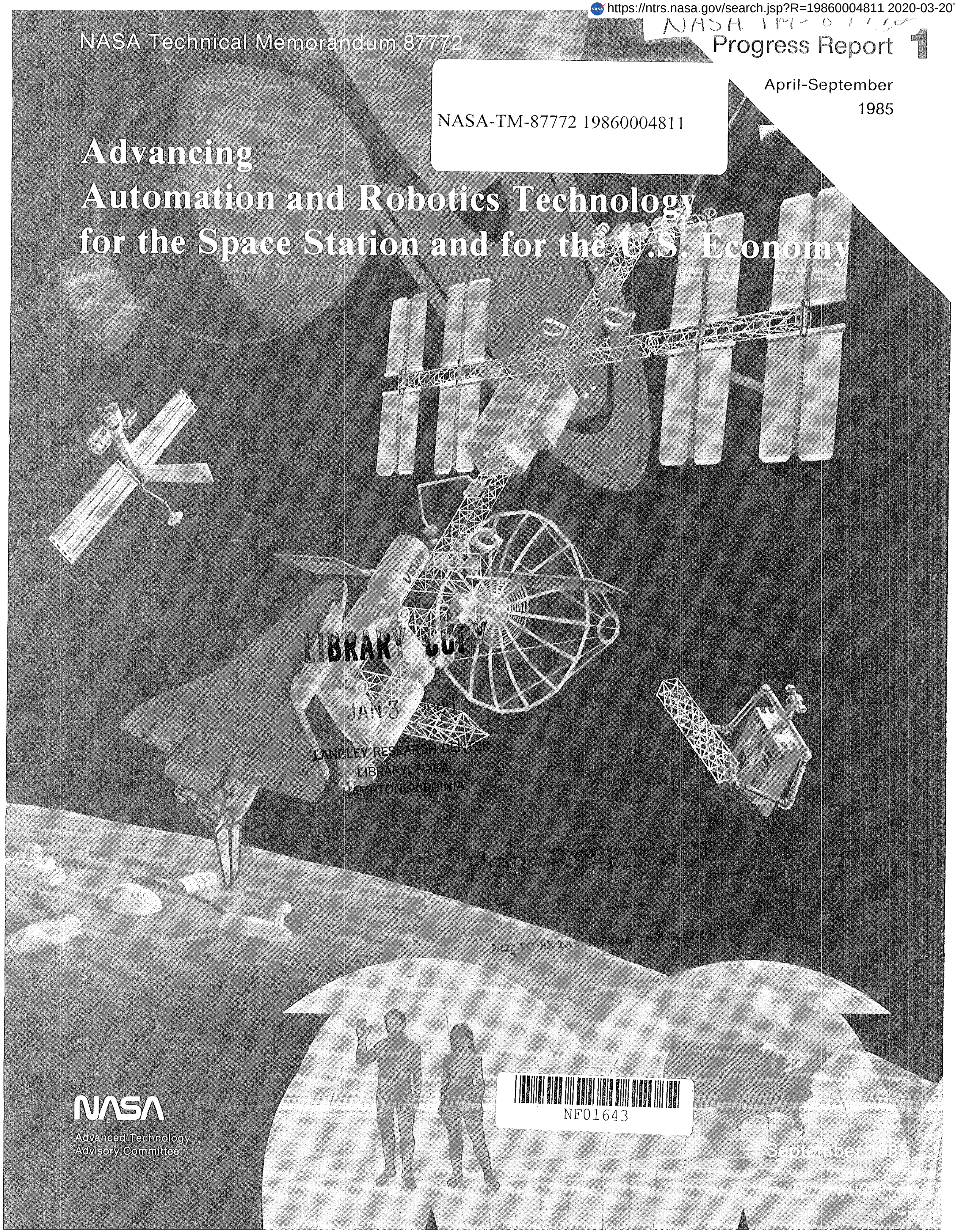
NASA Technical Memorandum 87772

Progress Report 1

April-September 1985

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



NASA

Advanced Technology
Advisory Committee

September 1985

The cover painting captures the spirit of the machine intelligence and robotics policy described in this report. Prominently depicted are both the Space Station complex of platform and core stations in low Earth orbit and the United States—the two recipients of productivity increases due to creating and using this technology. The man and woman represent each of us benefiting from an improved interaction with more capable machines—a few in space, the majority on Earth. The commercial use of space, made easier by the Space Station, is depicted by low cost, co-orbiting automated manufacturing facilities. The sweeping vision from a lunar manufacturing facility or base to Mars and Saturn and beyond to the deepest reaches of the cosmos pictures a continuing exploration of space.

The painting is an artistic rendition by Raymond J. Bruneau of an original design by Roy L. Magin, both of the Technical Information Branch at the Lyndon B. Johnson Space Center.

NASA Technical Memorandum 87772

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

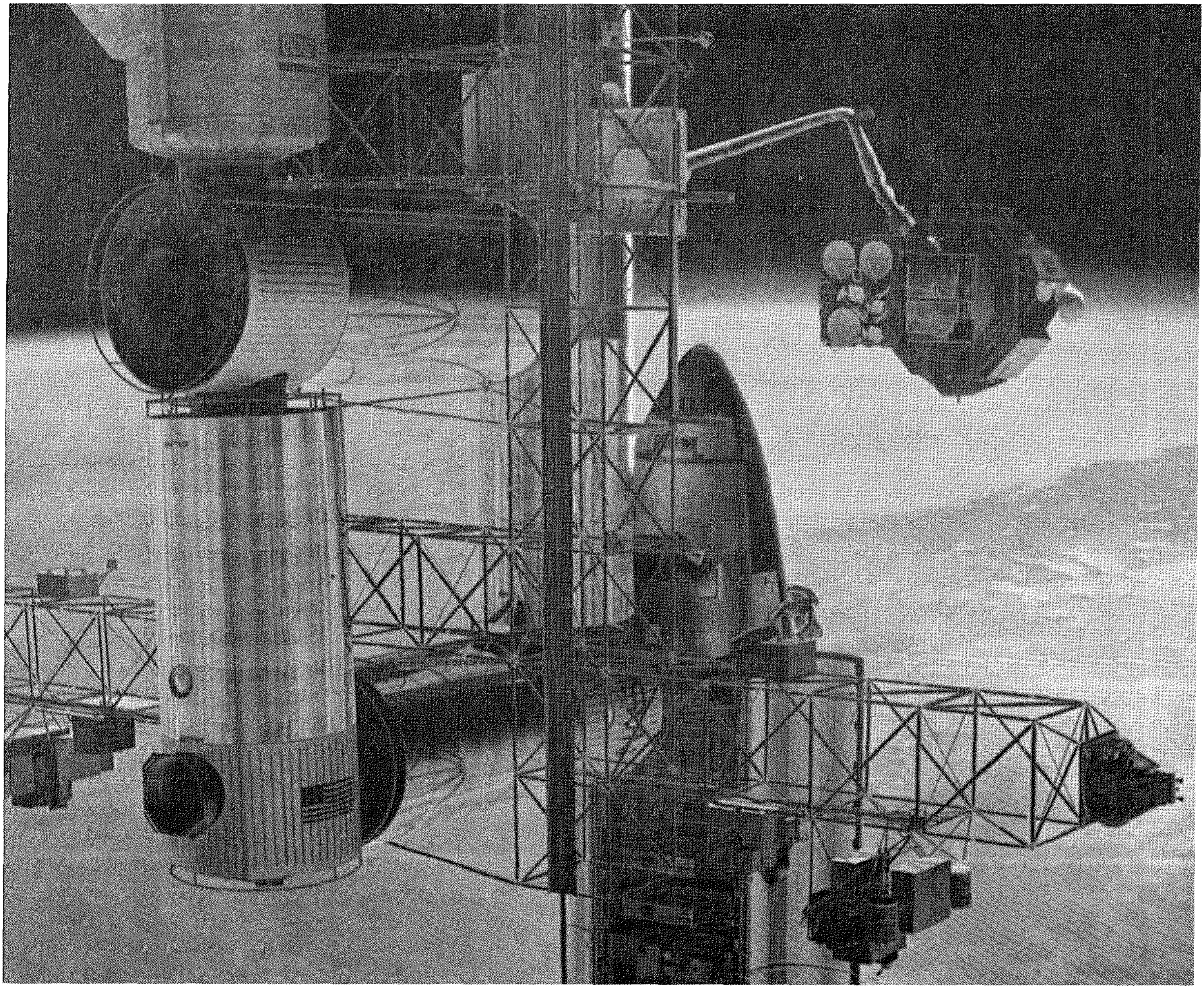
Progress Report 1 — April through September 1985

Advanced Technology Advisory Committee
National Aeronautics and Space Administration

Submitted to the
United States Congress
October 1, 1985

NASA
National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas


A space station is a facility that serves many needs.

Synopsis

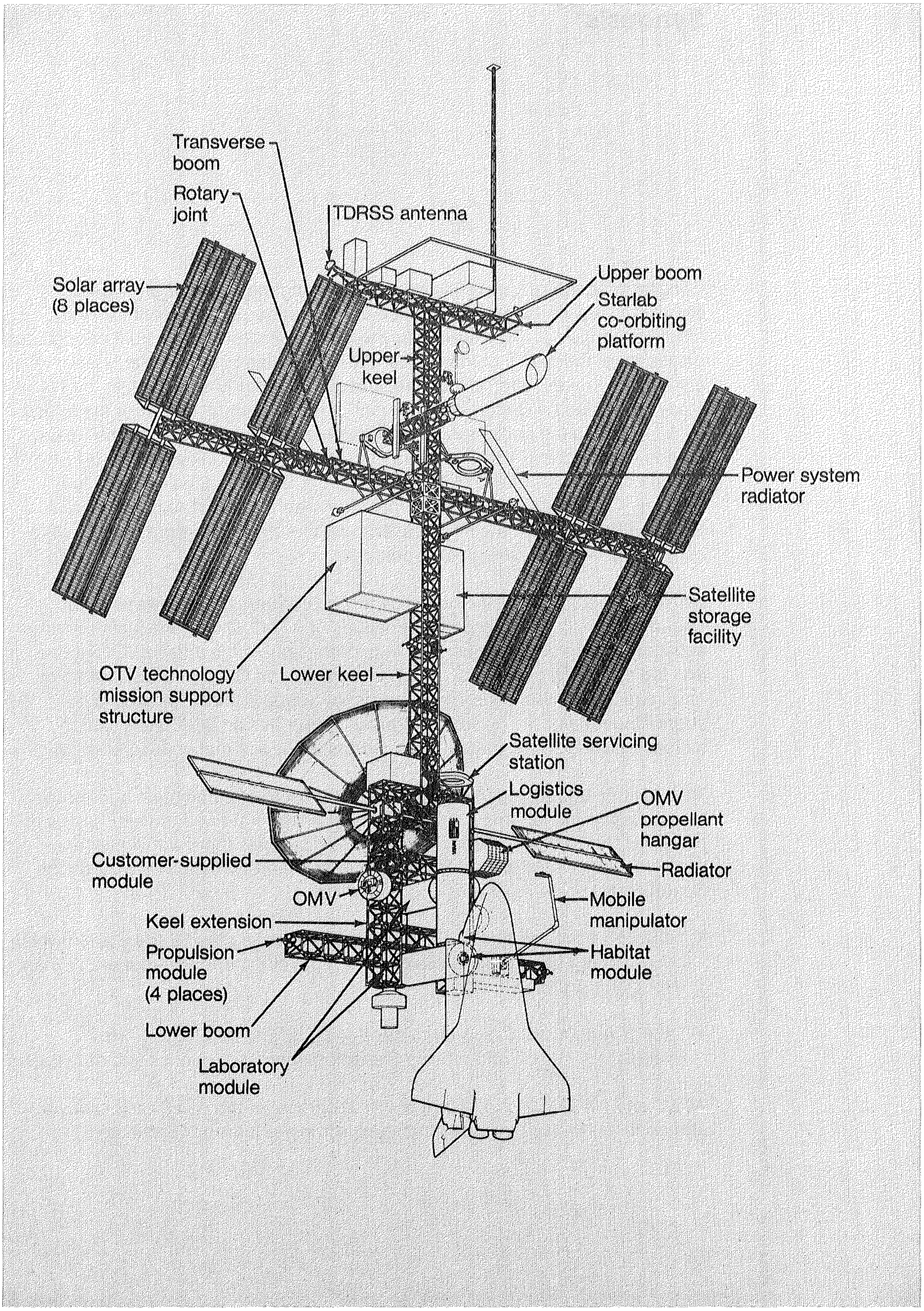
Congress recognized, in 1984, the merit of using the Space Station as a stimulus to develop a new generation of general purpose automation and robotics technology. This technology would be efficient and flexible enough not only to meet the needs of the Space Station but also to benefit the U.S. economy by meeting terrestrial needs as yet only partly specified. In the NASA study mandated by Congress, a number of recommendations were made and an approach to the implementation of automation and robotics on the Space Station was outlined. This work was documented in the initial report (NASA Technical Memorandum 87566, April 1985) of the Advanced Technology Advisory Committee (ATAC). A companion report from the Automation and Robotics Panel enunciated the research and technology program required to support the ATAC development scenario.

NASA has accepted for the definition and preliminary design phase of the Space Station the basic recommendations of ATAC. During the last 6 months, substantial progress has been made in promulgating the intent of Congress and the approach outlined by ATAC throughout the Government, contractor, and academic communities responsible for Space Station design and supporting research. The work currently in progress on the Space Station includes paying serious attention to the matter of automation and robotics.

ATAC is confident that NASA recognizes the merit of automation and robotics for the Space Station and is taking steps to incorporate needed technology in the initial station. While these indications are positive, there are significant problems associated with optimizing automation and robotics (A & R) on the Space Station. The most pressing issues are

- Lack of a concrete and specific plan for automating the Space Station which coordinates Space Station design, A & R development, and research for an evolutionary station
- Lack of resources dedicated to developing new technology for an evolutionary station and moving this automation and robotics into actual use

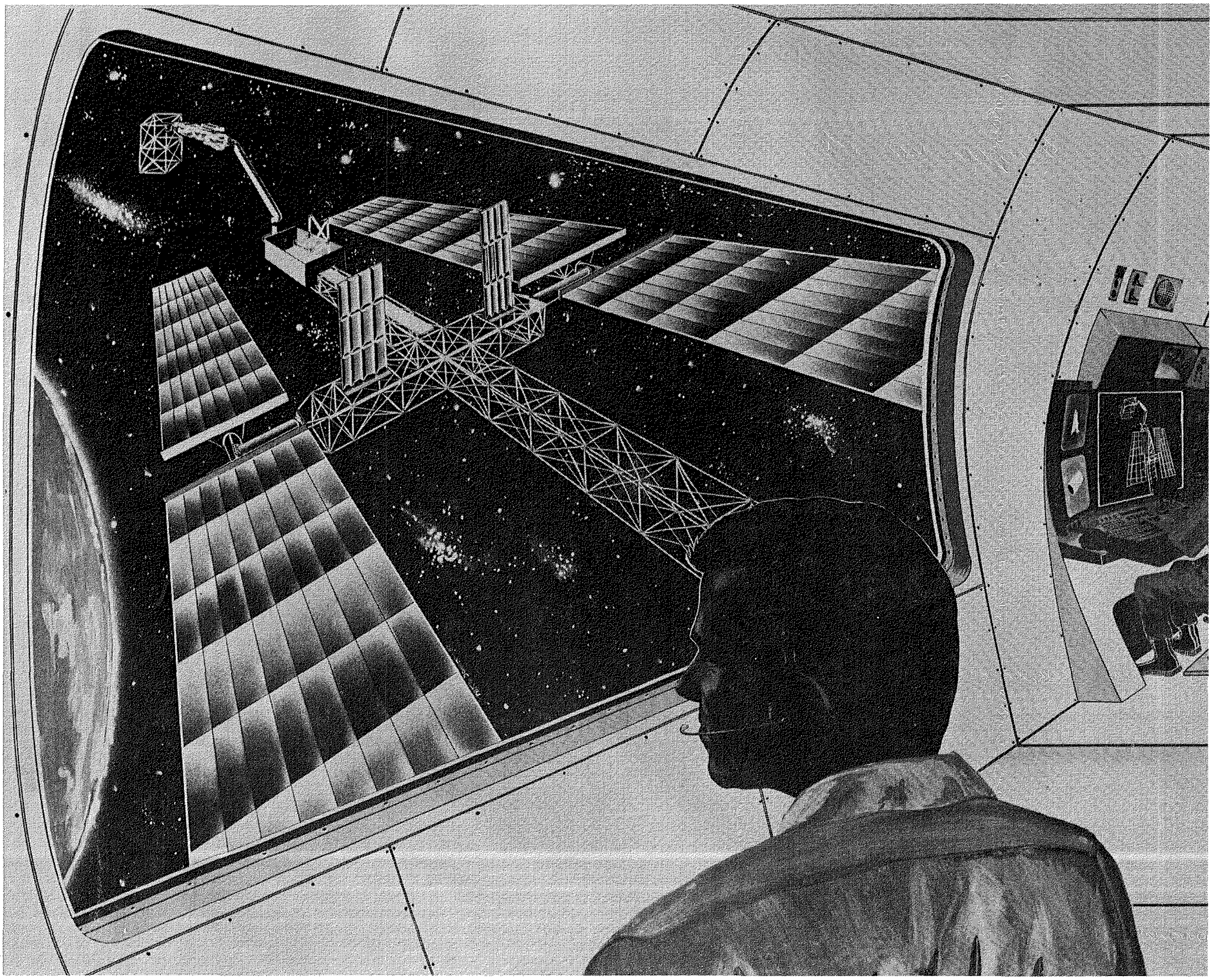
ATAC and NASA are in agreement with the thrust of the congressional intent and continue to pay close attention to this important area of technology.



The Space Station will be a permanent facility for reaching toward a future limited only by imagination and commitment.

Preface

In April 1985, as required by Public Law 98-371, the NASA Advanced Technology Advisory Committee (ATAC) reported to Congress the results of its study of automation and robotics technology for use on the Space Station. A further requirement of the law is that ATAC follow NASA's progress in this area and report to Congress semiannually. This report is the first in a series of progress updates and covers the period between April 1 and September 30, 1985.



People and machines will work together.

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Introduction

The National Aeronautics and Space Administration has adopted the recommendations of the Advanced Technology Advisory Committee (ATAC) as documented in the study mandated by Congress (ref. 1) and made a strong start in mounting the necessary implementation efforts. It has also accepted in principle the findings of the Automation and Robotics Panel (led by Cal Space) which described (ref. 2) a research and technology program to support the development scenario put forth by ATAC.

Specific responsibility for automation and robotics has been assigned to individuals in the Space Station organization. Assignments have been made in the Space Station Program Office (level B) and in the four project offices (level C) that are responsible for managing the contractors. Implementation plans and guidelines have been promulgated to acquaint managers and designers with the goals and approach desired by NASA.

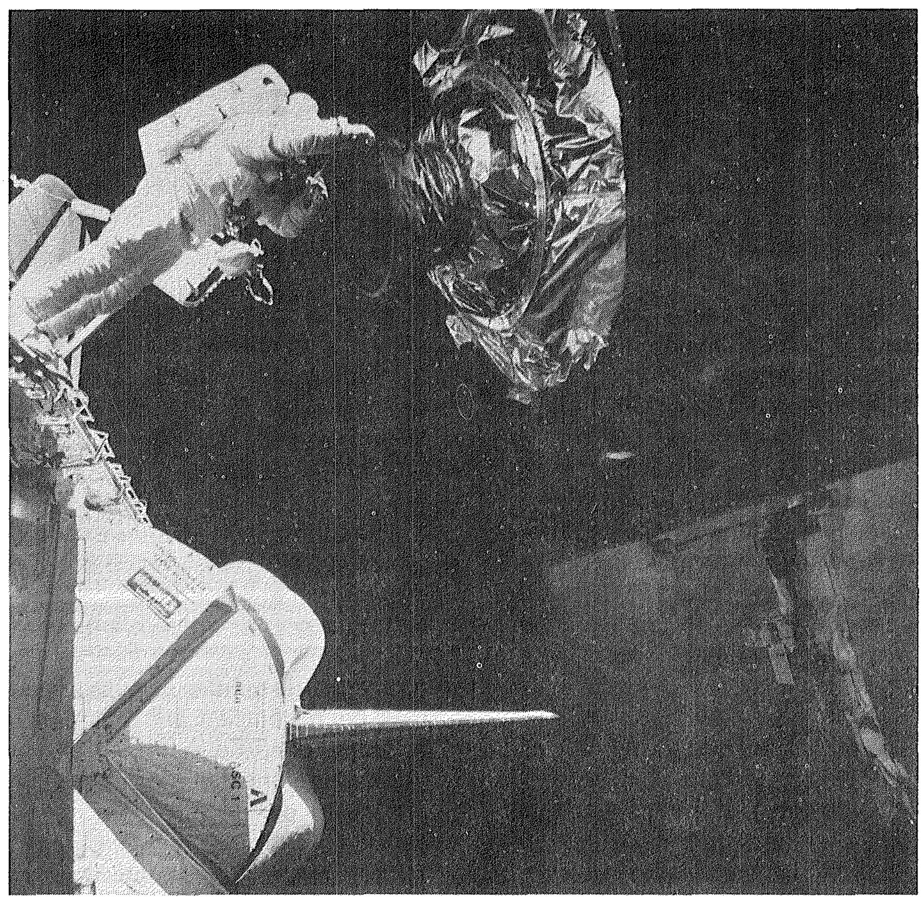
In an agencywide effort, NASA technical staff and their contract researchers have been included in workshops and briefings to acquaint all participants with the needs of the Space Station, the technology available, and the thrust of research in progress.

The progress reported herein has been assessed largely from the documentation of Space Station Program reviews and of a workshop held by ATAC to survey activity within NASA. In the future, the committee plans to call for its own reviews in addition to utilizing those of the program.

The committee would urge the reader to keep in mind that it is difficult to maintain a balanced view of automation and robotics at this stage. There is cause for euphoria because the possibilities are so many and so exciting. At the same time there is cause for pessimism considering the limited resources and, so far, scant tangible progress. We believe, however, that a sound program can be forged and that the broad goals of Congress—advanced technology for the Space Station and consequent benefits for the U.S. economy—can be realized.

An assessment of progress with respect to each of the ATAC recommendations is given in the next section. This assessment, along with the section on expenditures and the conclusion, provides a top-level view of progress for this reporting period.

Tedious repair tasks in space will be eased by robotic devices.



Progress with Respect to ATAC Recommendations

This section provides a summary assessment of progress toward fulfilling the recommendations originally made by the Advanced Technology Advisory Committee. For convenience, each recommendation is stated before the assessment of progress.

1. Automation and robotics should be a significant element of the Space Station Program.

NASA planning and research and the work of Space Station contractors to date indicate thoughtful attention to automation and robotics (A & R) in the program. The major shortcoming we see is the extent of the efforts being made. The early indication is that these efforts are not sufficient to meet the intent of Congress in driving A & R technology to the new plateaus that will benefit the U.S. economy in a substantial way.

2. The initial Space Station should be designed to accommodate evolution and growth in automation and robotics.

NASA and the Space Station study contractors are addressing this issue in a serious way. It is too early to tell whether adequate provisions for these longer range concerns can be made with the limited resources available for the early phases of the program.

The committee made a number of specific suggestions pursuant to this recommendation, and performance on these specifics is mixed. Performance seems good with respect to

- Designing the Space Station data system and ready access to it
- Maintaining flexibility in the design
- Using standard programming languages
- Providing numerous sensors
- Designing for operational autonomy

More attention needs to be paid to

- Capturing design information and rationale in the Space Station data base
- Facilitating robot use

We would elaborate on the point made in the initial report concerning design information in the Space Station data base. The practice of capturing such information is intended to apply to all station design matters, not just those presently seen as related to automation and robotics. This information is important not only to meet the usual needs of continuing engineering and but also to support the eventual application of A & R technology to any element of the station. Furthermore, this practice must apply to all external systems with which the Space Station may eventually interact; for example, satellites to be serviced.

3. The initial Space Station should utilize significant elements of automation and robotics technology.

A rather large number of possibilities have been identified, and these will be further examined in the remainder of the definition and preliminary design phase. We consider it likely that good progress will be made in meeting the intent of this recommendation. The suggested set of progressive demonstrations has not yet been defined. We consider this very important and suggest it be pursued vigorously. The astronaut corps is involved in automation and robotics and can be expected to work productively with the station designers.

4. Criteria for the incorporation of A & R technology should be developed and promulgated.

The task of developing criteria for the actual selection of A & R applications has been given to the study contractors and good progress is being made.

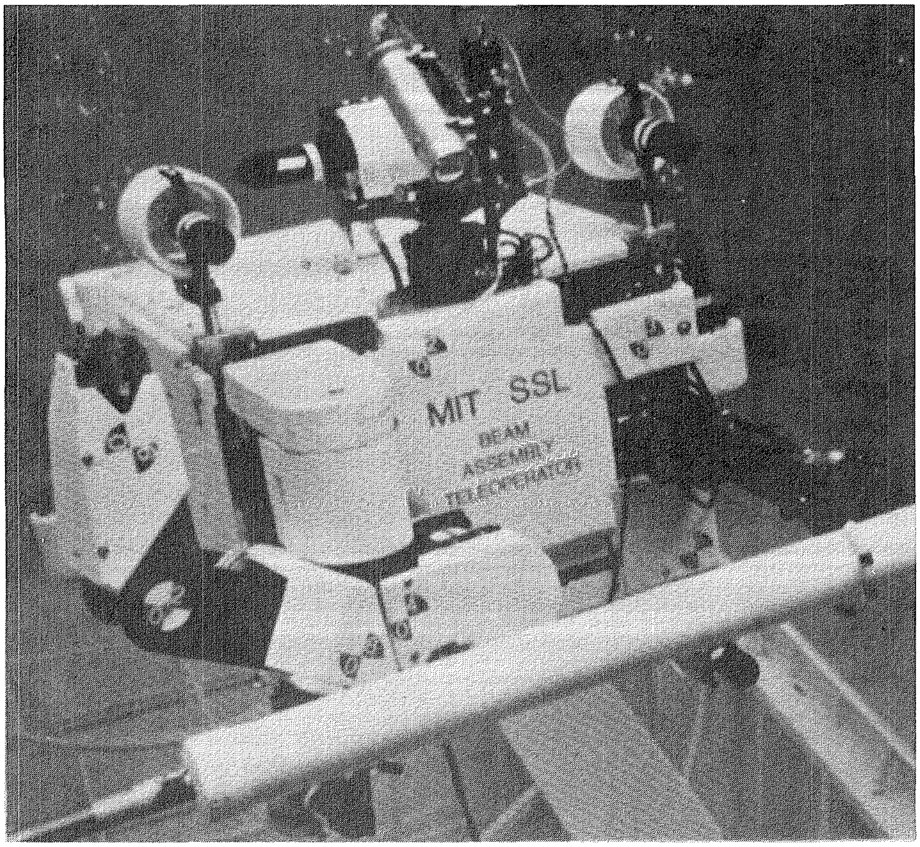
In general, assessments of the merit of A & R applications should also extend to costs and benefits associated with platforms, satellites, and other external systems that the Space Station will support.

5. Verification of the performance of automated equipment should be stressed, including terrestrial and space demonstrations to validate technology for Space Station use.

It is too early to assess the program for test and verification of Space Station equipment. However, the lack of a clear plan for demonstrating A & R technology is of concern. The merit of using specified demonstrations to drive technology has been shown in the Strategic Computing Program developed by the Defense Advanced Research Projects Agency (DARPA).

6. Maximum use should be made of technology developed for industry and Government.

Within the family of NASA centers and their contractors there is a need for better meshing of plans. Following the ATAC workshop, the committee recommended a review



Assembly of the Space Station could be aided by a beam assembly teleoperator. A prototype of such a device has been tested.

of all study contractor work in automation and robotics and closer coordination between the Space Station Program and the research elements of NASA. Such a review has not been held. The committee continues to believe that the review is important and suggests that it be held well before the next ATAC progress report is due. There has been significant dialog between program and research elements, but even closer ties are needed.

An arrangement has been made for research elements of NASA to keep abreast of Department of Defense technology. But broader and more frequent contact should be made. Areas of common interest should be identified and then followed jointly. Fortuitously, an additional avenue for transfer of technology exists through the study contractors since many of them have work both with NASA and with the Department of Defense.

The committee suggested that a more commercial approach to A & R hardware and software should be taken. Space Station Program Office members have argued that the stringent safety, reliability, and quality assurance requirements levied on space systems prohibit this approach. We would point out that the Space Station, unlike the space vehicles of the past, will provide a rather forgiving environment suitable for use as a test-bed.

7. The techniques of automation should be used to enhance NASA's management capability.

The use of advanced computing technology to handle the challenging problems of Space Station design and management is planned by NASA. A special project within the Space Station Program—the Technical and Management Information System (TMIS)—has been established and funded for this purpose. The initial phase (to be implemented during 1985 and 1986) will include programwide capabilities for electronic mail and calendar, scheduling, document interchange and library, budget planning, and management of data bases for engineering, customer requirements, and mission scenarios. Success in implementing TMIS would have significant benefits for other large, complex programs.

Although progress has been made in the area of office automation, there is concern that the linkage of all program participants for transfer of CAD/CAE information will not occur. This is, potentially, a troublesome deficiency.

8. NASA should provide the measures and assessments to verify the inclusion of automation and robotics in the Space Station.

Reasonable progress has been made in defining goals for the technology to be incorporated in the Space Station although these goals have not yet been quantified, as recommended by the committee. Greater attention to this issue can come, quite properly, when the design process is further along and the actual applications of automation and robotics have been chosen.

Meanwhile, however, the committee believes that some important groundwork needs to be laid with respect to measures. In particular, careful attention needs to be given to the definition of

- What constitutes advanced automation and robotics technology and the measures to be used to assess it. There must be at least two different types of measures—detailed performance measures quantifying the key technical characteristics and measures for more generic characteristics, such as reliability, productivity, evolvability, maintainability, safety, speed, accuracy, repeatability

- How to estimate the cost of the station elements incorporating such technology. This concern is addressed further in the section on expenditures for advanced automation and robotics.

- How to assess technology readiness. The eight levels defined in reference 3 provide a good starting point.

The further recommendations given in the initial ATAC report, numbers 9 through 13, were made on the contingency of an augmented program that would enhance the technology base.

We believe that congressional funding of an adequate research program, along the lines defined by the Automation and Robotics Panel, to support the Space Station development scenario envisioned by the Advanced Technology Advisory Committee is a matter of great urgency. Closely related to this is the matter of carrying forward the technology so developed into the engineering, test, and implementation phases. The committee is concerned that, while the Space Station Program is planning to make provisions for the incorporation of new automation and robotics technology, the steps involved in the "adaptive" engineering (levels 5 through 8 in our terminology) are not being addressed.

These concerns should be pursued as vigorously as the general planning and funding situation for the total Space Station Program will permit. Otherwise, we face the prospect, several years hence, of a Space Station on which provision has been made for all manner of advanced technology but for which the technology has not been developed.

The committee plans to conduct its own review, prior to the next report, of progress in three major areas: initial utilization of automation and robotics; provisions for future technology; and criteria for Space Station applications.

Key Events and Activities Since the Initial Report

NASA has endorsed the recommendations of the Advanced Technology Advisory Committee and encouraged the implementation of these recommendations in the Space Station Program. We describe the most significant events and activities of this reporting period in the following paragraphs.

Specific Responsibilities Have Been Assigned

Overall responsibility for implementation of automation and robotics on the Space Station has been assumed by Philip Culbertson, Associate Administrator for Space Station. The organization for managing the Space Station Program is shown in the following figure.

Mr. Culbertson has in turn charged the Space Station Program Office (level B) with the task of reflecting the ATAC recommendations in a specific plan for Space Station implementation. The day-to-day responsibilities for this plan and its implementation have been assigned to a staff specialist for automation and robotics who reports directly to the Manager of the Systems Engineering and Integration Office. The staff of this office includes detailees from several NASA centers to assure an agencywide emphasis.

The definition and preliminary design work on the Space Station (phase B) is being conducted in four "work packages," one at each of four NASA centers. At each such center there is a Space Station Projects Office and, in each of these offices, there is a specialist in automation and robotics to assure that contracted work reflects the desired emphasis.

An Automation and Robotics Plan for Space Station Has Been Issued

The level B program office has issued an Automation and Robotics Implementation Plan (ref. 4) which reflects the ATAC recommendations and provides some programmatic guidance. This plan was issued very shortly after the ATAC report itself was released and was promulgated among the "work package" centers—Marshall Space Flight Center, Johnson Space Center, Goddard Space Flight Center, and Lewis Research Center.

Space Station Study Contracts Have Been Awarded

Perhaps the most significant event in this reporting period was the award of eight contracts for definition and preliminary design of the Space Station. Table 1 gives a brief summary of the scope of the work and lists the companies doing the work.

Organization of Space Station management occurs at three levels.

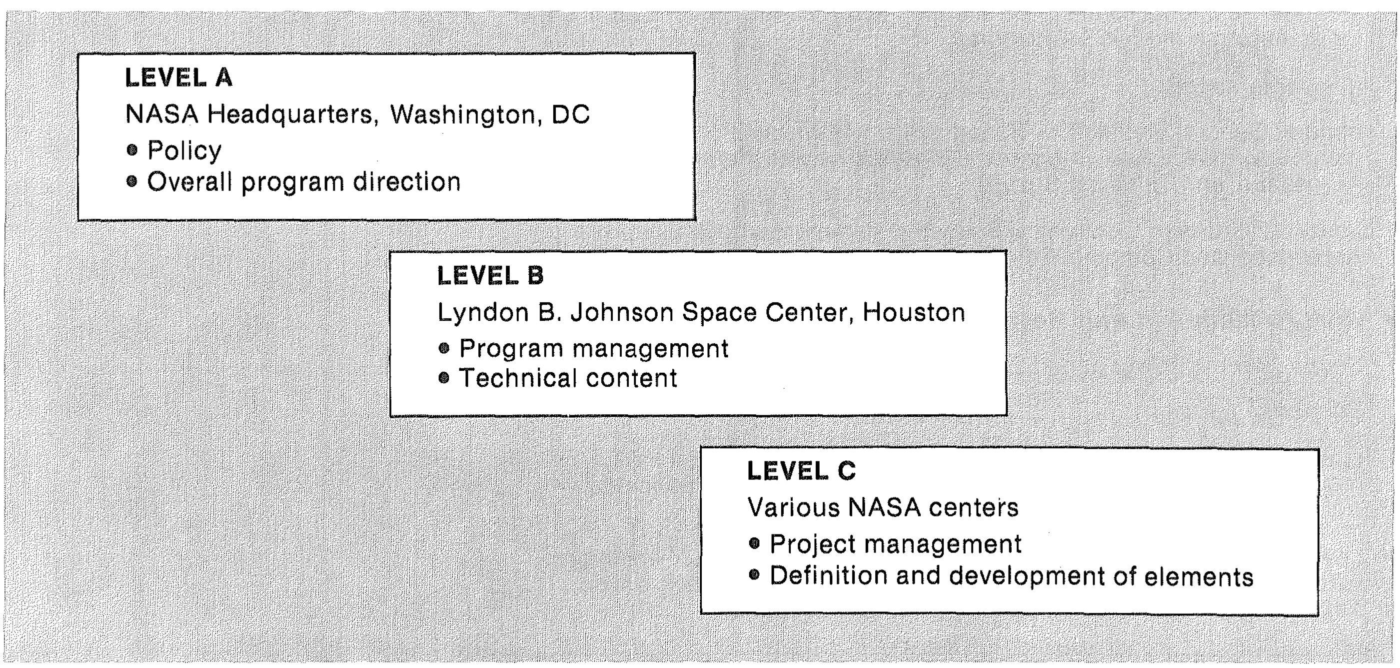


TABLE 1.- SPACE STATION WORK PACKAGES—SCOPE AND TEAMS

- **Work Package 1—Marshall Space Flight Center, Huntsville, AL**

  Scope: Common pressurized modules for use as laboratories, living areas, and logistics areas; environmental control and propulsive systems; and a plan for accommodating orbital maneuvering and transfer vehicles

  Contractor teams:

  Leader, Boeing Aerospace Co., Seattle—members, Teledyne Brown, General Electric, Vought, OAO, Thermacore, Garrett, Hamilton Standard, Life Systems, Lockheed, Umpqua, Perkin-Elmer, Fairchild, Aerojet, Rocketdyne, Eaton, Sundstrand, Westinghouse, Rockwell Autonetics, TRW, Computer Tech Associates, Hughes, Telephonics, and Camus

  Leader, Martin Marietta Aerospace, Denver—members, McDonnell Douglas Technical Services Co., Hamilton Standard, Honeywell, Hughes, Hercules, and Wyle Labs.

- **Work Package 2—Johnson Space Center, Houston**

  Scope: Structural framework; interface between Space Station and visiting Shuttle; mechanisms, including remote manipulators; attitude control; thermal control; communications and data management; a plan for equipping a module with sleeping quarters, a wardroom, and a galley; and a plan for extravehicular activity

  Contractor teams:

  Leader, McDonnell Douglas Astronautics, Huntington Beach, CA—members, IBM, Honeywell, RCA, Lockheed, Ball Aerospace, Computer Sciences Corp., Design West, Communications and Data Systems Associates, Eagle Engineering, Essex, Fluor, Ford Aerospace, Hamilton Standard, ILC Space Systems, SPAR Aerospace, and LTV Aerospace

  Leader, Rockwell International Space Station Systems Division, Downey, CA—members, Grumman, Harris, Sperry, Intermetrics, and SRI International

- **Work Package 3—Goddard Space Flight Center, Greenbelt, MD**

  Scope: Automated free-flying platforms and provisions to service, maintain, and repair the platforms and other free-flying spacecraft; provisions for instruments and payloads to be attached to the Space Station; and a plan for equipping a module as a laboratory

  Contractor teams:

  Leader, General Electric Co., Space Systems Division, Philadelphia—members, TRW, Essex, Integrated Systems Analysts, Perkin-Elmer, SPAR Aerospace, and Teledyne Brown

  Leader, RCA Astro Electronics, Princeton—members, Lockheed, Ball Aerospace, and Computer Sciences Corp.

- **Work Package 4—Lewis Research Center, Cleveland, OH**

  Scope: Electric Power generation, conditioning, and storage

  Contractor teams:

  Leader, Rockwell International, Rocketdyne Division, Canoga Park, CA—members, Sundstrand, Ford Aerospace, Harris, Lockheed, Spectralab, Acurex, and Georgia Tech

  Leader, TRW Federal Systems Division, Redondo Beach, CA—members, General Electric, Grumman, General Dynamics, Perkin-Elmer, United Technology, Mechanical Technology, and Life Systems

The Space Station definition and preliminary design work began in April 1985 and will continue for 21 months. A number of important events are scheduled during this time, many of which relate to automation and robotics. The top-level schedule for this work is given in table 2 for both work package and program activities. The timing of each activity is indicated by its relationship to major reviews as follows:

• CSD	Contract start date	April 1985
• RUR-1	Requirements Update Review #1	July 1985
• RUR-2	Requirements Update Review #2	October 1985
• IRR	Initial Requirements Review	January 1986

For this reporting period, the first of the requirements update reviews (RUR-1) is the event of greatest significance. The next section of this report, "Progress on Space Station Design for Use of Automation and Robotics," will synopsize the results presented as part of RUR-1.

Manipulating devices can be tested first in ground facilities.

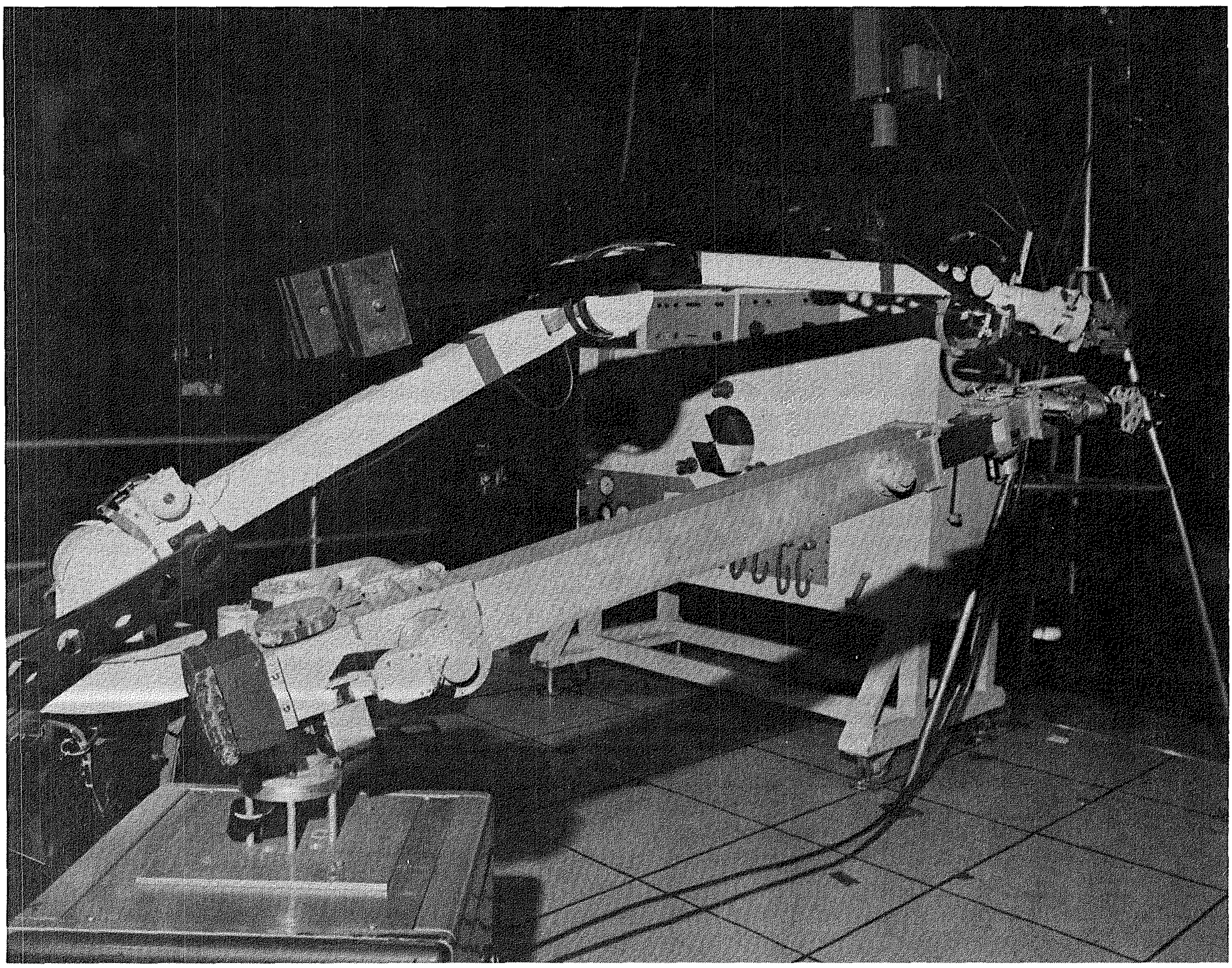


TABLE 2A.- AUTOMATION AND ROBOTICS EVENTS FROM THE SPACE STATION ENGINEERING MASTER SCHEDULE: WORK PACKAGE CENTERS (INCLUDING CONTRACTORS)

Define A & R application candidates for initial Space Station

—RUR-1: Describe candidate functions to be automated, with supporting rationale
—RUR-2: Revise list of candidate functions to be automated, with detailed impact characterization
—IRR: Define candidate functions, with quantitative impact characterization to support general automation guidelines

Define selection criteria

—RUR-1: Propose criteria (including supporting rationale) for selecting
(1) Candidate functions to be automated
(2) Candidate A & R technologies to be applied to selected functions
—RUR-2: Define selection criteria, with supporting rationale

Select A & R technology candidates

—RUR-1: Update technology assessment to identify A & R technologies available for the initial station
—RUR-2: Describe candidate A & R technologies for application to functions selected for the initial station
—IRR: Recommended A & R technologies for application to the initial station, with supporting rationale

Define provisions to be made for A & R evolution

—RUR-1: Identify functional applications and available technologies for future automation and robotics
—RUR-2: Characterize provisions to be made in the initial station to accommodate future technologies as identified in RUR-1
—IRR: Characterize impacts (design, cost, etc.) of provisions for identified future A & R technologies

TABLE 2B.- AUTOMATION AND ROBOTICS EVENTS FROM THE SPACE STATION ENGINEERING MASTER SCHEDULE: PROGRAM ACTIVITIES (LEVEL B)

Publish ATAC plan and implementation plan

—CSD: Distribute ATAC report and level B implementation plan to work package centers

Integrate and evaluate

—RUR-1: Identify requirements for system engineering and integration (SE&I) tools for A & R; define quantitative measures of progress; evaluate "nontechnical" program requirements, constraints on A & R implementation (e.g., congressional mandates)
—RUR-2: Evaluate preliminary work package data; develop initial guidelines on program A & R implementation
—IRR + 1 month: Recommend A & R implementation as to
—Growth strategies
—Application thrusts
—Technology thrusts
—Advanced development guidelines

Analyze costs

—RUR-1: Adopt tools to estimate cost of technology/application candidates
—RUR-2: Make preliminary analysis of technology/application candidates for initial and evolutionary stations
—IRR: Make final cost analysis of recommended technologies/applications

Update implementation plan

—RUR-1: Define scope of
(1) Work-package-specific automation
(2) A & R as an additional "discipline"* in the Engineering Master Schedule
—RUR-2: Draft update of A & R implementation plan
—IRR + 2 months: Publish updated A & R implementation plan

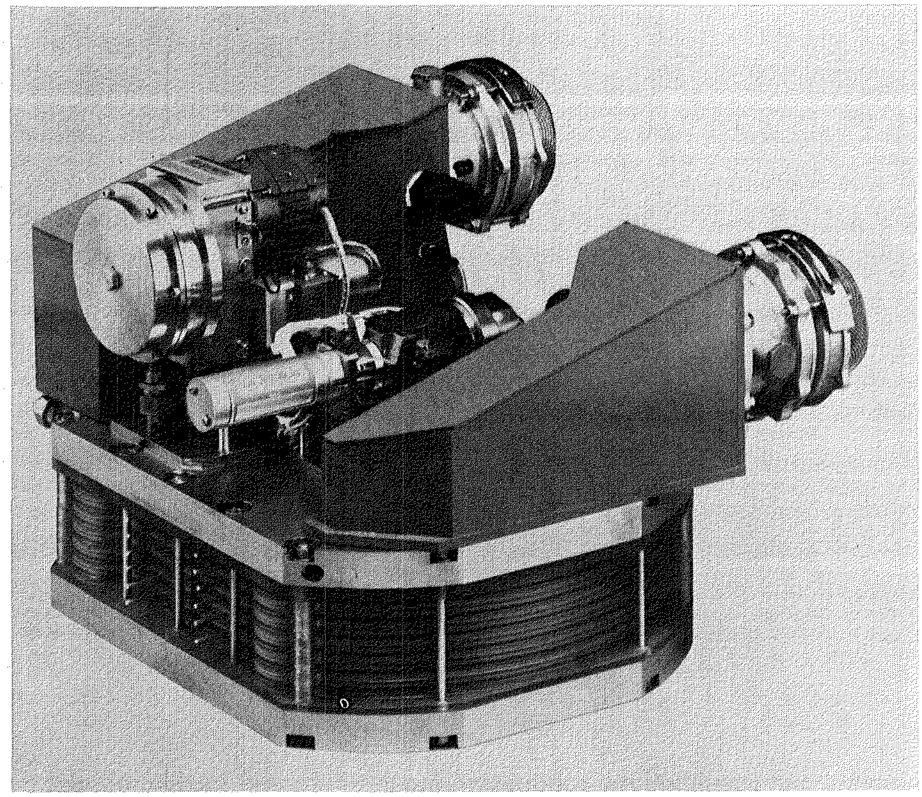
*The Space Station Program originally recognized 10 "disciplines" (since expanded to 12) in its advanced development activities. ATAC recommends that automation and robotics be added to the roster.

Automation and Robotics Work Is Being Supported by the Space Station Program Office and by the Phase B Study Contractors

The widespread concern over the readiness of A & R technology has stimulated significant efforts on a broad front. To understand this activity, it is useful to see it in terms of the various stages or levels of technological readiness. These levels (more fully described in ref. 3) are given in table 3.

The organizations close to the actual Space Station design process will be working at the later stages of this continuum, levels 5 through 8. The various research centers are concentrating on the earlier stages, levels 1 through 4.

The Space Station Program has included some automation and robotics work in its program of Advanced Development. The sponsored activities are described in this report under "Status of Automation and Robotics Efforts."



Important life support components such as this may be kept in service more reliably by expert systems than by humans.

The study contractors have indicated their high interest in automation and robotics by making modifications to their own research and development work. This work includes both the discretionary "independent" R & D (IR&D) and contracted R & D (CR&D).

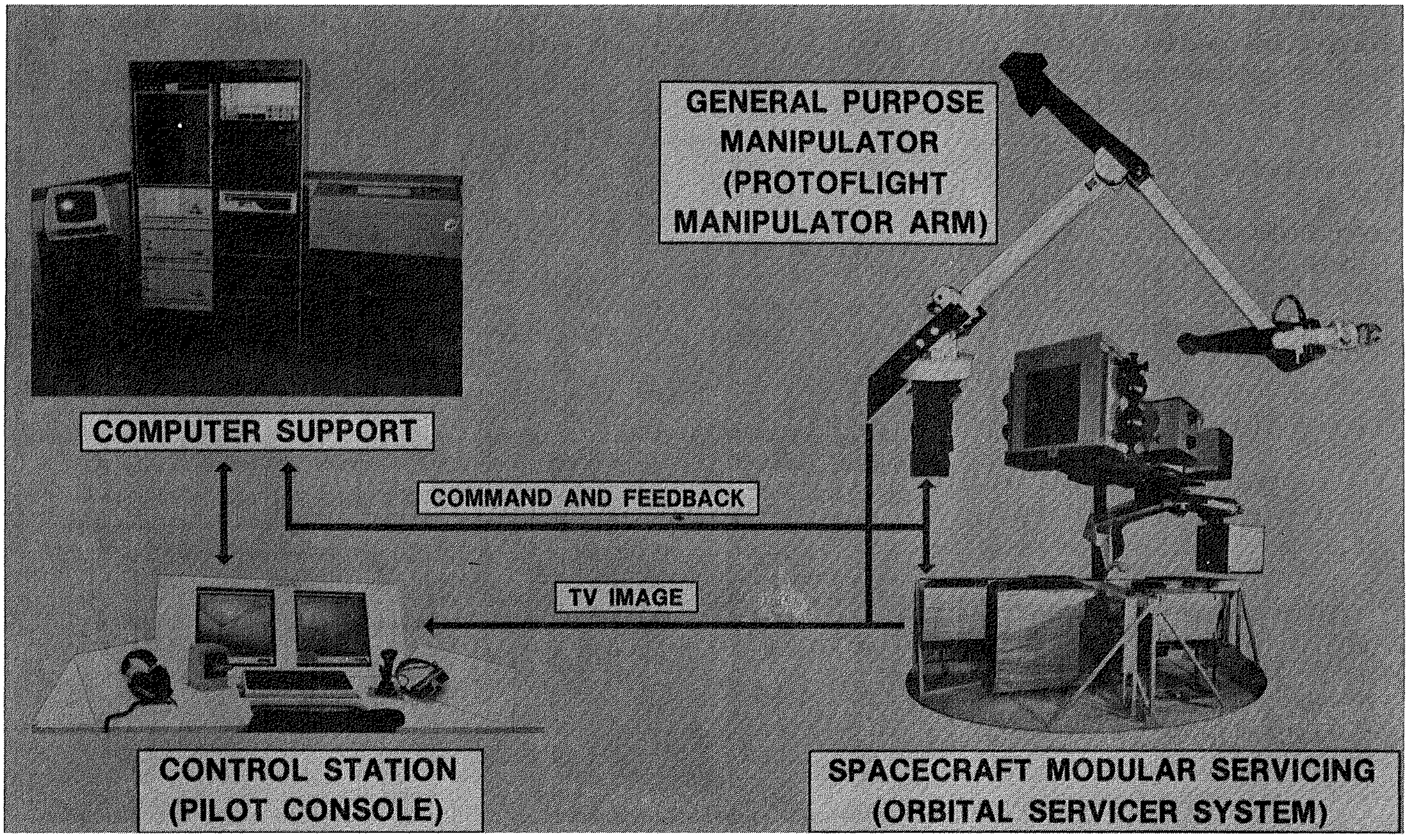
TABLE 3.- LEVELS OF TECHNOLOGICAL READINESS

Readiness level	Definition
1	Basic principles observed and reported
2	Conceptual design formulated
3	Conceptual design tested analytically or experimentally
4	Critical function/characteristic demonstration
5	Component/breadboard tested in relevant environment
6	Prototype/engineering model tested in relevant environment
7	Engineering model tested in space
8	Full operational capability (incorporated in production design)

NASA's Office of Aeronautics and Space Technology Has Increased Its Emphasis on Automaion and Robotics

The Office of Aeronautics and Space Technology (OAST) has been conducting research in fundamental aspects of automation and robotics for many years. Two major research and technology thrusts are of major interest—telerobotics and system autonomy. The framework within which work is proceeding has five general areas: (a) operator interface, (b) task planning and reasoning, (c) control execution, (d) sensing and perception, and (e) systems architecture and integration.

The program being conducted is balanced between core technology (2/3) and demonstrations (1/3). The demonstrations will lead to hardware capable of doing complex manipulations in a highly



Test facilities for robotic devices can explore many aspects of their use.

autonomous manner. There will be a ground demonstration site for telerobotics and another for system autonomy. Each of these sites will evolve to accommodate tests of increasing sophistication. The demonstrations will also include flight experiments conducted in conjunction with the Space Flight and Space Station offices.

Work in FY 1985 was reprogrammed to increase the level of research effort, and additional funding has been requested. Much of this work has now been focused on Space Station concerns.

Resource Issues Have Been Identified

NASA Administrator James Beggs has identified three categories of advanced automation and robotics applications:

- Those things which are crucial to the Space Station's basic operations. Funding for these things will be included in the budget projected for the station.

- Those things which would enhance the productivity of the station but are not mandatory for its operation. The funding for some but not all of these items is in the projected budget.

- Additional applications which would provide a new generation of machine intelligence and robotics for an evolutionary space station. Such advances would also be of great benefit to the U.S. economy. NASA clearly needs additional funding to pursue these items as they were never envisioned during the preliminary scoping of the Space Station budget.

The most productive applications not currently funded have been identified to the chairman and staff of the Senate Appropriations Subcommittee on HUD and Independent Agencies. A result of these discussions is the recognition that attempts to reduce the deficit in the U.S. budget and redirections in Space Station plans might work against the ability to fund the building of the technology base for automation and robotics. Such underfunding might prove inadequate for the A & R capability needed for the initial station, let alone an evolutionary station.

A Methodology to Analyze Potential A & R Applications Has Been Developed

It is important that potential uses of automation and robotics on the Space Station be assessed according to a consistent set of rules and analytical methods. One method which may serve this purpose has been developed by NASA's Jet Propulsion Laboratory (ref. 5). This candidate method has been set forth in the Space Station Program Office's "Advanced Automation and Robotics Data Products Report" (ref. 6).

The Astronaut Corps Has Taken a Supportive Position on Automation and Robotics

Representatives of the astronaut corps have prepared a position paper (appendix F) on automation and robotics. The essence of their position is supportive of the ATAC view that automation and robotics provide for amplification of human abilities and for effective use of crew resources. The astronauts identified important aspects of the human/machine interface and affirmed the initial ATAC statement that

> . . . the design approach should incorporate manual means to override automatic systems. This way crew confidence in automated systems and robotic devices would be developed and safety would be assured.

Automation and Robotics Emphasis Is Being Well Publicized

Even before the submission of the ATAC report to Congress in April 1985, we worked diligently to acquaint key communities with the congressional intent, the results of NASA's automation study (including the work of ATAC), and plans for Space Station applications. Many presentations have been made, not only within NASA but also to various committees and panels, to contractors, and to academic and professional groups. The reception has been most favorable. There has been broad general support for the basic goals of advancing automation and robotics and for the recommendations of ATAC. The various audiences reached are listed in table 4.

TABLE 4.- GROUPS AND INDIVIDUALS BRIEFED IN 1985 ON ATAC WORK

Date	Audience
Feb. 6	Robert Frosch, VP, General Motors and Chairman of Automation and Robotics Panel Steering Committee
Feb. 6	Senior staff at the Johnson Space Center
Feb. 11	Philip Culbertson, NASA Associate Administrator, Office of Space Station
Feb. 12	Marty Reiss, Senate Appropriations staff
Mar. 11	NASA managers for Advanced Development
Mar. 14	Senate Subcommittee on HUD & Independent Agencies, of the Committee on Appropriations
Mar. 14	Joint Artificial Intelligence Symposium
Mar. 15	Level B program office
Mar. 19	James Beggs, NASA Administrator
Mar. 25	IEEE meeting in St. Louis
Apr. 3	Senate Subcommittee on Science, Technology, and Space, of the Committee on Commerce, Science, and Technology
Apr. 22	Phase B contractors
Apr. 23	Representative Bill Green (R-NY); Marty Reiss, Senate Appropriations staff; and Richard N. Malow, House HUD & Independent Agencies staff
Apr. 30	NASA Advisory Council
May 29	Task Force on Scientific Uses of the Space Station (Banks Committee)
June 7	AIAA Space Systems Technical Committee
June 26	Science Advisory Board of the USAF
June 27	Instrument Society of America, First Annual Symposium on Robotics and Expert Systems
July 1	Philip Chandler, Office of Technology Assessment
July 25	President's Commission on Space
Sept. 4	AIAA/NASA Symposium on Automation, Robotics and Advanced Computing for the National Space Program

An Agencywide Workshop Was Held to Survey NASA Work

The committee sponsored a workshop in Houston May 13-17, 1985. The purposes of the workshop were

- To provide for an information exchange among all the participants in automation and robotics at the NASA centers
- To give a report to NASA management on what is being done and by whom
- To identify gaps in the overall A & R effort where an augmentation, if available, would be beneficial

Some 75 members of NASA's technical and managerial staff attended and all centers were well represented. Forty-seven papers were presented, representing the work of many more investigators. The proceedings of the workshop were published in four volumes (ref. 7), and the highlights of this work are described later.

One important outcome of the workshop was a series of further observations regarding the implementation of automation and robotics on the Space Station and the research that supports such implementation. The essence of these observations is incorporated in this progress report. Another outcome was the stimulation of better communication among the people within NASA who are active in automation and robotics. This should have important long-term benefits.

ATAC and an Independent Panel Will Continue

On May 10, 1985, NASA's Office of Space Station reaffirmed its intent to keep ATAC actively involved in overseeing the design efforts of the phase B contractors pertaining to advanced automation and robotics.

At the same time, NASA resolved to have an advisory panel continue to oversee the Space Station Advanced Development Program as it concerns automation and robotics and the generic A & R research sponsored by the Office of Aeronautics and Space Technology. This panel, consisting of university and industrial professionals, will be led by James Arnold of Cal Space.

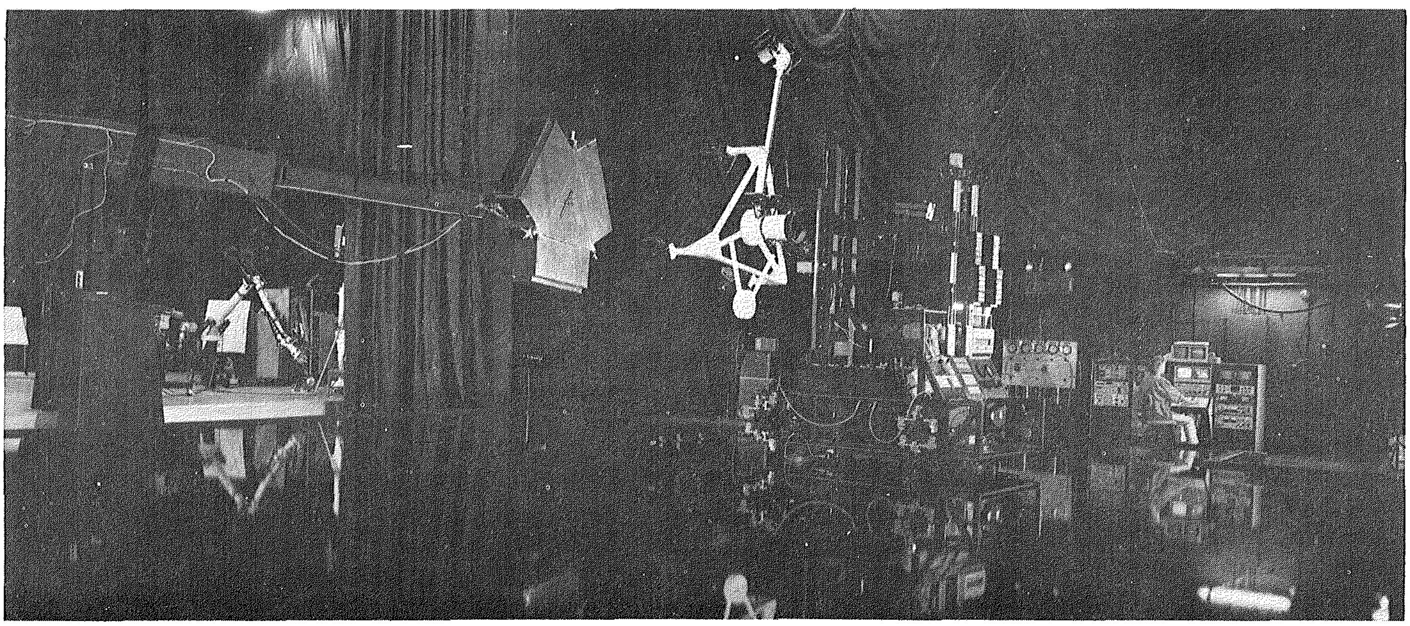
NASA Has Supported a Review by the Office of Technology Assessment

At the request of the Senate Committee on Commerce, Science, and Transportation, Congress's Office of Technology Assessment (OTA) is preparing a report on the inclusion of A & R initiatives in Space Station phase B planning. To review progress, OTA held workshops on July 15 and 22, 1985. NASA personnel, including members of ATAC, supported these workshops.

The issues addressed in OTA's review were

- A summary and critique of NASA-sponsored and NASA-inspired studies of automation and robotics over the past year

Important tasks such as rendezvous and docking can be ground tested under conditions close to those in space.



- How various proposed A & R initiatives may be factored into NASA phase B Space Station planning in a significant way

- Outlining the U.S. technology resource base that can be drawn upon to advance automation and robotics in the Space Station Program

- Pinpointing space A & R initiatives that would be of particular benefit to ground-based research and development

OTA plans to report to Congress by September 30, 1985.

Other NASA Elements Are Promoting Automation and Robotics

It is encouraging that elements of NASA outside the Space Station Program recognize the importance of automation and robotics. The work of the Office of Aeronautics and Space Technology has already been cited.

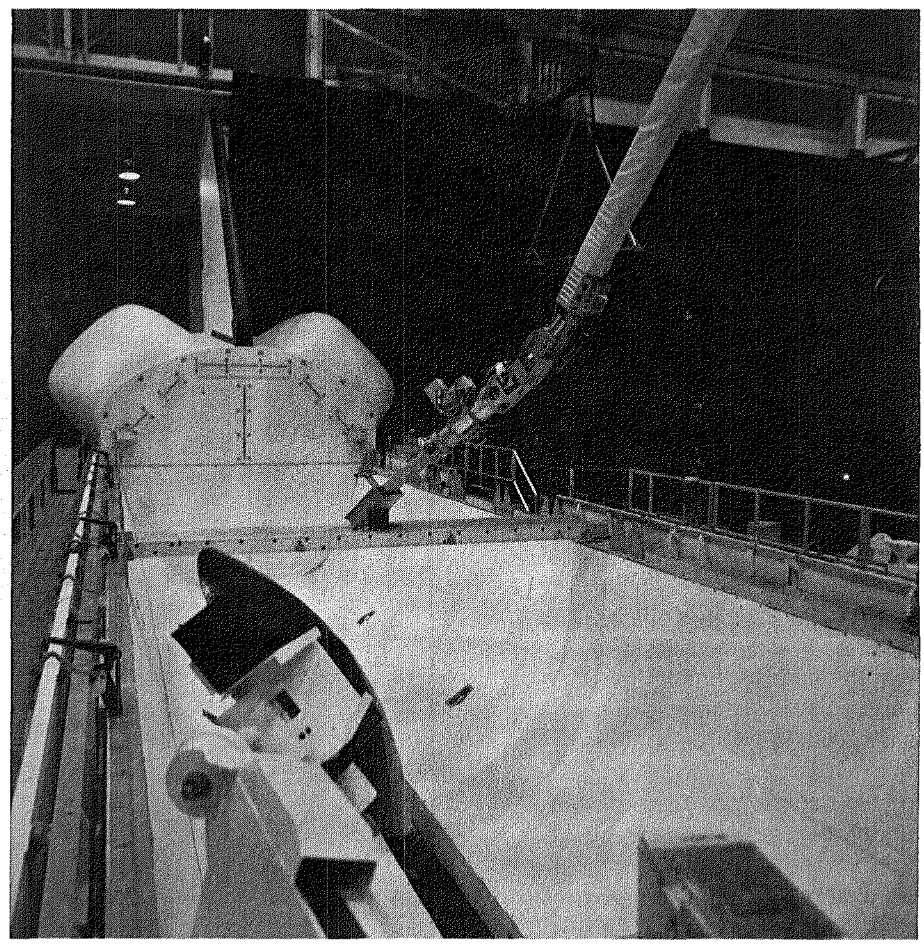
The Office of Commercial Programs is concerned with the commercialization and privatization of space, including attention to automation and robotics technology. This office has an activity called the Small Business Innovative Research Program. In response to the program's solicitation for initiatives in automation and robotics, nearly 300 proposals were submitted to NASA for funding. Only about 30 of these can be funded.

NASA Sponsored a Major Symposium on "Automation, Robotics and Advanced Computing for the National Space Program"

NASA, in cooperation with the American Institute for Aeronautics and Astronautics, sponsored an important symposium on "Automation, Robotics and Advanced Computing for the National Space Program." Each year NASA focuses on one important issue at its fall symposium; this year the focus was, fittingly, on automation and robotics and their vital concomitant, advanced computing.

The symposium was held in Washington, DC, September 4-6. Among the speakers and panelists were top managers and technical professionals concerned with automation and robotics. Government officials, industrial representatives (including some of the Space Station phase B contractors), and university researchers (including some outstanding authorities in various aspects of artificial intelligence and automation and robotics) participated. The symposium was very well attended. We believe that it has promoted interest and new initiatives that should benefit both the Space Station and the U.S. economy.

The Shuttle could provide a test-bed for advanced technology.



Progress on Space Station Design for Use of Automation and Robotics

The Space Station definition and preliminary design has been approached with serious attention to automation and robotics matters.

The progress made to date by the study contractors in Space Station automation and robotics was provided to NASA in Requirements Update Review #1. At this review, the contractors were asked to provide their latest thinking on four issues:

- Candidate subsystems and functions for application of automation and robotics on the initial station
- Criteria for actual selection of applications
- Technology readiness update
- Provisions to be made initially on the Space Station to allow for the incorporation of future advances in automation and robotics

All contractors addressed these issues and presented the results of their work, some in much more detail than others. The results of this review were summarized by the NASA level C project offices. The essence of this material, as synopsized by Johnson Space Center's Artificial Intelligence Office, is included in this report.

In some cases, contractors went further than required and recommended applications for the initial station or identified areas in which technology emphasis was required. While the committee does not yet take a position on such specifics, we present them as a matter of interest.

Our initial assessment is that the work was addressed with much thought and that the proposals, while at a very preliminary stage, show promise of significant application of automation and robotics on the Space Station. For this promise to be fulfilled, however, a test program must be funded and carried out to advance candidate applications through levels 5 to 8 to provide confidence in their use on the station.

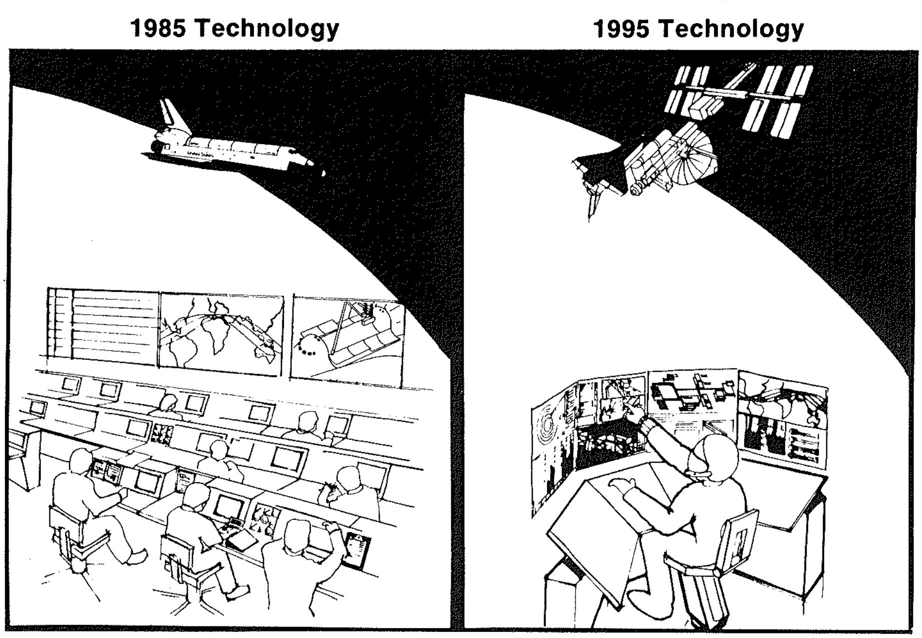
Not all the study contractors focused on the concept of advanced automation and robotics—technology available but not previously used on spacecraft or technology beyond the current state of the art. However, those contractors not focusing specifically on advanced technology are doing a careful study of all uses of automation and robotics. This is a valid process and should lead to the incorporation of traditional applications and toward advanced technology.

Candidate Applications of Automation and Robotics on the Initial Space Station

Study contractors identified the program elements and subsystems to which the techniques of automation and robotics could be applied initially. More specifically, they named functions that could be carried out in such a manner.

The candidate applications of automation and robotics suggested by the study contractors are tabulated in table 5. The table is structured in two parts. The first covers the Space Station subsystems or program elements addressed by ATAC in their statement of "Proposed Goals for Automation and Robotics Applications, Initial Space Station" (table 2, ref. 1). The second part of table 5 presents candidate applications not specifically mentioned by ATAC in its report or not mentioned in the context of the initial station. The committee thinks that these additional application possibilities indicate a very positive mindset toward the use of automation and robotics on the part of the study contractors.

The Space Station will be designed to operate in a highly autonomous manner.



It is clear from table 5 that virtually all elements of the Space Station Program are seen as able to benefit to some degree from automation and robotics. This reinforces our assertion in the original ATAC report that "automation would enhance all elements of the Space Station Program . . . ."

A number of other important areas—including operations planning, training, and mission control—are direct concerns of NASA and hence were not specifically addressed by the study contractors in the RUR-1 review. The committee has not done a review of these areas. However, the indications from program office staff are favorable. For example, operational autonomy in the first year of station operation is an established goal. Future progress reports will address this area in greater detail.

TABLE 5A.- CANDIDATE A & R APPLICATIONS ON THE INITIAL SPACE STATION: PROGRAM ELEMENTS ADDRESSED BY ATAC

Subsystem/program element	Function/functional element	Source (work package)
Electric Power	System health monitoring, fault recognition	2
Generation, storage, and conditioning	Failure prediction	2
	Fault isolation and reconfiguration	2, 4
	Maintenance, repair, retest	2, 4
Common module	On-orbit checkout	1
	Trend analysis	1
	Fault management	1
Logistics module	Umbilical connect/disconnect	1
Laboratory module, platforms, and attached payloads	Trend analysis	3
	Fault diagnosis	3
Guidance, Navigation and Control	Maintaining the orbit	2
	GNC monitoring and maintenance	2
	Space traffic control	2
	Collision avoidance	2
	Deboost	2
	Proximity operations	2
Platforms, customer servicing/accommodation	Rendezvous navigation	3
Laboratory module, platforms, and attached payloads	Fault diagnosis	3
Communication and Tracking	External communications control	2
	Tracking control	2
Common module	Communication scheduling	1
	Rendezvous tracking	1
	Data rate selection	1
Laboratory module, platforms, and attached payloads	Data rate selection	3
	Communication scheduling	3
	Rendezvous tracking	3

TABLE 5A.- Concluded

Subsystem/program element	Function/functional element	Source (work package)
Information and Data Management	System monitoring and diagnosis	2
	Diagnosis and performance prediction for external subsystems	2
	Continuity and opportunity planning	2
	Display interpretation	2
	Robot control	2
Common module	Module safety advisor	1
	Inventory management	1
	System status assessment	1
	Fault diagnosis	1
	Redundancy and configuration management	1
	Data base management	1
	Trend analysis	1
Laboratory module, platforms, and attached payloads	Trend analysis	3
	Fault diagnosis	3
	Subsystem status assessment	3
	Redundancy and configuration management	3
	Data base management	3
Environmental Control and Life Support	Fire detection and suppression	1
	EVA support	1
	Waste management	1
	Fault diagnosis	3
	Trend analysis	3
	Hyperbaric chamber operation	3

TABLE 5B.- CANDIDATE A & R APPLICATIONS ON THE INITIAL SPACE STATION: PROGRAM ELEMENTS NOT SPECIFICALLY ADDRESSED BY ATAC

Subsystem/program element	Function/functional element	Source (work package)
Thermal Systems	Inspection	2
	Repair, replacement	2
EVA Systems	Customer service	2
	Assembly support	2
	Rendezvous and docking	2
	EVA equipment support and servicing	2
Fluids	Storage and transfer operations	2
Structures and Mechanisms	Assembly of	2
	—Mounting plates	
	—Truss articulation control	
	Inspection of	2
	—Utility run	
	—Truss articulation control	
	—Lubrication	
	Maintenance and repair of	2
	—Utility run	
	—Bolt torque preventive maintenance	
	—Remote manipulator	
	—Gimbal system	
	Thermal curvature control	2
	Station utilities management	2
	Medical assistance in airlock	2
Modules	Connect/interconect	2
	—Berthing assistance	
	—Utilities connection and verification	
	—Latch verification	
	—Inspection of seals	
	—Tunnel inspection	
	—Chemical decontamination	
	—Airlock actuation	
	Interconnect inspection and repair	2
Orbital Maneuvering Vehicle and Orbital Transfer Vehicle	Berthing and deployment	1
	Navigation and control	1
	Fluid transfer	1
	Maneuvering	1
	Payload integration	1
	Maintenance and servicing	1
	—Checkout of orbital replacement units	
	—Inventory accounting	
	—Activity scheduling	
Logistics Module	Inventory management for items going to and from the Space Station	1
	Propellant transfer	1
	Spares relocation (inside and outside)	1

TABLE 5B.- Concluded

Subsystem/program element	Function/functional element	Source (work package)
Laboratory Module	Resource scheduling	1
Material technology	Checkout of customer equipment interface	1
	Experiment monitoring	1
	Analysis of experiment products	1
	Furnace operation	1
	Crystal handling and inspection	1
	Spectrographic analysis	1
	Mechanical stress/strain measurements	1
	Fluids dispensing	1
Life sciences	Experiment operation	3
	Exacting specialized tasks	3
	Fetching of supplies	3
	Test protocol verification	3
	Experiment data processing	3
Operations	Crew training	2
	Shuttle proximity operations/berthing	2
	Shuttle interface inspection and repair	2
	Shuttle manipulator coordination	2
	Chemical decontamination	2

Selection Criteria

There was a fair measure of commonality among the contractors in regard to their view of criteria. Table 6 presents criteria for selecting applications of automation and robotics.

Examples of Interim Recommendations for Applications

As indicated earlier, some contractors recommended applications for the initial station. These are of interest in the sense that, even at this early stage, their advocates believe that these applications meet the proposed criteria for incorporating automation and robotics in the Space Station. Such applications should be viewed at least as prime candidates.

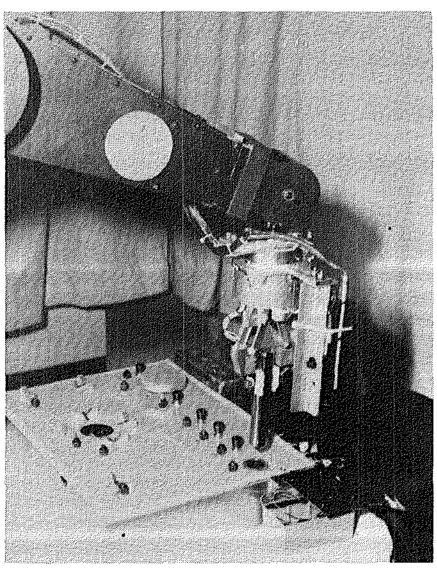
Specific applications so recommended include

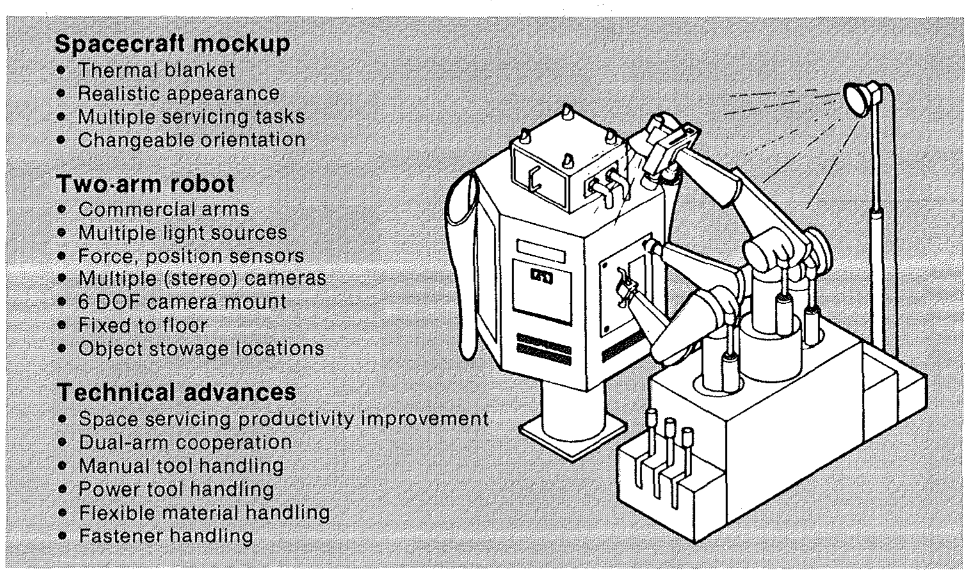
- A mobile, extravehicular robot to assist Space Station personnel in assembly and checkout
- A rail-mounted intravehicular robot for laboratory service (inspection, maintenance, and repair)
- Stationary "workbench" robots including "smart" hardware such as automated utility containers

TABLE 6.- CRITERIA FOR SELECTING APPLICATIONS OF AUTOMATION AND ROBOTICS

Proposed criterion	Considerations
Crew and station safety	Need for extravehicular activity Handling hazardous materials
Performance	System weight, volume, and power Accuracy and repeatability of operation Maintainability and reliability Contribution to mission reliability Adherence to customer-imposed requirements
Productivity	Crew productivity, time saved, response-time improvements, extending performance beyond the capability of unaided crew Commonality among functions to be supported Ground operations productivity Training Compatibility of A & R hardware and software with other Space Station equipment and systems
Cost	Non-recurring development costs Operating—i.e., "life cycle" costs
Growth and evolvability	Potential for enhanced capability Application in other space contexts Benefits to the U.S. economy
Risk	Developmental readiness Reliability and maintainability Crew, station, and mission safety Knowledge representability, availability, and ease of validation

Progress in robotics will be demonstrated on realistic tasks.





Technology Readiness

Each of the study contractors carried out an assessment of automation and robotics technology for the RUR-1 event. Typically, this was done by reviewing information existing within the contractor team as well as that available from the results of the NASA automation study. From these reviews, automation and robotics technology was assessed to determine the current status and to formulate plausible directions for growth during the years 1992 through 2010.

This assessment was made in varying levels of detail. In most cases the assessment was rather general but, in one case, the contractor assessed status for each item in the list of candidate applications. This thorough effort was undertaken to determine which of the candidates would require the most development work. This contractor found that many of the candidates were achievable for the initial station.

Another contractor focused on key technologies and made judgments, item by item, as to whether the technology definitely would be ready for initial station operation, would be ready given sufficient development, or definitely would not be be ready. This assessment is believed to be generally valid and is provided in table 7.

The committee cautions, however, that what technology will actually be ready for use on the initial Space Station will hinge on the funding and execution of adequate test programs to move technology currently at levels 1 through 4 to higher levels for implementation.

An expert system to diagnose the Shuttle's liquid oxygen (LOX) system is already in use.

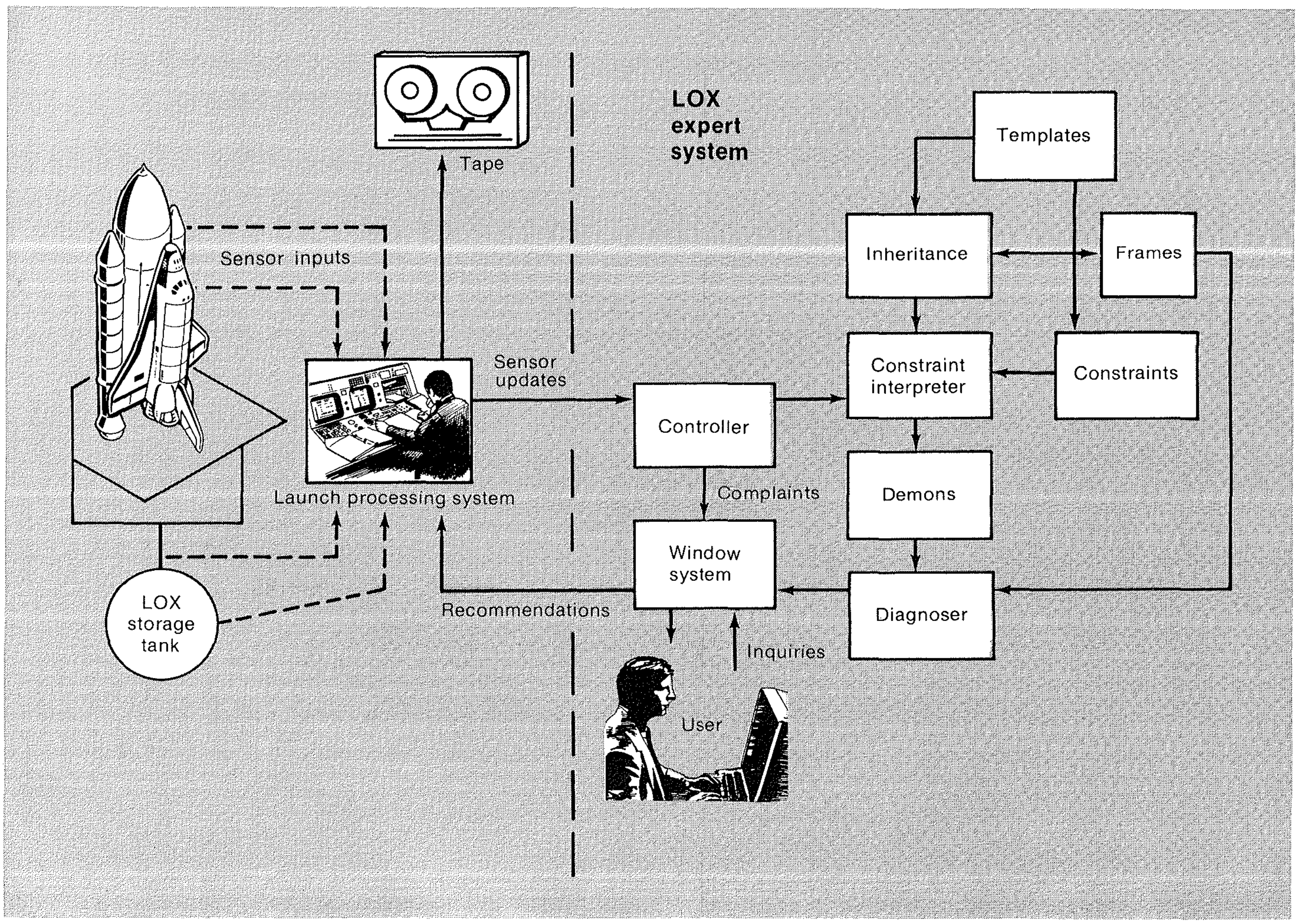


TABLE 7.- A PROJECTED TECHNOLOGY STATUS

- **Control Systems and Software**

  Definitely ready for the initial station
  —Master/slave manipulator control with force feedback
  —Simple voice control system
  —Camera pointing by operator head movement
  —Servicing-assistant expert system

  Possibly ready for the initial station
  —Manipulator with advanced force control
  —High-performance voice control system
  —Supervisory control (conventional or knowledge-based)
  —Servicing-consultant system

  Not ready for the initial station
  —Camera control by eye motion
  —Advanced supervisory control
  —Advanced adaptive control
  —Autonomous, knowledge-based robot software

- **Manipulators**

  Definitely ready for the initial station
  —Mobile remote manipulator system and related arms
  —Arms based on industrial robot technology

  Possibly ready for the initial station
  —Interchangeable arms
  —Lighter, more versatile arms
  —Non-anthropomorphic arms

  Not ready for the initial station
  —Manipulators fully equivalent to human arms

- **End Effectors**

  Definitely ready for the initial station
  —Grippers with open/close operation
  —Simple grapplers
  —Simple interchangeable tools

  Possibly ready for the initial station
  —Generalized, dextrous grippers
  —Advanced mechanisms for tool interchange

  Not ready for the initial station
  —Human-hand-equivalent grippers

- **Sensors**

  Definitely ready for the initial station
  —Proximity sensors
  —Motor current force and torque sensors
  —Arm position sensors
  —Laser bar-code readers

  Possibly ready for the initial station
  —Slip sensors (detect motion relative to grippers)
  —Fiberoptic force and torque sensors
  —Laser range and position sensors (in wrist or hand)

  Not ready for the initial station
  —High-fidelity tactile sensors

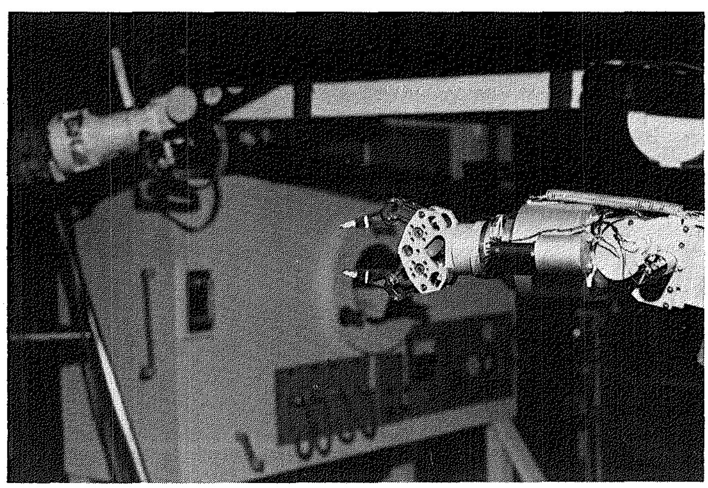
- **Vision**

  Definitely ready for the initial station
  —Goggle-like helmet stereo displays (monochrome)
  —Conventional and infrared stereo cameras

  Possibly ready for the initial station
  —Goggle-like helmet stereo displays (color)
  —Wide-angle stereo displays
  —Simple video-image computer augmentation

  Not ready for the initial station
  —Advanced video-image computer augmentation
  —Predictive video displays
  —Scanning laser imager
  —Holographic displays

End effectors are key to manipulations; for example, removing and replacing components.



While not called for specifically in RUR-1, areas where research and development are required were identified by a number of contractor teams. These are listed in table 8.

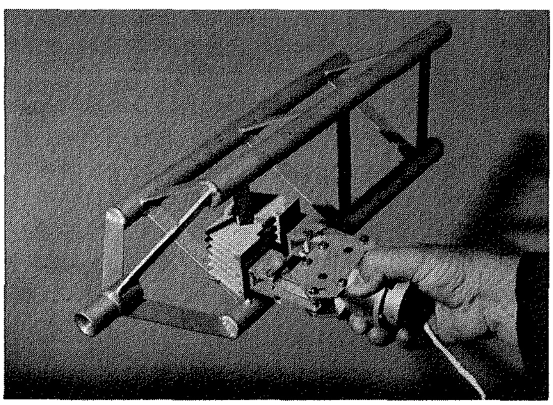
TABLE 8.- AREAS OF NEEDED EMPHASIS

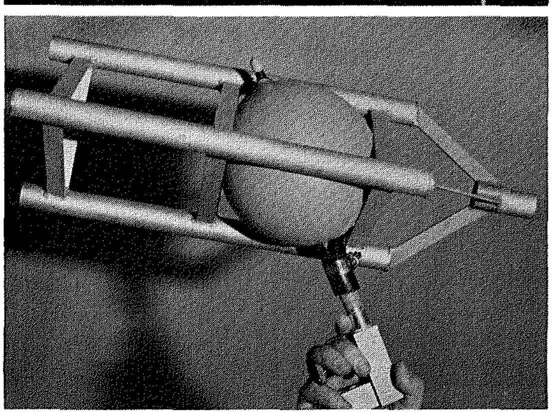
Expert systems including
—Distributed hardware processors
—Parallel processors
—Symbolic processors
—Computer languages and development tools

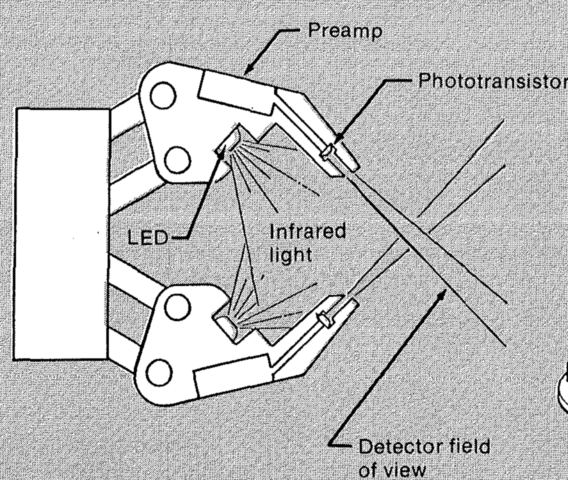
Robotics elements including
—Manipulator arms
—End effectors
—Actuators
—Robot mobility
—Sensing (including vision, force and tactile feedback, proximity determination, and sniffers)
—Sensor fusion (combining disparate inputs)
—Robotic control

Human-machine interfaces, specifically
—Voice recognition and synthesis
—Advanced graphics and displays

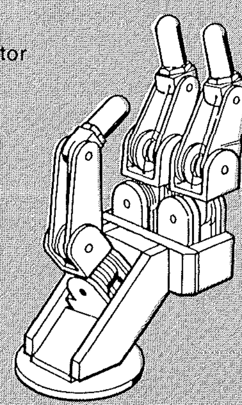
Many imaginative types of end effectors have been tried.







Typical gripper with proximity sensors


Three-fingered hand

Provisions on the Initial Station for Future Advances in Automation and Robotics

If the Space Station is to utilize and stimulate advanced automation and robotics, it must be designed with a view to easy incorporation of new technology as it becomes available. During this reporting period, the study contractors made a good start at postulating the candidate applications of automation and robotics likely to occur during the growth and evolution of Space Station and the provisions needed on the initial station to accommodate this growth and evolution. Some of the more important provisions suggested are listed in table 9.

In addition to these provisions suggested by the study contractors, the committee would point out that adequate provisions for Space Station automation and robotics must extend to all spacecraft, instruments, and systems expected to be tended, docked, or housed near Space Station elements.

This robot employs force feedback to test precision assembly.

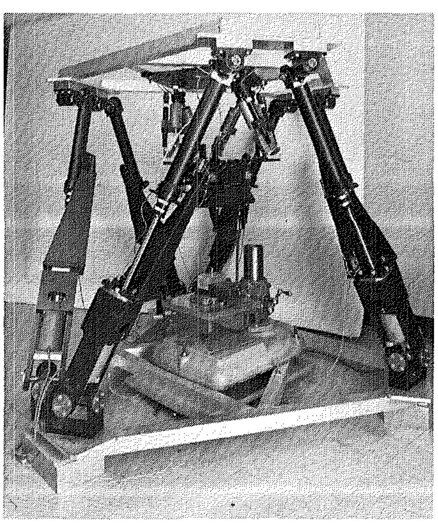


TABLE 9.- PROVISIONS NEEDED FOR FUTURE A & R APPLICATIONS

- **General**

  A design for structures, modules, and fittings adapted to assembly by anticipated manipulators

  Definition of "robot friendly" interface standards for
  —Connectors
  —Fasteners
  —Replacement unit designs
  —Pathways
  —Data interchange

  Umbilical connections and attachment fittings that will accommodate power, communications, and fluids supply and provide stability for robots

  Incorporation of markings and lights to simplify computer vision implementation

  Growth toward autonomous robots

- **Sensors**

  At least the reservation of locations, connectors, and processing capacity for sensors to permit the monitoring and analysis of important trends

  Accommodation of evolutionary sensor systems (computer vision, for example) to support the operation of vehicles in proximity to the station

- **Information and Data Management**

  Provision for prognostication routines that will track the performance of station components and permit replacement on the basis of need rather than on a maintenance schedule

  Provisions for the incorporation of built-in test equipment on all data systems

  Provision for understanding and responding to fault indications (including access to CAD/CAM/CAE data bases)

  Growth capacity (memory and processing speed) without major rework

- **Guidance, Navigation, and Control**

  Provision for computer control of all Space Station traffic, including support for the control of multiple free-flyers

  Evolution of automated docking of free-flyers

  Provision for an expert system to perform trend identification and attitude control and to serve as an interface with the mass management control systems to keep the Space Station's center of gravity within design limits

- **Communication and Tracking**

  Accommodation of miniature television cameras and laser radars to support more automated docking and berthing

- **Habitability**

  Support for computer vision hardware and sophisticated analysis tools in the health maintenance facility

- **Extravehicular Activity**

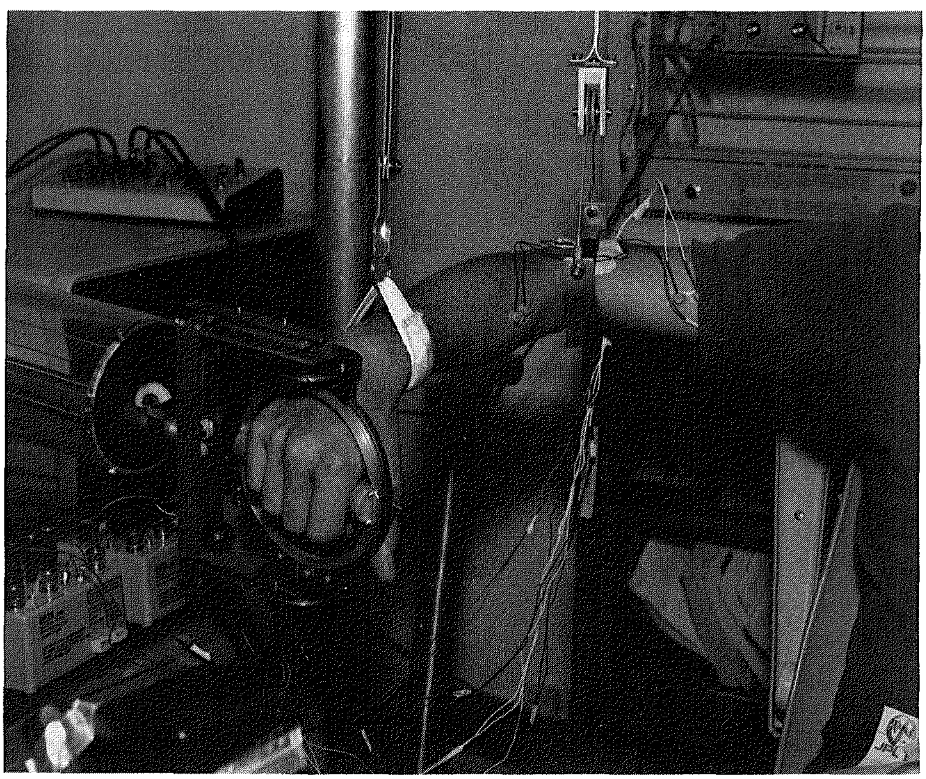
  Provision for specialized computer vision and monitoring software for operation of the airlock as an emergency hyperbaric chamber

Compliance with the ATAC Guidelines

The committee believes that the study contractors have made a good start toward implementing the ATAC recommendations in their design work. True, it is still very early in the process, but a very substantial measure of imagination has been brought to bear on the Space Station design as it pertains to automation and robotics.

Most, if not all, of the goals suggested by ATAC have been addressed. In some cases, excellent elaboration on the notions has been forthcoming. In fact, the committee is pleased to note that its goals, which were set forth in part to stimulate imaginative thinking, have already served a useful purpose.

Methods are being studied to enable a human to control a complex manipulating device.



Status of Automation and Robotics Efforts

A great deal of work relevant to Space Station automation and robotics is being done. NASA, the aerospace contractors carrying out the Space Station definition and preliminary design, and a number of research institutions are all involved.

To give the flavor of some of the automation and robotics work going on and to show how it relates to the Space Station, we present in appendix E a synopsis of work described at the workshop the committee sponsored in May 1985. The workshop covered what each participating NASA center felt was representative of their automation and robotics work—proposed, planned, or in progress. Details of many of these activities can be found in the workshop proceedings, reference 7.

It should also be noted that only a small fraction of these efforts are sponsored by the Space Station Program. Also, by no means has all of the work relevant to automation and robotics been included.

The synopsis shows the stage of the work in terms of the technological readiness levels discussed earlier. It also categorizes each activity according to a preliminary classification scheme (appendix D) being tested by NASA.

The committee thinks that particular attention should be given to two areas:

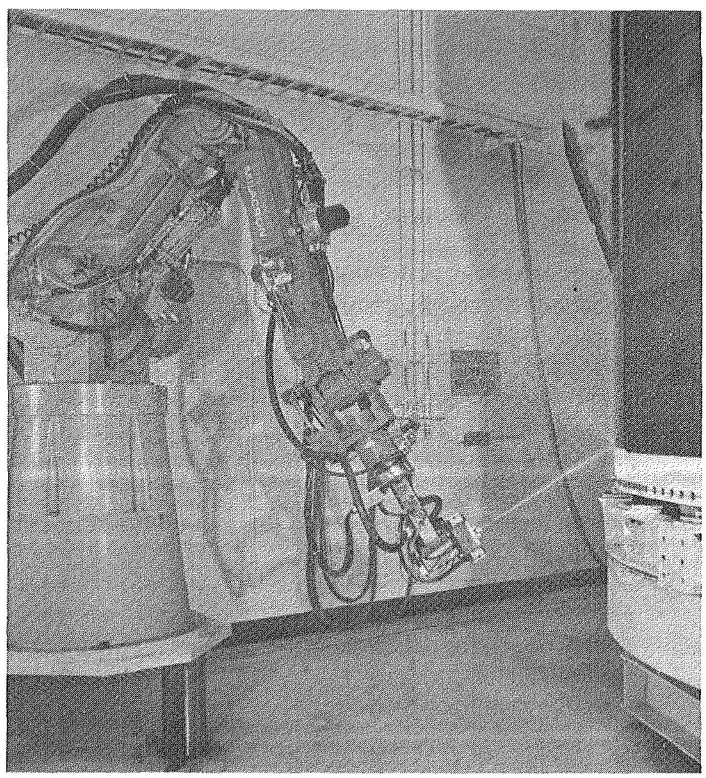
- Capturing the knowledge upon which A & R systems depend

- Creating the intelligent linkage between sensing and perception on the one hand and actuation and manipulation on the other

Effort in these areas is key to advancing intelligent systems beyond the limits of expert systems and robots today. Success in these important research areas will lead to vital capabilities

—To deal with imprecise data
—To deal with real-time sensor data
—To assess the consistency of sensor data with information in the knowledge base
—To deal with conflicting data sources for problem solving
—To acquire knowledge from multiple experts
—To plan and execute complex mechanical tasks

The committee is encouraged that many key technical people within NASA and the associated contract and research communities are focusing their efforts on automation and robotics. Not only is there intrinsically good work being done, but also the educational process to tip thinking in the direction of automation and robotics seems to be taking place andthose active in automation and robotics are communicating. We believe that this bodes well for the future.



A robotic device is currently employed in servicing solid rocket boosters.

Expenditures for Advanced Automation and Robotics

The committee recognizes its responsibility to assess the extent to which the Space Station Program has complied with the suggested utilization of 10 percent of program funds for automation and robotics. We believe that it is much too early to form a valid judgment of the extent of compliance. This is because the fraction which automation and robotics represent in the definition, preliminary design, and advanced development work now taking place does not necessarily bear any relationship to the fraction of the total program which it will comprise in the long run.

Nevertheless, NASA has obliged with estimates of the expenditures for automation and robotics during fiscal years 1985 and 1986. The expenditures by the Space Station Program, totaling $7.3 million in FY 1985, are summarized in table 10. These estimates are necessarily rough because the system for tracking Space Station expenditures, which was set up before the ATAC report, does not address automation and robotics as a specific item.

Significant funding is being devoted to A & R technology by elements of NASA outside the Space Station Program. NASA presented, at the September symposium in Washington, the general level of such funding in FY 1985 as follows:

- Aeronautics and Space Technology—for research in telerobotics and system autonomy—$8.2 million.
- Space Flight—for advanced development of telerobotics and expert systems for operations, planning, and control—$6.7 million.
- Space Tracking and Data Systems—for automation of ground operations—$900 thousand.

The total funding thus allocated to automation and robotics by NASA amounts to over $23 million. Furthermore, Space Station contractors will devote, during their phase B studies, an estimated additional $1.6 million of independent research and development funds to automation and robotics.

We recognize the need for NASA to satisfy the spirit of the congressional mandate and to show that the intended level of Space Station Program support is being provided. The committee believes that the best step to take now is to develop a sound method for estimating the projected cost of subsystems utilizing advanced automation and robotics. The Space Station Program Office has indicated that it will try to provide the desired traceability of expenditures.

In the case of efforts like the Advanced Development part of the Space Station program, separate tracking of A & R work is straightforward and should be done. Also to be included are the efforts of NASA elements outside the Space Station Program—offices such as Aeronautics and Space Technology, Space Flight, and Commercial Programs (including Small Business Innovative Research). For future ATAC progress reports, these offices should assess the extent to which their work relates to the congressional mandate and estimate the expenditures involved.

As a cautionary note, the committee would point out that the estimation of one specific component of cost in a program as complex as the Space Station is not a trivial matter. This is especially so in the case of efforts like automation and robotics which permeate the program, affecting every system and discipline. Hence NASA needs to devise sensible methods that will not require undue (and perhaps unrealistic) accounting detail.

Furthermore, there appear to be differing interpretations of the "important" costs for the Space Station. Some program and contractor personnel maintain that annual expenses or cash flow is the critical item. Others think that total initial cost is what is important. Neither of these interpretations is likely to yield a vigorous program in advanced automation and robotics. The committee would like to have managers and designers concentrate on life-cycle costs. Only in this way will the expense of new technology early in the program be tolerated. The potential payoff is believed to be immense.

TABLE 10A.- AUTOMATION AND ROBOTICS FUNDING IN THE SPACE STATION BUDGET

Activity	Funding (× 1000)	
	FY 1985	FY 1986
Advanced development and focused technology —Sensing and perception —Expert systems —Actuators and mechanisms —Human/machine interface —Automation of environmental and life support system —End effectors —Medical information —Power systems	$3500	$3800
Systems engineering and analysis —ATAC support —Analysis tools —Remote operations analysis	1000	1000
Operations —Fault detection and analysis —Expert systems for operations —Automated configuration control	250	600
Phase B contracts —Fault-tolerant architecture —Planners, schedulers —Automated power distribution —Knowledge-based maintenance —Automated payloads and orbital replaceable units —Very high speed integrated circuits and expert systems hardware —Robotic umbilicals	2500	3300
Totals	$7250	$8700

TABLE 10B.- AUTOMATION AND ROBOTICS EXPENDITURES AND THEIR RELATION TO THE TOTAL SPACE STATION BUDGET

	A & R (× 1000)	Total (× 1000)	Fraction, percent
Fiscal year 1985	$7250	$150 000	4.8
Fiscal year 1986	$8700	$200 000	4.4

Conclusions

The committee is pleased at the progress made by NASA in implementing the recommendations of its April report. There is widespread understanding of the nature, motivation, and importance of the congressional mandate and, in most quarters, a thoughtful effort is being made to meet the spirit of the mandate.

The definition and preliminary design work on the Space Station reflects considerable attention to automation and robotics applications and the developmental work needed to support the applications. NASA research work likewise is addressing Space Station needs.

While these indications are positive, there are significant problems associated with optimizing automation and robotics on the Space Station. The most pressing issues are

- Lack of a concrete and specific plan for automating the Space Station which coordinates Space Station design, A & R development, and research for an evolutionary station

- Lack of resources dedicated to developing new technology for an evolutionary station and moving this automation and robotics into actual use

Our overall concern is that the needed advance in the technology base of automation and robotics and the adaptive engineering and tests to implement such technology will not be available in a timely fashion without major additional funding. This advance is necessary to support future users and customers of Space Station facilities. Furthermore, we believe that the expense of such an advance would be more than recouped by savings in station operating costs.

There is no reason to believe that the research scenario developed by the Automation and Robotics Panel is not essentially valid in its scope and cost. This research program is believed to be essential if the true intent of Congress for Space Station development is to be realized.

APPENDIX A

NASA Advanced Technology Advisory Committee

Aaron Cohen, Chairman, Director of Research and Engineering, Lyndon B. Johnson Space Center (JSC)

John H. Boeckel, Director of Engineering, Goddard Space Flight Center (GSFC)

J. Larry Crawford, Director of Engineering Division, Office of the Chief Engineer, NASA Headquarters

Lynwood C. Dunseith, Assistant to the Director of Space Operations, JSC

J. Stuart Fordyce, Director of Aerospace Technology, Lewis Research Center (LeRC)

Robert H. Gray, Manager of Space Station and Advanced Projects, John F. Kennedy Space Center (KSC)

Lee B. Holcomb, Director of Information Sciences and Human Factors Division, NASA Headquarters

James E. Kingsbury, Director of Science and Engineering, Marshall Space Flight Center (MSFC)

Allen J. Louviere, Manager of Space Station Level B Systems Engineering and Integration

Henry H. Lum, Chief of Information Sciences Office, Ames Research Center (ARC)

Robert R. Nunamaker, Director for Space, Langley Research Center (LaRC)

Donna L. Pivirotto, Manager of Space Station Office, Jet Propulsion Laboratory (JPL)

APPENDIX B

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APPENDIX C
Acronyms

A & R	automation and robotics
AI	artificial intelligence
ATAC	Advanced Technology Advisory Committee
CAD	computer-aided design
CAE	computer-aided engineering
CAM	computer-aided manufacturing
CSD	contract start date
EVA	extravehicular activity
IRR	Initial Requirements Review
NASA	National Aeronautics and Space Administration
OMV	orbital maneuvering vehicle
ORU	orbital replaceable unit
OTA	Office of Technology Assessment (Congress)
OTV	orbital transfer vehicle
RMS	remote manipulator system
RUR	requirements update review

APPENDIX D

NASA's Categories for Automation and Robotics Work

1. *Knowledge*
   Representation and reasoning
   Surface and deep knowledge
   Problem solving, control methods, search techniques
   Deduction and theorem proving
   Knowledge acquisition and learning
   Diagnosis, monitoring
   Planning, simulation, execution
   Perceptual reasoning, object recognition
2. *Sensing*
   Force, torque
   Proximity, range, rate
   Tactile, kinesthetic
   Visual, optical
   Auditory, acoustic
   Pressure, flow, temperature, dewpoint, speed, voltage, current
   Integration of sensor information
3. *Actuation and manipulation*
   Control technology
   —Coordination
   —Collision avoidance
   —Compliance
   —Error recovery
   Manipulators, end effectors, propelling mechanisms
   Actuation in dynamic and distributed expert systems
4. *Supporting software and hardware*
   Fault-tolerant architecture
   Specialized artificial intelligence architectures
   Programming languages
5. *Human/machine interface*
   Displays
   Force feedback
   Controls and input mechanisms
   Natural language processing
   Voice synthesis and recognition
   Interfaces
   —Users of expert systems
   —Reprogramming and maintenance
   —Options for levels of automation
   Automation tradeoffs
6. *System design and integration*
   Environments for automation
   Verification and validation
   Automatic test and checkout
   Automatic programming
   Knowledge engineering
   Engineering automation
7. *Application systems*
   Expert systems
   —Controllers
   —Fault management
   —Executives
   —Planning/scheduling/sequencing
   Engineering automation systems
   Robotic systems
   —Automatic assembly
   —Parts handling
   —Repair
   Computer vision systems, automatic inspection.

APPENDIX E

R & D Activities Related to Automation and Robotics

Institution	Objectives of the research	Potential Space Station use	Level
Category 1—Knowledge Representation and Reasoning			
Ames Research Center	Representational issues including —Time (duration and causality) —Actions and their effects —Spatial information (models, CAD) Decision-making under uncertainty Learning Fault diagnosis	Astronaut and equipment scheduling System operation Construction Autonomous robots	2
Goddard Space Flight Center	Geometric knowledge base Autonomous reasoning for assembly/disassembly/replacement	Servicing and assembly	4
Marshall Space Flight Center	Intelligent servicing Task automation including —World modeling —Task planning —Task sequencing	Automation of robot servicing, ORU replacement	2
Category 2—Sensing			
Johnson Space Center	Development of TV systems for target recognition, identification, and attitude determination Voice command systems	Automated tracking	2
Johnson Space Center	Laser vision development Spatial positioning using controlled-position light beams Infrared remote control techniques	Robotic sensing and control	3
Lewis Research Center	Techniques for sensor-failure detection, isolation, and accommodation	System monitoring	4
Langley Research Center	Laser-based image and ranging systems Focal-plane preprocessing for improved sensitivity and speed	Autonomous robots	2
Jet Propulsion Laboratory	Development of sensors—tactile, proximity, and torque Displays to enable teleoperation	Robotic and teleoperated grippers with force and moment feedback	3
Marshall Space Flight Center	Development of autonomous docking sensor	OMV and OTV berthing and servicing	3-4
Marshall Space Flight Center	Robotic engine-welding system using a vision sensor to correct the robot path in real time	Automated processes in the space environment	6
Marshall Space Flight Center	Robotic system utilizing vision sensor feedback for removing solid rocket booster thermal protection	Automated processes in the space environment	3-4
Goddard Space Flight Center	Compliant force feedback and applications to use devices with such feedback	ORU replacement and assembly	4

R & D ACTIVITIES RELATED TO AUTOMATION AND ROBOTICS (continued)

Institution	Objectives of the research	Potential Space Station use	Level
Category 3—Actuation and Manipulation			
Johnson Space Center	Robotic test facility for Space Station hardware interfacing requirements Actuator laboratory for advanced robotic and docking systems Programmable mechanisms for assisting the RMS in payload handling	Manipulators and robotics	2
Langley Research Center	Parallel-jaw end effectors with proximity detection Quick-change tool systems High-level command systems Six-degree-of-freedom force and torque sensors and displays	Generic robotics and teleoperation	3
Lewis Research Center	Smart remote power controllers and remote bus isolators for power limiting and fault detection and isolation	Autonomous electrical power system	4
Marshall Space Flight Center	Protoflight manipulator	Servicing and construction	5-6
Marshall Space Flight Center	Orbital servicer system	Servicing	4-5
Marshall Space Flight Center	Intermeshing end effector	Servicing and construction	4
Category 4—Supporting Software and Hardware			
Ames Research Center	Programming environments for expert, fault-diagnosis, and procedure-planning systems Real-time simulation and modeling Tradeoffs between human understanding and machine processing and intelligence	Expert systems, human/machine interfaces, and task partitioning	2-4
Ames Research Center	Development of a spaceborne very high speed integrated circuit (VHSIC) symbolic processor for "intelligent" processing	Advanced "intelligent" processing	2
Langley Research Center	Design and assessment methods for integrated, fault tolerant flight control systems Methods for validating the performance and reliability of complex electronic systems A test facility for advanced computer architectures	Fault tolerant systems	2
Langley Research Center	Advanced information-network architectures that are fault tolerant, self-correcting, and self-repairing Optical components for high-density circuits	More reliable and efficient circuits	3
Jet Propulsion Laboratory	Self-checking computer modules Autonomous redundancy management systems Advanced high-speed computers	More reliable and efficient computing	2-3
Kennedy Space Center	Expert systems software for operational system diagnostics, test, and control imbedded as firmware on system hardware	Automated diagnostics, test, and control of Space Station systems	
Kennedy Space Center	Expert system for scheduling, planning, replanning, and resource allocation	Automated system scheduling and resource allocation	
Kennedy Space Center	Higher order language for automated procedure development and systems communications	User friendly language for Space Station system operations and software maintenance	

R & D ACTIVITIES RELATED TO AUTOMATION AND ROBOTICS (continued)

Institution	Objectives of the research	Potential Space Station use	Level
Category 5—Human/Machine Interface			
Johnson Space Center	Development of virtual-image, helmet-mounted displays Anthropomorphic hand manipulator Automatic control of EVA cooling	More efficient extravehicular activity	2
Ames Research Center	Information to create telepresence Procedural aids for system automation Models of human vision, voice input/output, command language	Improved human/machine interface	2-3
Langley Research Center	Improved crew station technology —Display media including 3-D —Advanced graphics —Improved input/output (control)	More efficient use of crew time and workstation space	2-3
Jet Propulsion Laboratory	Evaluation and analysis tools to assess the merit of automating various functions and decide where the human/machine interface should be	Optimal extent of automation and robotics utilization	4
Kennedy Space Center	Advancement of design capability by human/machine (CAD) interface	Improved human/machine interface	
Marshall Space Flight Center	Operator station with stereo, video, graphics, and voice/touch control capabilities	Telepresence interface servicing and assembly	2-3
Marshall Space Flight Center	Graphical simulation for predictive display, off-line auto-sequence display, and system checkout	Teleoperated and automated servicing and assembly	2-3
Marshall Space Flight Center	Expert system allowing non-simulation personnel to perform studies with complex simulation systems via a natural language interface	Reduced-cost Space Station simulations	4
Category 6—System Design and Integration			
Johnson Space Center	Demonstration of a technique for automated control, being tested on air-revitalization components of the environmental control system	Automatic control and monitoring of Space Station subsystems	3
Johnson Space Center	Simulation, including visual displays, of docking and berthing activities among the Space Station, Shuttle, and orbital maneuvering vehicle	Development and training	2-4
Johnson Space Center	Support to definition of on-orbit assembly sequences and methods Berthing dynamics and simulation of orbital operations	Optimum assembly of the Space Station	2
Langley Research Center	Simulation of robotic systems to define and analyze performance Test-bed for AI and robotics interfaces Intelligent control of robots, vision systems, sensors, graphics, etc. Design of a space manipulator	Improved robots and robotic control	2-4
Kennedy Space Center	Development of a robotics test-bed to study the application of robotics to hazardous conditions such as refueling of rockets	Space servicing of satellites	2

R & D ACTIVITIES RELATED TO AUTOMATION AND ROBOTICS (continued)

Institution	Objectives of the research	Potential Space Station use	Level
Kennedy Space Center	Integrated distance sensing and robotic vision techniques for the control and movement of large structures	Mating, docking, and assembly activities	
Lewis Research Center	Development of power system test-bed with network control to evaluate automation strategies	Autonomous electrical power system	3
Marshall Space Flight Center	Simulation, including video displays, of rendezvous and docking activities of OMV and OTV	Development and training	2-4
Marshall Space Flight Center	Simulation of teleoperator and robotic systems to define and analyze performance of manipulator test-bed for evolutionary automation, manipulator control systems, and sensor interfaces	Improved teleoperator and robotic systems	3-5
Marshall Space Flight Center	Autonomous management of large spacecraft power system	Electrical power system automation	4
Marshall Space Flight Center	Determining expert systems applicability and rapid prototyping for common-module electrical power system	Electrical power system automation	2
Marshall Space Flight Center	Flexible simulation of robot kinematics, dynamics, and control, allowing experiments in new manipulator designs, AI, and planning and control of robot paths	Reduced costs for evaluating new methodologies	6
Marshall Space Flight Center	Simulation of vehicle-contact dynamics using a moving platform and force sensors to verify operation of docking and berthing mechanisms	Verification of prototype and flight docking and latching mechanisms	6
Category 7—Application Systems			
Johnson Space Center	Automated fault management of a CO_2 removal device	Environmental control and life support	3
Johnson Space Center	Expert systems for designing simulation software for —Design of control systems for flexible structures —Rendezvous and approach planning —Task interpreter for intelligent end effector	Proximity operations Manipulator operations	3
Johnson Space Center	Expert systems for Space Station avionics	Power management Optical attitude reference Electrical mate/demate for robotic applications	2
Johnson Space Center	Development and demonstration of a telerobotic workstation with capability equivalent to a suited astronaut	EVA servicing or repair activities	3
Johnson Space Center	Expert system prototyping	Navigation, flight analysis, and orbit determination Monitoring mission control software Scheduling power use	3-4
Johnson Space Center	Computer augmentation/automation for integrating data formatting, computations, expert systems, displays, etc. in a distributed system	Orbital systems monitoring	2

R & D ACTIVITIES RELATED TO AUTOMATION AND ROBOTICS (continued)

Institution	Objectives of the research	Potential Space Station use	Level
Goddard Space Flight Center	Techniques for changing food cassettes, fixing specimens, drawing blood, and sampling and controlling wastes	Automated life science laboratory management	2
Goddard Space Flight Center	Design of ORUs, including tooling, manipulators, sensors, automatic control, and human interface Standardization of interfaces Uses of robotics	Servicing free-flying satellites, scientific payloads, and platforms	2
Goddard Space Flight Center	Expert systems for crew operations and scheduling	Space Station autonomy	4
Goddard Space Flight Center	Technology Development Mission (TDM) experiment—expert systems for planning and scheduling	Payload automation	2
Goddard Space Flight Center	Expert systems for planning satellite operations and for scheduling and managing the network control center	Payload data systems management	3-4
Lewis Research Center	Expert systems, simulators, and facilities for studies in power management	Mission planning and scheduling for power growth and loads Onboard power management —Generation —Storage —Load distribution —Access to power system —Configuration —System monitoring —Fault and trend analysis	2-4
Lewis Research Center	Expert system for structural analysis Robotic manipulators and positioners State-estimation methodology	Power system analysis and control	2-3
Lewis Research Center	Expert systems to increase productivity and provide aid to new employees at the center	Program management	2
Kennedy Space Center	Expert system for Shuttle cargo processing schedules and detailed "subschedules"	Logistics planning and support	2
Kennedy Space Center	Expert system for scheduling cargo directly from the manifests for each Shuttle flight	Logistics management	3
Kennedy Space Center	Expert systems for diagnosing liquid oxygen system faults and identifying candidate causes	Automated fluids management	5
Kennedy Space Center	Knowledge-based automatic test equipment that will design, execute, and control tests and analyze results	Laboratory and station operation	2
Kennedy Space Center	Expert systems for weather forecasting for Shuttle launch and landing	Logistics planning	2
Jet Propulsion Laboratory	Three-dimensional computer recognition of moving targets made of complex polyhedra	Robotic recognition of targets to be manipulated or serviced	3
Jet Propulsion Laboratory	Expert systems for forming and testing hypotheses, planning configurations of systems, and planning schedules	Operations	2
Jet Propulsion Laboratory	Expert system application of electric power management, including interactive load scheduling	Onboard operations	2

R & D ACTIVITIES RELATED TO AUTOMATION AND ROBOTICS (concluded)

Institution	Objectives of the research	Potential Space Station use	Level
Langley Research Center	Systems-level research in robotics —Evolution from teleoperation to a goal-directed robot —Integration and analysis of the total robot system	Complete "integrated" robots	2
Marshall Space Flight Center	Guidelines for ORU design and utilization	EVA/remote servicing	1-2
Marshall Spac Flight Center	Fault diagnosis expert system for the test-bed for Space Telescope battery power	Fault diagnosis for various subsystems	2
Marshall Space Flight Center	Fault isolation expert system	Fault isolation for various subsystems	4
Marshall Space Flight Center	Planner/scheduler expert system for payloads	Planning and scheduling	2
Marshall Space Flight Center	Expert system that plans the use of shared resources for Spacelab experiments and operations	Mission planning and operations onboard Space Station	6

APPENDIX F

Astronaut White Paper on Automation and Robotics

U.S. Government

MEMORANDUM

Lyndon B. Johnson Space Center — NASA

REFER TO:	DATE	INITIATOR	ENCL
CB-85-027	APR 1 1985	CB/McCandless/Parker:td:12/20/84	1

TO: PA/Manager, Space Station Program

CC: See list below

FROM: CA/Director, Flight Crew Operations

SIGNATURE: Original signed by George W. S. Abbey
George W. S. Abbey

SUBJ: Space Station Crew White Paper on Automation and Robotics

During the past year, Capt. Bruce McCandless and Dr. Robert Parker, representing the Flight Crew Operations Directorate, participated in your Space Station RFP preparation and subsequent evaluation activities. As members of your Operations group, they were involved in a number of definition activities including the potential use of automation and robotics in station operations. As part of these activities, they were requested by your Operations group to prepare a crew position paper on use of automation and robotics. That paper is included in this memorandum.

As technology progresses, the scope of tasks amenable to automation or to accomplishment by robot means increases. In less than a quarter of a century we have evolved from the computerless, hardwired, Mercury spacecraft to a fly-by-wire, multi-computer controlled, reusable spacecraft that is dependent upon uninterrupted, accurate, high speed digital computations for flight control and aerodynamic stability as well. At this stage of evolution of the Space Station Program it is appropriate to attempt to assess the role that these technologies should be assigned in the developmental stages so as to result in the most effective utilization of crew resources. It is assumed that at least the current level of automation of guidance and control systems will be incorporated into the station design.

In order to be realistically available to support the 1992 Initial Operational Capability (IOC) date, commercial prototype or operational laboratory systems must be available by the end of FY86. This is not to imply that later blooming technology should be barred from the Space Station; only that we must be able to get along at IOC with whatever exists in tangible, useful form elsewhere by the end of FY86. Premature implementation of automation and robotics will only lead to unnecessary complexity, cost, and degradation of Space Station performance.

JSC Form 1180 (MOD Ethernet) | INCREASED PRODUCTIVITY = LOWER COST | Page 1 of 3

NASA-JSC

The following are submitted as working groundrules.

a. Automation and/or roboticization of Space Station systems should be based on cost-effective increases in productivity or on meeting systems operational requirements rather than solely for the sake of advancing the state of such technologies. "Spin-off" technological benefits will be an inherent product of this effort.

b. Target areas should be those that offer the greatest potential for relieving the crew of time-consuming, time-critical, repetitious, physically taxing, hazardous, non-creative, or boring activities. Supervisory decision-making control should normally be reserved to human operators, either onboard or on the ground. Efforts to automate supervisory decision functions must always provide human override capability.

c. Automated systems must be capable of being reconfigured and reprogrammed by the crew. Consequently, the software packages must be as independent as possible so as to not interfere with the safe operation of the station while work on an individual system is under way.

d. Currently budgeted allocations of crew time to tasks such as systems management, replanning, training and unscheduled activities are based on years of accumulated spaceflight experience. These values should be retained for IOC planning until such time as sufficient experience is gained with expert systems in a flight environment to warrant reductions. Increased time available for direct customer support may eventually be realized as such systems are phased in and mature, but should not be anticipated for IOC planning.

e. All essential functions performed by automated or robotic means must have effective means available to the crew for the override, troubleshooting, and functional backup of the subject system.

f. Normal crew interaction with an automated or robotic system must be maintained at a minimal but sufficiently high level that operator proficiency and familiarity with its features are not lost over time, with the loss only being recognized when the system quits or suddenly exhibits unfamiliar or anomalous behavior.

g. In order to develop credibility and maturity, Shuttle technology demonstration flights of essential automation/robotics elements should be scheduled and funded ASAP.

h. Monitoring and alarm means (e.g., caution & warning systems) should be kept independent of control means so as to avoid common failure modes. Additionally, while an "expert system" for failure diagnosis might profitably be incorporated into the caution and warning system, and could display appropriate schematics and the rules leading up to its diagnosis, the basic functions of a C & W system must be readily available even if the expert system itself should prove troublesome.

i. Early emphasis should be placed on achieving originally intended performance from existing automated systems that do not function satisfactorily. A specific example of this is the Orbiter cabin temperature controller; if it is not manually pinned into position, it drives to one limit or the other. Only on the thirteenth flight of the Orbiter (STS 41-G) has this system been made to function in a proportional, but still uncalibrated, mode.

j. On-orbit maintenance operations should not be reduced to rote repetition activities via a system such as a heads-up display based automated video maintenance information system. Such an approach would lead to crew indifference and ignorance due to concentration on manipulative "nuts and bolts" tasks at the expense of intellectual involvement and comprehension.

k. Robotic systems must include "teaching pendants" or similar means for on-orbit "re-education" of the devices or development of new tasks. An effective means of collision avoidance and contact sensing must be provided.

A number of specific tasks or areas considered particularly appropriate for automation and/or roboticization by the flight crew are listed in the Appendix to this "white paper".

Several of the recommended tasks or areas in the Appendix were proposed in the early Space Shuttle designs such as onboard automated flight planning, automated systems management, and automated malfunction procedures with automated trouble shooting. The cost of these few jobs in time, in data processing system memory, and in software programing was excessive. Hopefully, the data processing systems in the Space Station will handle the Appendix requirements cheaply and efficiently. It is recommended that the Space Station Program carefully control automation and gradually phase it into Space Station operations. Anything near total automation of the Appendix items will surely slip the IOC of the Space Station. This is because of the significant but now hidden automation burden of time, manpower, software, and dollars.

Glossary

[Many of these definitions are from Gevarter, 1983.]

A

Analogic reasoning: A type of reasoning that builds on analogies with related situations.

Artificial (or machine) intelligence (AI): A discipline devoted to developing and applying computational approaches to intelligent behavior. Also referred to as machine intelligence or heuristic programing.

Automation: The technology by which control of physical processes or devices can be exercised according to preestablished rules and, normally, without human intervention.

Autonomous: Capable of independent action.

C

Computer vision (robotic vision, machine vision): Perception by a computer, based on visual sensory input, in which a symbolic description is developed of a scene depicted in an image. It is often a knowledge-based, expectation-guided process that uses models to interpret sensory data. Used somewhat synonymously with image understanding and scene analysis.

Co-orbiting: Said of a satellite orbiting in an orbit close to and readily accessible to the Space Station orbit.

D

Data base: An organized collection of data about some subject.

Data base management system: A computer system for the storage and retrieval of data about some domain.

Dextrous manipulator: A mechanical device that can carry out physical tasks with a facility approaching that of a human.

E

Effector: The portion of a manipulator that causes the desired action, such as gripping or positioning.

Expert system: A computer program that uses knowledge and reasoning techniques to solve problems normally requiring the abilities of human experts.

F

Fail-safe/fail-operational: Said of a design approach for a spacecraft component in which a failure of the component will result in a condition that is operational if possible or at least safe.

G

Geosynchronous/geostationary: Of an orbit around the Earth at just the correct height so that a satellite in such an orbit will appear stationary with respect to a point on the surface.

H

Human/machine interface: The devices, programs, and procedures by which a human interacts with a machine.

Hyperbaric: Higher than atmospheric pressure.

I

Image understanding (IU): Visual perception by a computer employing geometric modeling and the AI techniques of knowledge representation and cognitive processing to develop scene interpretations from image data. IU has dealt extensively with 3-D objects.

Intelligent: Said of a machine capable of performing or planning actions for which it was not specifically designed; in effect, displaying characteristics which, if exhibited by a human, would be thought intelligent.

K

Knowledge base: An AI data base that is not merely a file of uniform content but rather a collection of facts, inferences, and procedures corresponding to the types of information needed for problem solution.

M

Microelectronics/microelectronic chips: Electronic devices or circuits which are very small and compactly packaged. Chips are very small, thin wafers that comprise many circuits and can carry out basic computing functions.

Multisensory data: Data from several sensors all simultaneously available. Sight, sound, touch, etc. provide human beings with a multisensory data set.

N

Natural language understanding : Response by a computer based on the meaning of a natural language input.

Nonmonotonic reasoning: Reasoning in which results are subject to revision as more information is gathered.

P

Phases B, C, D: Stages in implementing a space project; respectively, (B) preliminary design and definition, (C) detailed design, (D) construction.

Platform: A flight element of the Space Station Program which carries out special tasks in a separate orbit from that of the station and which is serviced in some way by the station.

Proximity sensor: A sensing device that detects when an object comes within a specified distance of the device.

R

Robotics: The technology and devices (sensors, effectors, and computers) for carrying out, under human or automatic control, physical tasks that would otherwise require human abilities.

S

Speech recognition: Recognition by a computer (primarily by pattern-matching) of spoken words or sentences.

Speech synthesis: Developing spoken speech from text or other representations.

Speech understanding: Speech perception by a computer.

T

Teleoperation: The execution of physical tasks by a manipulating device under human control.

Telepresence: The concept of remotely controlled manipulation in which the manipulators at the worksite have the dexterity to perform normal human functions and the operator at the control site has sensory feedback sufficient to provide the feeling of being present at the remote site where the action is taking place.

W

Wafer: A thin slice of a special material on which electronic circuits can be placed to create a chip.

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16. Abstract

In April 1985, as required by Public Law 98-371, the NASA Advanced Technology Advisory Committee (ATAC) reported to Congress the results of its studies on advanced automation and robotics technology for use on the Space Station. This material was documented in the initial report (NASA Technical Memorandum 87566).

A further requirement of the Law was that ATAC follow NASA's progress in this area and report to Congress semiannually. This report is the first in a series of progress updates and covers the period between April 1 and September 30, 1985.

NASA has accepted the basic recommendations of ATAC for its Space Station efforts. ATAC and NASA agree that the thrust of Congress is to build an advanced automation and robotics technology base that will support an evolutionary Space Station Program and serve as a highly visible stimulator affecting the U.S. long-term economy.

The progress report identifies the work of Space Station study contractors, research in progress, and resource issues connected with building an adequate technology base.

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