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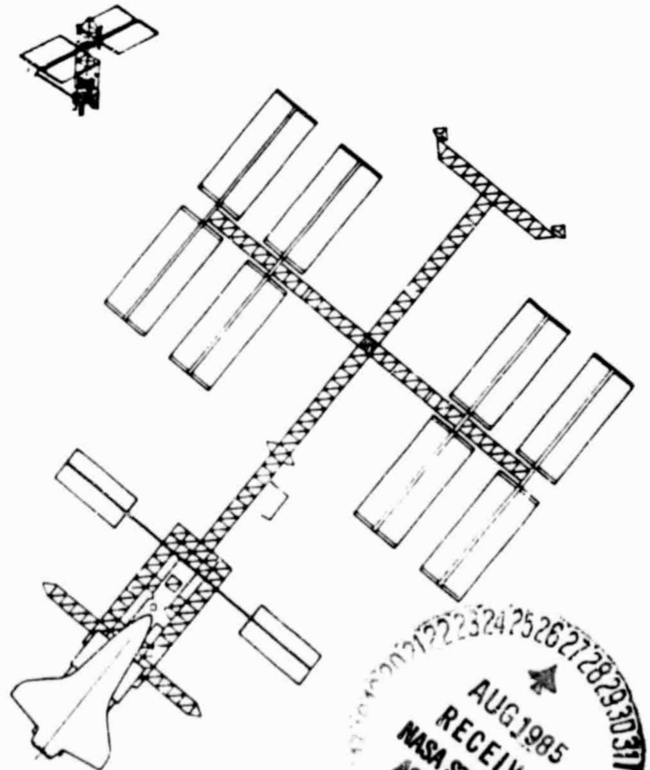

Statement by:

Aaron Cohen

Director, Research and Engineering
Johnson Space Center

Chairman, Space Station Advanced Technology Advisory Committee

99th Congress

Statement of

Aaron Cohen

Director, Research and Engineering
Johnson Space Center

and

Chairman, Space Station Advanced Technology Advisory Committee

National Aeronautics and Space Administration

before the

Subcommittee on Science, Technology, and Space
Committee on Commerce, Science, and Transportation
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Mr. Chairman and Members of the Subcommittee:

It is a pleasure to appear before you today to discuss the activities of NASA's Space Station Advanced Technology Advisory Committee. This testimony will briefly review Advanced Technology Advisory Committee (ATAC) activities over the last year in preparation of the report to Congress on the potential for advancing automation and robotics technology for the Space Station and for the U.S. economy.

BACKGROUND AND INTRODUCTORY REMARKS

In April 1984, at the request of the House and Senate Committees on Appropriations, NASA initiated a study to evaluate alternative Space Station systems design concepts and systems technologies which would use advanced automation and robotics. To accomplish this automation study, NASA contracted with the California Space Institute to oversee an independent, non-aerospace industry/university team. Additionally, four aerospace contractors (GE, Hughes, Martin Marietta and TRW) were tasked with automation and robotics conceptual design studies of representative functions on the space station and Boeing contributed a fifth case study. Finally, SRI International was engaged to perform certain technology evaluation and forecasting, in general and in support of the case studies.

As part of the Conference Report (House Report 98-867) accompanying the FY 1985 HUD-Independent Agencies Appropriations Act (P.L. 98-371), the Conferees noted that the Space Station program offers an opportunity to stimulate the development of advanced technologies in the fields of automation and robotics. To that end, P.L. 98-371, dated July 18, 1984, provides that:

> "...the Administrator shall establish an Advanced Technology Advisory Committee in conjunction with NASA's Space Station program and the Committee shall prepare a report by April 1, 1985, identifying specific space station systems which advance automation and robotics technologies, not in use in existing spacecraft, and that the development of such systems shall be estimated to cost no less than 10 per centum of the total Space Station costs."

In their report the Conferees further noted that NASA should examine existing systems "whose potential for enhancing automation and robotics technologies appears promising," and that it was their expectation that such technologies might not only "increase the efficiency of the station itself" but also "enhance the Nation's scientific and technical base leading to more productive industries here on Earth."

As a result of its examination, the Advanced Technology Advisory Committee agrees that a key element of the "right" technology for the Space Station era is extensive use of advanced, general purpose automation, robotics, and artificial intelligence. This could include many systems and devices (such as computer vision, expert systems, and dextrous manipulators) that have been made possible by recent advances in artificial intelligence, robotics, computer science, and microelectronics. However, the experts in this technology tell us that while many of these systems are or will be available for the initial Space Station, other technologies, which would provide general purpose infrastructure support functions, characterized by greater flexibility, adaptability, autonomy and intelligence, will require substantial research and development investment in order to reach maturity for use in evolutionary Space Station.

The Advanced Technology Advisory Committee (ATAC) was constituted in the fall of 1984, and has drawn upon the work of the Automation and Robotics Panel, led by the California Space Institute. The California Space Institute study is being submitted with the ATAC report to the Congress. As a result of our examination directed by the Congress and our review of the Cal Space Panel and contractor efforts, and an assessment of the engineering implications of the user and customer mission requirements, the ATAC has come to believe that a great deal of advanced automation and robotics may be needed on an evolving Space Station complex to provide the kind of flexible, adaptable, multi-purpose facilities in space which will be most productive and supportive of the users, customers, and operators. The Space Station (and the manned space program in general) would have used a significant amount of automation and robotics, so in one sense we are dealing with how much more advanced, general purpose automation and robotics may be used. A great deal has already been achieved to integrate advanced automation and robotics planning into not only the NASA activities, but also those of the Space Station Phase B contractors through the requirements stated in the Request for Proposals.

I believe the ATAC report (consisting of two volumes) can guide NASA in implementing this advanced technology to meet the needs of the Space Station users with highly productive and low operating cost facilities. This will be important to the commercialization of space as well.

Following my appointment by the NASA Administrator as Chairman of the ATAC, I selected a group of distinguished members, not only because of their professional experience and capabilities, but also because the organizations they represent will be responsible for assuring a high level of automation and robotics accommodation aboard the initial Space Station and its associated platforms which NASA undertakes as a result of the recommendations of both the Cal Space and ATAC studies. This gives the best opportunity to sustain the enthusiasm and guide the activities at the working level.

The membership of the Advanced Technology Advisory Committee is as follows:

Mr. Aaron Cohen, Chairman Director of Research and Engineering	Johnson Space Center
Mr. John H. Boeckel Director of Engineering Center	Goddard Space Flight
Mr. J. Larry Crawford Assistant to Chief Engineer	NASA Headquarters
Mr. Lynwood C. Dunseith Assistant to the Director of Space Operations	Johnson Space Center

Dr. J. Stuart Fordyce
Director of Aerospace Technology Lewis Research Center

Mr. Paul F. Holloway
Deputy Director Langley Research
Center

Mr. James E. Kingsbury
Director of Science
and Engineering Marshall Space Flight
Center

Mr. Allen J. Louviere
Manager of Level B Systems
Engineering and Integration Johnson Space Center

Dr. Robert R. Nunamaker
Chief Engineer Ames Research Center

Mrs. Donna L. Pivirotto
Manager, Space Station Office Jet Propulsion
Laboratory

A key element of the approach taken by ATAC from the outset was to be aggressive in identifying the best the technology has to offer as input to the Space Station definition and preliminary design process, but not to subvert or overly constrain the process or the managers prior to this very detailed activity.

Another objective was to involve industry, academia, and aerospace contrators in identifying specific Space Station systems which advance automation and robotics technologies through cooperation with, and integration of, the various automation/robotics tasks: the aerospace contractor case studies; the Cal Space Automation and Robotics Panel effort; and the Advanced Technology Advisory Committee (ATAC) study. The organizational methodology used for NASA's Space Station automation studies is depicted in Figure A. The Manager of the automation study is Mr. Dan Herman, NASA Headquarters Office of Space Station, and the Deputy Manager is Dr. Victor Anselmo, NASA Headquarters. Dr. Robert A. Frosch, Vice President of General Motors, served as Chairman of the Steering Committee. The California Space Institute of the University of California formed the Automation and Robotics Panel which consisted of representatives of industry, academia, and government as listed here:

*Prof. J. R. Arnold, Cal Space
Prof. R. Cannon, Stanford U
Dr. R. Cliff, DARPA
Mr. A. Cohen, NASA/JSC
Dr. Sanjay Mittal, Xerox PARC
Dr. J. Niehoff, Science Appl.

Mr. C. J. Cook, Bechtel, Inc.
Dr. D. R. Criswell, Cal Space
Dr. D. Evans, Los Alamos Nat'L Lab
Dr. H. Forsen, Bechtel Nat., Inc.
*Dr. R. A. Frosch, Gen. Mtrs. Res. Lab.
Dr. O. Garriott, NASA/JSC
Dr. D. Groce, Science Appl.
Dr. R. M. Hambright, SW Res. Inst.
Dr. H. Hudson, U of C at San Diego
Mr. D. G. Jelatis, Sargent Indust.
Prof. G. Konecci, U of TX
Prof. G. Kozmetski, U of TX
Dr. M. Knasel, SAI
Dr. P. B. Linhart, AT&T Bell Labs
Prof. M. Minsky, MIT & TM
Dr. R. Perkins, LANL
Dr. M. Raibert, Carnegie Mellon U.
Mr. M. Reiss, U.S. Senate
*Dr. C.Rosen, Machine Intell.
Dr. C. Ruoff, JPL
Prof. J. Schwartz, NY Univ.
Dr. S. Starks, U of TX Arlington
Prof. I. Triffet, U of AZ
Prof. R. Volz, U of MI
Dr. B. West, La Jolla
Prof. T. Williams, Purdue
Dr. M. Wiskerchen, Stanford, U

*Member of the Steering Committee

The panel was divided into subpanels to prepare the various sections of the Cal Space report. The ATAC Committee has tried to listen very closely to this Panel's technical recommendations.

As part of the effort, several aerospace contractors studied automation and robotics in specific areas, as follows:

Boeing	Operator/System Interface
General Electric	Space Manufacturing Concepts
Hughes	Subsystems and Mission Ground Support
Martin-Marietta	Autonomous Systems and Assembly
TRW	Satellite Servicing

In addition, SRI International provided a technology assessment based on the contractors studies, their knowledge of technology, and the anticipated technology readiness.

Because of the very limited time available, the contractors were directed to identify "drivers," or factors, for advanced automation leading to the identification of representative systems or mission scenarios within their study area. They were asked to study the automation/robotics application for the evolutionary Space Station without cost or technology readiness constraints. It was not intended that the contractor studies address all aspects of automation and robotics applications to the Space Station program, but to address representative applications believed to be typical of those requiring advanced automation.

An ATAC Support Group was formed to assist these efforts, as listed here:

Dr. Jon D. Erickson, Chairman	Artificial Intelligence Office, Johnson Space Center
Dr. Victor Anselmo	NASA Headquarters
Mr. Jon B. Haussler	Space Station Office, Marshall Space Flight Center
Dr. Stephen J. Katzberg	Space Station Office, Langley Research Center
Mr. Louis E. Livingston	Space Station Program Office
Dr. Henry H. Lum	Information Sciences Office, Ames Ames Research Center

They functioned as members of the Space Station Automation Study Team, observers at the Automation and Robotics Panel meetings, and as major participants in the support to ATAC. The ATAC support group assimilated the inputs from various contributors into the two-volume ATAC report. The Johnson Space Center Artificial Intelligence Office provided the initial draft of the report and integrated comments and revisions for the final version. Another eighteen NASA and JPL employees provided draft material. This further broadened the base of involvement in the Agency at the working level.

In addition to membership on ATAC and the ATAC Support Group, the Level B Space Station Program Office was involved through periodic briefings and copies of draft documents. All prime bidders for NASA's Space Station Phase B systems definition contracts were also provided draft documents in a timely manner so they were aware of our thinking.

The entire process for the Space Station Automation Study was open and iterative. In addition to the three iterative loops displayed in Figure A, there were many information interchanges. All meetings, presentation documentations, etc., were completely open and available to all participants. All substantive outputs of this effort were made available in a timely manner to all interested parties. This total effort required and received extraordinary cooperation from all participants.

The objectives of the ATAC examination are several:

- o Identify potential advances in the state-of-the-art in automation and robotics technologies for use in the Space Station and to benefit the U.S. economy.

- o Provide guidance for NASA Space Station program managers and prospective Space Station definition contractors to direct their efforts toward examination of the potential for advancing automation and robotics technologies though their incorporation in the overall development of the Space Station.

- o Document, in a single convenient source, important considerations in automation and robotics, specifically:

  --NASA Space Station engineering and programmatic aspects
  --Recommendations of the academic and industrial community
  --Descriptive and background material on the relevant technology
  --Case studies of applicaions of advanced automation and robotics
  --Technology projections and research recommendations

Documentation of the results, which are nearing completion, will be provided as follows:

- o The Executive Overview, Volume I, which synopsizes the major findings of the study.

- o The Technical Report, Volume II, which provides:

  --Some general background to familiarize the reader with the technologies and potential of automation and robotics
  --The Space Station design considerations of importance for automation and robotics

--The state of the technology and needed advances
--The guidance to be given to potential Space Station contractors so their efforts will result in a plan for advancing these technologies
--Considerations for technology transfer to U.S. industry and for space commercialization

o The companion document "Automation and Robotics for the National Space Program," by the Automation and Robotics Panel, led by the California Space Institute, which provides independent, corollary findings.

Related documentation of studies done by aerospace companies and by SRI International is referenced by SRI International is referenced and should be read in conjunction with the ATAC report.

PRELIMINARY RESULTS STILL UNDER REVIEW

For space activities, the ATAC believes the benefits of advanced machine intelligence, robotics, and automation could be:

o Increased productivity--with astronauts functioning as managers on behalf of station users rather than as operators carrying out routine functions.

o Increased responsiveness to innovation--with the automated Space Station being more flexible and adaptable.

o Lower cost of operations--with systems that can run at peak efficiency.

o Improved reliability--with improved detection, diagnosis, repair and recovery from abnormal situations.

o Greater autonomy--with improved monitoring and control of station systems and less reliance on ground support.

o The ability to perform tasks unsuited to humans alone--such as the assembly of large structures.

o A reduced exposure of humans to hazardous situations, such as extravehiculr activities, fueling tasks, and servicing satellites in very high (geosynchronous) orbits where radiation may be harmful.

Benefits could also accrue to the U.S. economy because:

- o The Space Station would be more suitable for commercial ventures with flexible and reliable systems and crew time for management action.

- o The advances in automation and robotics stimulated by space ventures could be applied in terrestrial situations in settings ranging from the factory floor, to the bottom of the sea, to the home-bound elderly.

The ATAC has identified guiding principles, which are intended to reflect the level and general areas to which advanced automation and robotics should be applied. Some are "baseline," in the sense that they should be followed loosely, independent of the actual level of funding made available for the Space Station effort. Others are meant to apply to an augmentation of the effort, should additional funds be made available along the lines indicated by the Automation and Robotics Panel. A summary of the preliminary "baseline" recommendations are as follows:

1. Automation and robotics (A & R) should be a significant element in the Space Station Program.

2. The Initial Space Station should be designed to accommodate future evolution and growth in A & R.

3. The Initial Space Station should utilize significant elements of A & R technology.

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

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

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

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

8. NASA should provide the measures and assessments to verify the inclusion of A & R in the Space Station Program.

Additional recommendations for an <u>augmented</u> effort are as follows:

9. The Initial Space Station should utilize as much automation and robotics technology as time and resources permit.

10. The evolutionary station should achieve, in stages, a very high level of advanced automation.

11. An aggressive program of long range technology advancement should be pursued recognizing areas NASA must lead, leverage, or exploit.

12. A vigorous program of technology transfer to U.S. industries and R & D communities should be pursued.

13. Satellites and their payloads accessible from the Space Station should be designed, as far as possible, to be serviced and repaired by robots.

NASA should use the Space Station "Definition and Preliminary Design" process (Phase B) to define the uses of automation and robotics to achieve increased human-machine productivity and the advances needed as the Space Station Program evolves. I understand that an implementation plan for assuring that Phase B will address automation and robotics needs adequately using a systems approach is being prepared by the Office of Space Station.

The potential for automation on the Space Station includes almost all systems and functions. There will be an evolutionary progression toward the goal of an autonomous Space Station. However, all initial designs should utilize as much mature automation as technologically feasible within cost constraints while not precluding eventual growth. Subsystems design should be targeted conceptually for the mature (year 2010) Space Station, and modifications should be made as necessary for the initial station, recognizing the readiness of the technology and the lead time required to achieve implementation.

Table A depicts some preliminary goals for advanced automation and robotics applications on the initial station.

TABLE A - IOC AUTOMATION & ROBOTICS APPLICATIONS GOALS

o ELECTRICAL POWER

Controllers Enhanced by Expert Systems for
--load distribution & switching
--solar array orientation
--trend analysis
--fault diagnosis

- GUIDANCE, NAVIGATION & CONTROL

  Enhanced by Expert Systems for
  --station atitude control
  --experiment pointing
  --orbital maintenance & reboost
  --rendezvous navigation
  --fault diagnosis

- COMMUNICATION & TRACKING

  An Executive Enhanced by Expert Systems for
  --communication scheduling
  --rendezvous and docking
  --data rate selection
  --antenna pointing

- INFORMATION & DATA MANAGEMENT

  An Executive Enhanced by Expert
  Systems Control of
  --subsystem statusing
  --trend analysis
  --fault diagnosis expert system
  --redundancy & configuration management
  --data base management

- ENVIRONMENTAL CONTROL & LIFE SUPPORT

  Knowledge-based Controllers for
  --trend analysis
  --fault diagnosis
  --crew alarm
  --station atmosphere monitor & control
  --hypersonic chamber

- GENERAL

  Teleoperation of Mobile Remote Manipulator with
  collision avoidance

  Mobile multiple-arm robot with dextrous manipulators
  for EVA & IVA inspection/ORU exchange

  Systems designed to be serviced, maintained, and
  repaired by robots

Primary Space Station control in space with appropriate backup

CONCLUSION

As you can see from the above activities, we are taking this subject quite seriously. ATAC feels an evolving Space Station could contain a high level of general-purpose automation and robotics. As a result of the Phase B activity, we will learn about the cost of the initial system, which could use this advanced automation and robotics, beyond what we would normally have employed.

We may find that using this advanced, general-purpose technology could increase initial costs, but significantly lower operating costs. However, those added funds might be wise investments to obtain a relatively large payoff when also taking account of potential for terrestrial applications. We are closely involved with the Space Station preliminary design process, so we will develop a good feel for uses, and systems and costs. Equally important, NASA should promote the transfer of the new technology to terrestrial situations where it will benefit the U.S. economy. These systems will provide the United States with important new methods of generating and exploiting space knowledge, and will thereby help preserve U.S. leadership in space.

We look forward to continuing to work with the Congress on advancing automation and robotics technologies.

Mr. Chairman, that concludes my prepared statement. I would be happy at this time to answer any questions that you or the Subcommittee might have.

Figure A.— Methodology for the Space Station automation study.