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Technologies for Space Station Autonomy

Robert L. Staehle

June 15, 1984

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ABSTRACT

This report presents an informal survey of experts in the field of spacecraft automation, with recommendations for which technologies should be given the greatest development attention for implementation on the initial 1990s NASA Space Station. The recommendations implemented an autonomy philosophy that was developed by the Concept Development Group's Autonomy Working Group during 1983. They were based on assessments of the technologies' likely maturity by 1987, and of their impact on recurring costs, non-recurring costs, and productivity. The three technology areas recommended for programmatic emphasis were: 1) artifical intelligence expert (knowledge based) systems and processors; 2) fault tolerant computing; and 3) high order (procedure oriented) computer languages.

This report also describes other elements required for Station autonomy, including technologies for later implementation, system evolvability, and management attitudes and goals. The cost impact of various technologies is treated qualitatively, and some cases in which both the recurring and non-recurring costs might be reduced while the crew productivity is increased, are also considered. Strong programmatic emphasis on life cycle cost and productivity is recommended.

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I. EXECUTIVE SUMMARY

An informal survey was made of several experts in space system automation, seeking their advice on which technologies would be required to implement a high level of automation and autonomy for the Space Station Program. Autonomy/automation goals and definitions were taken from discussions during meetings of the Concept Development Group's Autonomy Working Group (AWG), which met several times during the last four months of 1983. Adoption of specific architectural guidelines developed by the AWG will enable implementation of the autonomy/automation goals beginning at IOC (initial operational capability).

Based on the assessments made of which technologies would have the greatest favorable impact on Station productivity and recurring cost, three generic areas were chosen as having the greatest likelihood of sufficient maturity by 1987 to be incorporated in the IOC Space Station:

Artificial Intelligence: Expert Systems & Processors
Fault Tolerant Computing
High Order (Procedure Oriented) Languages

Each requires a modest amount of application-specific development support, but has seen enough application to date to be relatively assured of its beneficial implementation in the Space Station Program. Other technologies were also identified with lower Space Station-specific development priorities and/or later maturities with high desirability for post-IOC implementation. Some desired technologies appear to be receiving sufficient development attention outside the Space Station Program. Evolvability must be built into Space Station Program hardware, software and operating procedures from the beginning to allow the station to incorporate important new technologies as they rapidly become available.

Technology selections were based on assumed maximum periods of autonomy from different levels of ground involvement in Station operations: 90 days without STS revisit, up to 5 days without routine support, and up to 24 hours without communication.

Strong management discipline and an in-depth, program-wide adherence to an aggressive autonomy philosophy are required to realize the recurring cost benefits of autonomy. Existing flight and ground personnel should be involved in the design process, and alternative technology plans should be prepared in high risk situations to lower the perceived risk of reliance on the proposed new technologies. There are some situations where new automation technologies might reduce net non-recurring costs while resulting in recurring cost and productivity improvements.

Likely customer needs for Station automated equipment and capacity need to be determined and allocated early in phase B, along with standard interface specifications for Station subsystems and customer equipment.

Several other early actions are required to realize the benefits of autonomy for the Space Station Program: Quantitative assessment of the impact of each high-priority technology on productivity, recurring cost, and non-recurring cost; identification of technology development programs which should be monitored, supported, or adopted on behalf of the Space Station Program; development of autonomy and robotics accommodation plans to be incorporated in Station design; and strong programmatic emphasis on life cycle cost and Station productivity.

II. STUDY OBJECTIVE

The objective of the study reported herein was to identify those technologies in the field of automation which are most likely to be needed aboard the IOC Space Station in order to implement the autonomy goals agreed by members of the Autonomy Working Group (AWG), an arm of the Space Station Concept Development Group (CDG), during late 1983.

Lacking defined customer requirements, the goals were written in terms of facility (i.e., non-payload) operations, though there will always be links between facility operations and payload activity (as in an office building where heating, air conditioning, and lighting utilities are operated based on customer schedule and control inputs). Note the discussion entitled "Customer Accommodation" in Section VII, Programmatic Concerns.

Those goals are as follows: [1]

Autonomy/Automation Philosophy

A. Subsystem/system monitoring and control will be performed onboard.

B. Systems monitoring and control will be automated.

C. Fault detection and isolation will be an automated function for all subsystems.

D. Redundancy management, including reconfiguration, will be performed automatically onboard.

E. Reverification of systems/subsystems elements will be performed automatically onboard.

F. Near term (i.e., next 1 to 3 days) operations planning and scheduling will be performed onboard.

G. The degree of automation will increase as the Space Station matures and new technologies become available.

H. Collection and analysis of trend data will be automated onboard.

I. The Space Station Platform shall have at least the same degree of automation onboard as the manned base.

These goals were written with the intent to avoid specifying how they might be achieved, other than recognizing that their realization requires extensive use of automation to enable many facets of autonomous operation aboard the Space Station.

A closely related set of Architectural Guidelines was also drafted, as follows:

1. Automated fault detection, isolation and recovery will be carried out giving highest priority to crew life support and primary mission objectives.

2. Automated systems architecture is distributed and hierarchical.

3. Fault detection, isolation and recovery is accomplished at as low a level as possible in the hierarchy.

4. The required fault tolerance capabilities may be accomplished using either fault tolerant computers or appropriate network approaches, or both.

5. Architecture shall facilitate development and test of individual subsystems independent of other subsystems.

6. Architecture should minimize subsystem interactions at all levels of architecture. Where interaction is required, it shall be performed at the highest feasible level.

7. Only processed results will routinely progress upward through the hierarchy. Lower level data will be accessible at higher levels when required [2].

8. Architecture will allow manual intervention in all automated processes. Appropriate safeguards should be provided to prevent inadvertent or unauthorized disabling of essential automated processes [2].

An underlying desire of the goals and architecture proposed by the AWG was to make the Station independent of "marching armies" of large numbers of ground controllers involved in hour-by-hour decision making. Based on this and operational considerations set by other working groups, three discreet periods of Station autonomy from the ground were specified for normal operations:

* 90 days without STS revisit
* 5 days without routine space station ground support
* 24 hours without any communication with the ground

These specifications do not mean during normal operations that STS revisits, routine ground support, or communications with the ground will be carried out no more frequently than indicated; they do mean that the system is to be designed to accommodate these maximum intervals without interruption of normal operations. The 90 day specification was a programmatic requirement not set by the AWG. The 5 day specification was meant to allow for the longest holiday weekends for ground controllers. The 24 hour specification was intended to keep congested communications (especially via TDRSS) from becoming a major bottleneck in operations, and to force designers and planners to think of how to make decisions and conduct normal operations without consulting with the ground about every little action.

Further, these autonomy periods refer to facility operations, and not to all customer payload operations. For example, during observation of a unique solar event occurring on a weekend, discussions between the ground-based investigator team and cognizant crewmembers would not be precluded as a part of normal operations. Likewise, the installation of a massive payload module need not occur at a resupply interval. Some facility operations will generally be required to support such customer operations, though the philosophy goals A, B and F were intended to obviate the routine need for facility ground controllers being on line at such times.

III. AUTONOMY GOALS AND BACKGROUND

Goals

The whole intent behind placing automation in the Space Station system is to make the system operate more effectively (as measured by both cost and performance) for the customer. In order to fulfill this intent, the approach is taken to "use machines (automation) to do what machines do best, and use humans to do what humans do best." The technologies of automation, along with certain policy decisions and management implementations, are used to provide the orbiting Space Station facility with a high degree of autonomy from the ground. It is widely believed that a degree of autonomy much higher than that which existed during Apollo, Skylab and Shuttle/Spacelab missions will lead to greater productivity on behalf of Space Station customers and lower operating costs. Skylab and Spacelab experience, as well as numerous sociological studies cited by B. J. Bluth [3], have indicated the near necessity of greater facility autonomy for crew well-being and enhanced productivity on long-duration missions.

The varied technologies of automation, because of their present capability and their very rapid evolution, will play a key role in Space Station operations. While there is often considerable debate between the best respective roles for people and machines in space, the debate itself is beyond the scope of this study, and is in any case being dealt with in other studies, especially some recent ones led by personnel at Marshall Space Flight Center (MSFC) [4].

Initial Space Station operations appear likely to begin in a heavily-supervised mode with ground personnel and crew members issuing many discreet commands. With proper design and operations discipline, this situation can rapidly evolve to smooth, skilled operation by a small number of people assisted by highly capable automated systems. Without proper design and discipline, the initial operational environment can rapidly become onerous and expensive.

Certain system, facility, and payload architectural characteristics appear necessary to design and implement the full Space Station system in a manner which will permit the fullest use of automation technologies as they become available. Using automation, it is possible, when compared with present complex space systems, to increase system capability, visibility, flexibility, controllability, evolvability, safety and customer satisfaction. It is also possible to reduce operations costs, especially by reducing the required number of ground personnel, and to reduce the sensitivity to turnover of trained personnel and the costs of training new team members. Without the proper architecture, these positive attributes will be difficult to achieve, and automation could become a burden on system operators and customers.

Because of the lack of definition of the Space Station missions (especially), and to a lesser extent of design and subsystem technologies, results reported here should be considered as preliminary, incomplete, and subject to revision. Several areas where further study is needed are noted at the end.

Definitions

Automation is the use of a machine, often controlled by a computer, to perform a particular function with or without the involvement of a "person-in-the-loop," regardless of the location of the persons involved (if any), the machine, or the function itself. For example, an automated function could be effected aboard the station based on calculations made by a computer at the station operator's mission control site, with authorization to proceed coming from a person at a payload operations facility at another ground location.

Automation can involve everything from a simple mechanical device like a thermostat to very complex learning knowledge-based artificial intelligence (AI) systems running on large digital computers. The key element in automation is that a person does not actually perform the function described, though one or several individuals in several locations may input information to initiate or authorize an automated activity, or may select from a set of options for different automated activities.

Automation is not synonomous with autonomy. As a design parameter, automated systems may be highly dependent on information input, initiation or authorization to proceed given by crewmembers, ground controllers, and payload operators; or they may operate largely independent of human intervention or verification (i.e., autonomously). In many cases the degree of autonomy employed by an automated function may be made selectable, with frequent changes permitted during the course of a Space Station mission.

Autonomy describes the degree of control information which crosses the boundary between the function or system being described and the outside world. A system with defined boundaries is autonomous if it operates for a given period of time without external control inputs. A "system," for the purpose of describing its level of autonomy, must be described by a boundary which is either physical, functional, or both. Thus a thermostat operates autonomously so long as its control settings are left unchanged. A spacecraft, with or without a crew, may operate with autonomy from ground controllers so long as instructions or control inputs are not required from the ground. Data transfer between the Station and the ground might take place autonomously for a given payload, with elements of this autonomous system aboard the Station facility, its payload, and at several locations on the ground. Such a communications function might be controlled by an AI expert system selecting data rates and paths, store and dump periods, and data formats, all without the direct supervision of persons on the ground or aboard the Station.

In order to implement any particular function aboard a spacecraft, one must choose within the spectrum which contains fully manual operation, teleoperation from the ground, and complete automation with autonomy from human control. The best choice is often a blend of these which varies depending on technology availability, and is selectable during the course of operations.

Autonomy Working Group

The Autonomy Working Group (AWG) consisted of the following individuals, working mainly on an ad hoc basis, who met several times from September through December of 1983:

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History

Since the United States' first space station, Skylab, the technology of automation has blossomed. Sophisticated computer-based automation has penetrated the office, communications, routine laboratory research, and planetary spacecraft, to name a few fields which have embraced the various rapidly evolving technologies. Very few of the Skylab operations functions were automated, and there was not even a central computer aboard the station, although the Apollo command service module did have a computer of limited capability by today's standards. There were limited capability control systems using electromechanical devices, but these were hard-wired and intended for single functions such as temperature control or limited functions such as attitude control (attitude control used a small digital computer for some functions) [5].

On Skylab, the station's final configuration could be assumed in great detail before flight, permitting designers to accommodate very specific requirements. We have assumed from the outset that the configuration of the Space Station will be constantly changing from payload to payload, and evolving as the basic facility is expanded. All subsystems must carry this flexibility, and the overall system, especially in the operational sense, must allow day-to-day and year-to-year flexibility in order to maintain the value of the large initial investment.

Skylab required hundreds of controllers on the ground, and a modest fraction of crew time was used to monitor and reconfigure station systems [6]. In addition, there was a period of a few months between each crew's occupation during which planning and analysis could take place. This involved hundreds more people, very large volumes of documentation, and several levels of review. Assuming a basic cost of $100K per workyear, a 1,000 person team requires $100M per annum to support when benefits and overhead are accounted. Without using extensive automation on the ground and aboard the Space Station, the operating work level could easily exceed this number. An important guideline will be to design an operations system which allows high flexibility to take advantage of unique human decision-making abilities, while reducing the workload for routine and mundane tasks such as subsystem monitoring and detailed scheduling.

Autonomy Is Not the Whole Answer

Autonomy, and the automation technologies required for its implementation, are most often supported on the basis of expected Space Station operating cost savings. In most cases, placing a higher degree of automation aboard the IOC station than is used aboard present crewed spacecraft (Shuttle, Spacelab, Salyut) results in higher capital facility cost than would be the case if existing technologies and procedures were simply adapted without modification. It can be reasonably argued that these increments in non-recurring capital costs will be made up very soon in reduced operating costs, increased system performance, and better customer accommodations. (Recurring and non-recurring cost impact of various candidate automation technologies were two of the topics on which study participants were surveyed.)

The cost-saving arguments are usually made in the context of reducing the direct ground operations support staff from the level of hundreds experienced during Apollo, Skylab, Viking and Shuttle/Spacelab [6] to perhaps as low as ten or twenty. This is a worthwhile goal, but a simple calculation will show that such direct cost savings are small compared to the expected overall program operating costs. While these costs have never been estimated publicly, Shuttle experience would suggest that they could exceed $1 billion per year, based on the fact that early Shuttle flights have cost in the neighborhood of $300 million apiece, not including amortization of non-recurring costs. In contrast, the direct annual savings from eliminating the need for 100 engineers with direct mission support duties would be on the order of $10 million.

The real savings must come from the vast numbers of indirect program support personnel among the NASA centers, contractors, and payload operators. Hundreds of people must be equipped to do the work presently done by thousands; though perhaps a number of equivalent positions can simply be eliminated as confidence rises and overkill requirements of backup planning, reliability, and documentation are relaxed.

Automation, and a command structure emphasizing Station autonomy, can enable the desired savings in indirect operating costs, but the real initiative must come from hard management discipline and a commercially-oriented approach to station operations. Automation can enable flow of the required management information, and permit the required gains in productivity among the line workers. But automation must be accompanied at all times by thorough and conservative budgeting, cost accounting and strenuous recurring cost goals in order to achieve the levels of savings which proponents suggest are available through the use of a highly autonomous Space Station.

IV. SURVEY TECHNIQUE

During the end of 1983, an informal survey was taken, asking members of the Autonomy Working Group and other interested and knowledgeable persons which of a list of generic automation technologies would be most desirable for implementation aboard the Space Station at IOC. The list of generic technologies, reproduced in Table 1, was derived during discussions among members of the AWG during a meeting in October, with additional input from Martin Marietta personnel under contract to JPL. The list was intended to represent those technologies not yet fully available which would be required in some form in order to implement the AWG's Autonomy/Automation Philosophy. (See Part II, Study Objective.)

Each survey recipient was asked, for those technologies with which he or she was familiar, to estimate the impact which each of the technologies would have on productivity, recurring costs, and non-recurring costs for the Space Station. Respondents characterized the impact of IOC availability for each technology as a small, moderate or large increase or decrease. Respondents could also indicate if they felt the technology in question would have no impact. Thus a particular respondent noted that artificial intelligence subsystem monitoring software (an expert system) would result in a moderate increase in productivity, a large decrease in recurring cost, with a moderate increase in non-recurring cost.

Three other questions were asked about each technology in the survey. First, how desirable would it be to incorporate a particular technology in the IOC Station? This was asked largely without regard to the potential availability of each technology. Desirability was ranked as essential, useful, helpful or none.

Second, if present development efforts for each particular technology were continued at expected rates, or if developments not coming as result of Space Station program influence were to occur as expected, how likely is it that the technology would be mature enough in 1987 to be selected for incorporation aboard the IOC Station? In essence, this question asked how likely each technology was to be available in 1987 without regard to development work initiated in support of the Space Station Program. Expected readiness was ranked as certain, likely, indeterminate, unlikely, or impossible. "Impossible" meant that only a major, very costly, dedicated development program could bring the subject technology to the required level of maturity by 1987.

Third, based on the desirability and readiness of a given technology, respondents were asked to recommend a level of development effort which should be considered for support of the Space Station Program. Recommended levels of development emphasis were: major, moderate, minor, monitor, or none. A copy of the survey, along with explanations of what was meant by each type of ranking, can be found in Appendix 2.

Table 1. Generic Technologies in Survey

Artificial Intelligence

- Learning Expert Systems (Ground)
- Learning Expert Systems (Onboard)
- * Expert Systems
- Explanation Mechanism
- * Fault Detection, Diagnosis & Recovery Software
- * Fault Recovery Software
- * Planning & Scheduling Software
- * Subsystem Monitoring Software
- * Symbolic Processor (Onboard)
- Power System & Load Management

Control Techniques

- Adaptive
- Distributed Parameter
- Hierarchical
- Multivariable
- Non-Linear
- Optimal

Data Storage

- Onboard
- Archival Storage (Onboard)
- Mass Storage (Onboard)

*Fault Tolerant Computing

- Architecture
- Data Transfer (Onboard)
- Data Transfer (Between Station and Ground)
- Mass Storage (Onboard)
- Processors (Onboard)
- Software

*High Order (Procedure Oriented) Language (HOL or VHOL)

- Reprogrammable Onboard Procedures & Software
- Software

High Speed Computing

- Data Bus (Onboard)
- Memory (Onboard)
- Memory (Ground)
- Processors (Onboard)
- Processors (Ground)

Table 1 (cont.)

Crew-Machine Interface (part of HOL)

Text Generation
Natural Language Annunciation
Natural Language Understanding

Robotics

Dextrous Manipulators
Image Processing
Image Understanding
Pattern Recognition
Teleoperation**
Telepresence**
Dextrous Arm
Intelligent Manipulation
Intelligent Mobility

Simulation Techniques

Analysis Tools
Integrated Design

Very Large Scale Integration/Very High Speed Integrated Circuits (VLSI/VHSIC)

Minimum Instruction Set Computers (Onboard)

Note: Some of the technologies noted above were not on the original survey, but were added by respondents.

* Recommended for highest Space Station Program management priority. See Section VI, Technology Priorities.

** Within the categories of teleoperation and telepresence, no distinction was made between short-range control, where the communications link introduces no significant time delay, and long-range control, where one or more signal hops to geostationary satellites may introduce significant and varying time delays into the control loop. While short-range control has been demonstrated frequently, long-range control still carries significant technical risk for early implementation.

Statistical Significance

The survey was not intended to be a formal scientific sampling of opinion. It was an informal, organized set of relevant questions asked of experts in various fields. Their answers should not be "averaged" or otherwise mathematically manipulated to arrive at any "best" or "most likely" answers in any rigorous statistical sense. This compilation of survey results is meant to give the reader an understanding of the state of knowledge of automation technologies as they relate to anticipated Space Station operations. While not statistically rigorous, it is felt that the results can be used, along with other means of review, in determining where the greatest technology development emphasis should be placed in order to achieve the stated goals of Space Station autonomy, productivity, and recurring cost savings.

V. SURVEY OBSERVATIONS

Lack of Agreement

Survey respondents were asked only to rank those technologies with which they felt comfortable or familiar. It should be noted that different respondents had widely varying backgrounds, job responsibilities and levels of operational experience. Each also had generally different areas of expertise. With this variation, it should come as little surprise that responses to the different questions about each technology varied.

There was indeed wide variation in response, which is probably indicative of the newness of many of the proposed technologies, and the lack of hands-on experience by some of the respondents. Interpretive differences are also likely, where different individuals were thinking differently regarding what was meant by a given technology, or what the qualitative relationship is between such adjectives as "large," moderate," and "small," or "essential," "useful," and "helpful."

Ten persons offered responses for AI planning software, more than for any other technology. Among those who attended AWG meetings, there was reasonable agreement regarding what this technology meant. All ten indicated that its use would result in increased productivity and decreased recurring costs. Six indicated a "moderate" increase in productivity, while three characterized the increase as "large," and one characterized it as "small." Estimates of recurring cost impact were split almost evenly, with four indicating a "small" decrease, and three each indicating "moderate" and "large" decreases. All but one indicated a non-recurring cost increase, with the exception, who probably has the most experience developing AI planning software, indicating a small decrease in non-recurring cost. This is presumbaly based on his experience with both classical and AI planning techniques on the Voyager mission, and may represent the most informed opinion. Others may not have thought to consider the non-recurring costs saved by needing a much smaller planning workforce and shorter lead time for planning efforts afforded through the use of AI techniques. The indication of a small decrease was not meant to suggest that AI planning software could be developed for nothing or that it would make money!

In the case of AI planning software, none felt it was essential, but eight ranked it as "useful," the second highest category of desirability for IOC. The other two ranked this technology as "helpful." Two considered this technology's availability as "certain," including the one who has been developing it for Voyager. Five ranked its availability as "likely," one considered it "indeterminate," and two "unlikely."

Five felt that the Space Station Program's emphasis of AI planning software development should be "moderate," one suggested "major," and three recommended "minor." The one working on Voyager felt that the Space Station Program need only monitor other efforts prior to 1987.

An obvious lesson here is that the most experienced experts should be consulted before making research commitments. Hopefully this would occur in any case.

Responses regarding AI planning software are boxed in Appendix 3, Report #1.

Another indication of the lack of agreement among respondents was the fact that for many of the technologies, only one respondent felt that its readiness in 1987 without Space Station Program intervention was assured ("certain"). However, some of these respondents actually knew of availability of the technology in question, at least in a form adaptable to Space Station utilization. This was the case for natural language annunciation, AI planning software (though not as complex as needed for Space Station), and some fault tolerant data transmission techniques. AWG members were frequently unaware of recent developments in others' fields, which of course was one of the better reasons for convening the AWG.

"Essential" Technologies (Appendix 3, Report #4)

Fourteen technologies were labeled by two or more respondents as "essential" for IOC in order to implement the agreed autonomy philosophy. Particular attention should be paid to development efforts for these technologies if autonomy is to be a major design goal for the Space Station. These technologies are:

	# Respondents
AI Fault Detection, Diagnosis & Recovery Software	2
Hierarchical Control Techniques	3
Multivariable Control Techniques	2
Mass Data Storage (Onboard)	3
Fault Tolerant Onboard Mass Data Storage	3
Fault Tolerant Onboard Data Transfer	4
Fault Tolerant Uplink and Dowlink Data Transfer	3
Fault Tolerant Onboard Processors	3
Fault Tolerant Computing through Software Techniques	2
High Order Language Procedure Reprogramming Onboard	2
High Order/Procedure Oriented Language Software	2
High Speed Data Bus	2
Simulation Analysis Tools (Ground)	4
Simulation of Integrated Designs (Ground)	3

High Leverage Technologies (Appendix 3, Report #2)

Certain of the technologies show promise for having higher leverage than others in boosting productivity while possibly reducing both recurring and non-recurring cost. If we disregard the response of one of the respondents, who noted this condition for 18 of the 47 technologies in Table A, there are six technologies for which at least one respondent felt would increase productivity while decreasing both types of cost. These were:

Technology

AI Fault Recovery Software
AI Planning Software
AI Subsystem Monitoring Software
AI Symbolic Processors (Onboard)
High Order Language Software (procedure oriented, can be written by subsystem engineers with minimal programming experience or training)
Simulation Analysis Tools

It is certainly arguable that a combination of AI techniques to do planning, performance monitoring, and fault recovery could greatly reduce the volume and complexity of software required for these functions onboard and on the ground. This will only be the case, however, if the heuristic AI techniques can be substituted with confidence for high-capacity communication links to the ground and large numbers of ground controllers. It is not clear to what extent the AI software could reduce the amount of deterministic software required for these functions, but the main issue in all these substitutions becomes verification of the reliability of the heuristic techniques to the satisfaction of project management and all reasonable safety concerns.

High Order Language software [sometimes referred to as Very High Order Language (VHOL) software, to distinguish procedure-oriented languages like the Systems Tests and Operations Language (STOL) from traditional programming languages like Fortran], would probably mesh well with AI techniques (though the two are not required to be utilized together), and could substantially reduce software costs by letting engineers familiar with their subsystems, rather than programmers, write much of the onboard and ground control software [7].

Better simulation analysis tools than exist today could conceivably reduce the costs associated with more hardware-oriented simulations required to verify configuration and other changes to the Space Station system.

<u>Productivity, Recurring Cost, and Development Emphasis</u> (Appendix 3, Report #11)

Two or more respondents identified 14 technologies which, while promising a large or moderate increase in productivity along with a large or moderate decrease in recurring cost, also received a recommendation for major or moderate development emphasis. At least one respondent ranked each technology's desirability as "useful" (the second highest ranking) or higher. Without regard to non-recurring cost (the estimates for which ranged from small decrease to large increase), this set should probably receive the greatest consideration for Space Station-specific developmental support during Phase B. In the long run, it is these technologies which are most likely to fulfill the goals of Space Station autonomy:

Technology	# Respond.
AI Learning Expert Systems (Ground)	2
AI Learning Expert Systems (Onboard)	3
AI Fault Detection, Diagnosis & Recovery Software	6
AI Planning Software	4
AI Subsystem Monitoring Software	4
AI Symbolic Processor (Onboard)	2
Fault Tolerant Computing	2
High Order Language Reprogramming (Onboard)	3
High Order Language Software	4
High Speed Data Bus	2
High Speed Memory	2
High Speed Processor	2
Teleoperation	3
Telepresence	3

It is apparent from the above list that the greatest promise was expected from AI techniques. This is not surprising, given the breadth of fields in which AI has so quickly found a niche in the last three years [8]. The basis of the so called "fifth generation" planned in the computing industry, artificial intelligence should be able to find frequent applications in space projects where costs, even on the ground, can be so sensitive to numbers of required operations personnel.

Some of the technologies noted above are unlikely to come to fruition in time for IOC, so that the emphasis on their development might better be subordinated to emphasis on nearer-term technologies. Also, for the post-IOC introduction technologies, significant developments outside of the fields of astronautics may be far more productive than significant pressure from within the Space Station program, until such time as these technologies can be readily adapted for Space Station use from techniques established and tested for non-space applications. Learning Expert Systems, those which not only mimic the thought process of experts in a given field, but which can modify, add to, and improve their knowledge bases with experience, are probably a good example of a technology which should develop on its own for a few more years before significant intervention on behalf of the Space Station Program.

According to respondents, the non-learning expert system techniques (fault detection, diagnosis & recovery; planning; and subsystem monitoring) are more likely to be adaptable to Space Station needs in time for IOC. The need for and readiness of onboard symbolic processors on which AI software is best run, should be investigated along with the near-term software techniques. Experts consulted outside the survey had differing opinions of whether the AI-optimized symbolic processors would be required in space-qualified form to run software, or whether more conventional space-qualified computers would suffice. The answer is a matter of software complexity, acceptable running speed, and the capabilities of space-qualified computers. The last item may be very important for a broad spectrum of automation tasks, because the capabilities of the largest and fastest space qualified hardware lags far behind common ground based machine capabilties.

According to one participant in AI expert system development, changes to the knowledge base by the addition or modification of a heuristic rule can often be made more quickly than writing or modifying, adding, and verifying the equivalent module of deterministic code [9]. Expert system rule changes can be composed and implemented in less than a day when working on a symbolic processor. In this way the "learning" of an expert system is done manually, but appears possible with significantly less delay than would be expected for deterministic software.

The generic technology of Fault Tolerant Computing (FTC) was noted by two respondents, but none of the specific FTC technologies were identified by more than one respondent. While often ranked as useful or essential by the respondents, this may be because most feel that the FTC technologies do not have a substantial impact on recurring cost or productivity. It may also be because many of the respondents felt that this technology was well on the way to readiness (indeed, there has been much DoD work here), and therefore often recommended a development emphasis of "minor" or "monitor."

Implementation of procedure-oriented programming languages, and their use for onboard reprogramming by crewmembers, were included in this category by three and four respondents, respectively. Most felt that these technologies were likely to be ready by 1987 for development leading to IOC incorporation, but still recommended moderate and major development emphasis. There are probably two reasons for this recommendation in light of apparent readiness. One is the long lead time required for software development. Software must often be ready before hardware is begun so that hardware designers can count on the availability of the particular software they wish to take advantage of. A second possible reason is that while the technology of procedure oriented languages is not difficult, there is not a language presently available which is considered capable of satisfying the need of the Space Station Program [10]. The underlying language must of course exist before the thousands of complex procedures required at and before IOC can be written. Procedure-oriented software and programming techniques look very attractive for IOC, and offer the potential of eliminating the need for a large number of programmers who today must act as translators between engineers and software code. The message for the Space Station appears to be that because of the lead times involved, work on a suitable HOL (or VHOL, if you like), must get going soon.

Less of a case is made for High Speed techniques, almost certainly here because the readiness of these technologies without Space Station Program intervention before 1987 is considered by most to be either "certain" or "likely." While probably not requiring a great deal of development emphasis from within the Space Station Program, these technologies are important to both productivity enhancement and recurring cost reduction, and so should be utilized by designers from the outset where available.

Robotic techniques of teleoperation (i.e., including real-time control of manipulation using vision and sensor feedback automatically) and telepresence (i.e., by creating and integrating an environment in which the operator can optimally control the manipulation process via additional sensor feedback, such as force and touch) were listed by three respondents each. All were given a "moderate" recommended development emphasis. Many on the AWG did not feel that these technologies would (or could) be important at IOC, but most felt they would take on increasing importance. (See also footnote regarding teleoperation and telepresence in Table 1). A strong case was made to assure the compatibility of the IOC station with the addition of mobile robotic equipment for intra- and extra-vehicular activity (IVA and EVA) later in the program. Two aspects of this were a controlled dimensional and visual environment so that machine vision systems could be made to operate, and standardized robotic interfaces ("handholds" and the like), both of which would be much easier to incorporate in design from the outset than to retrofit later in the program. Therefore a robotics accommodation plan is recommended for development during Phase B.

Recurring Cost (Appendix 3, Report #10)

If we look only at recurring cost, there were 13 technologies for which two or more respondents indicated there would be a "large decrease." In some cases, as with onboard mass storage, respondents did not feel that major development emphasis was required on the part of the Space Station Progam because other rationales were driving development at a rapid enough pace for Space Station needs.

The technologies singled out for their greatest benefit to recurring costs were:

Technology	# Respond.
AI Learning Expert Systems (Ground)	4
AI Learning Expert Systems (Onboard)	4
AI Fault Detection, Diagnosis & Recovery Software	4
AI Planning Software	3
AI Subsytem Monitoring Software	2
AI Symbolic Processors (Onboard)	4
Mass Data Storage (Onboard)	2
Fault Tolerant Data Transfer (Onboard)	2
Fault Tolerant Data Transfer (Uplink & Downlink)	2
Fault Tolerant Processor (Onboard)	2
HOL Reprogrammable Procedures & Software (Onboard)	2
HOL Software	2
Pattern Recognition	2

Again, the various AI techniques stand out for their potential in recurring cost reductions. Unlike the AI techniques, the HOL technologies were rated "essential" to implementing the desired autonomy philosophy in three out of the four responses in this category. Of all the respondents commenting on these two HOL technologies, all but 2 out of 14 responses rated them as essential or useful, the two highest categories of desirability.

One respondent (who ranked the recurring cost impact as a moderate decrease) noted that the onboard reprogramming capability would be most useful during the first year of operations when procedures would be evolving the fastest and the crew would be operating at the greatest learning rate, not having the benefit of prior crews' experience.

Productivity-Oriented Technologies Requiring Development Attention
(Appendix 3, Report #5)

It could be that the amount of money spent on development of the Space Station and its requisite technologies, and on Station operation, will be small compared with the value of the station's "product" over a few years after it begins operation. If this is to be the case (no attempt is made here to assess whether or not this will be the case), then one's emphasis should be more on productivity than on either recurring or non-recurring costs. Eleven technologies were ranked by at least two respondents as a) resulting in a large increase in productivity, b) being essential or useful to implementing the autonomy philosophy at IOC, and c) requiring major or moderate development emphasis in order to be ready to be brought into the start of Phase C/D in 1987. These technologies were:

Technology	# Respond.
AI Learning Expert Systems (Ground)	2
AI Learning Expert Systems (Onboard)	2
AI Fault Detection, Diagnosis & Recovery Software	4
AI Symbolic Processors (Onboard)	2
Distributed Parameter Control Techniques	2
Hierarchical Control Techniques	3
Multivariable Control Techniques	2
Fault Tolerant Data Transfer (Onboard)	2
High Order Language Software	2
High Speed Data Bus	3
Teleoperation	2

In the case of the Learning Expert Systems, these respondents felt their readiness in 1987 was either indeterminate or impossible, whereas the other technologies ranked higher in likely availability by 1987.

The notable difference between this productivity ranking and the cost-biased rankings is the appearance here of the distributed parameter, hierarchical and multivariable control techniques. These may be important to maximizing the Station productivity, but might increase both recurring and non-recurring cost. There was disagreement over whether recurring cost would go up or down, while all respondents cited here indicated an increase in non-recurring cost.

"Impossible" Technologies (Appendix 3, Report #8)

As a final look at the direct survey results, four technologies were noted by two respondents each as being "impossible" to have ready by 1987 without massive development efforts beyond the likely affordability of the Space Station Program. They are:

AI Learning Expert Systems (Ground)
AI Learning Expert Systems (onboard)
Robotic Image Understanding
Telepresence

Most respondents disagreed with this assessment, though many indicated the readiness without Space Station Program intervention as unlikely or indeterminate. It should be emphasized that this readiness evaluation depends on varying interpretations and technology maturity levels assumed by different respondents.

VI. TECHNOLOGY PRIORITIES

As can be seen from the various methods of looking at the survey response data, setting priorities for technology development depends to some extent on whether cost reduction or productivity enhancement is the principal selection criterion for new technologies to implement Space Station autonomy.

The technologies which appeared in survey responses most often with desirable characteristics were those of Artificial Intelligence, Fault Tolerant Computing and High Order (Procedure Oriented) Languages. Several control techniques were prominent with a bias toward increased productivity, while fault tolerant techniques were more prominent with a bias toward recurring cost reductions. AI techniques and HOL software remained priorities with either bias. AI techniques and HOL software were the only technologies which appeared with both biases and which were placed in the "high leverage" category of increasing productivity while reducing both recurring and non-recurring cost.

Highest management priority is therefore recommended for the following three generic technology areas:

Artificial Intelligence*
Fault Tolerant Computing
High Order (Procedure Oriented) Languages

These technology areas are most likely to bring operational dividends whether Space Station Program improvement is measured in terms of increased productivity, reduced recurring costs, or a balance of the two. Each is mature enough to have significant positive impact on design by 1987, and to be implemented by IOC with a reasonable amount of developmental support.

Within the group of AI technologies, early development efforts should focus on various types of non-learning expert systems and possibly on onboard symbolic processors. Early efforts are not likely to be particularly fruitful with learning expert systems as they are unlikely to be ready for incorporation into the Phase C/D effort. However, learning expert systems appear to be a top priority for development leading to post-IOC implementation.

The importance of a number of other technologies should not be understated; recall that all the basic technologies were felt by most AWG members to be required in order to implement the desired autonomy philosophy. There are however, two factors which recommend selection of the AI, Fault Tolerant and HOL genera as priorities. First, other useful technologies are often receiving considerable development attention from other quarters, particularly from the Department of Defense (DoD). Second, it is assumed that technology development resources (funding and workforce levels) will be inadequate to cover all the suggested technologies. It will not be possible to implement all aspects of the desired autonomy philosophy on the IOC station. Therefore, of those technologies requiring development attention, those with the greatest potential for yielding large productivity increases and/or large decreases in recurring costs should be favored.

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*See Section IV, Table 1.

Unresolved issues of space qualification arose in various discussions which may not have received adequate attention in the survey. These issues concern a) software validation and verification, and b) processor, memory and databus device hardness [11].

Certification requirements and validation techniques for HOL and knowledge-based software need to be developed and implemented before either the HOL or AI techniques can developed for or used aboard Space Station. Especially in the case of heuristic software, space qualification for critical functions is entirely new, and could cause a serious obstacle to implementation regardless of productivity and cost benefits. There may have been enough experience with HOL procedures at Kennedy Space Center (KSC) for the STS launch processing, and at the University of Colorado for Solar Mesosphere Explorer (SME) mission operations to adopt their verification techniques, but even ground based AI applications have only barely begun for Voyager at JPL.

Electronic devices such as processors, memories, database components, and some peripheral equipment such as displays and printers may be susceptible to unique problems of the space flight environment, even though the capabilities of office and lab-type systems are growing rapidly on the ground [12]. Whereas on the ground software is often the pacing item restricting computer capability, hardware may be the pacing item aboard the Space Station unless a number of basic devices are qualified over the next 3-5 years. The radiation and magnetic field environment of the low Earth orbit can seriously interfere with the operation of some types of devices, but not others. Convective cooling without forced air also does not operate in microgravity, so basic equipment layout and cooling must be different from the ground.

Mechanical launch loads, vibration, and acoustics are another problem. These trials can be severe, but unlike airborne and shuttle environments, they are a one-time occurrence for Space Station equipment. It could prove fruitful to investigate a new approach to electronic equipment deployment in space by launching fragile components in specialized shipping containers, then assembling a piece of equipment like a computer once in orbit. In reality, this might only involve plugging in circuit cards and verifying continuity on the same piece of equipment which was assembled and fully tested before launch, then partially disassembled for flight to the Space Station. This approach introduces a new element of risk into hardware deployment, but might prove less expensive than designing and hardening fully-assembled equipment for the launch environment.

Solutions to both the electronic hardware and launch loads problem can be verified with minor experiments on shuttle flights over the next few years. Common equipment can be prepared for flight, disassembled for launch if necessary, and tested for faults, error rate, and degradation once in orbit. A good example of this (done for other reasons) was the recent flight of a Compass/Grid personal microcomputer aboard the shuttle to plot Orbiter ground tracks. Such demonstrations with a wide variety of equipment should be encouraged.

VII. PROGRAMMATIC CONCERNS

With the technology priorities set, there remain a number of programmatic concerns about accommodation of the Space Station "customer," incorporation of later technologies not receiving top development priority, the risks associated with even the top priority technologies, and the ability of the Space Station Program to act as an integrated whole in implementing and utilizing the available autonomy technologies.

Customer Accommodation

The autonomy philosophy was drawn up with primary consideration for the Space Station facility operator (i.e., the NASA Space Station Program). Because customer needs with respect to autonomy are largely unknown, nearly exclusive attention was paid to the perceived desires of the facility owner/operator. Two primary concerns were in the best interest of customers in general. These were a) to increase the productivity and flexibility of the onboard crew in order that they may devote maximum attention to customer operations, and b) to reduce recurring costs, which might very well be passed onto the customer (ignoring likely subsidies in a government-operated program).

Specific (unknown) customer needs were not considered, but the need to give maximum system flexibility was, along with the need for facility visibility into certain customer equipment and operations. Architecture Guidelines 7 & 8 in Part II were intended to apply to payloads and facility equipment alike wherever desired by the customer, and wherever necessitated by safety or criticality of customer equipment.

Many customer operations will be relatively unique events with differing hardware, where a principal advantage of Space Station use will be the availability of the crew to alter procedures and make adjustments mid-stream. It is envisioned that such operations will rely mainly on customer-provided equipment for commanding, data collection and processing. Unique or nearly unique operations will have little use for extensive facility automation.

More repetitive operations, such as the housekeeping functions on laboratory modules, will occur often enough over a long period of time to possibly justify control, data collection and processing via installed Space Station automated systems. Specific examination of this possibility and the resulting requirements should be undertaken during Phase B. One example where such an extensive interface might be effective is in the case of a life sciences or materials processing laboratory operation as a module attached to the Space Station facility.

Lacking a clear definition of customer needs and desires, the autonomous operating capabilities of the Space Station are viewed as being available to customers on an as-wanted basis. Most complex customer equipment is likely to have built-in command and data processors, and after IOC, it becomes less and less likely that customer computing hardware will be the same as facility hardware, because of rapidly evolving technology. However, there will be standard data, control, and data bus protocols on the Space Station, and these specifications should be made available to customers, along with detailed manuals and consultants describing how to build and verify an interface. The hierarchical nature of the Space Station command and data system should make interfaces with customer equipment much easier to establish than on current spacecraft such as the Shuttle. Specific allocations of customer interface ports, software, and control/display equipment should be made during Phase B design work.

A decision must be made early in Phase B regarding the level of customer accommodation to be built into IOC automated systems, and the amount of flexibility for such future accommodation to be designed in as well. Such basic parameters as main bus data rates, control and display techniques, and overhead costs assignable to all users will be affected by this decision.

Evolvability & Growth

A major guideline for the entire Space Station Program is to make all systems capable of incorporating new technologies and expanding in capacity. The ability to take advantage of new technologies is especially important in the case of the automation technologies used to implement the Program autonomy goals. This is because it is expected that automation technologies will be improving as rapidly after IOC as they are today, or perhaps even faster. Also, the technologies available in 1987, when basic design must be frozen for a 1991-92 IOC, may not be capable of implementing the entire autonomy philosophy which is felt to lead to the most productive Space Station working environment. Rather than have non-mature enabling technologies frozen out of the system, it is important to design automated equipment and procedures so that these new technologies may be brought online as they become available.

As with other components on the Space Station, automated equipment must be designed and installed in modular fashion, as much as possible with standardized, well-defined, and accessible interfaces. In programs where costs are severely constrained or little attention is paid to these matters during early stages of development, these qualities are especially easy to drop, making future upgrades quite difficult and disruptive.

Enough capacity must be built into IOC automated equipment to permit significant growth over time. A good example is data bus capacity, because the physical hardware of data bus links (e.g., fiber optic or electrical conductor cabling) can be very difficult to replace, much as with the wiring in an office building or wire harnesses in an aircraft. Data buses and their associated processors should be designed with a very large capacity margin over expected throughputs immediately post-IOC. Otherwise, data or control rate capacity could become a major factor limiting or increasing the cost of future facility expansion. One could argue that the design capacity might well be 3 to 10 times the expected peak utilization during the first two years of operation.

Finally, automated equipment, such as data buses, command processors, analog to digital converters, sensors, and other components should be integrated in such a fashion that single units, or one type of unit may be replaced a) without having to replace all other like components, or all other differing components of a given subsystem such as a data bus, and b) without requiring more than a few hours of "down-time" for normal customer operations. There would be a great deal of opposition to any system upgrade which would require weeks for installation and testing if standard customer services and crew availability were interrupted for such a period.

Development Initiative

While development of automation technologies proceeds at an unprecedented pace for industrial and commercial service applications, one finds NASA far behind the leaders in incorporating much of this technology into its own day-to-day operations. This contrasts sharply with the Agency two decades ago, when the latest computer technology was employed to solve the engineering and management problems of Apollo. There is a significant danger that this slowness to bring the best technologies on line will extend beyond the ground and into flight equipment for the Space Station Program, if a conscious effort is not maintained at high levels to put a priority on autonomy.

Part of the problem for flight equipment is of course that space-qualified electronic components are often much more costly, and not nearly as powerful, as their ground-based counterparts. This is due in part to the unique environmental characteristics of low Earth orbit, such as particle radiation causing single event upsets and the potential for permanent circuit damage as feature sizes shrink in ever-higher scales of integration in micro-electronics. Also, the reliability requirements for life- and mission-critical electronics in an orbiting facility potentially three months away from resupply make some commercial electronic components unacceptable or unattractive.

These problems simply argue more for early technology efforts to increase the spectrum of space-qualified electronics, and to review the reliability specifications in light of the resupply and on-line maintenance capability afforded by the Space Station. With a crew onboard and relatively frequent resupply flights, standards may not need to be as high as in the case of traditional spacecraft with 5-10 year design lives and no opportunity for repair.

Development efforts should be paced by the fact that technologies for incorporation into the IOC Space Station will need to be relatively mature by 1987. Without this maturity, program managers will not accept the risk, and a given technology which might be very effectively applied, will simply not be considered for IOC. High priority automation technologies should be chosen in the very near future, and available resources applied without hesitation if there is to be any chance of implementing a significant portion of the autonomy philosophy in a 1992 Station. The alternative is to operate for at least the first several years in today's "classical" manner with a very large support staff on the ground, a need for continuous wide-band communication links, and an operating environment where nearly all procedural decisions will need to be made on the ground, rather than by the crewmembers who must do the work. This is at best an unattractive alternative.

Readiness Risk

Closely related to the need for inspired initiative to develop the technology required for autonomy is the matter of the risk taken by incorporating in immature technologies during Phase B. The higher the perceived risks, the less likely the required management initiative will be taken to develop a given technology and direct its incorporation during Phase B planning.

Of the three technologies most strongly recommended as a result of the reported survey, Artificial Intelligence techniques probably carry the greatest perceived risk. And because of their potential power in handling difficult operations problems such as scheduling and power management, AI techniques may face the greatest opposition from groups presently solving similar Shuttle and Spacelab problems using classical techniques. Few people will wish to risk their reputations and abandon established procedures which work, however cumbersome these "classical" procedures are. On one hand, AI may turn out to revolutionize their function, making it easier to perform and much more responsive to "customer needs." On the other hand, it may be that near term AI capabilities have been oversold, or will introduce many new and unanticipated problems for which solutions will be difficult and expensive.

One method of mitigating this perceived (and real) risk is to pursue parallel options until a safer decision may be made, or until technology selections are frozen, presumably prior to the start of Phase C/D. With a firm backup plan based on proven technologies, program managers are more likely to encourage the development of new technologies where the potential payoff in productivity and recurring costs is large.

One final aspect of the readiness risk is procrastination: the longer development efforts are postponed, the greater becomes the risk (real and perceived) of counting on new technologies. The automation technologies recommended for development offer a clear opportunity for incorporation at IOC because there is enough time to engage in meaningful development and demonstration between now and 1987. AI, Fault Tolerant Computing, and Very High Order Language efforts within the Agency and DoD are well enough established to yield demonstrated high leverage technologies for incorporation in Phase C/D. However, this will only be possible if certain Space Station-specific advanced technology efforts are funded beginning in FY 1985.

System & Subsystem Compatibility

Autonomy is to be an across-the-board feature of the Space Station system, intimately involving nearly all subsystems, both in orbit and on the ground. To be most effective, all appropriate subsystems should be designed from the outset with standard interfaces to the automated equipment used to implement Station autonomy. It would be unfortunate, for example, if the electrical power subsystem operated with the full autonomy capabilities, while the life support subsystem required a large ground monitoring crew and frequent manual control inputs from the ground and crew.

To ensure comprehensive implementation of whatever automation techniques are to be used at IOC and later, subsystem development managers must have visibility into and an opportunity to influence autonomy aspects of the Space Station System design, they must be given clear guidelines and interface specifications, and they must sense a commitment on the part of senior program management to an achievable and helpful autonomy philosophy. Without these programmatic characteristics, there is serious danger that different subsystems will operate with differing levels of autonomy, and only a fraction of the potential gains will be realized.

The appropriate interface specifications and guidelines should be developed and disseminated early in Phase B, preferably not later than 1986 October, and perhaps for both highly autonomous and "classical" control methods.

VIII. AUTONOMY IN PERSPECTIVE

There are two principal reasons to implement Space Station autonomy in the fashion proposed by the AWG, and two principal obstacles to be overcome in doing so. The principal reasons are productivity enhancement and cost savings, while the main obstacles are non-recurring cost increases in some areas and acceptance by crew and ground personnel.

Productivity Enhancement

Autonomy in the manner described, if incorporated into Space Station planning from the outset, will lead to considerably greater productivity of the Station as a national facility than would be the case if operations were conducted in the "classical" manner. This productivity enhancement can occur in a very broad sense, besides just a greater number of basic crew operations during a given period of time. By following the guidelines noted in Part II of this report, autonomy will permit much greater flexibility in operational techniques and the introduction of new technologies and improved procedures, beyond what has been possible with past systems such as Apollo, Skylab, the Shuttle and Spacelab. The hierarchical command and data architecture, modularity and standard interfaces used for automated systems, and English-like very high order procedure languages will all allow system capabilities to grow far beyond IOC levels. Access to all control and data points, and the reliance on software instead of "hardwired" techniques for most control and data processing will result in system flexibility unprecedented in astronautics.

Cost Savings

If autonomy is properly implemented, recurring cost savings will be substantial. Only a high degree of management discipline, and confidence built over a thorough verification program and early operations will enable these cost savings to be realized, however. Immediate savings can come from a reduction in the number of direct ground support personnel: From three-shift support teams totalling a few hundred to single-shift operations with fewer than fifty personnel. While dramatic on the surface and certainly worthy of achievement (see Part III, "Autonomy Is Not the Whole Answer"), this saving alone will not justify autonomy in financial terms. It is the thousands of indirect support personnel at field centers and contractors that should be the direct target of autonomy implementation, for it is here that Shuttle operating costs mount into the hundreds of millions per mission. Management and operating personnel throughout the Space Station Program need to be given whatever information they need, quickly, and in already interpreted form, with accuracy and reliability, in order to confidently utilize the Station [13]. The vast majority of burdensome accounting-type tasks involved in mission planning must be taken over by machines, which are much better at these tasks in any case, if properly programmed. Matters such as attitude maneuvers and propellant burn, tape recorder management, software control, life support subsystem monitoring and a myriad of other tasks must and will be handled. If not handled by automated machines, these will be handled by large numbers of people, just as with the Shuttle today. Nearly all the analysts, programmers, engineers and their support personnel must be replaced with automation if meaningful recurring cost reductions are to occur. Such replacement is already occurring in some companies within some industries, and much more will occur in the future, freeing employers to have people do the tasks people do best. AI expert systems have already permitted large recurring cost reductions and productivity increases in many of their few commercial applications to date [14]. "User-friendly" software and English-like database management languages have yielded fast and accurate responses to the operational questions of many executives who were otherwise dependent on programmers or did without important information. Capabilities are rapidly expanding, while cost reductions and productivity improvements have been demonstrated over and over. But whatever the capabilities extant in a few companies, it will take strong management initiative to bring these and enhanced capabilities into the Space Station Program.

Crew and Ground Personnel Acceptance

The initiative mentioned above is mainly a management issue, but there must also be acceptance of the on-line operating personnel, both the Station crew and direct and indirect support personnel on the ground. Without this acceptance autonomy will not bring the sought-after improvements, flexibility and responsiveness will diminish and staff sizes will rise. Existing flight and ground personnel should be brought into the mainstream of the autonomy design process from the beginning, because they know best what jobs need to get done, and they will put up the greatest resistance to change if kept in the dark. When involved from the beginning, these people will learn the capabilities of the latest generation of automation and will be impressed by how much easier their jobs can become. Without this involvement, new techniques will, at least initially, be perceived as a threat, and will not meet the need of the people who must rely on the automation.

Non-Recurring Costs

Just as nearly all survey respondents indicated that implementation of the new automation technologies in the Space Station Program would result in better productivity, nearly all indicated that each technology would also result in rising non-recurring costs. As is generally the case, an investment in research and capital is required to realize a long term saving. Payback periods are certain to vary for different applications of different technologies.

There is not enough information available to quantitatively estimate payback periods for the different Space Station autonomy technology options. Some cases of commercial application of AI expert systems have resulted in payback periods of less than a year. It is worthy of note that this has occurred in largely non-subsidized environments (beyond the basic research stage), as in the case of Elf Aquataine (the French oil company) for oil drilling problem diagnosis, and with Digital Equipment Corp. for configuration selection of VAX computers [14]. These were relatively simple applications demonstrated at a very early stage of commercial AI application. While the technology has progressed, presumably many of the Space Station functions where AI might be applied are more complex, so it remains to be seen how the payback periods will be affected.

Much of the cost of developing the basic technologies of greatest interest to the Space Station Program (AI, High Order Languages, and Fault Tolerant Computing (FTC)) has already been sunk and need not be borne by the Program or

NASA. Considerable DoD effort has gone into FTC, while the former two technologies take on increasing prominence in the commercial sector. For all applications of these technologies there is application-specific work which must be done before utilization can begin, and this results in increased non-recurring costs.

There is also the need for capital expenditures for hardware, software, and user training, in order to utilize any new technology. These costs also must be borne prior to IOC for any technology to be installed and verified for early use.

Some respondents have argued that certain of the proposed technologies would actually result in a net decrease in non-recurring costs (as well as recurring costs). This is conceivable, though not clearly demonstrated, in many cases. Perhaps the strongest case can be made for (very) high order procedure oriented languages and programming. If executed properly, verified, and available early (i.e., before the start of Phase C/D), software costs might be reduced from those encountered if most software were to be written in such languages as assembly and Fortran. This could occur by elimination of the computer programmer as the "middle-man" between the engineer and hardware. As has been the case with some Shuttle launch processing functions at KSC [15], and other mission operations functions for the Solar Mesosphere Explorer at the University of Colorado [7], engineers can write procedures in English-like phrases (though with rather strict syntax) which are directly interpreted and executed by system software.

Even in the case of procedure oriented languages, it is important to note that a suitable procedure oriented language does not yet exist for the Space Station, and therefore must be written and tested. There are also new costs associated with hardware on which the software runs, and with training and verification. How quickly these initial costs will pay off is open to question and should be examined.

AI techniques could pay off again by reducing the required amount of software in cases where relatively small heuristic knowledge bases might displace large volumes of deterministic software. It is expected, however, the AI expert systems may frequently call subroutines written in deterministic software languages in order to perform detailed calculations and control many functions. The relationship between AI techniques and procedure oriented languages has not been closely examined.

Fault Tolerant Computing might reduce non-recurring costs by reducing equipment requirements resulting from the need for system-level fault tolerance. For example, the Shuttle achieves computer fault tolerance primarily by having four identical processors running simultaneously with the same software, with a fifth different processor ready as a backup with different software. With chip- and board-level fault tolerance, equipment requirements might arguably be reduced. Also, the data rate of onboard, uplink and downlink data paths might be reduced by fault tolerant computing at most system nodes, and of course through the overall implementation of autonomy for the orbiting facility.

There is not enough quantitative evidence for a strong case to be made favoring autonomy from the point of view of non-recurring costs. However, there are enough plausible situations where certain non-recurring costs may be saved that more such situations should be sought out in an effort to reduce the overall added non-recurring cost of autonomy implementation.

IX. CONCLUSIONS & RECOMMENDATIONS

Based on the technology survey, discussions among members of the AWG, and opinions of the author, a number of conclusions have been drawn and recommendations made for further automation and autonomy work within the Space Station Program. Along with these are some important observations regarding the initiative required to maximize the Space Station's benefit from today's burgeoning automation technologies.

Technology Selection

Highest development priority should be given to the following three generic technology areas:

Artificial Intelligence-Expert Systems & Processors*
Fault Tolerant Computing
High Order (Procedure Oriented) Languages

These technology areas are most likely to bring operational dividends whether Space Station Program improvement is measured in terms of increased productivity, decreased recurring costs, or a balance of the two. Each is mature enough to have significant positive impact on design by 1987, and to be implemented by IOC with a reasonable amount of developmental support.

While the development of these technologies has achieved a relatively advanced stage with commercial and DoD funding, there is application-specific development which must take place prior to Phase C/D for each of these technologies to be considered mature in the Space Station environment.

The most effective use of automation is "to use machines (automation) to do what machines do best, and use humans to do what humans do best." There is an optimum division of tasks between humans, machines, and teleoperation on the ground and in orbit, which, through proper study and definition of optimization criteria, may be approximated in design. Optimization criteria should be defined and enforced at the highest management levels, and are most likely to include productivity and life cycle cost (return on investment would be the criterion for a commercial venture, and may be approximated in the Space Station Program).

The survey on which the selection of the most promising automation technologies was based consisted of a small set of relevant questions asked of an ad hoc group of experts in various fields of automation. The survey was not intended as a formal scientific sampling of opinion. Respondents had widely differing backgrounds, and wide variations in responses were encountered.

It must be determined whether the extensive use of AI expert systems aboard the Station requires space-qualified symbolic processors. Space qualified computers, either symbolic or conventional, which can run expert system software should receive immediate attention, and may require a development effort beginning in 1985.

Procedure-oriented software and programming techniques are very attractive for IOC (some ranked this technology as "essential"), and offer the potential of

*See Section IV, Table 1.

eliminating the need for large numbers of programmer "middle-men" interposed between engineers and working equipment. Because of the lead times involved, a suitable High Order Language (e.g., Language for User Control and Communications, or LUCC) must be developed or selected within the next two years.

The utility of onboard reprogramming of procedures using an HOL will be most valuable during the first year of Space Station operations, when procedures will be evolving the fastest and the crew will be operating at its greatest learning rate.

The various "High Speed" technologies considered are likely to be ready by 1987 with little Space Station Program support. Their potential for productivity enhancement and recurring cost reduction is important, and these technologies should be utilized by designers from the outset.

Sophisticated robotic techniques are probably beyond achievement in time for IOC, but should be available in a few years thereafter. Specific design features assuring a controlled dimensional and visual environment aboard the station, along with standardized mechanical and electronic robotic interfaces should be incorporated into the IOC station. A detailed Robotic Accommodation Plan should be prepared during Phase B to assure that this technology can be effectively utilized when it becomes available.

When technology rankings were biased toward productivity increase, distributed parameter, hierarchical, and multivariable control techniques took on importance not indicated in the recurring cost-biased rankings. Their utility and cost impact should be investigated early in Phase B to determine whether they should be given top or secondary priority.

Verification techniques for HOL and AI software, and fault tolerant computing should be developed, reviewed, and adopted for the Space Station during Phase B.

A wide variety of computing-related hardware, some off-the-shelf, should be launched and tested aboard the shuttle for space environment and launch effects. Consideration should be given to final assembly of fragile electronic equipment in orbit after launch in protected shipping containers, as an alternative to integrated redesign to withstand transient launch loads.

Goals & Guidelines

The autonomy goals described in Part II, "Automation/Autonomy Philosphy," are the best present design target for the operating Space Station System. It will not be possible to fully implement each of these goals aboard the IOC station, but it will be possible to implement all within a few years of IOC. Even without full implementation, the IOC station can embody a quantum leap in crewed spacecraft automation, resulting in a large increase in productivity and substantial decrease in operating costs, compared to a non-autonomous facility relying mainly on ground control.

The eight architectural guidelines listed in Part II are important design features required to implement the Automation/Autonomy philosophy for non-payload, or facility, operations. A specific top-level design requirement defining autonomy periods is necessary to give designers quantitative time periods to work with. While more optimal periods may be found and later substituted, the following three maximum periods were assumed (see Part II):

90 days without STS revisit,
5 days without routine Space Station ground support,
24 hours without any communication with the ground.

Management

Priority for autonomy implementation must come from the top, along with visible and enforced design measurement criteria such as life cycle cost or return on investment. Significant implementation of autonomy will require a great deal of management initiative before Phase B begins. Interface specifications and programmatic guidelines for autonomy and automation should be published early in Phase B, preferably by 1986 January.

Reluctance to pursue heavily automated design options may be mitigated by pursuing parallel technology options (one mature, one in development) for different functions until the start of Phase C/D. Backup plans should be prepared for those IOC technologies considered to have the greatest development risk.

Existing flight and ground personnel should be brought into the mainstream of the autonomy design process from the beginning, because they know best what jobs need to get done, and they will put up the greatest resistance to change if kept in the dark.

Space Station Evolution

Initial Space Station operations are likely to begin in a heavily supervised manner with large human involvement. With proper design and operations discipline, this situation can rapidly evolve to smooth, skilled operation by a small number of persons assisted by automated equipment. Without proper design and discipline, operations can rapidly become onerous and expensive.

In order to maintain the value of the large initial investment in the Space Station, all systems and subsystems must be operationally flexible, allowing day-to-day procedural and year-to-year configurational flexibility. The Architectural Guidelines in Part II are essential to achieving this required level of flexibility. Procedures must be largely software-controlled, and the controlling software must be easily changed, verified and certified.

Some of the technologies considered offered great potential for the Space Station, but appeared unlikely to be mature enough by 1987 for incorporation in Phase C/D for the IOC station. Development efforts for these technologies should be subordinated to efforts for IOC technologies during the next three years, but should be reemphasized in technology programs soon after the IOC station enters Phase C/D.

It is important to design automated equipment and procedures so that non-mature technologies can be incorporated later when they become mature and useful. Without specific design measures, these new technologies may be frozen out of the system.

Data and control rate capacities built into the IOC station should be several times the expected peak loads during the first two years of operation to avoid severe limitations later in the Program.

Automated equipment should be integrated so that single units or one type of unit may be replaced with minimal impact on similar or connected units, and without requiring more than brief periods of interruption of normal customer operations.

The relationship between heuristic AI software and deterministic "classical" software needs to be examined and defined, especially in light of the stringent flight certification requirements for the Space Station System. Both types of software will be used for various functions with intimate, dynamic interfaces. These new software interface requirements need definition prior to the start of Phase C/D.

Cost Impact

While significant reductions in the number of direct ground support personnel are possible through autonomy, it is the number of indirect support personnel which must be most dramatically reduced from prior programs in order to control Space Station Program recurring costs. Autonomy and automation offer the opportunity to achieve these savings, but strict management discipline and a commercially oriented approach to operations will be required to yield the full potential benefit.

Recurring cost savings usually require a higher net non-recurring cost, as measured from a point design, though it is arguable that this may not be the case with each automation technology considered. Net life cycle cost should be considered for each candidate technology, within ceilings of non-recurring cost.

There are some plausible situations where the introduction of one of the automation technologies could result in a net decrease in non-recurring as well as recurring costs.

With a crew onboard and relatively frequent resupply flights, automated (and other) equipment may not require as high reliability as is traditional with spacecraft having a 5-10 year design life. Costs of reliability must be balanced with costs of crew time required to deal with failed or degraded equipment.

Customer Accommodation

Customer needs for autonomy and automation provided to them as part of the Space Station facility are largely unknown. An investigation of these needs should be undertaken soon, with decisions made on customer capability and interface allocations early in Phase B.

Standardized specifications for data and control formats should be made available to customers along with detailed manuals and consultants describing how to build and verify interfaces between customer equipment and the Space Station System.

Specific allocations of interface ports, software, and control/display equipment should be made for customers during Phase B.

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XI. ACKNOWLEDGEMENTS

I wish to thank the Autonomy Working Group members and especially the Survey Respondents for their valuable input. Several of the recipients of the draft made useful suggestions, including Ed Kan and Kristan Lattu.

XII. APPENDICES

Appendix 1: Survey Respondents

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Appendix 2. <u>Sample Survey</u>

Beginning on the next page is a copy of the survey used to acquire the data listed in Appendix 3 from the respondents listed in Appendix 1. The definitions used follow the survey. See Part IV, Survey Technique, for additional explanation. Responses were requested in light of the AWG Autonomy/Automation Philosophy, a later version of which (with few differences from that which accompanied the survey) appears in Part II, Study Objective.

[Abbreviations used in reports are shown in square brackets in 2nd column.]
Space Station Automation Technology Needs and Readiness

Please return this table to arrive at JPL by November 10, or bring to the November 9-10 AWG meeting. Thank you.

Name:______________________________ Organization:__________________________

Address:____ Mail Stop: _____________

City: _____________________ State:_____ Zip:_______ Phone: ______________

Automation Technology	Productivity Impact	Recurring Cost Impact	Non-Rec. Cost Impact	Desir. for IOC	Readiness '87 w/o interven.	Recommended Development Emphasis
[ratings in descending order]	large moderate small --------- increase decrease none e.g. "small increase"	as with productiv.	as with productiv	essen-tial useful helpful none	certain likely indeter-minate unlikely impossible	major moderate minor monitor none
[for example--feel free to disagree:]						
AI symbolic processors (onboard)	moderate increase	large decrease	moderate increase	useful	unlikely	minor
1. AI Expert Sys:	[AI/ES]					
symbolic processors (onboard)	[AIsymproc]					
planning & sched. s/w tools	[AIpls/w]					
subsystem monitoring s/w tools	[AIsubmons/w]					
fault detec diagnosis & recovery s/w tools	[AIfddrs/w]					

Space Station Automation Technology Needs and Readiness (continued)

Automation Technology	Productivity Impact	Recurring Cost Impact	Non-Rec. Cost Impact	Desir. for IOC	Readiness '87 w/o interven.	Recommended Development Emphasis
learning expert sys (onboard)	[AI LES-o]					
(ground)	[AI LES-g]					
2. Robotics:	[ROB]					
image understand-ing	[ROBiu]					
pattern recog'n.	[ROBpatrec]					
image proc.	[ROMimproc]					
teleopera-tion	[ROBteleop]					
tele-presence	[ROBtelepr]					
dextrous manipula-tion	[ROBdexman]					
3. Fault Tolerant Computing	[FTC]					
processors (onboard)	[FTpro-o]					
mass stor-age (onboard)	[FTmasst-o]					
data xfer (onboard)	[FTdxfer-o]					
(between station & ground)	[FTdxfersg]					

Automation Technology	Productivity Impact	Recurring Cost Impact	Non-Rec. Cost Impact	Desir. for IOC	Readiness '87 w/o interven.	Recommended Development Emphasis

Space Station Automation Technology Needs and Readiness (continued)

Automation Technology	Productivity Impact	Recurring Cost Impact	Non-Rec. Cost Impact	Desir. for IOC	Readiness '87 w/o interven.	Recommended Development Emphasis
software	[FTs/w]					
via architecture vs. hdw. (onboard)	[FTarch]					
4. High-Order Languages	(e.g. programmable by engineering "non-programmers.")					
	[HOL]					
software	[HOLs/w]					
natural language annunciation	[NLA]					
natural language understand-ing	[NLU]					
onboard reprogramming	[HOLrpr-o]					
5. Data Storage (onboard)	(see also Fault Tolerant Computing)					
	[DS-o]					
mass storage	[DSms-o]					
archival storage	[DSarchstor-o]					

Space Station Automation Technology Needs and Readiness (continued)

Automation Technology	Productivity Impact	Recurring Cost Impact	Non-Rec. Cost Impact	Desir. for IOC	Readiness '87 w/o interven.	Recommended Development Emphasis
6. Simulation	[SIM]					
integrated design	[SIMid]					
analysis tools	[SIManal]					
7. Control Techniques	[CT]					
hierarchical	[CThier]					
multi-variable	[CTmv]					
nonlinear	[CTnl]					
distributed parameter	[CTdistpar]					
optimal	[CTopt]					
adaptive	[CTadap]					
8. High Speed Computing	[HSC]					
processors	[HSproc]					
memory	[HSmem]					
data bus	[HSbus]					

*** Please add any others on next page which you feel are appropriate to be considered in light of the proposed autonomy philosophy. Note any appropriate further breakdown of above categories.

Definition of Terms

Automation Technology: field of automation with potential application aboard Space Station. Sub-fields, as in the case of fault-tolerant computing (e.g., mass storage, processors, data transfer, etc.) should generally be listed separately if different techniques are required to achieve practicality.

Productivity Impact: the likely influence of a particular technology on the amount of useful mission work achievable by the Space Station system with fixed physical resources (power, mass, volume, cooling, pointing, etc.) and a given number of crew and ground personnel. Also refers to the ability of the Station to sustain new types of tasks otherwise impractical with a lower level of technology. A few words of elaboration on a separate sheet of paper would be helpful to describe the envisioned impact. Please characterize your estimate of the likely overall effect as being an increase or decrease (or none at all) of large, moderate or small magnitude.

Recurring Cost Impact: the likely influence of a particular technology on operating costs throughout the Space Station System. For example, onboard subsystem monitoring using AI techniques might reduce the number of ground crew required. A few words of elaboration on a separate sheet of paper would be helpful to describe the envisioned impact, including a brief note regarding each area or subsystem where a significant impact would be likely and why. Please characterize your estimate of the likely overall effect as being an increase or decrease (or none at all) of large, moderate or small magnitude.

Non-Recurring Cost Impact: the likely influence of a particular technology on capital costs (e.g., design, development, test & engineering (DDT&E), procurement, crew training) throughout the Space Station System. For example, onboard subsystem monitoring using AI techniques might increase DDT&E and crew training costs, decrease ground personnel training costs, and decrease the cost of the telemetry and data analysis equipment by reducing the required housekeeping data telemetry throughput (and resulting subsystem capacity) to the ground. A few words of elaboration on a separate sheet of paper would be helpful to describe the envisioned impact, including a brief note regarding each area or subsystem where a significant impact would be likely and why. Please characterize your estimate of the likely overall effect as being an increase or decrease (or none at all) of large, moderate or small magnitude.

Desirability for IOC Space Station: Given the Station philosophy discussed at the last AWG meeting (summary chart enclosed), how important is having the particular technology applied within the Space Station System? (Emphasis here is on onboard hardware and software, but availability on the ground may also be important.) Please characterize the desirability for having a given technology at IOC as essential, useful, helpful, or none at all. Also please note whether this applies to having equipment incorprrating the technology onboard, on the ground, or both.

Readiness in 1987 without Intervention: How probable is it that this technology will have been demonstrated in breadboard or brassboard form by 1987 if the Space Station program does not seek to encourage its development? "Demonstrated" implies that program managers would have enough confidence to incorporate the technology in Phase C/D Space Station development and count on its operational readiness at or within a few months of IOC. (For example, processors optimized for AI symbolic manipulation will be generally available in 1987, but clear solutions to the problem of their space and man-rated qualification may not be evident without specific attention from NASA prior to 1987. Hence the readiness of space qualified, man-rates AI symbolic processors might be rated "unlikely," but not "impossible." Please rank readiness as "certain" (already or soon to be demonstrated in space-qualified form today), "likely," "indeterminate" (don't know or too many variables to say), "unlikely," or "impossible" (nothing short of a costly crash development program could bring confidence to a high enough level by 1987).

Recommended Development Emphasis: To what extent should the Space Station program attempt to influence the development of this technology in order to implement the philosophy described at the last AWG meeting? Base this on the level of desirability in relation to the expected level of readiness without Space Station intervention. Please characterize the recommended level of emphasis as "major" (Space Station-specific funding probably required in direct support of development in order to achieve philosophy objectives), "moderate" (modest funding probably required to adapt the technology for station use). "minor" (influence from Space Station program probably required to assure readiness, but little or no specific funding likely to be required), "monitor" (if development proceeds as expected the proper level of readiness is likely, but the Space Station program should maintain cognizance of the development of this technology in case outside development emphasis is altered), or "none" (the technology is already demonstrated to the necessary level of confidence).

Appendix 3: Survey Data

Survey data was taken from questionnaires and placed in a data base using Ashton-Tate dBase II software on a microcomputer. The file structure is listed in Table A-1. Data reports, consisting of different selections of the survey responses, are summarized in Table A-2. Responses are listed in alphabetical order of the technology name used, the same order as in Table 1 in Part IV of this paper. Each data report, titled by its selection criteria, follows Table A-2.

Table A-1. File Structure

Display Structure

Structure for File: A:TECHPOLL.DBF
Number of Records: 00231
Date of Last Update: 02/06/84
Primary Use Database

FLD	Name	Type	Width	DEC
001	LNAME	C	015	
002	ORG	C	008	
003	TECHNOLOGY	C	010	
004	PROD	C	008	
005	RECCOST	C	008	
006	NRCOST	C	008	
007	DESIRIOC	C	008	
008	READI87	C	008	
009	RECEMPH	C	008	
010	NOTE1	C	080	
Total			00162	

Notes for Table A-2 (next page)

Each report lists those technologies for which a respondent indicated that the attribute in each column was as listed in the table. For an attribute (column) that is left blank, this attribute did not affect selection of technologies contained in this report; therefore Report #1 (all columns blank) lists all responses for all technologies. Refer to Appendix #2 and the sample survey for the ranking of each attribute.

Table A-2. Summary of Technology Survey Data Reports

Report #	Impact On			Desirability	Readiness '87	Recommended Dev. Emphasis	Remark
	Productivity	Rec. Cost	NR Cost				
1							All Responses
2	Increase	Decrease	Decrease				High Leverage
3	Large Increase						Productivity Bias
4				Essential			
5	Large Increase			Essential, Useful or Helpful		Major or Moderate	
6				Essential or Useful	Unlikely, Impossible, or Indeterminate	Major or Moderate	
7	Large Increase			Essential or Useful	Unlikely, Impossible, or Indeterminate	Major or Moderate	Null Set Intersection of 3 and 6
8					Impossible		
9					Certain		
10		Large Decrease					Cost Bias
11	Large or Moderate Increase	Large or Moderate Decrease				Major or Moderate	Need Attention

Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Zapalac	MDAC	AI LES-g	mod inc	lar dec	lar inc	use	imp	min	
Aichele	MSFC	AI LES-g	mod inc	sm dec	sm inc	use	unl	mod	
Palmer	ARC-MVSD	AI LES-g	sm inc	sm dec	mod inc	none	unl	min	
Samms	LaRC FMB	AI LES-g	mod inc	lar dec	mod inc	use	unl	min	
Friedman	JPL 364	AI LES-g	lar inc	lar dec	sm inc	use	idt	mod	
Hinchion	MMC	AI LES-g	mod inc	sm dec	lar inc	use	idt	min	
Krchnak	JSC EH3	AI LES-g	lar inc	lar dec	lar inc	use	imp	mod	
Zapalac	MDAC	AI LES-o	mod inc	lar dec	lar inc	use	imp	min	
Aichele	MSFC	AI LES-o	mod inc	sm dec	sm inc	use	unl	mod	
Palmer	ARC-MVSD	AI LES-o	sm inc	mod dec	mod inc	none	unl	min	
Holt, et al.	LaRC FTS	AI LES-o	mod inc	mod dec	pos dec	use	unl-lik	maj	see notes 4,5 on questionnaire
Samms	LaRC FMB	AI LES-o	mod inc	lar dec	mod inc	use	unl	min	
Friedman	JPL 364	AI LES-o	lar inc	lar dec	sm inc	use	idt	mod	
Hinchion	MMC	AI LES-o	mod inc	sm dec	lar inc	use	idt	min	
Krchnak	JSC EH3	AI LES-o	lar inc	lar dec	lar inc	use	imp	mod	
Globus	ARC	AI/ES	mod inc	sm dec	mod dec	help	idt	mod	
Aichele	MSFC	AI/ES	mod inc	sm dec	sm inc	use	unl	mod	
Samms	LaRC FMB	AI/ES	lar inc	lar dec	mod inc	use	idt	maj	
Yonemoto	Hughes	AI/ES	sm inc	none	sm dec	use	lik	mon	
Hinchion	MMC	AI/ES	?	mod dec	lar inc	?	?	?	? = blank
Hinchion	MMC	AIexplMech	mod inc	none	lar inc	des	idt	mod	AI
Zapalac	MDAC	AIfddr s/w	lar inc	lar dec	mod inc	use	lik	maj	seems best of AI applications
Palmer	ARC-MVSD	AIfddr s/w	mod inc	mod dec	mod inc?	use	idt	mod	
Holt, et al.	LaRC FTS	AIfddr s/w	mod inc	lar dec	mod inc	use	lik	maj	
Samms	LaRC FMB	AIfddr s/w	mod inc	lar dec	mod inc	use	unl	mod	major emphasis for 2000
Friedman	JPL 364	AIfddr s/w	lar inc	mod dec	sm dec	use	cer	mon	diagnosis only: see next for Recovery tools
Yonemoto	Hughes	AIfddr s/w	mod inc	sm dec	mod inc	ess	lik	min	
Hinchion	MMC	AIfddr s/w	lar inc	sm dec	sm inc	use	lik	mod	
Krchnak	JSC EH3	AIfddr s/w	lar inc	lar dec	lar inc	use	unl	maj	SSTF should monitor
Friedman	JPL 364	AIfrecovs/w	lar inc	lar dec	sm dec	ess	lik	mod	
Globus	ARC	AIplan s/w	mod inc	mod dec	sm inc	use	lik	mod	
Zapalac	MDAC	AIplan s/w	mod inc	lar dec	mod inc	use	cer	mod	reduce ground ops
Aichele	MSFC	AIplan s/w	mod inc	sm dec	sm inc	use	unl	mod	
Palmer	ARC-MVSR	AIplan s/w	sm inc	sm dec	sm inc	help	lik	min	
Holt, et al.	LaRC FTS	AIplan s/w	lar inc	mod dec	mod inc	use	idt	maj	
Samms	LaRC FMB	AIplan s/w	mod inc	lar dec	mod inc	use	unl	mod	
Friedman	JPL 364	AIplan s/w	lar inc	mod dec	sm dec	use	cer	mon	
Yonemoto	Hughes	AIplan s/w	mod inc	sm dec	sm inc	use	lik	min	
Hinchion	MMC	AIplan s/w	mod inc	sm dec	sm inc	use	lik	mod	
Krchnak	JSC EH3	AIplan s/w	lar inc	lar dec	lar inc	help	lik	min	RTOP already funded
Hinchion	MMC	AIplms/w	lar inc	lar dec	lar inc	des	idt	mod	

ORIGINAL PAGE IS
OF POOR QUALITY

PAGE NO. 00002
02/15/84

Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Zapalac	MDAC	AIsubmon s/w	mod inc	dm dec	sm inc	help	unl	min	will use algorithmic IC(??) autom.
Aichele	MSFC	AIsubmon s/w	mod inc	sm dec	sm inc	use	lik	mod	
Palmer	ARC-MVSD	AIsubmon s/w	mod inc	mod dec	mod inc?	use	lik	mod	
Holt, et al.	LaRC FTS	AIsubmon s/w	mod inc	lar dec	mod inc	use	idt	maj	
Samms	LaRC FMB	AIsubmon s/w	mod inc	mod dec	sm inc	use very	lik	mod	
Friedman	JPL 364	AIsubmon s/w	lar inc	mod dec	sm dec	use	cer	mon	
Yonemoto	Hughes	AIsubmon s/w	lar inc	mod dec	mod inc	ess	lik	min	
Hinchion	MMC	AIsubmon s/w	mod inc	sm dec	sm inc	des	idt	mod	
Krchnak	JSC EH3	AIsubmon s/w	lar inc	lar dec	lar inc	use	unl	maj	
Globus	ARC	AIsymproc	sm inc	mod inc	lar inc	help	unl	none	
Zapalac	MDAC	AIsymproc	mod inc	lar dec	mod inc	use	unl	min	can use mainframe comp./int??
Holt, et al.	LaRC FTS	AIsymproc	sm inc	lar dec	sm inc	use	lik	mod	see notes on form 1,2,3
Samms	LaRC FMB	AIsymproc	lar inc	lar dec	mod inc	use	idt	maj	
Friedman	JPL 364	AIsymproc	lar inc	mod dec	sm dec	use	unl	mod	
Yonemoto	Hughes	AIsymproc	sm inc	sm dec	none	use	idt	mon	
Hinchion	MMC	AIsymproc	mod inc	none	mod inc	use	unl	mod	
Krchnak	JSC EH3	AIsymproc	lar inc	lar dec	mod inc	use	unl	min	OAST, not SSTF, should fund
Hinchion	MMC	AIteleop/pr	lar inc	sm dec	sm inc	des	lik	mon	
Hinchion	MMC	CT adap	mod inc	sm inc	lar inc	benefici	unl	min	
Zapalac	MDAC	CTadap	lar inc	lar dec	mod inc	ess	lik	maj	
Meintel, Jr.	LaRC ATB	CTadap	mod inc	?	?	?	?	?	see note 14 on Q. As applied to teleop.
Krchnak	JSC EH3	CTadap	lar inc	mod inc	lar inc	help	unl	min	
Zapalac	MDAC	CTdistpar	sm inc	sm dec	mod inc	use	lik	min	
Hinchion	MMC	CTdistpar	lar inc	lar inc	lar inc	ess	lik	maj	
Krchnak	JSC EH3	CTdistpar	lar inc	sm inc	mod inc	use	lik	maj	
Zapalac	MDAC	CTheir	mod inc	mod dec	mod inc	ess	lik	mod	
Meintel, Jr.	LaRC ATB	CTheir	lar inc	dec	mod inc	use	lik	mod	see notes 8,14,15 in Q. As applied to Teleop.
Hinchion	MMC	CTheir	lar inc	lar inc	lar inc	ess	lik	maj	
Krchnak	JSC EH3	CTheir	lar inc	sm dec	sm inc	ess	lik	maj	
Zapalac	MDAC	CTmv	mod inc	mod dec	mod inc	ess	lik	mod	
Meintel, Jr.	LaRC ATB	CTmv	mod inc	?	?	?	?	?	see note 14 on Q. As applied to teleop.
Hinchion	MMC	CTmv	lar inc	lar inc	lar inc	ess	lik	maj	
Krchnak	JSC EH3	CTmv	lar inc	sm dec	mod inc	use	unl	maj	
Zapalac	MDAC	CTnl	sm inc	sm dec	mod inc	use	lik	min	
Meintel, Jr.	LaRC ATB	CTnl	mod inc	?	?	?	lik	mod	see notes 14 & 15 on Q. As applied to teleop.

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Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Hinchion	MMC	CTnl	mod inc	mod inc	mod inc	benefici	idt	mod	
Krchnak	JSC EH3	CTnl	lar inc	mod inc	lar inc	help	unl	min	
Zapalac	MDAC	CTopt	sm inc	sm dec	lar inc	use	unl	mon	
Meintel, Jr.	LaRC ATB	CTopt	mod inc	?	?	?	lik	mod	see notes 14,15
Hinchion	MMC	CTopt	mod inc	mod inc	lar inc	ess	idt	mod	
Krchnak	JSC EH3	CTopt	mod inc	mod inc	lar inc	help	unl	min	
Globus	ARC	DS-o	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	DSarchstor-o	maj inc	maj dec	maj dec	ess	unl	mod	
Zapalac	MDAC	DSarchstor-o	sm inc	sm dec	mod inc	use	unl	mon	
Yonemoto	Hughes	DSarchstor-o	sm inc	-	-	use	lik	none	
Hinchion	MMC	DSarchstor-o	sm inc	none	sm inc	des	lik	mon	
Krchnak	JSC EH3	DSarchstor-o	none	sm inc	mod inc	none	-	minor	
Globus	ARC	DSms-o	maj inc	maj dec	maj dec	ess	unl	mod	
Zapalac	MDAC	DSms-o	lar inc	lar dec	sm inc	ess	cer	mon	
Yonemoto	Hughes	DSms-o	sm inc	-	-	use	lik	none	
Hinchion	MMC	DSms-o	mod inc	none	sm -	use	lik	mon	
Krchnak	JSC EH3	DSms-o	mod inc	lar dec	sm inc	ess	lik	mon	
Zapalac	MDAC	FTC							required for criticality but results in productivity gain-- applies to all FT
Palmer	ARC-MVSD	FTC	mod inc	mod inc	mod inc	use	idt	mod	no breakdown for different FT technologies
Holt, et al.	LaRC FTS	FTC	lar inc	lar dec	none	use	lik	maj	see note 6 on Q'aire: extends sys lifetime, reduces ground, crew involvement
Hinchion	MMC	FTC	lar inc	mod dec	mod inc	des	lik	mod	
Krchnak	JSC EH3	FTC	-	-	-	-	-	see note	"FTC hardware is being adequately funded by OAST and DoD."
Yonemoto	Hughes	FTarch	sm inc	sm inc	sm inc	use	lik	min	
Krchnak	JSC EH3	FTarch	lar inc	sm dec	lar inc	use	imp	maj	not clear if he thinks OAST & DoD apply here
Globus	ARC	FTdxfer-o	maj inc	mod dec	mod dec	ess	unl	mod	
Zapalac	MDAC	FTdxfer-o	mod inc	min inc	mod inc	ess	cer	min	
Holt, et al.	LaRC FTS	FTdxfer-o	lar inc	lar dec	none	use	lik	maj	
Yonemoto	Hughes	FTdxfer-o	sm inc	none	sm inc	use	lik	min	
Hinchion	MMC	FTdxfer-o	lar inc	-	-	ess	idt	maj	
Krchnak	JSC EH3	FTdxfer-o	lar inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Globus	ARC	FTdxfersg	maj inc	mod dec	mod dec	ess	lik	min	

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Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Zapalac	MDAC	FTdxfersg	mod inc	min inc	mod inc	ess	cer	min	
Holt, et al.	LaRC FTS	FTdxfersg	mod inc	lar dec	none	use	lik	mod	
Yonemoto	Hughes	FTdxfersg	sm inc	none	sm inc	use	lik	min	
Krchnak	JSC EH3	FTdxfersg	mod inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Globus	ARC	FTmasst-o	maj inc	maj dec	maj dec	ess	unl	mod	
Zapalac	MDAC	FTmasst-o	mod inc	min inc	mod inc	ess	cer	min	
Holt, et al.	LaRC FTS	FTmasst-o	mod inc	mod dec	none	use	lik	maj	
Yonemoto	Hughes	FTmasst-o	sm inc	none	sm inc	use	lik	min	
Krchnak	JSC EH3	FTmasst-o	mod inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Globus	ARC	FTpro-o	maj inc	maj dec	maj dec	ess	unl	mod	
Zapalac	MDAC	FTpro-o	mod inc	min inc	mod inc	ess	cer	mod	
Holt, et al.	LaRC FTS	FTpro-o	lar inc	lar dec	none	use	lik	maj	
Yonemoto	Hughes	FTpro-o	sm inc	sm inc	sm inc	use	lik	none	
Hinchion	MMC	FTpro-o	lar inc	-	-	des	lik	mon/min	DoD VHSIC
Krchnak	JSC EH3	FTpro-o	lar inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Zapalac	MDAC	FTs/w	mod inc	sm decc	lar inc	use	unl	mon	
Holt, et al.	LaRC FTS	FTs/w	mod inc	?	s-m dec	ess	lik	maj	see note 7 on Questionnaire
Yonemoto	Hughes	FTs/w	sm inc	sm dec	sm inc	use	lik	none	
Krchnak	JSC EH3	FTs/w	lar inc	lar dec	lar inc	ess	unl	maj	not clear if he thinks OAST &DoD apply here
Palmer	ARC-MVSD	HOL	mod inc	sm dec	sm inc	use	lik	mod	
Hinchion	MMC	HOL	lar inc	sm inc	sm inc	ess	lik	min	
Globus	ARC	HOLrpr-o	mod inc	mod dec	mod inc	help	unl	mod	
Zapalac	MDAC	HOLrpr-o	mod inc	sm dec	sm inc	use	lik	min	
Aichele	MSFC	HOLrpr-o	lar inc	lar dec	lar inc	use	unl	min	
Samms	LaRC FMB	HOLrpr-o	mod inc	lar dec	sm inc	ess	lik	maj	
Friedman	JPL 364	HOLrpr-o	mod inc	sm dec	none	use	lik	mod	
Hinchion	MMC	HOLrpr-o	idt	-	sm inc	ess	lik	mon	
Krchnak	JSC EH3	HOLrpr-o	sm inc	mod inc	mod inc	none	lik	min	
Dorofee	KSC	HOLrpr-o	mod inc	mod dec	mod inc	use	lik	maj	for VHOL, non life-critical: must be adapted for SS, esp useful 1st yr
Globus	ARC	HOLs/w	maj inc	maj dec	mod inc	use	imp	maj	
Zapalac	MDAC	HOLs/w	lar inc	mod dec	mod inc	use	idt	mod	
Aichele	MSFC	HOLs/w	mod inc	mod dec	mod inc	use	lik	maj	
Samms	LaRC FMB	HOLs/w	lar inc	lar dec	mod dec	ess	lik	maj	
Krchnak	JSC EH3	HOLs/w	lar inc	lar dec	mod inc	ess	lik	min	
Dorofey	KSC	HOLs/w	mod inc	mod dec	vsm inc	use	lik	maj	RECCOST= sm-mod dev could be NASA or minor funding to IEEE to ensure ready-both

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Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Dorofee	KSC	HOLsups/w	lar inc	mod dec	mod inc	use	unl	maj earl	see notes: some s/w dev tools to be avail commercially: some SS-specific
Zapalac	MDAC	HSdbus	lar inc	lar dec	sm inc	ess	cer	mod	
Palmer	ARC-MVSD	HSdbus	lar inc	mod dec	sm inc	use	lik	mod	
Yonemoto	Hughes	HSdbus	sm inc	sm inc	sm inc	use	lik	none	
Hinchion	MMC	HSdbus	lar inc	sm dec	lar inc	ess	idt	maj	
Krchnak	JSC EH3	HSdbus	mod inc	none	mod inc	use	lik	min	
Zapalac	MDAC	HSmem	lar inc	lar dec	sm inc	ess	cer	mod	
Palmer	ARC-MVSD	HSmem	mod inc	mod dec	sm inc	use	lik	mod	
Yonemoto	Hughes	HSmem	none	none	none	?	?	?	
Krchnak	JSC EH3	HSmem	lar inc	mod dec	mod inc	use	lik	min	
Globus	ARC	HSmem-g	maj inc	maj dec	maj dec	help	lik	min	
Zapalac	MDAC	HSproc	lar inc	lar dec	sm inc	ess	cer	mod	
Palmer	ARC-MVSD	HSproc	mod inc	mod dec	sm inc	use	lik	mod	
Yonemoto	Hughes	HSproc	sm inc	sm inc	sm inc	use	idt	none	
Krchnak	JSC EH3	HSproc	mod inc	mod dec	mod inc	use	lik	min	
Globus	ARC	HSproc-g	maj inc	maj dec	maj dec	help	lik	min	
Hinchion	MMC	MMtextgen	sm inc	sm dec	lar inc	help	unl	mon	
Globus	ARC	NLA	min inc	min dec	min inc	help	lik	none	
Zapalac	MDAC	NLA	lar inc	mod dec	lar inc	use	imp	mon	iff connected to word recognition
Aichele	MSFC	NLA	lar inc	lar dec	lar inc	use	unl	min	
Palmer	ARC-MVSD	NLA	sm inc	sm dec	lar inc	none	like	mon	
Hinchion	MMC	NLA	sm inc	none	sm inc	help	lik	min	"voice readback"
Krchnak	JSC EH3	NLA	mod inc	mod dec	mod inc	use	unl	min	
Dorofee	KSC	NLA	lar inc	sm dec	mod inc	use	cer	min mon	esp. C&W, some exists
Globus	ARC	NLU	min inc	min dec	maj inc	none	imp	none	
Zapalac	MDAC	NLU	lar inc	mod dec	mod inc	use	idt	min	
Aichele	MSFC	NLU	lar inc	lar dec	lar inc	use	unl	min	
Palmer	ARC-MVSD	NLU	sm inc	sm dec	lar inc	none	unl	mon	
Samms	LaRC FMB	NLU	mod inc	mod dec	sm inc	use	unl	mod	
Friedman	JPL 364	NLU	mod inc	sm inc	sm inc	help	idt	min	
Hinchion	MMC	NLU	mod inc	sm dec	lar inc	use	idt	min	
Krchnak	JSC EH3	NLU	mod inc	mod dec	mod inc	help	unl	min	
Dorofee	KSC	NLU	vlar inc	mod inc	lar inc	help	unl	min	reliability central, wait for outside develop. User-oriented lang. more rel <$
Krchnak	JSC EH3	ROB	-	-	-	see note	-	-	"No firm requirement for robotics identified for IOC station"

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Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Globus	ARC	ROBdexman	maj inc	maj dec	maj dec	use	imp	maj	
Zapalac	MDAC	ROBdexman	mod inc	mod dec	mod inc	?	?	?	? = not shown on questionnaire
Palmer	ARC-MVSD	ROBdexman	mod inc	mod dec	mod inc	help	idt	mod	
Meintel, Jr.	LaRC ATB	ROBdexman	mod inc	dec	sm inc	none	unl	minor	see notes 8,11,12,13 in Q. Special end effectors good and to be ready
Krchnak	JSC EH3	ROBdexman	lar inc	lar dec	mod inc	none	idt	none	"No firm requirements for robotics identified for IOC station"
Globus	ARC	ROBimproc	mod inc	mod dec	mod inc	use	lik	min	
Zapalac	MDAC	ROBimproc	mod inc	mod dec	mod inc	use	unl	min	
Aichele	MSFC	ROBimproc	mod inc	?	?	use	lik	min	
Palmer	ARC-MVSD	ROBimproc	sm inc	sm inc	sm inc	none	unl	mon	
Hinchion	MMC	ROBimproc	lar inc	none	sm inc	des	lik	min	Vision
Krchnak	JSC EH3	ROBimproc	lar inc	lar dec	mod inc	none	unl	mon	
Globus	ARC	ROBiu	mod inc	mod dec	mod inc	help	idt	mod	
Zapalac	MDAC	ROBiu	mod inc	lar dec	lar inc	use	imp	min	
Aichele	MSFC	ROBiu	lar inc	?	?	use	unl	maj	
Palmer	ARC-MVSD	ROBiu	sm inc	sm dec	lar inc	none	unl	mod	
Maintel, Jr.	LaRC ATB	ROBiu	sm inc	dec	sm inc	help	low	min	see note 1 on questionnaire
Hinchion	MMC	ROBiu	sm inc	none	lar inc	help	unl	mon	Vision (separated from Robotics by MMC)
Krchnak	JSC EH3	ROBiu	lar inc	mod dec	mod inc	none	imp	mon	
Globus	ARC	ROBpatrec	mod inc	mod dec	mod inc	use	lik	min	
Zapalac	MDAC	ROBpatrec	mod inc	lar dec	lar inc	use	imp	min	
Aichele	MSFC	ROBpatrec	mod inc	?	?	use	lik	min	
Palmer	ARC-MVSD	ROBpatrec	sm inc	sm dec	mod inc	none	unl	mon	
Meintel, Jr.	LaRC ATB	ROBpatrec	mod inc	dec	sm inc	help	lik	min	see notes 2,3,4 on Q requires HS computing. Also useful for Earth Res.
Hinchion	MMC	ROBpatrec	sm inc	none	sm inc	help	cer	mon	Vision
Krchnak	JSC EH3	ROBpatrec	lar inc	lar dec	mod inc	none	unl	mon	
Globus	ARC	ROBteleop	maj inc	maj dec	?	use	unl	maj	
Zapalac	MDAC	ROBteleop	mod inc	mod dec	mod inc	use	lik	mod	
Aichele	MSFC	ROBteleop	mod inc	?	?	use	lik	min	
Palmer	ARC-MVSD	ROBteleop	lar inc	mod dec	lar inc	use	idt	mod	
Meintel, Jr.	LaRC ATB	ROBteleop	lar inc	dec	sm inc	use	lik	maj	see notes 7-10 in Q. RMS is demonstrated teleop, but more develop for better

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Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Krchnak	JSC EH3	ROBteleop	mod inc	mod dec	lar inc	use	unl	mod	
Globus	ARC	ROBtelepr	mod inc	mod dec	sm dec	help	imp	mod	
Zapalac	MDAC	ROBtelepr	mod inc	mod dec	mod inc	use	lik	mod	
Aichele	MSFC	ROBtelepr	?	?	?	?	?	?	"This is just another form of teleoperation"
Palmer	ARC-MVSD	ROBtelepr	lar inc	mod dec	lar inc	use	idt	mod	
Meintel, Jr.	LaRC ATB	ROBtelepr	mod inc	dec	sm inc	use	lik	mod	see notes 7-10 in Q
Krchnak	JSC EH3	ROBtelepr	mod inc	mod dec	mod inc	help	imp	min	
Hinchion	MMC	Rdextarm	lar inc	mod dec	lar inc	ess	unl	maj	Robotics
Hinchion	MMC	Rintelman	mod inc	mod dec	lar inc	use	idt	mod	
Hinchion	MMC	Rintelmob	mod inc	mod dec	lar inc	use	unl	mod	Robotics
Globus	ARC	SIM	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	SIManal	maj inc	maj dec	maj dec	ess	unl	mod	
Zapalac	MDAC	SIManal	mod inc	sm dec	sm dec	ess	cer	mod	
Hinchion	MMC	SIManal	sm inc	sm dec	mod inc	ess	lik	min	
Krchnak	JSC EH3	SIManal	mod inc	sm dec	sm inc	ess	unl	maj	
Globus	ARC	SIMid	maj inc	maj dec	maj dec	use	unl	mod	
Zapalac	MDAC	SIMid	mod inc	sm dec	sm inc	ess	cer	mod	
Hinchion	MMC	SIMid	sm inc	sm dec	mod inc	ess	lik	min	
Krchnak	JSC EH3	SIMid	mod inc	sm dec	sm inc	ess	unl	maj	
Globus	ARC	TFs/w	maj inc	maj dec	maj dec	ess	unl	maj	
Hinchion	MMC	VLSI/VHSIC	lar inc	lar dec	lar inc	ess	lik	mon/maj	
Globus	ARC	VLSIdt	mod inc	mod dec	mod dec	help	lik	min	
Globus	ARC	VLSIsp-o	mod inc	mod dec	mod dec	help	unl	mod	
Hinchion	MMC	imps/w val	lar inc	-	-	ess	lik	maj	non-AI- improved s/w validation tools
Globus	ARC	minins-o	mod inc	mod dec	mod dec	help	unl	mod	Minimum instr. set computers

2. Productivity Increase, Non-Recurring Cost Decrease, and Recurring Cost Decrease

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Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Holt, et al.	LaRC FTS	AI LES-o	mod inc	mod dec	pos dec	use	unl-lik	maj	see notes 4,5 on questionnaire
Globus	ARC	AI/ES	mod inc	sm dec	mod dec	help	idt	mod	
Friedman	JPL 364	AIfddr s/w	lar inc	mod dec	sm dec	use	cer	mon	diagnosis only: see next for Recovery tools
Friedman	JPL 364	AIfrecovs/w	lar inc	lar dec	sm dec	ess	lik	mod	
Friedman	JPL 364	AIplan s/w	lar inc	mod dec	sm dec	use	cer	mon	
Friedman	JPL 364	AIsubmon s/w	lar inc	mod dec	sm dec	use	cer	mon	
Friedman	JPL 364	AIsymproc	lar inc	mod dec	sm dec	use	unl	mod	
Globus	ARC	DS-o	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	DSarchstor-o	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	DSms-o	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	FTdxfer-o	maj inc	mod dec	mod dec	ess	unl	mod	
Globus	ARC	FTdxfersg	maj inc	mod dec	mod dec	ess	lik	min	
Globus	ARC	FTmasst-o	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	FTpro-o	maj inc	maj dec	maj dec	ess	unl	mod	
Samms	LaRC FMB	HOLs/w	lar inc	lar dec	mod dec	ess	lik	maj	
Globus	ARC	HSmem-g	maj inc	maj dec	maj dec	help	lik	min	
Globus	ARC	HSproc-g	maj inc	maj dec	maj dec	help	lik	min	
Globus	ARC	ROBdexman	maj inc	maj dec	maj dec	use	imp	maj	
Globus	ARC	ROBtelepr	mod inc	mod dec	sm dec	help	imp	mod	
Globus	ARC	SIM	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	SIManal	maj inc	maj dec	maj dec	ess	unl	mod	
Zapalac	MDAC	SIManal	mod inc	sm dec	sm dec	ess	cer	mod	
Globus	ARC	SIMid	maj inc	maj dec	maj dec	use	unl	mod	
Globus	ARC	TFs/w	maj inc	maj dec	maj dec	ess	unl	maj	
Globus	ARC	VLSIdt	mod inc	mod dec	mod dec	help	lik	min	
Globus	ARC	VLSIsp-o	mod inc	mod dec	mod dec	help	unl	mod	
Globus	ARC	minins-o	mod inc	mod dec	mod dec	help	unl	mod	Minimum instr. set computers

3. Productivity: "Large Increase"

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Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Friedman	JPL 364	AI LES-g	lar inc	lar dec	sm inc	use	idt	mod	
Krchnak	JSC EH3	AI LES-g	lar inc	lar dec	lar inc	use	imp	mod	
Friedman	JPL 364	AI LES-o	lar inc	lar dec	sm inc	use	idt	mod	
Krchnak	JSC EH3	AI LES-o	lar inc	lar dec	lar inc	use	imp	mod	
Samms	LaRC FMB	AI/ES	lar inc	lar dec	mod inc	use	idt	maj	
Zapalac	MDAC	AIfddr s/w	lar inc	lar dec	mod inc	use	lik	maj	seems best of AI applications
Friedman	JPL 364	AIfddr s/w	lar inc	mod dec	sm dec	use	cer	mon	diagnosis only: see next for Recovery tools
Hinchion	MMC	AIfddr s/w	lar inc	sm dec	sm inc	use	lik	mod	
Krchnak	JSC EH3	AIfddr s/w	lar inc	lar dec	lar inc	use	unl	maj	SSTF should monitor
Friedman	JPL 364	AIfrecovs/w	lar inc	lar dec	sm dec	ess	lik	mod	
Holt, et al.	LaRC FTS	AIplan s/w	lar inc	mod dec	mod inc	use	idt	maj	
Friedman	JPL 364	AIplan s/w	lar inc	mod dec	sm dec	use	cer	mon	
Krchnak	JSC EH3	AIplan s/w	lar inc	lar dec	lar inc	help	lik	min	RTOP already funded
Hinchion	MMC	AIplms/w	lar inc	lar dec	lar inc	des	idt	mod	
Friedman	JPL 364	AIsubmon s/w	lar inc	mod dec	sm dec	use	cer	mon	
Yonemoto	Hughes	AIsubmon s/w	lar inc	mod dec	mod inc	ess	lik	min	
Krchnak	JSC EH3	AIsubmon s/w	lar inc	lar dec	lar inc	use	unl	maj	
Samms	LaRC FMB	AIsymproc	lar inc	lar dec	mod inc	use	idt	maj	
Friedman	JPL 364	AIsymproc	lar inc	mod dec	sm dec	use	unl	mod	
Krchnak	JSC EH3	AIsymproc	lar inc	lar dec	mod inc	use	unl	min	OAST, not SSTF, should fund
Hinchion	MMC	AIteleop/pr	lar inc	sm dec	sm inc	des	lik	mon	
Zapalac	MDAC	CTadap	lar inc	lar dec	mod inc	ess	lik	maj	
Krchnak	JSC EH3	CTadap	lar inc	mod inc	lar inc	help	unl	min	
Hinchion	MMC	CTdistpar	lar inc	lar inc	lar inc	ess	lik	maj	
Krchnak	JSC EH3	CTdistpar	lar inc	sm inc	mod inc	use	lik	maj	
Meintel, Jr.	LaRC ATB	CTheir	lar inc	dec	mod inc	use	lik	mod	see notes 8,14,15 in Q. As applied to Teleop.
Hinchion	MMC	CTheir	lar inc	lar inc	lar inc	ess	lik	maj	
Krchnak	JSC EH3	CTheir	lar inc	sm dec	sm inc	ess	lik	maj	
Hinchion	MMC	CTmv	lar inc	lar inc	lar inc	ess	lik	maj	
Krchnak	JSC EH3	CTmv	lar inc	sm dec	mod inc	use	unl	maj	
Krchnak	JSC EH3	CTnl	lar inc	mod inc	lar inc	help	unl	min	
Zapalac	MDAC	DSms-o	lar inc	lar dec	sm inc	ess	cer	mon	
Holt, et al.	LaRC FTS	FTC	lar inc	lar dec	none	use	lik	maj	see note 6 on Q'aire: extends sys lifetime, reduces ground, crew involvement
Hinchion	MMC	FTC	lar inc	mod dec	mod inc	des	lik	mod	
Krchnak	JSC EH3	FTarch	lar inc	sm dec	lar inc	use	imp	maj	not clear if he thinks OAST & DoD apply here

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Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Holt, et al.	LaRC FTS	FTdxfer-o	lar inc	lar dec	none	use	lik	maj	
Hinchion	MMC	FTdxfer-o	lar inc	-	-	ess	idt	maj	
Krchnak	JSC EH3	FTdxfer-o	lar inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Holt, et al.	LaRC FTS	FTpro-o	lar inc	lar dec	none	use	lik	maj	
Hinchion	MMC	FTpro-o	lar inc	-	-	des	lik	mon/min	DoD VHSIC
Krchnak	JSC EH3	FTpro-o	lar inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Krchnak	JSC EH3	FTs/w	lar inc	lar dec	lar inc	ess	unl	maj	not clear if he thinks OAST &DoD apply here
Hinchion	MMC	HOL	lar inc	sm inc	sm inc	ess	lik	min	
Aichele	MSFC	HOLrpr-o	lar inc	lar dec	lar inc	use	unl	min	
Zapalac	MDAC	HOLs/w	lar inc	mod dec	mod inc	use	idt	mod	
Samms	LaRC FMB	HOLs/w	lar inc	lar dec	mod dec	ess	lik	maj	
Krchnak	JSC EH3	HOLs/w	lar inc	lar dec	mod inc	ess	lik	min	
Dorofee	KSC	HOLsups/w	lar inc	mod dec	mod inc	use	unl	maj earl	see notes: some s/w dev tools to be avail commercially: some SS-specific
Zapalac	MDAC	HSdbus	lar inc	lar dec	sm inc	ess	cer	mod	
Palmer	ARC-MVSD	HSdbus	lar inc	mod dec	sm inc	use	lik	mod	
Hinchion	MMC	HSdbus	lar inc	sm dec	lar inc	ess	idt	maj	
Zapalac	MDAC	HSmem	lar inc	lar dec	sm inc	ess	cer	mod	
Krchnak	JSC EH3	HSmem	lar inc	mod dec	mod inc	use	lik	min	
Zapalac	MDAC	HSproc	lar inc	lar dec	sm inc	ess	cer	mod	
Zapalac	MDAC	NLA	lar inc	mod dec	lar inc	use	imp	mon	iff connected to word recognition
Aichele	MSFC	NLA	lar inc	lar dec	lar inc	use	unl	min	
Dorofee	KSC	NLA	lar inc	sm dec	mod inc	use	cer	min mon	esp. C&W, some exists
Zapalac	MDAC	NLU	lar inc	mod dec	mod inc	use	idt	min	
Aichele	MSFC	NLU	lar inc	lar dec	lar inc	use	unl	min	
Krchnak	JSC EH3	ROBdexman	lar inc	lar dec	mod inc	none	idt	none	"No firm requirements for robotics identified for IOC station"
Hinchion	MMC	ROBimproc	lar inc	none	sm inc	des	lik	min	Vision
Krchnak	JSC EH3	ROBimproc	lar inc	lar dec	mod inc	none	unl	mon	
Aichele	MSFC	ROBiu	lar inc	?	?	use	unl	maj	
Krchnak	JSC EH3	ROBiu	lar inc	mod dec	mod inc	none	imp	mon	
Krchnak	JSC EH3	ROBpatrec	lar inc	lar dec	mod inc	none	unl	mon	
Palmer	ARC-MVSD	ROBteleop	lar inc	mod dec	lar inc	use	idt	mod	
Heintel, Jr.	LaRC ATB	ROBteleop	lar inc	dec	sm inc	use	lik	maj	see notes 7-10 in Q. RMS is demonstrated teleop, but more develop for better

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Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Palmer	ARC-MVSD	ROBtelepr	lar inc	mod dec	lar inc	use	idt	mod	
Hinchion	MMC	Rdextarm	lar inc	mod dec	lar inc	ess	unl	maj	Robotics
Hinchion	MMC	VLSI/VHSIC	lar inc	lar dec	lar inc	ess	lik	mon/maj	
Hinchion	MMC	imps/w val	lar inc	-	-	ess	lik	maj	non-AI-improved s/w validation tools

4. "Essential" for IOC
"Essential Technologies"

Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Yonemoto	Hughes	AIfddr s/w	mod inc	sm dec	mod inc	ess	lik	min	
Friedman	JPL 364	AIfrecovs/w	lar inc	lar dec	sm dec	ess	lik	mod	
Yonemoto	Hughes	AIsubmon s/w	lar inc	mod dec	mod inc	ess	lik	min	
Zapalac	MDAC	CTadap	lar inc	lar dec	mod inc	ess	lik	maj	
Hinchion	MMC	CTdistpar	lar inc	lar inc	lar inc	ess	lik	maj	
Zapalac	MDAC	CTheir	mod inc	mod dec	mod inc	ess	lik	mod	
Hinchion	MMC	CTheir	lar inc	lar inc	lar inc	ess	lik	maj	
Krchnak	JSC EH3	CTheir	lar inc	sm dec	sm inc	ess	lik	maj	
Zapalac	MDAC	CTmv	mod inc	mod dec	mod inc	ess	lik	mod	
Hinchion	MMC	CTmv	lar inc	lar inc	lar inc	ess	lik	maj	
Hinchion	MMC	CTopt	mod inc	mod inc	lar inc	ess	idt	mod	
Globus	ARC	DS-o	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	DSarchstor-o	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	DSms-o	maj inc	maj dec	maj dec	ess	unl	mod	
Zapalac	MDAC	DSms-o	lar inc	lar dec	sm inc	ess	cer	mon	
Krchnak	JSC EH3	DSms-o	mod inc	lar dec	sm inc	ess	lik	mon	
Globus	ARC	FTdxfer-o	maj inc	mod dec	mod dec	ess	unl	mod	
Zapalac	MDAC	FTdxfer-o	mod inc	min inc	mod inc	ess	cer	min	
Hinchion	MMC	FTdxfer-o	lar inc	-	-	ess	idt	maj	
Krchnak	JSC EH3	FTdxfer-o	lar inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Globus	ARC	FTdxfersg	maj inc	mod dec	mod dec	ess	lik	min	
Zapalac	MDAC	FTdxfersg	mod inc	min inc	mod inc	ess	cer	min	
Krchnak	JSC EH3	FTdxfersg	mod inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Globus	ARC	FTmasst-o	maj inc	maj dec	maj dec	ess	unl	mod	
Zapalac	MDAC	FTmasst-o	mod inc	min inc	mod inc	ess	cer	min	
Krchnak	JSC EH3	FTmasst-o	mod inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Globus	ARC	FTpro-o	maj inc	maj dec	maj dec	ess	unl	mod	
Zapalac	MDAC	FTpro-o	mod inc	min inc	mod inc	ess	cer	mod	
Krchnak	JSC EH3	FTpro-o	lar inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Holt, et al.	LaRC FTS	FTs/w	mod inc	?	s-m dec	ess	lik	maj	see note 7 on Questionnaire
Krchnak	JSC EH3	FTs/w	lar inc	lar dec	lar inc	ess	unl	maj	not clear if he thinks OAST &DoD apply here
Hinchion	MMC	HOL	lar inc	sm inc	sm inc	ess	lik	min	
Samms	LaRC FMB	HOLrpr-o	mod inc	lar dec	sm inc	ess	lik	maj	
Hinchion	MMC	HOLrpr-o	idt	-	sm inc	ess	lik	mon	
Samms	LaRC FMB	HOLs/w	lar inc	lar dec	mod dec	ess	lik	maj	
Krchnak	JSC EH3	HOLs/w	lar inc	lar dec	mod inc	ess	lik	min	
Zapalac	MDAC	HSdbus	lar inc	lar dec	sm inc	ess	cer	mod	
Hinchion	MMC	HSdbus	lar inc	sm dec	lar inc	ess	idt	maj	
Zapalac	MDAC	HSmem	lar inc	lar dec	sm inc	ess	cer	mod	
Zapalac	MDAC	HSproc	lar inc	lar dec	sm inc	ess	cer	mod	
Hinchion	MMC	Rdextarm	lar inc	mod dec	lar inc	ess	unl	maj	Robotics
Globus	ARC	SIM	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	SIManal	maj inc	maj dec	maj dec	ess	unl	mod	

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Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Zapalac	MDAC	SIManal	mod inc	sm dec	sm dec	ess	cer	mod	
Hinchion	MMC	SIManal	sm inc	sm dec	mod inc	ess	lik	min	
Krchnak	JSC EH3	SIManal	mod inc	sm dec	sm inc	ess	unl	maj	
Zapalac	MDAC	SIMid	mod inc	sm dec	sm inc	ess	cer	mod	
Hinchion	MMC	SIMid	sm inc	sm dec	mod inc	ess	lik	min	
Krchnak	JSC EH3	SIMid	mod inc	sm dec	sm inc	ess	unl	maj	
Globus	ARC	TFs/w	maj inc	maj dec	maj dec	ess	unl	maj	
Hinchion	MMC	VLSI/VHSIC	lar inc	lar dec	lar inc	ess	lik	mon/maj	
Hinchion	MMC	imps/w val	lar inc	-	-	ess	lik	maj	non-AI- improved s/w validation tools

5. Productivity "Large Increase," and Essential, Useful, or Helpful @ IOC, and Major or Moderate Development Emphasis.

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. Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Friedman	JPL 364	AI LES-g	lar inc	lar dec	sm inc	use	idt	mod	
Krchnak	JSC EH3	AI LES-g	lar inc	lar dec	lar inc	use	imp	mod	
Friedman	JPL 364	AI LES-o	lar inc	lar dec	sm inc	use	idt	mod	
Krchnak	JSC EH3	AI LES-o	lar inc	lar dec	lar inc	use	imp	mod	
Samms	LaRC FMB	AI/ES	lar inc	lar dec	mod inc	use	idt	maj	
Zapalac	MDAC	AIfddr s/w	lar inc	lar dec	mod inc	use	lik	maj	seems best of AI applications
Hinchion	MMC	AIfddr s/w	lar inc	sm dec	sm inc	use	lik	mod	
Krchnak	JSC EH3	AIfddr s/w	lar inc	lar dec	lar inc	use	unl	maj	SSTF should monitor
Friedman	JPL 364	AIfrecovs/w	lar inc	lar dec	sm dec	ess	lik	mod	
Holt, et al.	LaRC FTS	AIplan s/w	lar inc	mod dec	mod inc	use	idt	maj	
Krchnak	JSC EH3	AIsubmon s/w	lar inc	lar dec	lar inc	use	unl	maj	
Samms	LaRC FMB	AIsymproc	lar inc	lar dec	mod inc	use	idt	maj	
Friedman	JPL 364	AIsymproc	lar inc	mod dec	sm dec	use	unl	mod	
Zapalac	MDAC	CTadap	lar inc	lar dec	mod inc	ess	lik	maj	
Hinchion	MMC	CTdistpar	lar inc	lar inc	lar inc	ess	lik	maj	
Krchnak	JSC EH3	CTdistpar	lar inc	sm inc	mod inc	use	lik	maj	
Meintel, Jr.	LaRC ATB	CTheir	lar inc	dec	mod inc	use	lik	mod	see notes 8,14,15 in Q. As applied to Teleop.
Hinchion	MMC	CTheir	lar inc	lar inc	lar inc	ess	lik	maj	
Krchnak	JSC EH3	CTheir	lar inc	sm dec	sm inc	ess	lik	maj	
Hinchion	MMC	CTmv	lar inc	lar inc	lar inc	ess	lik	maj	
Krchnak	JSC EH3	CTmv	lar inc	sm dec	mod inc	use	unl	maj	
Holt, et al.	LaRC FTS	FTC	lar inc	lar dec	none	use	lik	maj	see note 6 on Q'aire: extends sys lifetime, reduces ground, crew involvement
Krchnak	JSC EH3	FTarch	lar inc	sm dec	lar inc	use	imp	maj	not clear if he thinks OAST & DoD apply here
Holt, et al.	LaRC FTS	FTdxfer-o	lar inc	lar dec	none	use	lik	maj	
Hinchion	MMC	FTdxfer-o	lar inc	-	-	ess	idt	maj	
Holt, et al.	LaRC FTS	FTpro-o	lar inc	lar dec	none	use	lik	maj	
Krchnak	JSC EH3	FTs/w	lar inc	lar dec	lar inc	ess	unl	maj	not clear if he thinks OAST &DoD apply here
Zapalac	MDAC	HOLs/w	lar inc	mod dec	mod inc	use	idt	mod	
Samms	LaRC FMB	HOLs/w	lar inc	lar dec	mod dec	ess	lik	maj	
Dorofee	KSC	HOLsups/w	lar inc	mod dec	mod inc	use	unl	maj earl	see notes: some s/w dev tools to be avail commercially: some SS-specific
Zapalac	MDAC	HSdbus	lar inc	lar dec	sm inc	ess	cer	mod	

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Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Palmer	ARC-MVSD	HSdbus	lar inc	mod dec	sm inc	use	lik	mod	
Hinchion	MMC	HSdbus	lar inc	sm dec	lar inc	ess	idt	maj	
Zapalac	MDAC	HSmem	lar inc	lar dec	sm inc	ess	cer	mod	
Zapalac	MDAC	HSproc	lar inc	lar dec	sm inc	ess	cer	mod	
Aichele	MSFC	ROBiu	lar inc	?	?	use	unl	maj	
Palmer	ARC-MVSD	ROBteleop	lar inc	mod dec	lar inc	use	idt	mod	
Meintel, Jr.	LaRC ATB	ROBteleop	lar inc	dec	sm inc	use	lik	maj	see notes 7-10 in Q. RMS is demonstrated teleop, but more develop for better
Palmer	ARC-MVSD	ROBtelepr	lar inc	mod dec	lar inc	use	idt	mod	
Hinchion	MMC	Rdextarm	lar inc	mod dec	lar inc	ess	unl	maj	Robotics
Hinchion	MMC	imps/w val	lar inc	-	-	ess	lik	maj	non-AI-improved s/w validation tools

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6. Essential or Useful @ IOC Impossible, Unlikely or Indeterminate in 1987
Major or Moderate Development Emphasis

Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	[illegible] IOC	Readi '87	Rec. Emph.	Remarks
Aichele	MSFC	AI LES-g	mod inc	sm dec	sm inc	use	unl	mod	
Friedman	JPL 364	AI LES-g	lar inc	lar dec	sm inc	use	idt	mod	
Krchnak	JSC EH3	AI LES-g	lar inc	lar dec	lar inc	use	imp	mod	
Aichele	MSFC	AI LES-o	mod inc	sm dec	sm inc	use	unl	mod	
Holt, et al.	LaRC FTS	AI LES-o	mod inc	mod dec	pos dec	use	unl-lik	maj	see notes 4,5 on questionnaire
Friedman	JPL 364	AI LES-o	lar inc	lar dec	sm inc	use	idt	mod	
Krchnak	JSC EH3	AI LES-o	lar inc	lar dec	lar inc	use	imp	mod	
Aichele	MSFC	AI/ES	mod inc	sm dec	sm inc	use	unl	mod	
Samms	LaRC FMB	AI/ES	lar inc	lar dec	mod inc	use	idt	maj	
Palmer	ARC-MVSD	AIfddr s/w	mod inc	mod dec	mod inc?	use	idt	mod	
Samms	LaRC FMB	AIfddr s/w	mod inc	lar dec	mod inc	use	unl	mod	major emphasis for 2000
Krchnak	JSC EH3	AIfddr s/w	lar inc	lar dec	lar inc	use	unl	maj	SSTF should monitor
Aichele	MSFC	AIplan s/w	mod inc	sm dec	sm inc	use	unl	mod	
Holt, et al.	LaRC FTS	AIplan s/w	lar inc	mod dec	mod inc	use	idt	maj	
Samms	LaRC FMB	AIplan s/w	mod inc	lar dec	mod inc	use	unl	mod	
Holt, et al.	LaRC FTS	AIsubmon s/w	mod inc	lar dec	mod inc	use	idt	maj	
Krchnak	JSC EH3	AIsubmon s/w	lar inc	lar dec	lar inc	use	unl	maj	
Samms	LaRC FMB	AIsymproc	lar inc	lar dec	mod inc	use	idt	maj	
Friedman	JPL 364	AIsymproc	lar inc	mod dec	sm dec	use	unl	mod	
Hinchion	MMC	AIsymproc	mod inc	none	mod inc	use	unl	mod	
Krchnak	JSC EH3	CTmv	lar inc	sm dec	mod inc	use	unl	maj	
Hinchion	MMC	CTopt	mod inc	mod inc	lar inc	ess	idt	mod	
Globus	ARC	DS-o	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	DSarchstor-o	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	DSms-o	maj inc	maj dec	maj dec	ess	unl	mod	
Palmer	ARC-MVSD	FTC	mod inc	mod inc	mod inc	use	idt	mod	no breakdown for different FT technologies
Krchnak	JSC EH3	FTarch	lar inc	sm dec	lar inc	use	imp	maj	not clear if he thinks OAST & DoD apply here
Globus	ARC	FTdxfer-o	maj inc	mod dec	mod dec	ess	unl	mod	
Hinchion	MMC	FTdxfer-o	lar inc	-	-	ess	idt	maj	
Globus	ARC	FTmasst-o	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	FTpro-o	maj inc	maj dec	maj dec	ess	unl	mod	
Krchnak	JSC EH3	FTs/w	lar inc	lar dec	lar inc	ess	unl	maj	not clear if he thinks OAST &DoD apply here
Globus	ARC	HOLs/w	maj inc	maj dec	mod inc	use	imp	maj	
Zapalac	MDAC	HOLs/w	lar inc	mod dec	mod inc	use	idt	mod	
Dorofee	KSC	HOLsups/w	lar inc	mod dec	mod inc	use	unl	maj earl	see notes: some s/w dev tools to be avail commercially: some SS-specific

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Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Hinchion	MMC	HSdbus	lar inc	sm dec	lar inc	ess	idt	maj	
Samms	LaRC FMB	NLU	mod inc	mod dec	sm inc	use	unl	mod	
Globus	ARC	ROBdexman	maj inc	maj dec	maj dec	use	imp	maj	
Aichele	MSFC	ROBiu	lar inc	?	?	use	unl	maj	
Globus	ARC	ROBteleop	maj inc	maj dec	?	use	unl	maj	
Palmer	ARC-MVSD	ROBteleop	lar inc	mod dec	lar inc	use	idt	mod	
Krchnak	JSC EH3	ROBteleop	mod inc	mod dec	lar inc	use	unl	mod	
Palmer	ARC-MVSD	ROBtelepr	lar inc	mod dec	lar inc	use	idt	mod	
Hinchion	MMC	Rdextarm	lar inc	mod dec	lar inc	ess	unl	maj	Robotics
Hinchion	MMC	Rintelman	mod inc	mod dec	lar inc	use	idt	mod	
Hinchion	MMC	Rintelmob	mod inc	mod dec	lar inc	use	unl	mod	Robotics
Globus	ARC	SIM	maj inc	maj dec	maj dec	ess	unl	mod	
Globus	ARC	SIManal	maj inc	maj dec	maj dec	ess	unl	mod	
Krchnak	JSC EH3	SIManal	mod inc	sm dec	sm inc	ess	unl	maj	
Globus	ARC	SIMid	maj inc	maj dec	maj dec	use	unl	mod	
Krchnak	JSC EH3	SIMid	mod inc	sm dec	sm inc	ess	unl	maj	
Globus	ARC	TFs/w	maj inc	maj dec	maj dec	ess	unl	maj	

7. Intersection of Reports 3 and 6.

Report #7: Large Productivity Increase
"Essential" or "Useful" at IOC
"Impossible" or "Indeterminate" readiness in 1987
"Major" or "Moderate" recommended development emphasis

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Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Zapalac	MDAC	AI LES-g	mod inc	lar dec	lar inc	use	imp	min	
Krchnak	JSC EH3	AI LES-g	lar inc	lar dec	lar inc	use	imp	mod	
Zapalac	MDAC	AI LES-o	mod inc	lar dec	lar inc	use	imp	min	
Krchnak	JSC EH3	AI LES-o	lar inc	lar dec	lar inc	use	imp	mod	
Krchnak	JSC EH3	FTarch	lar inc	sm dec	lar inc	use	imp	maj	not clear if he thinks OAST & DoD apply here
Globus	ARC	HOLs/w	maj inc	maj dec	mod inc	use	imp	maj	
Zapalac	MDAC	NLA	lar inc	mod dec	lar inc	use	imp	mon	iff connected to word recognition
Globus	ARC	NLU	min inc	min dec	maj inc	none	imp	none	
Globus	ARC	ROBdexman	maj inc	maj dec	maj dec	use	imp	maj	
Zapalac	MDAC	ROBiu	mod inc	lar dec	lar inc	use	imp	min	
Krchnak	JSC EH3	ROBiu	lar inc	mod dec	mod inc	none	imp	mon	
Zapalac	MDAC	ROBpatrec	mod inc	lar dec	lar inc	use	imp	min	
Globus	ARC	ROBtelepr	mod inc	mod dec	sm dec	help	imp	mod	
Krchnak	JSC EH3	ROBtelepr	mod inc	mod dec	mod inc	help	imp	min	

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Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Friedman	JPL 364	AIfddr s/w	lar inc	mod dec	sm dec	use	cer	mon	diagnosis only: see next for Recovery tools
Zapalac	MDAC	AIplan s/w	mod inc	lar dec	mod inc	use	cer	mod	reduce ground ops
Friedman	JPL 364	AIplan s/w	lar inc	mod dec	sm dec	use	cer	mon	
Friedman	JPL 364	AIsubmon s/w	lar inc	mod dec	sm dec	use	cer	mon	
Zapalac	MDAC	DSms-o	lar inc	lar dec	sm inc	ess	cer	mon	
Zapalac	MDAC	FTdxfer-o	mod inc	min inc	mod inc	ess	cer	min	
Zapalac	MDAC	FTdxfersg	mod inc	min inc	mod inc	ess	cer	min	
Zapalac	MDAC	FTmasst-o	mod inc	min inc	mod inc	ess	cer	min	
Zapalac	MDAC	FTpro-o	mod inc	min inc	mod inc	ess	cer	mod	
Zapalac	MDAC	HSdbus	lar inc	lar dec	sm inc	ess	cer	mod	
Zapalac	MDAC	HSmem	lar inc	lar dec	sm inc	ess	cer	mod	
Zapalac	MDAC	HSproc	lar inc	lar dec	sm inc	ess	cer	mod	
Dorofee	KSC	NLA	lar inc	sm dec	mod inc	use	cer	min mon	esp. C&W, some exists
Hinchion	MMC	ROBpatrec	sm inc	none	sm inc	help	cer	mon	Vision
Zapalac	MDAC	SIManal	mod inc	sm dec	sm dec	ess	cer	mod	
Zapalac	MDAC	SIMid	mod inc	sm dec	sm inc	ess	cer	mod	

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Space Station Technology Poll

Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Zapalac	MDAC	AI LES-g	mod inc	lar dec	lar inc	use	imp	min	
Samms	LaRC FMB	AI LES-g	mod inc	lar dec	mod inc	use	unl	min	
Friedman	JPL 364	AI LES-g	lar inc	lar dec	sm inc	use	idt	mod	
Krchnak	JSC EH3	AI LES-g	lar inc	lar dec	lar inc	use	imp	mod	
Zapalac	MDAC	AI LES-o	mod inc	lar dec	lar inc	use	imp	min	
Samms	LaRC FMB	AI LES-o	mod inc	lar dec	mod inc	use	unl	min	
Friedman	JPL 364	AI LES-o	lar inc	lar dec	sm inc	use	idt	mod	
Krchnak	JSC EH3	AI LES-o	lar inc	lar dec	lar inc	use	imp	mod	
Samms	LaRC FMB	AI/ES	lar inc	lar dec	mod inc	use	idt	maj	
Zapalac	MDAC	AIfddr s/w	lar inc	lar dec	mod inc	use	lik	maj	seems best of AI applications
Holt, et al.	LaRC FTS	AIfddr s/w	mod inc	lar dec	mod inc	use	lik	maj	
Samms	LaRC FMB	AIfddr s/w	mod inc	lar dec	mod inc	use	unl	mod	major emphasis for 2000
Krchnak	JSC EH3	AIfddr s/w	lar inc	lar dec	lar inc	use	unl	maj	SSTF should monitor
Friedman	JPL 364	AIfrecovs/w	lar inc	lar dec	sm dec	ess	lik	mod	
Zapalac	MDAC	AIplan s/w	mod inc	lar dec	mod inc	use	cer	mod	reduce ground ops
Samms	LaRC FMB	AIplan s/w	mod inc	lar dec	mod inc	use	unl	mod	
Krchnak	JSC EH3	AIplan s/w	lar inc	lar dec	lar inc	help	lik	min	RTOP already funded
Hinchion	MMC	AIplms/w	lar inc	lar dec	lar inc	des	idt	mod	
Holt, et al.	LaRC FTS	AIsubmon s/w	mod inc	lar dec	mod inc	use	idt	maj	
Krchnak	JSC EH3	AIsubmon s/w	lar inc	lar dec	lar inc	use	unl	maj	
Zapalac	MDAC	AIsymproc	mod inc	lar dec	mod inc	use	unl	min	can use mainframe comp./int??
Holt, et al.	LaRC FTS	AIsymproc	sm inc	lar dec	sm inc	use	lik	mod	see notes on form 1,2,3
Samms	LaRC FMB	AIsymproc	lar inc	lar dec	mod inc	use	idt	maj	
Krchnak	JSC EH3	AIsymproc	lar inc	lar dec	mod inc	use	unl	min	OAST, not SSTF, should fund
Zapalac	MDAC	CTadap	lar inc	lar dec	mod inc	ess	lik	maj	
Zapalac	MDAC	DSms-o	lar inc	lar dec	sm inc	ess	cer	mon	
Krchnak	JSC EH3	DSms-o	mod inc	lar dec	sm inc	ess	lik	mon	
Holt, et al.	LaRC FTS	FTC	lar inc	lar dec	none	use	lik	maj	see note 6 on Q'aire: extends sys lifetime, reduces ground, crew involvement
Holt, et al.	LaRC FTS	FTdxfer-o	lar inc	lar dec	none	use	lik	maj	
Krchnak	JSC EH3	FTdxfer-o	lar inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Holt, et al.	LaRC FTS	FTdxfersg	mod inc	lar dec	none	use	lik	mod	
Krchnak	JSC EH3	FTdxfersg	mod inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Krchnak	JSC EH3	FTmasst-o	mod inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate

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Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Holt, et al.	LaRC FTS	FTpro-o	lar inc	lar dec	none	use	lik	maj	
Krchnak	JSC EH3	FTpro-o	lar inc	lar dec	mod inc	ess	lik	mon	OAST & DoD adequate
Krchnak	JSC EH3	FTs/w	lar inc	lar dec	lar inc	ess	unl	maj	not clear if he thinks OAST &DoD apply here
Aichele	MSFC	HOLrpr-o	lar inc	lar dec	lar inc	use	unl	min	
Samms	LaRC FMB	HOLrpr-o	mod inc	lar dec	sm inc	ess	lik	maj	
Samms	LaRC FMB	HOLs/w	lar inc	lar dec	mod dec	ess	lik	maj	
Krchnak	JSC EH3	HOLs/w	lar inc	lar dec	mod inc	ess	lik	min	
Zapalac	MDAC	HSdbus	lar inc	lar dec	sm inc	ess	cer	mod	
Zapalac	MDAC	HSmem	lar inc	lar dec	sm inc	ess	cer	mod	
Zapalac	MDAC	HSproc	lar inc	lar dec	sm inc	ess	cer	mod	
Aichele	MSFC	NLA	lar inc	lar dec	lar inc	use	unl	min	
Aichele	MSFC	NLU	lar inc	lar dec	lar inc	use	unl	min	
Krchnak	JSC EH3	ROBdexman	lar inc	lar dec	mod inc	none	idt	none	"No firm requirements for robotics identified for IOC station"
Krchnak	JSC EH3	ROBimproc	lar inc	lar dec	mod inc	none	unl	mon	
Zapalac	MDAC	ROBiu	mod inc	lar dec	lar inc	use	imp	min	
Zapalac	MDAC	ROBpatrec	mod inc	lar dec	lar inc	use	imp	min	
Krchnak	JSC EH3	ROBpatrec	lar inc	lar dec	mod inc	none	unl	mon	
Hinchion	MMC	VLSI/VHSIC	lar inc	lar dec	lar inc	ess	lik	mon/maj	

11. Large or Moderate Productivity Increase, Large or Moderate Recurring Cost Reduction, and Major or Moderate Development Emphasis

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Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Friedman	JPL 364	AI LES-g	lar inc	lar dec	sm inc	use	idt	mod	
Krchnak	JSC EH3	AI LES-g	lar inc	lar dec	lar inc	use	imp	mod	
Holt, et al.	LaRC FTS	AI LES-o	mod inc	mod dec	pos dec	use	unl-lik	maj	see notes 4,5 on questionnaire
Friedman	JPL 364	AI LES-o	lar inc	lar dec	sm inc	use	idt	mod	
Krchnak	JSC EH3	AI LES-o	lar inc	lar dec	lar inc	use	imp	mod	
Samms	LaRC FMB	AI/ES	lar inc	lar dec	mod inc	use	idt	maj	
Zapalac	MDAC	AIfddr s/w	lar inc	lar dec	mod inc	use	lik	maj	seems best of AI applications
Palmer	ARC-MVSD	AIfddr s/w	mod inc	mod dec	mod inc?	use	idt	mod	
Holt, et al.	LaRC FTS	AIfddr s/w	mod inc	lar dec	mod inc	use	lik	maj	
Samms	LaRC FMB	AIfddr s/w	mod inc	lar dec	mod inc	use	unl	mod	major emphasis for 2000
Krchnak	JSC EH3	AIfddr s/w	lar inc	lar dec	lar inc	use	unl	maj	SSTF should monitor
Friedman	JPL 364	AIfrecovs/w	lar inc	lar dec	sm dec	ess	lik	mod	
Globus	ARC	AIplan s/w	mod inc	mod dec	sm inc	use	lik	mod	
Zapalac	MDAC	AIplan s/w	mod inc	lar dec	mod inc	use	cer	mod	reduce ground ops
Holt, et al.	LaRC FTS	AIplan s/w	lar inc	mod dec	mod inc	use	idt	maj	
Samms	LaRC FMB	AIplan s/w	mod inc	lar dec	mod inc	use	unl	mod	
Hinchion	MMC	AIplms/w	lar inc	lar dec	lar inc	des	idt	mod	
Palmer	ARC-MVSD	AIsubmon s/w	mod inc	mod dec	mod inc?	use	lik	mod	
Holt, et al.	LaRC FTS	AIsubmon s/w	mod inc	lar dec	mod inc	use	idt	maj	
Samms	LaRC FMB	AIsubmon s/w	mod inc	mod dec	sm inc	use very	lik	mod	
Krchnak	JSC EH3	AIsubmon s/w	lar inc	lar dec	lar inc	use	unl	maj	
Samms	LaRC FMB	AIsymproc	lar inc	lar dec	mod inc	use	idt	maj	
Friedman	JPL 364	AIsymproc	lar inc	mod dec	sm dec	use	unl	mod	
Zapalac	MDAC	CTadap	lar inc	lar dec	mod inc	ess	lik	maj	
Zapalac	MDAC	CTheir	mod inc	mod dec	mod inc	ess	lik	mod	
Zapalac	MDAC	CTav	mod inc	mod dec	mod inc	ess	lik	mod	
Holt, et al.	LaRC FTS	FTC	lar inc	lar dec	none	use	lik	maj	see note 6 on Q'aire: extends sys lifetime, reduces ground, crew involvement
Hinchion	MMC	FTC	lar inc	mod dec	mod inc	des	lik	mod	
Holt, et al.	LaRC FTS	FTdxfer-o	lar inc	lar dec	none	use	lik	maj	
Holt, et al.	LaRC FTS	FTdxfersg	mod inc	lar dec	none	use	lik	mod	
Holt, et al.	LaRC FTS	FTmasst-o	mod inc	mod dec	none	use	lik	maj	
Holt, et al.	LaRC FTS	FTpro-o	lar inc	lar dec	none	use	lik	maj	
Krchnak	JSC EH3	FTs/w	lar inc	lar dec	lar inc	ess	unl	maj	not clear if he thinks OAST &DoD apply here
Globus	ARC	HOLrpr-o	mod inc	mod dec	mod inc	help	unl	mod	
Samms	LaRC FMB	HOLrpr-o	mod inc	lar dec	sm inc	ess	lik	maj	
Dorofee	KSC	HOLrpr-o	mod inc	mod dec	mod inc	use	lik	maj	for VHOL, non life-critical: must be adapted for SS, esp useful 1st yr

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Respondent	Organiz.	Technology	Productiv.	RecCost	NR Cost	Desir IOC	Readi '87	Rec. Emph.	Remarks
Zapalac	MDAC	HOLs/w	lar inc	mod dec	mod inc	use	idt	mod	
Aichele	MSFC	HOLs/w	mod inc	mod dec	mod inc	use	lik	maj	
Samms	LaRC FMB	HOLs/w	lar inc	lar dec	mod dec	ess	lik	maj	
Dorofey	KSC	HOLs/w	mod inc	mod dec	vsm inc	use	lik	maj	RECCOST= sm-mod dev could be NASA or minor funding to IEEE to ensure ready-both
Dorofee	KSC	HOLsups/w	lar inc	mod dec	mod inc	use	unl	maj earl	see notes: some s/w dev tools to be avail commercially: some SS-specific
Zapalac	MDAC	HSdbus	lar inc	lar dec	sm inc	ess	cer	mod	
Palmer	ARC-MVSD	HSdbus	lar inc	mod dec	sm inc	use	lik	mod	
Zapalac	MDAC	HSmem	lar inc	lar dec	sm inc	ess	cer	mod	
Palmer	ARC-MVSD	HSmem	mod inc	mod dec	sm inc	use	lik	mod	
Zapalac	MDAC	HSproc	lar inc	lar dec	sm inc	ess	cer	mod	
Palmer	ARC-MVSD	HSproc	mod inc	mod dec	sm inc	use	lik	mod	
Samms	LaRC FMB	NLU	mod inc	mod dec	sm inc	use	unl	mod	
Palmer	ARC-MVSD	ROBdexman	mod inc	mod dec	mod inc	help	idt	mod	
Globus	ARC	ROBiu	mod inc	mod dec	mod inc	help	idt	mod	
Zapalac	MDAC	ROBteleop	mod inc	mod dec	mod inc	use	lik	mod	
Palmer	ARC-MVSD	ROBteleop	lar inc	mod dec	lar inc	use	idt	mod	
Krchnak	JSC EH3	ROBteleop	mod inc	mod dec	lar inc	use	unl	mod	
Globus	ARC	ROBtelepr	mod inc	mod dec	sm dec	help	imp	mod	
Zapalac	MDAC	ROBtelepr	mod inc	mod dec	mod inc	use	lik	mod	
Palmer	ARC-MVSD	ROBtelepr	lar inc	mod dec	lar inc	use	idt	mod	
Hinchion	MMC	Rdextarm	lar inc	mod dec	lar inc	ess	unl	maj	Robotics
Hinchion	MMC	Rintelman	mod inc	mod dec	lar inc	use	idt	mod	
Hinchion	MMC	Rintelmob	mod inc	mod dec	lar inc	use	unl	mod	Robotics
Globus	ARC	VLSIsp-o	mod inc	mod dec	mod dec	help	unl	mod	
Globus	ARC	mininс-o	mod inc	mod dec	mod dec	help	unl	mod	Minimum instr. set computers