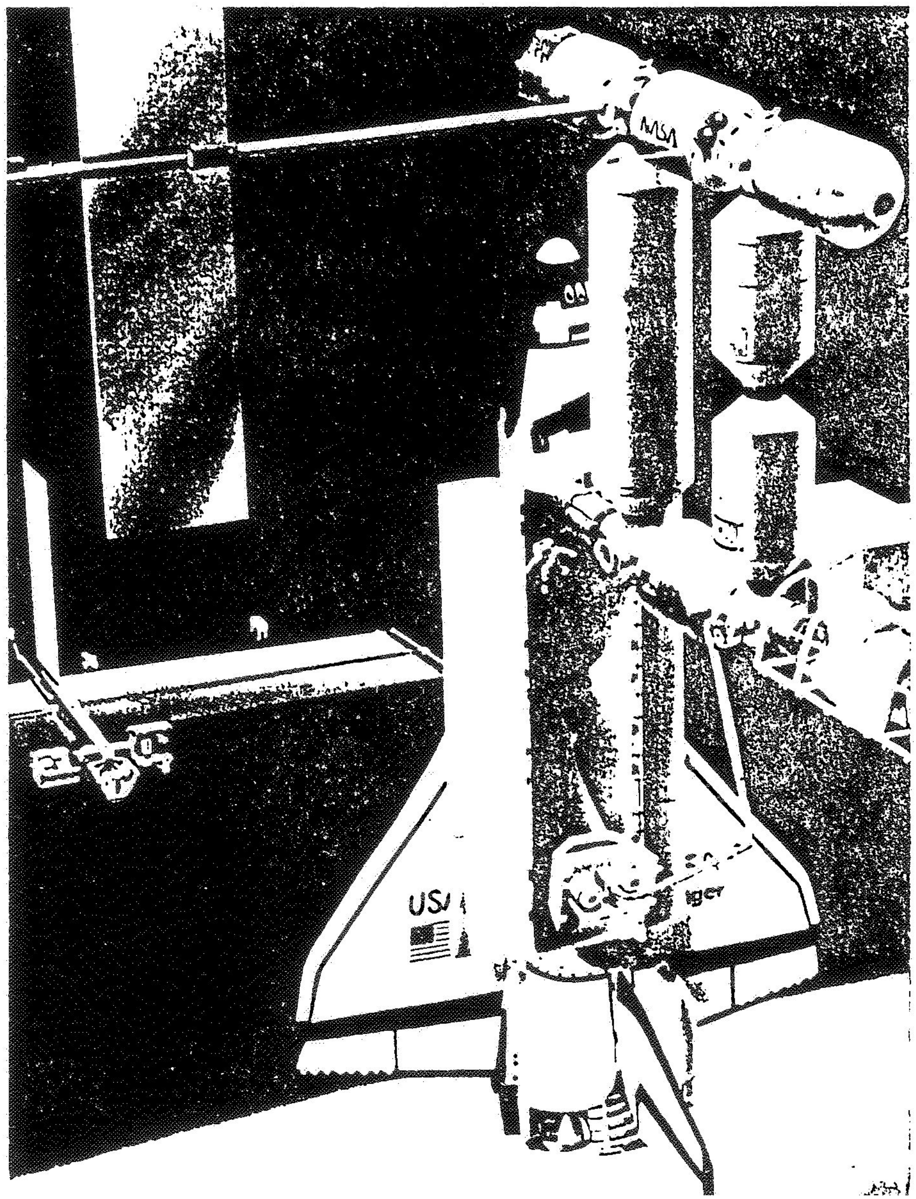
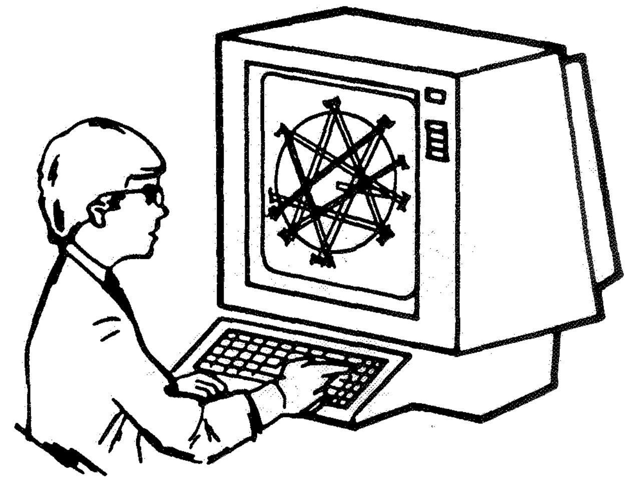
INFORMATION SCIENCES DIVISION

FAULT MANAGEMENT OF COMPLEX SYSTEMS



- Understand System in Failure Space
  - Global FMEA's
  - Failure Tolerance
- Provide Capability to Quantify, Assess, and Manage Risk
- Testability
- Model Based Reasoning Algorithm(s)
- Maintenance Diagnostics and Operations
- Support
  - Design Decisions
  - Test Operations
  - Flight Operations
  - Training
  - Design Knowledge Capture
- Integrated Verification and Validation Test Requirements

PRESERVATION AND UTILIZATION OF PROGRAM LIFE-CYCLE KNOWLEDGE



GOALS

- Capture Knowledge Throughout Design, Construction, Test and Operations
- Integrate Knowledge From Many Disparate Sources
- Provide Focused Problem-Solving Capability

CURRENT APPLICATION PROJECTS

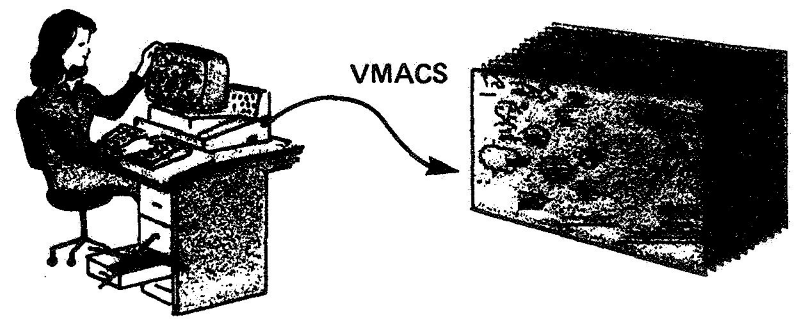
- Electronic Designers Notebook
  - Software for Routinely Capturing Formal and Informal Heuristic Design Knowledge (SIRTF Tertiary Mirror Assembly)
- Corporate Memory Facility (CMF) for Space Station Freedom TMIS
  - Knowledge-Base Technology for Enhancing Technical Management and Information System (TMIS)
- NASA/AF ALS Unified Information System
  - Distributed Intelligent Information Management System for Project Management, Control, and Real-time Scheduling - Vendor-Independent Environment

DESIGN KNOWLEDGE CAPTURE AND RETENTION

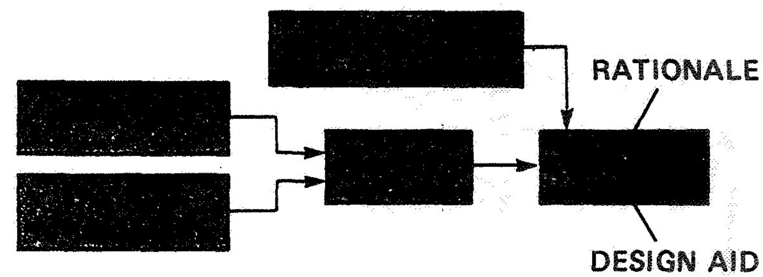
GOAL:
- ACQUIRE COMPUTER UNDERSTANDABLE MODEL OF DESIGN AND REQUIREMENTS
- RECORD RATIONALE FOR DESIGN DECISIONS

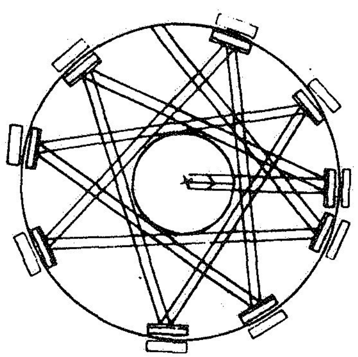
APPROACH:

1. PROVIDE AND ELECTRONIC NOTEBOOK →

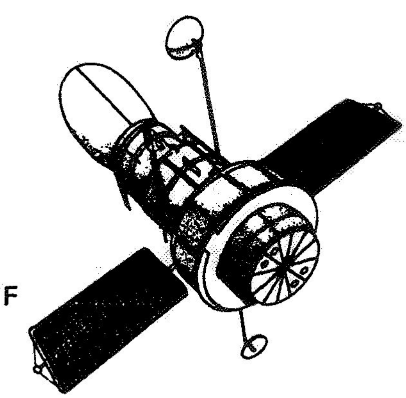


2. EVALUATE HOW WELL THE DESIGNS MEET THE REQUIREMENTS →





TERTIARY MIRROR



TELESCOPE: SIRTF

Technology Challenges

- Multiple Sensor Integration and Understanding
- Distributed Knowledge-based Systems
  - Cooperating Agents
  - Distributed Operating Systems
  - Real-time Networking
  - Distributed Programming Environment
- System Architecture and Integration
  - User Interfaces
  - Fault Management
  - Computational Environment
- System Verification and Validations
- Focused Testbed Applications

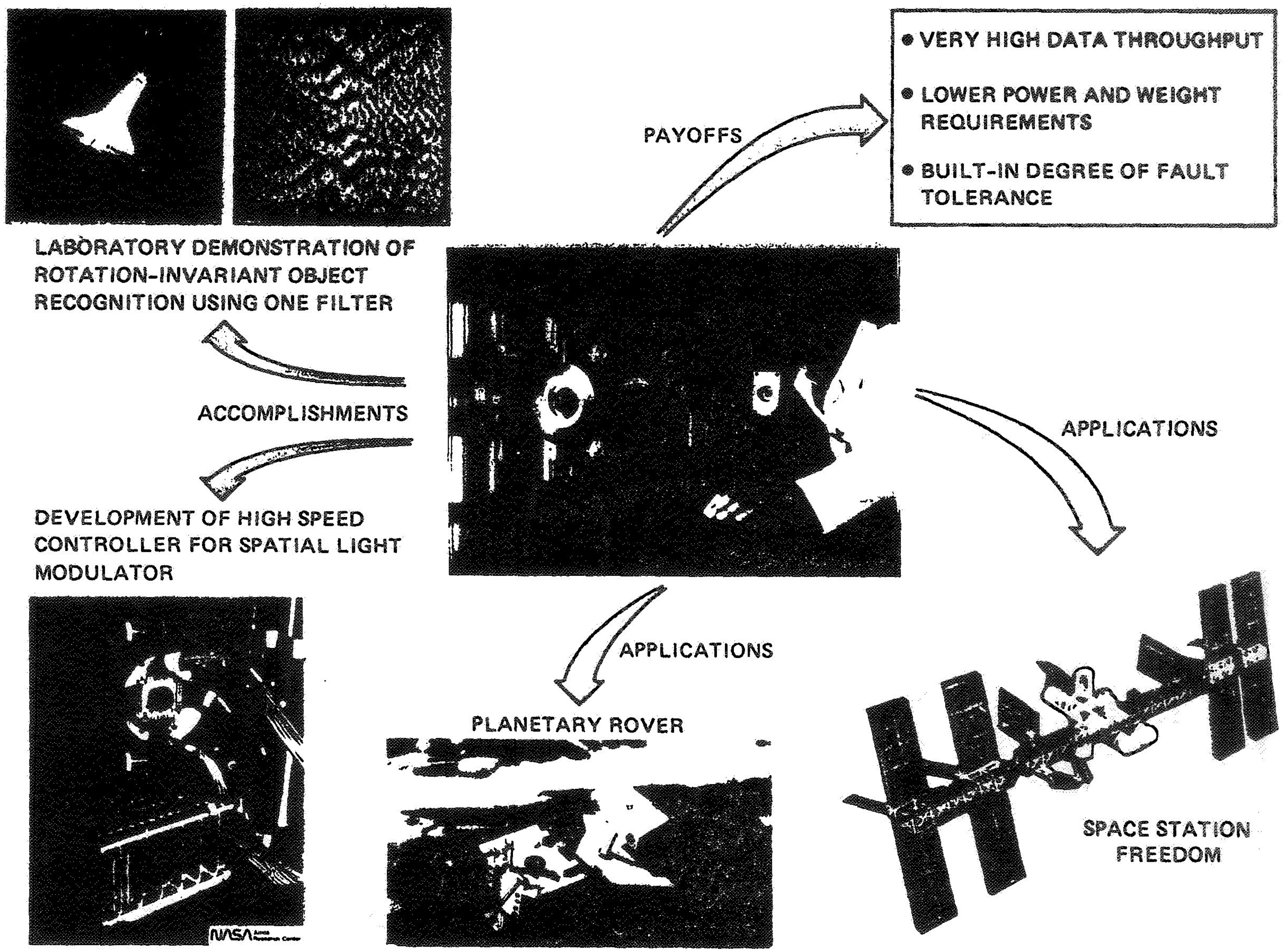
Recommended "Cultural" Changes for Implementation of Advanced Automation

- Integrate/Manage/Use all Agency Resources to Accomplish Project and Mission Goals and Objectives
    - Implement Effective Team Collaboration between Centers
    - Implement a Distributed Unified Information System for Project Management and Control
- Leverage/Use Commercial/Industry/DoD Standards and Technologies whenever Possible
- Accept/Use Advanced Automation and Expert Systems in Operational Environment
- Design and Manage for Evolutionary Growth and Technology Upgrades
- Incorporate System Fault Management from Design through Operations
- Use Life Cycle Design Costs for Determination of Return-on-Investment (ROI)

VERIFICATION AND VALIDATION CONCEPTS
CRITICAL FOR
AUTOMATION INSERTION IN FLIGHT PROGRAMS

"It's beginning to show *some* human characteristics—faulty reasoning, forgetfulness and repetition."

PHOTONIC PROCESSING



AMES COLLABORATIVE AI AND COMPUTER ARCHITECTURES RESEARCH TEAM

INFORMATION SCIENCES DIVISION (RI)

ACADEMIA

CARNEGIE-MELLON UNIVERSITY Mitchell Carbonell Mason Segall Cassent	Machine Learning, Planning, Fault Management, Optical Information Processing
STANFORD UNIV. Leifer Flynn Cannon Feigenbaum Nilsson Widrow	Cooperating Knowledge-Based Systems, AI/ Robotics Integration, R/T Control of Flexible Manipulator, and Conservation of Design Knowledge, Neural Network Controllers
Univ. of Mich. Laird	Teleautonomy and Machine Learning
U C BERKELEY Zadeh Stonebreaker	Fuzzy Logic DBMS
M I T Young	Intelligent On-board Space Sciences Systems
UNIV. OF ILLINOIS Wah	Parallel Architectures and O/S
USC ISI Rosenbloom Mizell Balzer	Machine Learning, Parallel Architectures, Automated Programming
RIACS Denning	Architectures S/W for Work Stations

GOVERNMENT

DARPA	AI Research and Advanced Computer Architectures
AF	Advanced Launch Systems Computer Architectures
NASA CENTER MOU'S	GFSC KSC LaRC JPL LeRC JSC MSFC

INDUSTRY

MDAC & LOCKHEED	Space Station Automation Technologies
BOEING	Corporate Memory Facility
SRI	Procedural Reasoning, Communicating Agents
INTEL SUN XEROX	Beta Test Site for Advanced Computer Architectures
ISX	Knowledge Systems Development Tools
TELEOS	Intelligent Mobile Robots

Recommendation from STATS Strategic Avionics Planning November 1989

Advanced Automation Applications

- Increased Emphasis on Automating Flight Vehicles
  - Health Status Monitoring
  - Onboard Test and Checkout
  - System Testability Design
  - Onboard Flight Design Process
  - Inflight Crew Training

Provides Maximum Return on Investment

Recommendation from STATS Strategic Avionics Planning
November 1989

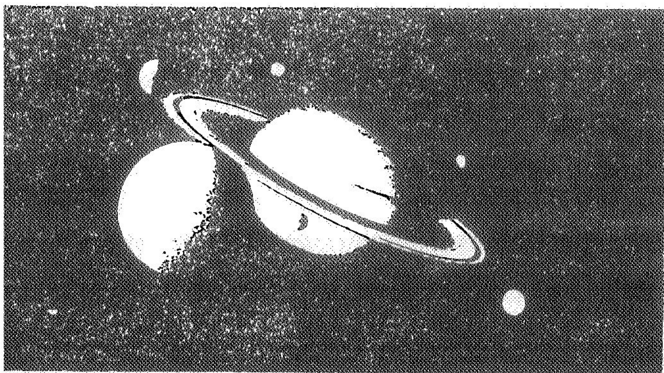
Implementation Strategy

- Build Appropriate Complexity into Hardware Early and Avoid Complex Software
- Develop Integrated Test and Verification Facilities that Support Multiple Programs
- Utilize Technology to Develop Multifunction Systems/Sensors as Opposed to Single Function Box Replacement

Cost-Effective Insertion of Evolving Technology
for
Maximum Productivity

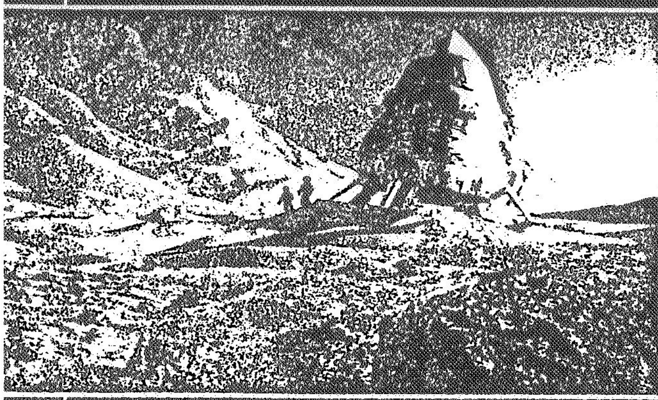
Benefits of Advanced Automation

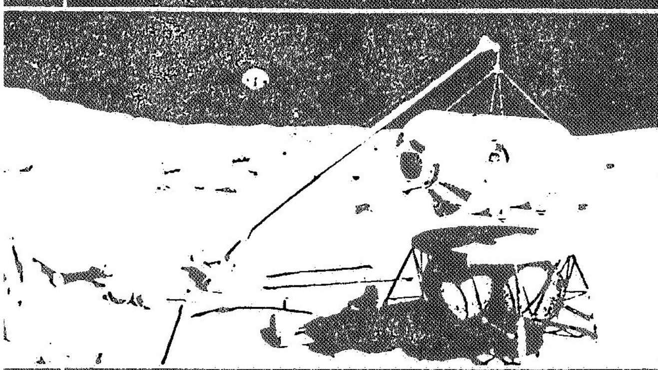
- Increased Functionality
- Increased Fault Management Capability
- Evolution of Highly Dependable Systems
- Increased Productivity
  - Skill Utilization
  - Training

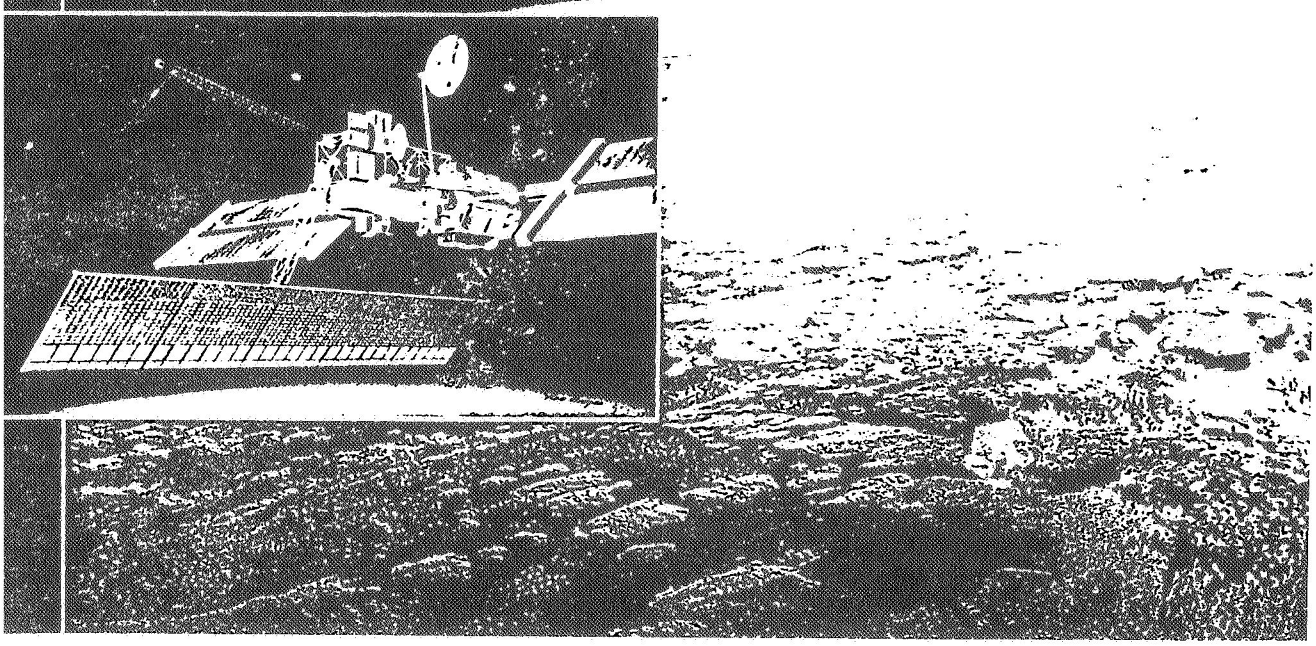


NASA

LEADERSHIP
and America's Future in Space







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APPENDIX 1 - FINAL AGENDA

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Appendix 1

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

Final Agenda

TUESDAY, JANUARY 16, 1990

8:00am - 12:00N	PLENARY SESSION
8:00am - 8:15am	Welcome *Arnold D. Aldrich* *Associate Administrator for Aeronautics and Space Technology*
8:15am - 8:45am	Keynote *Dr. William B. Lenoir* *Associate Administrator for Space Station*
8:45am - 9:00am	Workshop Overview *Dr. Judith H. Ambrus* *Acting Assistant Director for Space, Large Space Systems* *Office of Aeronautics and Space Technology*
9:00am - 9:45am	Space Station Phase I Configuration *Richard H. Kohrs* *Director, Space Station Freedom*
9:45am - 10:15am	BREAK
10:15am - 10:45am	Mission Requirements and Evolution Scenarios *Dr. Earle K. Huckins, III* *Director, Strategic Plans and Programs* *Office of Space Station*
10:45am - 11:15am	Space Station as a Transportation Node *Dr. Jeffrey Rosendhal* *Special Assistant for Policy* *Office of Exploration*
11:15am - 11:45am	Importance of Automation *Dr. Henry Lum, Jr.* *Chief, Information Sciences Division* *NASA, Ames Research Center*
11:45am - 12:00N	Workshop Instructions *Dr. Roger Breckenridge* *Manager, In-Space Technology Office* *Space Station Freedom Office* *NASA, Langley Research Center*

TUESDAY, JANUARY 16, 1990 (cont'd)

12:00N - 1:30pm	LUNCH
	Luncheon Speaker *James B. Odom* *President, CEO* *Applied Research, Inc.*
1:30pm - 6:00pm	ELEVEN DISCIPLINE BREAKOUTS
	ATTITUDE CONTROL AND STABILIZATION COMMUNICATIONS AND TRACKING DATA MANGEMENT SYSTEM ECLSS EVA/MAN SYSTEMS FLUID MANAGEMENT SYSTEM POWER SYSTEM PROPULSION ROBOTICS STRUCTURES/MATERIALS THERMAL CONTROL SYSTEM
1:30pm - 3:00pm	Current Station Subsystem Design *Level III Managers*
3:00pm - 3:30pm	BREAK
3:30pm - 4:30pm	Current OAST Program Overview *OAST Program Managers*
4:30pm - 6:00pm	*Invited Speakers*

WEDNESDAY, JANUARY 17, 1990

8:00am - 5:30pm	ELEVEN DISCIPLINE BREAKOUTS
	ATTITUDE CONTROL AND STABILIZATION COMMUNICATIONS AND TRACKING DATA MANAGEMENT SYSTEM ECLSS EVA/MAN SYSTEMS FLUID MANAGEMENT SYSTEM POWER SYSTEM PROPULSION ROBOTICS STRUCTURES/MATERIALS THERMAL CONTROL SYSTEM
8:00am - 10:00am	Panel Discussion of Space Station System Needs
10:00am - 10:30am	BREAK
10:30am - 12:00N	Panel Discussion of Projected Technology Advances
12:00N - 1:00pm	LUNCH
1:00pm - 3:00pm	Workshop Discussions
3:00pm - 3:30pm	BREAK
3:30pm - 5:30pm	Workshop Discussions

THURSDAY, JANUARY 18, 1990

8:00am - 5:00pm	ELEVEN DISCIPLINE BREAKOUTS
	ATTITUDE CONTROL & STABILIZATION COMMUNICATIONS & TRACKING DATA MANAGEMENT SYSTEM ECLSS EVA/MAN SYSTEMS FLUID MANAGEMENT SYSTEM POWER SYSTEM PROPULSION ROBOTICS STRUCTURES/MATERIALS THERMAL CONTROL SYSTEM
8:00am - 10:00am	Workshop Discussions
10:00am - 10:30am	BREAK
10:30am - 12:00N	Workshop Discussions
12:00N - 1:00pm	LUNCH
1:00pm - 3:00pm	Workshop Committees Prepare Reports
3:00pm - 3:30pm	BREAK
3:30pm - 5:00pm	Workshop Committees Prepare Reports

FRIDAY, JANUARY 19, 1990

8:00am - 12:00N	PLENARY SESSION
8:00am - 9:15am	Presentation of Workshop Reports
	Attitude Control and Stabilization Communications and Tracking Data Management System ECLSS EVA/Man Systems
9:15am - 9:45am	BREAK
9:45am - 11:15am	Presentation of Workshop Reports
	Fluid Management System Power System Propulsion Robotics Structures/Materials Thermal Control System
11:15am - 12:00N	Workshop Wrap-up
12:00N	ADJOURN

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APPENDIX 2 - ATTENDEES

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EVTEK ATTENDEES - MASTER LIST

Abbott, Larry W.	NASA/JSC
Akin, Dave	MIT
Anderson, Lynn	Nasa LeRC
Arndt, Dickey	NASA,JSC
Ashe, Tom	Garrett Fluid Systems
Asher, Jim	Parker Hannifin Corp.
Aswani, Mohan	Aerospace Corp.
Austin, Frank H.	NASA/SSS-1
Avans, Sherman L.	NASA MSFC
Aydelott, John	NASA LeRC
Ayers, J. Kirk	Lockheed
Baird, R.S.	NASA - JSC
Baker, Mary C.	Texas Tech University
Barry, Tom	NASA-JSC/EH3
Batten, Bobby G.	NASA LaRC
Bechtel, Bob	MSFC - EB 11
Behrend, Al	NASA, JSC
Bendett, Mark	Honeywell, Inc.
Benz, Harry F.	NASA/Langley
Bercaw, Robert	NASA LeRC
Berry, William E.	NASA, ARC
Blackburn, Greg C.	NASA/JSC/EF2
Blevins, Donald R.	JSC/EP
Bogus, Drew	Allied-Signal
Borden, Don	Motorola, Inc.
Bowles, David E.	NASA LaRC
Brandhorst, Henry	NASA LeRC
Brooks, Thurston	NASA/GSFC
Brown, Barbara	NASA, KSC
Brown, Robert H.	McDonnel Douglas
Brownfield, Jay	Allied-Signal, GFSD
Butler, Jr., John M.	NASA, MSFC
Calogeras, James	NASA/Lewis
Cardin, Joe	Moog Inc.
Carnes, James Ray	Boeing
Cassell, Sean	Ford Aerospace
Chen, Angela	McDonnell Douglas
Cheyney, Clay	M0OG - Space Products
Chung, Tae-Sang	University of Kentucky
Cirillo, William M.	NASA LaRC

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Clubb, Jerry J.	NASA/MSFC
Collier, Lisa	CTA Incorporated/LaRC
Conlan, James T.	Astro Aerospace Corp
Connolly, Denis J.	NASA LeRC
Cooper, Paul A.	NASA LaRC
Crawley, Edward F.	MIT
Culpepper, William X.	NASA, JSC
Cunningham, Harry	Lockheed ESC
Curtis, Henry	NASA/Lewis
Czajkowski, Eva	Analytic Service, Inc.
D'Andrade, Jim	ILC Dover, Inc.
Dahlstrom, Eric	Lockheed Engineering
Dalton, Danny A.	NASA, GSFC
Damsky, Steven	GRC
Davis, Bill	Boeing Computer Services
Davis, Tom	NASA, KSC
Dell, Jim	W - ESD
DeRyder, L.J.	NASA Langley
Deskevich, Joe	Grumman
Dewberry, Brandon	NASA MSFC
Diamant, Bryce L.	McDonnell Douglas
Dickinson, David W.	Ohio State University
Dietz, Reinhold H.	NASA, JSC
Digulla, Wendy J.	NASA, KSC
DiPirro, Mike	NASA/GSFC
Djinis, William	NASA HQ
Dochat, George R.	Mechanical Technology Inc
Doiron, Harold	McDonnell Douglas
Dollman, Tom	NASA MSFC
Domeniconi, Mike	Ford Aerospace
Dominick, Sam	Martin Marietta
Dorland, Wade D.	Wyle Labs
Dunkelberger, Bill	United Technologies/USBi
Eberhardt, Ralph	Martin Marietta
Eckle, John J.	Boeing
Edgell, Jo	U. of Alabama, Huntsville
Eisenberg, Al	McDonnell Douglas
Eisenhaure, Dave	SatCon Tech Corp
Ellis, Wil	NASA, JSC
Erickson, Daniel E.	JPL
Evanich, Peggy L.	NASA - OASR
Evans, Steve	Rocketdyne
Fisher, Tom	Lockheed

Fishkind, Stanley A.	NASA (HQTS/Level I)
Fleener, Terry	Ball Aerospace
Force, Edwin L.	NASA ARC
Fox, David A.	Westinghouse
Fraser, George F.	C. S. Draper Lab.
Friedman, Robert	NASA LeRC
Friefeld, Jerry	Rocketdyne
Gangal, Mukund	JPL/SSFPO Level II
Gates, Richard M.	Boeing
Gerber, Jr., Andrew J.	Fairchild Space Company
Ghassemi, Parviz	Booz-Allen
Giffin, Geoff	NASA HDQS
Giuntini, Ronald	Wyle Laboratories
Glover, Cynthia	Rockwell International
Goldman, Jeff	Foster-Miller
Gonzalez, Tony	Fairchild - Manhattan CA Bch
Gould, Marston	NASA LaRC
Gould, Patricia E.	MITRE
Griffin, Charles H.	NASA, KSC
Griffiths, Ron	Foster Miller
Grohowski, Jim	Westinghouse Space Division
Grupe, David	Olin Rocket Research
Hadaegh, Fred Y.	JPL
Hall, Jack	NASA - Reston
Hampel, Daniel	GE Aerospace
Hansen, Irv	NASA LeRC
Hastings, Leon	NASA MsFC
Hattis, Philip	C. S. Draper Lab.
Hay, Robert E.	Motorola
Hayduk, Robert J.	NASA HQ
Hayes, Paul J.	NASA/LaRC
Heard, Doug	NASA LaRC
Henderson, John B.	NASA/JSC
Hennig, Jay	MOOG
Hitchens, G. Duncan	LYNNTECH
Ho, Frank	Applied Solar Energy
Hoggard, Walter C.	NASA LaRC
Hoggatt, John T.	Boeing
Hollars, Michael G.	Ford Aerospace
Holloway, Reggie M.	NASA LaRC
Holt, Alan C.	NASA SSFPO/Reston
Horne, Ed	Boeing Co.
Housner, Jerry M.	NASA LaRC

Hunter, David G.	Canadian Space Agency
Iverson, James D.	Iowa State U.
Jackson, Stewart W.	Fairchild Space Company
Jayachandran, P.	SSEIC/Reston
Jefferson, David	NIST
Jelatis, Demetrius G.	Central Research Labs
Jenkins, Jim	OAST/NASA
Johnson, Anngienetta R.	NASA/Reston
Jones, Lee	NASA/MsFC
Jones, Michael	MDSSC
Karlheinz, Haag	DLR
Karr, Gerald R.	Univ. of Alabama (Huntsville)
Kaszubowski, Martin J.	CTA, Inc.
Keckler, Claude R.	NASA LaRC
Kelley, Jim	JPL
Kessler, Donald J.	NASA, JSC
Kish, Jim	NASA LeRC
Klusendorf, Roy E.	Spar Aerospace
Kolecki, Joseph C.	NASA/Lewis
Kondis, Peter	Rockwell International
Kosmo, Joe	NASA-JSC/EC3
Kowitz, Herbert R.	NASA, LaRC
Kozak, Dave	ASEC
Kramer, James J.	Univ. of Alabama (Huntsville)
Kumar, Renjith R.	AMA, Inc.
Kurdila, Andrew J.	Texas A&M Univ.
Lamparter, Richard	Lockheed
Larson, Vernon R.	Rocketdyne
Lee, Bill	Fairchild Control
Lee, John F.L.	Honeywell, Inc.
Lee, Roscoe	TRW
Lepanto, Janet	C. S. Draper Lab.
Lewis, Jim	NASA-JSC/SP
Liggett, Mark	General Dynamics
Lin, Chin	NASA, JSC
Lin, Jiguan Gene	Control Research Corp.
Little, Frank E.	Texas A&M Univ.
Liu, Yuan-Kwei	NASA/ARC
Llewellyn, Charles P.	AMA/LaRC
Lowry, Philip	General Dynamics
Lundstrom, Stephen F.	PARSA
Manering, Mark	McDonnell Douglas
Manfredi, Larry	NASA, KSC

Martinec, John L.	IBM Corporation
Masline, Richard	NASA/JPL
Mazanek, Dan	AMA (LaRC)
McElroy, Jim	Hamilton Standard
McGovern, Dennis J.	McDonnell Douglas
McKeritt, Frank	Tedinion, Inc.
McLallin, Kerry L.	NASA/Lewis
Meserole, Chip	Boeing/Seattle
Mettler, Edward	JPL
Mikulas, Jr., Martin M.	NASA LaRC
Mitchell, Fred	McDonnell Douglas
Morvano, Joe	MDSSC-SSD
Myron, Don	Boeing
Nagy, Kornel	NASA, JSC
Newsom, Jerry R.	NASA LaRC
Nichols, Hugh	MDSSC - KSC
Nichols, Jay A.	Rockwell International
Nored, Donald L.	NASA LeRC
O'Hair, Ed	Texas Tech University
Olsson, Eric	Lockheed
Olstad, Walter B.	Lockheed
Oran, William A.	Bendix Corp.
Ostrom, Lee	EG&G, Idaho
Parker, Ken	AIRESEARCH
Parlos, Alexander G.	Texas A&M Univ.
Patterson, Bob	TRW
Peterson, Bud	Texas A&M University
Petrozzi, Mike	Fairchild
Pinkerton, Robb	SSEIC/Ford Aerospace
Pinson, Larry D.	NASA LaRC
Pirri, Tony	Physical Sciences, Inc.
Piszczor, Michael	NASA/Lewis
Plotkin, Henry H.	NASA, GSFC
Poley, William A.	NASA/Lewis
Provost, David E.	NASA/GSFC
Purves, Robert Byron	Boeing
Putnam, David F.	UMPQUA
Quaid, Thomas B.	Motorola
Radtke, Robert	Tracor Applied Sciences
Raffi, Rhonda	SatCon Tech Corp
Rascoe, Dan L.	JPL
Ray, Charles D.	NASA MSFC
Redd, Bass	Eagle Engineering

Reinicke, Bob	Marotta Scientific
Reuter, Gerald J.	NASA/JSC
Reysa, Richard	Boeing
Rhodes, Marvin	NASA LaRC
Rinsland, Pamela L.	NASA LaRC
Rogan, Jim	MDSSC
Rogers, Tom D.	Texas A&M Univ.
Rohn, Douglas A.	NASA LeRC
Romanofsky, Robert	NASA HQ
Rose, Frank	Auburn University
Rosser, Ken	McDonnell Douglas
Rosser, Ken H.	MDSSC/KSC
Rouen, Michael	NASA-JSC/EH3
Rountree, Will	Eaton Corporation
Rudich, Bob	AIRESEARCH
Saha, H.	Alabama A&M University
Sanabria, Olga Gonzalez-	NASA LeRC
Sanabria, Rafael	NASA LeRC
Sasamoto, Washito	NASA, LaRC
Schneider, Steven J.	NASA/LeRC
Schnittgrund, Gary	Rocketdyne
Schober, Wayne	JPL
Schubert, Franz H.	Life Systems
Schuster, John	GD Space Systems
Shane, Rick	Hamilton Standard
Shaw, Roland W.	Shason Microwave
Shepard, G. Dudley	C. S. Draper Lab
Shull, Thomas A.	NASA LaRC
Simberg, Rand	Rockwell/STSD
Simon, Michael C.	General Dynamics
Slade, Howard	MDSSC-SSD
Slavin, Tom	Boeing
Smisek, Dick	AIRESEARCH
Smith, Jeffrey H.	JPL
Smith, Malcolm C.	ILC Space Systems Division
Smithrick, John	NASA/Lewis
Sokolov, Vladimir	Honeywell, Inc.
Starsman, Raymond E.	JPL
Stedman, Jay	IFC
Sullivan, Jim	Westinghouse
Summerfield, Martin	PCRL, Inc.
Sundberg, Gale	NASA LeRC
Sunkel, John W.	NASA, JSC

Swanson, Ted	NASA, GSFC
Swietek, Greg E.	NASA HQ
Symons, Pat	NASA LeRC
Talapatra, Dipak C.	NASA SSFPO/Reston
Talbot, Joe	NASA Langley
Taylor, Larry W.	NASA LaRC
Tenney, Darrel	NASA LaRC
Tesar, Delbert	University of Texas
Thakoor, Anil	JPL
Thiel, Dick	Rockwell Space Division
Thomas, Emory	Brunswick
Timoc, Constantin	SPACEBORNE, Inc.
Tolivar, Fernando	JPL
Tracy, John J.	McDonnell Douglas
Trusch, Raymond B.	Hamilton-Standard
Valenzuela, Javier	Creare
Van Sciver, Steve	Univ. of Wisconsin - Madison
Venator, Tom	Swales
Vernon, Richard	NASA, LeRC
Voigt, Susan J.	NASA Langley SSFO
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Wada, Ben K.	JPL
Wade, Donald	NASA, JSC
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Walter, Gervino A.	Dornier GMBH
Weisbin, Chuck	JPL
Wie, Bong	Arizona State Univ.
Wieland, Paul	NASA/MSFC
Willenberg, Harvey	Boeing - Huntsville
Willits, Chas	NASA/SSFPO
Willshire, Kelli	NASA - LaRC/152D
Winters, Al	BA&E/Resupply Ops
Witkowski, Larry	Texas Instruments
Wood, Robert M.	McDonnell Douglas
Woodcock, Gordon	Boeing - HuntsvillE
Wright, Lee	Motorola
Yeichner, John A.	Honeyell, Inc.
Yelverton, J. Ned	IBM/Houston Adv. Space Tech.
Yeo, Joseph E.	NASA, JSC
Youngblood, Wallace W.	Wyle Labs
Zernic, Mike	NASA/Lewis
Zimmerman, Robert K.	NASA, GSFC

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