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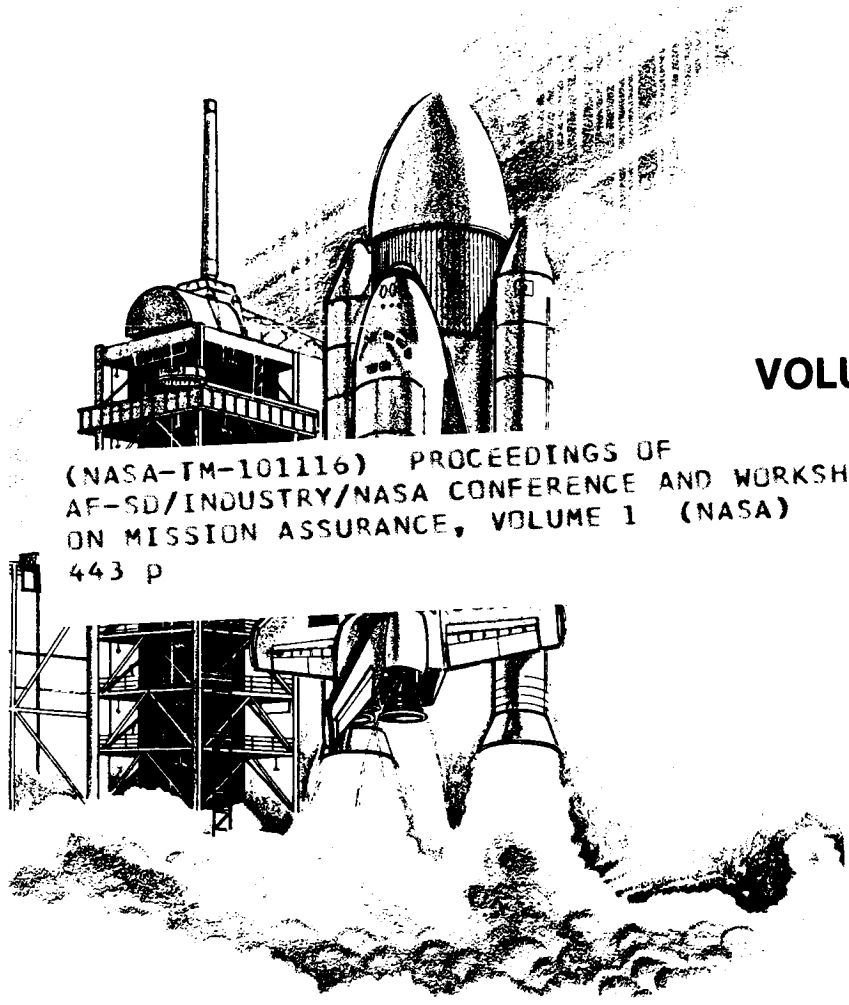

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AIA

Aerospace Industries Association

SPACE DIVISION

Space Division

NASA

National Aeronautics and Space Administration

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OBJECTIVES

Project:

In April 1980, a Mission Assurance Conference was sponsored jointly by the Air Force Space Division and Industry to discuss fundamental issues that would enhance spacecraft mission success. The 1980 Mission Assurance Conference resulted in the implementation by management of many of the recommendations generated in the conference. Because of the success in 1980, the Space Community consisting of Air Force Space Division, NASA and Industry Associations, NSIA and AIA have mutually agreed to conduct Mission Assurance-1983 to further explore the issues affecting both Government and Industry which inhibit mission success on Space Programs. Issues in program management, design, procurement craftsmanship, test effectiveness, motivation, development process and in other areas affecting mission success will be openly discussed and analyzed in workshops with audience participation. The final objective will be recommendations from the workshops directed at both Government and Industry management for implementation.

Goals:

- Identification of obstacles and counter-productive practices having an effect on mission attainment.
- Development of cost effective approaches or better utilization of information and resources to enhance mission success.
- Determination of new or better application of existing techniques providing a forcing function to mission risk minimization.

Conference:

The purpose of this conference is to provide the broadest exposure and most time efficient means of exploring significant tasks necessary to achieve mission assurance. This conference allows us to utilize the aggregate technical and managerial talents of Government and Industry to provide recommendations and guidelines in areas of their major concern.

The conference objectives are to:

1. Stimulate exchange of ideas between Industry and Government on management/technical/acquisition support aspects of mission assurance.
2. Provide a forum through which the total community can impact and address problem areas.
3. Provide a continuance to the next Space Division/NASA/Industry Mission Assurance Conference.

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CONFERENCE COMMITTEES

CONFERENCE CHAIRMEN

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NASA KEYNOTE ADDRESS

STANLEY I. WEISS
CHIEF ENGINEER
NASA

MISSION ASSURANCE CONFERENCE KEYNOTE SPEECH

Earlier this month I attended the Bottom Line II Conference sponsored by the Defense Logistics Agency. The "bottom line" that meeting focused on was the reliable performance of weapons and support systems provided to the Armed Services. Performance assurance was the objective. Our bottom line...Mission Assurance, is not much different--and behind both of these definitions lie a whole family of "assurances" involving products, operations, maintenance and people. This third Mission Assurance Conference has particular importance because it looks forward to a new era for all of us, highlighted by not just the introduction of our operational Space Transportation System but by the fact that our national dependence upon it mandates that its continued operational status must be assured. It means addressing new environments, solving new problems, meeting new challenges for mission success. The community represented by all of you, NASA, the Department of Defense, and industry, has a common objective which, because of the character of the Space Shuttle, requires closer working relationships than in the past, dealing not only with the technical demands of the system itself, but also dealing with the institutions within which we work. Some of these changes come about because of new partnerships we are developing in operation of the Shuttle--with a wide variety of users whose equipment compatibility with the Shuttle is as widely varied--with the Air Force in operating the Western Test Range and using the IUS; with ESA in using the Spacelab; and with industry as supplier and service contractor. The inspection and quality control requirements and maintenance of a 24 flight per year operation add whole new dimensions to our space program. Other changes will be driven by institutional factors, such as, initiation of a unified Shuttle processing contract at KSC or adoption of government-wide federal procurement regulations.

While there are new challenges that result from re-use of STS hardware, unique logistics considerations, and the requirement for maintainability both of the STS and of the systems we put into space, from the mission assurance standpoint we

still have old problems to deal with as well. History repeats itself sufficiently so that continued recognition of opportunities for failure as demonstrated by past experience is required. We still drop wrenches into space hardware; it is still possible to leave O-rings out of seals; there's the growing danger of a complacency with repeated operations that compounds the technical complexity of the systems we deal with. But we're not alone in our attention to assurance questions. This country has become increasingly aware that product improvement is mandatory for our national economic health in a world that has become increasingly competitive with once unchallenged U.S. technology. In the long run, the heart of product improvement is quality assurance--the end game of quality assurance--mission assurance.

The consciousness developed by the last Mission Assurance Conference and echoed in proliferating similar forums has increasingly affected, or perhaps just re-forcussed, our attention. But we have not achieved 100% mission successes, either with the Shuttle or other systems. Landsat D, the IUS, the Shuttle engine leaks, the first EVA suits, the booster recovery failure of STS-3, as well as some defense system mishaps, all remind us of the difficulties inherent in the sophisticated technologies we deal with. But we also do have remarkable successes: the continuing record of Shuttle performance, 35 straight successful Delta rockets, recovery of the TDRSS mission, and many others. However, the impact of the losses--not only lost dollars but also data and hardware--are not just perceptions but demand our continuing attention to most of the old issues and a variety of new needs. And in NASA they have begun to emerge in some initiatives of recent months. Our strong concern with workmanship standards, EEE parts and the like will continue and in the latter area we look forward to new cooperation with industry DCAS, DESC, and AFSD. New areas include the development of an agency-wide software management and assurance program, scoping of a materials assurance program, initiatives to develop new assurance technology (e.g., NDE for composites and VLSI) and a systematic look at the maintainability of

systems--both for a potential space station and for the retrievable spacecraft that we'll use in the Shuttle. Some recent failures have prompted us to recognize that in some cases, major changes have been made in our approach to systems development as a result of cost pressures that have had real bearing on our "mission assurance," particularly in reduction of test units. We are just beginning extensive re-reviews of how we and our contractors are doing business (e.g., the extent of required testing, independent reviews, etc.), we are addressing re-development of NASA-wide flight certification standards, as well as placing new emphasis on productivity improvement through quality enhancement. The last is taking place under an activity directed by the NASA Administrator, PIQE is examining both NASA internal operations and relations with contractors including NASA/contractor communications, technical reviews, contractual actions, incentives, standardization, front-end manufacturing considerations and NASA/contractor/subcontractor requirements. And recognizing the growing international nature of our space program, we are looking at ways to simplify our interfaces with ESA, e.g., inter-agency cross-referencing of NASA and ESA specs and standards.

With respect to the Space Transportation System, while we must strive for less detailed NASA control of user payloads if the Shuttle is to achieve the flexibility and low cost operation that has been our goal, we must maintain high assurance of payload safety and performance--at least to the extent that they can affect the Shuttle, its other payloads and mission objectives. That takes shared standards of quality and mission assurance objectives by Government, users, and contractors.

Mission Assurance requires setting high standards and meeting them. It requires that those standards are understood by customers, contractors, and the personnel that make up their organizations. And for those personnel, there must be

an expectation that meeting those standards will satisfy their needs as individuals and as members of their respective organizations. This means pride in organization, its products and achievements.

Tom Murrin, President of Westinghouse Electric's Public Systems Company, and initiator of its pioneering productivity center, recently said that productivity is largely determined by quality. Mission success is the equivalent in our business and it too is governed by quality. This quality must apply to all aspects of the process that yields mission success. This is mission assurance. It starts with concept and systems design. It must be reflected in the design rooms, in manufacturing, test assembly and operations. Deficiencies at any of these levels breed defects at the next. Mission assurance requires commitment to quality at all levels of the program and of the management of programs and cognizant institutions. In this new era of space transportation and exploitation of that capability, all these elements and the programs they relate to provide increasingly complex challenges to all of us. This Mission Assurance Conference is structured in recognition of this. The 10 workshops involve many of the lead people in the nation in their designated areas, plus this meeting affords us all a unique and timely opportunity to participate in assessing and shaping where "mission assurance" goes from here in those areas of interest and importance to all of us. Regardless of your particular interests, however, there is a common tie among all of the workshops--and that is their address to quality and excellence. That is also our common tie as individuals. So let us work together over the next few days as a precursor of what must be a continuing cooperation in solving our "community's" problems and leading the way toward 100% mission success. Our challenge as participants is to identify key issues, develop realistic assessments and recommendations and then translate these, when we leave, into reality--into true mission assurance. The time is right. Let's take advantage of our mutual objectives and let this conference help point the way to the future.

INDUSTRY KEYNOTE ADDRESS

G. W. JEFFS
PRESIDENT, NORTH AMERICAN SPACE OPERATIONS
ROCKWELL INTERNATIONAL

General Session

Industry Keynote

G. W. Jeffs

President, North American Space Operations

Rockwell International

Abstract

The continued striving for quality improvement is critical to hardware and mission objectives, and in military systems it is also fundamental to maintaining the freedom of our nation. Four areas significant to the quality process are emphasized: 1) design and test (drawings and process specifications, configuration management, design reviews, test conditions and requirements); 2) fabrication (planning tickets, verification, adequacy of tools, material review system, and understanding of hardware by subcontractors); 3) checkout (testing sequence and procedures); and 4) operations (integrated processes and ground handling of hardware. The issue of quality is people--the concern of the individual for quality, the concern of the individual as a participant on a team, and the concern of the team for total quality.

CLOSING REMARKS
LT. GENERAL FOREST S. McCARTNEY
COMMANDER, AIR FORCE SPACE DIVISION

General Mc Cartney provided an Overview of his recent assignment as Commander Space Division and Vice Commander, Space Command. He shared his viewpoint that his predecessor, Lt. General Richard C. Henry had assembled an efficient and smooth functioning organization, well staffed with competent people during his tenure as Space Division Commander. Therefore, he sees no reason to make any changes at this time. General Mc Cartney stated that in the coming year he would continue to emphasize two major items; Mission Assurance, and Cost Control. The bottom line in the space business is to have successful missions while at the same time keeping costs under control. Working Conferences such as this help us meet these goals by allowing both Government and Industry to share both good and bad experiences and working on solutions to mutual problems.

A review of the history of space activities from the late 50's through early 1983 reveals that space exploration is now a nationally recognized reality. The early periods of experimentation and exploration have given way to consolidation of what we have learned in those periods for the exploitation of space and the deployment of operational systems for: Navigation; Communications; Weather Reconnaissance; and Surveillance. Space Systems are now recognized as having an indispensable role in combat capabilities.

In the early days of experimentation and exploration some degree of failures were expected, accepted and tolerated. However, this is no longer true, we have now built such a good track record in space that more is expected of the space community. Risks are being taken now that would not have been considered years ago. Deployment of operational systems without the benefit of long qualification and development programs places a heavy burden on both Government and Industry Managers. In the 80's, there will not be the tolerance for failures that we experienced in the 1960's or even what we tolerated in the 1970's. This means that Mission Assurance, along with good cost control is a primary goal.

One of the products of the Space Division Product Assurance Program is the Mission Assurance Conference which gets people together to share experiences and to try finding ways to improve mission success. There are many facets to mission success, including all the subjects covered in the Mission Assurance Conference Workshops. The Space Division will continue to emphasize these programs. However, the burden is on management to see that the standards are set and each job is done right the first time. In the space business, the opportunity to fix a problem the second time around does not occur. Every step in designing, building and launching a spacecraft is important to do correctly from the first day. Management must set the standards to assure this attitude prevails throughout the entire life cycle. While the overall track record of space mission success is good, in the future all the benefits we learned in the past must be improved upon. We must continue to share experiences and search for ways to do our job better, for less. The bottom line is we must provide quality products at the best price for our customer--The American People.

WORKSHOP A
STS OPERATIONS

Chairmen:

Dick Colonna
Manager of Program Operation Office
NASA

Marty Adams
Division Director, Design and Product Assurance
Rockwell

Coordinator:

Pete Leonard, Rockwell

Subgroup Co-Chairmen:

- Payload Integration and System Safety
  - Lt. Col. Larry Combs, USAF Space Division
  - Dick Moke, NASA
  - B. J. Taylor, Space Communications
- Shuttle Utilization
  - Bob Everline, NASA
  - Bob Battey, NASA
  - Sandy Sanborn, Rockwell
- STS and Payload Ground Processing — ETR and WTR
  - Bill Husonica, NASA
  - Bernie Bienstock, Hughes
- NASA/AF Transition
  - TBD, USAF/VAFB
  - Bill Ramroth, Thiokol
  - Gale Waite, Rockwell

STS OPERATIONS WORKSHOP

CHAIRMEN: Dick Colonna, 713/483-5193
Manager of Program Operations Office
NASA JSC

Marty Adams, 213/594-3894
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Rockwell International

COORDINATOR: Pete Leonard, 213/922-1040
Rockwell International

INTRODUCTION

The purpose of this workshop was to thoroughly discuss the area of Shuttle operations. The workshop informed attendees of current policy and future plans. Areas known to be difficult and not fully understood were discussed, with the objective of identifying improvements and providing specific recommendations.

Typical topics included:

- System Safety Requirements
- Safety Certification Process
- NASA/DoD Schedule Protection/ Turnaround
- Payload Manifest Process
- Identification of Potentially Unnecessary Requirements

The workshop format included presentations of experience sharing and policy by Government and Industry.

Issues were raised, debate was vigorous, and the workshop participants had the opportunity to work closely on specific issues in order to arrive at conclusions and recommendations.

SYNOPSIS OF PRESENTATIONS

Except for one presentation for which a paper was submitted, the remainder consisted of briefings. The presentations are summarized below.

1 - SOLAR MAXIMUM REPAIR MISSION
Michael Bay, Fairchild Space Co.

The purpose of the Solar Max Repair Mission, which is planned for the STS-13 Shuttle launch, is to repair in orbit the Modular Attitude Control System. If successful, this repair will enable the SSM Observatory to once again be capable of precision pointing.

The SSM is unique in that it was the first spacecraft designed to be captured, retrieved, launched, or serviced by the STS. Its modular construction is designed specifically for EVA purposes.

The repair of the SSM Observatory will demonstrate STS capability for maintenance and repair and lead the way in demonstrating that "throwaway" spacecraft need not be any longer.

2. CARGO OPERATIONS/CUSTOMER/ INTERFACES
Bill Husonica, NASA KSC

The KSC organization and interfaces with other Government agencies and Industry were identified. The processing flow from "intent to fly" to hardware delivery and from hardware delivery to launch was described. Manifest concerns and customer concerns were discussed.

The requirements for Interface Control Drawings (ICDs) and Flight Safety Reviews were discussed as well as Cargo Level and Vehicle Level Readiness Reviews and Post Launch feedback.

As a result of mutual concerns, KSC identified specific enhancements for facilities, payload processing, and launch processing in order to be able to meet the goal of 30 launches per year.

3 - STS-5 PAYLOAD OPERATIONS
Bernard Bienstock, Hughes Aircraft

A scenario of events was presented, spanning the activities required to test, ship, integrate the payloads, perform pad testing, and launch the ANIK "C" and SBS communication satellites. Some of the problems encountered with the multitude of interface checks, duplication of testing, and the potential cost imposed upon a contractor because of launch delays were discussed. A key lesson was to gain early involvement of the payload developer in the definition of interface test requirements.

4 - STS PAYLOAD INTEGRATION
Dick Moke, NASA JSC

The objectives of the STS integration process are to establish a system to accommodate both complex and simple payloads. For instance, in the case of simple payload, interfaces are minimized as much as possible. In the first 40 STS flights, there are 101 payloads of which 63 will be different. In order to accommodate this quantity of payloads, Payload Integration Plans (PIPs) ICDs must be developed and customers must be made aware of the detail necessary to configure STS flight and ground systems and of the NASA safety requirements and the flight review process. The payload integration management function was identified in terms of Engineering and Operations working groups and the PIP annex book managers.

Projected efficiencies in the payload integration process were also described.

5 - STS-6 PAYLOAD CONTAMINATION PROBLEM
Bruce Aaront, Space Comm. Co.

The TDRS communication satellite which was launched on STS-6 encountered a potentially serious contamination problem. This was caused by a combination of factors. One was that the payload was in the change-out room for a much longer period than had been anticipated (47 days actual versus 20 days predicted).

The second was the fact that a severe storm hit the launch site with winds up to 57 knots. This caused the barriers which seal the cargo bay to the payload change-out room to open, thus allowing moist air and contaminants to flow into the room. Factor No. 3 was attributed to human error when someone inadvertently turned on the hypergolic fuel vent fans. This caused all the contamination to swirl for about 4 hours before it was discovered.

As a result of this experience, numerous changes are to be made to try to prevent future contamination problems. For instance, increase in the change-out room static pressure is to be instituted so that in the event of high external winds, enough positive pressure will exist to prevent contamination from blowing in.

The message is clear, however, the payload change-out room is a working area, it is a clean room but not a room free of contamination (white room). Consequently, payload users should make allowances in their design for contamination potentials which exceed "white room" levels.

6 - MANIFESTING FOR THE STS
Bob Everline, NASA JSC

The goals of the manifesting process are to be responsive to user requirements, maximize the utilization of the STS, and minimize turnaround and cost. The factors which affect the manifesting process are flight rate, systems capability, and limited resources. Any changes in these elements automatically cause change in the manifesting process.

7 - SPACE SHUTTLE - A NEW ERA OF SPACE CAPABILITY
Sandy Sanborn, Rockwell

The purpose of this presentation was to provide an update of STS capability and review progress in turnaround improvements.

The space transportation system capabilities highlights which were discussed are:

- o Emergency repair capability
- o Sortie missions (with equipment retained in payload bay)
- o Teleoperator maneuvering
- o Expanded utility assembly
- o Placement & recovery of satellites
- o Extended mission capability

Successful examples affecting turnaround improvements such as test requirements deletion, TPS improvements, and simultaneous hazardous fluid servicing were identified.

8 - VANDENBERG, LAUNCH AND LANDING SITE
Col. Fred Rochez, USAF

The need for a West Coast site capable of providing Polar launches was discussed. Vandenberg best satisfies the site selection criteria. Vandenberg is now being readied to have an STS initial launch capability in October 1985.

The Vandenberg organization, its interfaces with NASA and Industry were discussed.

The operations concept of Vandenberg and the changes to the KSC mode of operation were identified. The status of the activation plan and a description of the major facilities being developed were presented. The total program cost of developing Vandenberg for STS operations is approximately 4 Billion. At present, activation of the site is on schedule.

ISSUES AND RECOMMENDATIONS

The consensus of the workshop attendees is that the Shuttle Transportation System is reliable, durable, credible, and improving. The operator, NASA and USAF, and their customers have common goals. The mission to be "assured" is to:

- o Reduce orbiter processing turnaround
- o Reduce payload processing time/effort
- o Increase missions/payloads
- o Maintain safety
- o Standardize
- o Maximize the efficient use of this national asset

The issues discussed in the workshop affect or threaten the mission goals stated above. The major issue is inability to achieve the required flight rate, therefore, most of the issues of the workshop are oriented toward recognizing and counteracting this major threat. The issues and recommendations are discussed in the following text.

SUMMARY OF ISSUES AND RECOMMENDATIONS

STS OPERATIONS

SUMMARY OF
ISSUES AND RECOMMENDATIONS

1. Competition for Limited Resources

Issue

Resource limitations can constrain flight rate goals, particularly with the development of another major launch site at Vandenberg underway. Based on user and operator recent experience, the lack of such items as transport equipment, payload ASE, spares, and software have a noticeable effect on STS processing. These support resources are vitally needed, however gaining support for their acquisition is not as exciting or dramatic as the development of a new launch site or the acquisition of a new orbiter.

Recommendations

To focus attention on this area, the workshop suggested that a team be formed to identify and prioritize specific support resources for further acquisition. A second recommendation is to survey and catalog existing assets such as qualification test articles, development test articles, or items which were built but not required by the contract, etc. which could be refurbished and made available as spares. If pursued, these two recommendations could result in focusing attention on support resources and minimize their acquisition costs through intelligent scrounging.

Suggested OPR

Space Division/NASA

2. Lack of Customer Confidence/Understanding

Issue

Lack of confidence and understanding is caused by negative and inaccurate perception of the requirements a payload developer must satisfy to launch his payload. Inaccurate perceptions, including unwarranted fear, can be overcome through added emphasis and accomplishment of specific, directed actions.

Recommendations

a) In response to earlier requests, JSC has established a customer service center. This center is being formalized and it should be publicized and supported because it will provide the primary resource for complete and accurate information to potential customers.

b) Customers who have already been through the payload process could be assigned to share experience and to coach a new customer. This approach would provide an alternate credible source of information to prospective customers and serve to offset preexisting inaccurate or negative perceptions.

c) The workshop recommended that industry and the operator combine resources to coordinate and increase marketing the Shuttle Transportation System. An alliance of operator and existing industry customers could provide added marketing clout and credibility.

d) The workshop recommended that improved capability be provided and that accommodations for cargoes of opportunity, e.g., standby payloads, be publicized.

e) The workshop recommended that the manifesting procedural process be reviewed and streamlined to reduce time from payload conception to flight.

Suggested OPR

Item a) NASA
Item b) Industry
Item c) NASA/Industry
Item d) NASA
Item e) NASA

3. Cleanliness/Contamination

Issue

User and operator experience shows that payload processing facilities at KSC are not capable of maintaining precision clean or "white room" capabilities.

Recommendations

Update the core ICD to reflect probable contamination levels consistent with recent experience. Users should be advised that precision cleanliness can not be guaranteed by the operator and that the users must take design and procedural actions to safeguard their own payloads.

Suggested OPR

NASA

4. Standards for On-Orbit Repair/Service

Issue

The Solar Maximum Mission effort has developed tools, techniques, and design solutions to problems which may commonly affect future missions where repair or maintenance is intended. However, there are no existing standards.

Recommendations

Develop and publish a standard for on-orbit repair/service missions.

Suggested OPR

NASA

5. DoD Safety Review Process

Issue

A formal process for response to customer prepared safety noncompliance replies and action items is not clearly defined. Delays have occurred in the transmission of acceptance or rejection of contractor responses from the Safety Review Team through the USAF Program Office to the contractor.

Recommendations

USAF/SD amend SD127-4, System Safety Certification Procedures and Technical Requirements for DoD STS Payloads, to identify the responsible reply function and a time line for formal response.

Suggested OPR

USAF/SD

6. Payload Peculiar Risks

Issue

Workshop discussions of the Safety Review process disclosed that the primary focus is to safeguard the STS-related equipment and personnel involved in the total process. Larger threats to the general community may not be adequately considered.

Recommendations

Provisions should be made for appropriate non-operator agency reviews when peculiar payload risks are identified.

Suggested OPR

NASA/DoD

WORKSHOP B

PRODUCTIVITY-MOTIVATION-INCENTIVES-QUALITY IMPROVEMENTS

Chairmen:

Ralph Tortorich
Chief of Mission Success
Martin Marietta Aerospace

Ed Houston
Chief, Productivity Management Division
USAF Space Division

Coordinator:

Darlene Medina
Administrator of Motivation Programs
Rockwell

Subgroup Leaders:

- Motivation
  Kevin Welch
  Coordinator of Motivation Programs
  Martin Marietta Aerospace
- Quality Circles
  Dr. Philip C. Thompson
  Coordinator of Systems Refinement Teams
  Martin Marietta Aerospace
- Quality Improvement and Productivity Enhancement
  Ed Houston
  USAF Space Division

SESSION 1 — MOTIVATION AND QUALITY CIRCLES SUBGROUP

Quality Circles Northrop Experience	Robert Patchin, Northrop Corporation
Quality Circles — An Outline	Dr. Philip Thompson, Martin Marietta Aerospace

SESSION 2 — QUALITY IMPROVEMENT AND PRODUCTIVITY ENHANCEMENT PROGRAMS SUBGROUP

Space Division Quality Improvement Program	Jerry Robinson, USAF Space Division
Westinghouse Quality Improvement Program	Hal Jones, Westinghouse
General Dynamics Quality Improvement Program	Jim Talley, General Dynamics
Value Engineering	Tony Negrete, Hughes Aircraft Company
Manufacturing Technology	Dr. Gary Denman AFWAL/Materials Laboratory
Quality Circles in the Air Force	Major Russel Lloyd Wright-Patterson AFB/AFIT

WORKSHOP B

SESSION 2 — QUALITYY IMPROVEMENT AND PRODUCTIVITY ENHANCEMENT PROGRAMS SUBGROUND (Continued)

NASA Employee Teams Program and Policy	Dave Braunstein and Dave Austin NASA Headquarters
NASA Manned Flight Awareness Program	Darlene Medina, Rockwell
White House Council on Productivity and Motivation	Jerry McAdams, Maritz Corporation
Quality Circles in a Multi-Contractor Multi-Worksite Environment	Richard Fort, Martin Marietta
View of Motivation and Productivity	William Cramer, Boeing

QUALITY CONTROL CIRCLES

IN AN OFFICE ENVIRONMENT

BY

ROBERT I. PATCHIN

Our society has changed remarkably in the last 10 to 20 years. This has shown the need for new requirements for relating to our workforce, and Quality Circles is one technique for putting it all together.

I don't know if you've thought of it, but we are trying to move in two directions at once. On one hand, people are trying to express more individuality --yet we are more and more interdependent. This causes internal tensions that are brought to the workplace, and progressive managements are trying to understand the situation, and provide solutions.

To understand our employees, we can relate to the Maslow Heirarchy of Needs. While the older generation operates at the safety and survival levels, the young folks start much higher up the pyramid. They are better educated, have only known a high standard of living, and are taught that they have a right to be heard. All indicating a higher level of needs and desires.

Smart management is tuning in to this new employee, and the new phrase "Quality of Work Life" sets the criteria for the successful operation of the future. We are finding that the workforce deserves respect, and responds positively to dignified treatment. We find them to have a higher level of interest in their role in the organization, and a desire to participate that can be triggered by a solicitation of their ideas for improvement.

Putting these things together, we find a natural step to be a teaming arrangement to solve problems--from which will flow a natural, positive, recognition for a job well done. This is not to be entered into lightly, for participation requires clear goals, each program must be tailored to the climate of your company, and it will require an investment of resources. Finally, you must recognize that it will require a deep change in the way the business is conducted if it is to be successful for very long Experts suggest that 85% of the change is in management, and I agree.

Quality Control Circles offer a very specific package for an employee participation program. A circle is made up of a group of people who work together all week long. They voluntarily meet together, usually for an hour a week, to identify and solve the problems that keep them from being more productive. The supervisor is the circle leader, and another person is the helper or facilitator.

The program is built on a structured training package that will be explained in detail later. Basically, the circle is taught problem solving in a very specific manner, and a secondary benefit is that they develop a much better ability to communicate.

HISTORY

The history of the circles movement began with Japan's desire to live down their reputation for shoddy goods after World War II. They invited American experts to teach them modern statistical Quality Control--and by the late 1950s they were as good as anyone else in the world. Not satisfied, they asked for more help, and two American's, Juran and Deming, worked with Dr. Ishikawa to develop the circle program. Interestingly, while their first focus was on quality improvement, they quickly found that they had to include costs in their studies. Now they have moved beyond those subjects, to include quality of work life consider ations. Since we Americans are so new at this, I insist that we must focus on quality and cost improvements, and from successfully working the process we will get better working relationships.

There are some basic concepts at work here:

The employee is an expert, the employee wants to contribute, participation is voluntary,Circle chooses problems, outside help is available, process if formalized, and management is not obligated to accept evedry recommendation.

THE PROCESS

The process, and the training, teaches the circle to identify and rank problems, select one to work on, and how to gather data to establish the size of the problem, and then how to develop solutions in an orderly manner. We then teach a simple payoff analysis to allow the circle to scale the costs of the solution to the problem, and finally the circle presents their findings to management with a request for action.

As you get into circles, you find some new rules and jargon. A Steering Committee acts like a greenhouse to protect this very tender thing you are growing. It reviews status, establishes policy, coordinates circle support from outside experts and helps get suggested changes implemented.

The leader is responsible for the hour the circle members meet. He leads out in the circle, makes sure they stay with the process and provides encouragement and direction. The facilitator supports the leader at our company. He gathers data, or sees that the members do, and is responsible for the momentum of the process between meetings. In other companies the facilitator is not a part of the circle, but comes from a central office. In that case, the facilitator is the trainer and process expert, in addition to playing the continuity role.

TECHNIQUES USED

Quality circle brainstorming is not the free-for-all that some may picture with the term. The leader goes around the circle, with each member contributing in sequence, one idea at a time. If they don't have an input, they pass--but may come back on the next cycle with an idea that is built on a concept presented by another. Everyone contributes freely, and there is never to be a criticism or ridicule of an individual or an idea.

The data gathering is of the simplest score-keeping type. The members may keep track of variations in size, or defects, or good vs bad, in any appropriate useful way. They then convert this to scatter diagrams, histograms or simple trend analysis. One of the easier methods is to construct a pareto chart which focuses attention on the numerically largest criterion.

Once a problem has been isolated, it is identified as an "effect" on a "cause and effect analysis" chart. This is often called the fishbone chart in circles jargon, and helps the members brainstorm for solution clues. It breaks possible causes into the categories of "manpower," "material," "machines," and "methods." Once all possible causes are down on the chart, the members vote to select the largest, or most likely cause, to explore.

The group may gather additional data or move to the presentation to management. In essence, the circle says (to management) "this is the problem, this is how big it is (from the data gathered), this is what we think will solve the problem, and this is how it will benefit you,if you accept our recommendation." By allowing each member to participate in the presentation, each one can take a proprietary pride in the activity, and can be the recipient of the recognition that will naturally flow from a responsive management.

Management should then respond with a "yes" or "no" answer. It must explain a "no" answer. On occasion, they may ask for more information, suggest further avenues of exploration, or point out that the recommendation can not be implemented because of information that the circle did not have access to.

PROJECT BACKGROUND

My first exposure to Quality Circles occurred in July 1978 when a Japanese tour group visited our facility. In Japan, a reward system is established allowing for the presentation of quality circle "projects" within each plant. The best project is chosen for competition within city, county, state and national levels. Quality circles projects are presented at seminars and workshops

around Japan on the average of every three days. The top 17 competitors of 1978 were sponsored on a world tour traveling throughout Russia, Europe, South America and the United States. In Los Angeles, our company had the privilege of hosting the visit of the Japanese touring members. The pride and authorship that was exuded by these people was so magnetic that by the time the briefings were concluded the executives in the audience said "We don't know much about this, but we've got to have it!"

Further investigation was conducted, and a consultant's seminar was attended by several of our people. I instructed them "Don't come back and tell me the good points of the program , tell me what's wrong with it!" I couldn't understand, if the program was as good as it sounded, why it hadn't taken the world by storm. They came back and said they could not find a flaw. Subsequently, we purchased a training program to be conducted by experienced Quality Circle practitioners, and very quickly went from the barest knowledge in the third week of July to program implementation immediately following Labor Day.

PILOT PROJECT

The intial training phase, or "pilot project" included the identification of six circles within our assembly operations. The training team arrived in August to begin a four day training session, to be followed by two months each of Circle member training and then Quality Circle participation; management was promised a review of the project by the end of the year.

PILOT PROJECT COSTS

Pilot Project costs were as follows:

Training Project Package	$6000
Seminars	$3000
Training Materials	$1000

The standard Training Project Package provides training for one or two Circles; We bought a package to accommodate six Circles. In addition, one person was devoted full time for four months to training and the eight-member management group selected for the Steering Committee expended 200 hours. These labor costs totalled about $17,000, and when added to the $10,000 for the outside training, we had an out of pocket cost of $27,000 for the pilot project.

Interestingly, there was no production loss, either in output or in schedule. We make the flat statement that there is no cost for member involvement in Quality Circles. In fact, one group was nine units behind schedule on Labor Day, and on Thanksgiving it was two units ahead of schedule. This group experienced the same parts shortages, quality problems, tools and other problems; the only difference was that these people were immersed in Quality Circles and that worker attitudes changed from "why bother" to "can do."

COST SAVINGS

During the pilot project,the company documented $115,000 in savings. Implementation costs were $9,000 for a net savings of $106,000 from the ideas generated by the Circle groups during the first four months. In future years, approximately 8,450 hours annually will be saved as a result of these projects. Remembering the $27,000 investment, you can see that our savings were four times the investment. This was for the four months of the pilot project, half of which was used in training the circle members.

COMMUNICATIONS

Tremendous changes occur in the communication ability of people involved in Quality Circles. We call it the hidden benefit. People suddenly become able to present themselves in a much better manner, having been taught a logical communicative process. Instead of pounding the table, the worker now says that "this is the problem, this is what I would like to do about it, and these are the other things that I have considered; let's get something done."

EMPLOYEE ATTITUDES

The attitude survey mentioned earlier was conducted before people knew anything about Quality Circles, and a followup survey was conducted three months later. The following items from our attitude survey illustrate the dramatic change in worker attitudes resulting from their participation in Quality Circles.

	Before Pilot Project	After Pilot Project
"My Supervisor isn't fair"	31%	4%
"I don't like my job"	27%	13%
"I can't participate in decisions"	59%	33%
"I'm asked to do unnecessary work"	41%	21%

PILOT PROJECT RESULTS

In late December 1978, the promised report to management was given, reviewing the gains resulting from the program. Recommendations were made involving staffing and facility requirements and positive administrative decision was solicited, along with a departmental budget. The response was favorable: "We liked what we saw, go with it."

CURRENT PROGRAM

After two and one-half years, the plant has over 50 Circles, involvement in 13 departments, nearly 100 people trained as Circle Leaders, 100 more trained as Facilitators and over 500 Circle members. Circles have been implemented in assembly areas, fabrication shops and quality assurance organizations for three different airplanes in two geographical locations. White collar Circles have been formed in the areas of manufacturing engineering, materiel, facilities, finance, maintenance, employment and compensation, and aircraft services. Annual cost savings from the projects implemented by management during the first two and one half years totals over $1,000,000.

We have modified the consultants' training program, cutting it down to three days. This is used with new Circle leaders and part-time facilitators. An nine-week training course, one hour a week, is set up for Circle members and a dedicated meeting room is required for every 12-15 Circles (two hours per meeting during a 40-hour week). A pilot project can be conducted using borrowed rooms but a full-blown Circle program requires dedicated facility space. An additional suite of offices includes a training room for the three-day concentrated course for new Circle Leaders and Facilitators, and office space for the training unit, and one of the meeting rooms.

Since my main objectives were to improve productivity outside the factory, I was anxious from the beginning to try the circle process in an office environment.

With over 2 years experience at this time, some general observations can be made. No matter how well educated the office people are, we have found them to be less knowledgeable of the fundamentals of improvement thinking. They have not been challenged repeatedly like the factory folks have, to do things better and faster. They also tend to explore ideas more thoroughly, consequently the training may take a bit longer.

On the other hand, the very lack of emphasis over the years makes the office more fertile territory for exploring for improvements. The factory has had its industrial and manufacturing engineers, and its motivation and efficiency drives for years. They have "skimmed the cream" of good ideas. The office has not been worked over, so there are usually tremendous improvement opportunities.

One feature that can upset management, particularly your systems and procedures people, is that most office projects relate to paperwork improvements. If you stop to think about it, that is all most office workers do. They get paper from someone or create it themselves. They also subtract, add, or manipulate information and they then authorize the hand off to the next step. They seldom or never see a hardware product, so office circles tend to focus on combining or simplifying forms or reducing signatures and flow times. In summary, the office is fertile ground for the search for improvement implicit in the circles process.

Typical Projects

I will start with several typical examples of office circle projects and you will find tabular data on another 27 attached.

1. Our circle in the employment records area has been one of our most prolific. We have a modified cafeteria benefit plan involving a half dozen medical plans and several dental and life insurance plans. Each new employee was asked to fill out a form for each selection, that asked almost identical questions. This circle has combined all the possibilities onto one computerized form that eliminates the repitition and confusion--and saves over $25,000 per year.

2. The same circle suggested that we use a word processor to type the letter that accompanies the 90 day to 40 year service pins. This has saved $2000 in tedious typing.

3. This circle suggested and worked out all the details for combining the forms used to hire, promote, or transfer personnel. They then had to develop a training package, and train 350 department clerks to use their new system. This will save $35,000 per year, and is so successful that it is being adopted corporation wide.

4. I call this one the great leap backward in technology. One of our procurement circles was frustrated by the delays in processing the paperwork for low-value items. They found that we were buying whisk booms on the same paper and systems as multimillion dollar long lead forgings. Because their items were low value, they got delayed in the que, and often the items were delivered before the computer churned out the order. They proposed and sold the concept of a hand-write multi copy form that could be filled out as the order was placed over the phone. Used on items worth less than $500.00, this new system saves over $87,000 per year.

5. A circle in the employment office suggested that post cards be used to reply to mailed-in resumes and applications by checking off boxes on the card. The applicant is told "we received your resume on such a date, it has been referred to a named organization and you will hear again from us by another date". Admittedly, it is less personal than a dictated letter, but it goes out in a timely manner. Past practice was to accumulate such mail, then someone dictated the response, someone else typed it, then back for signatures, duplication, and filing; as well as mailing to the person. We are saving $8000 per year with this change.

REVIEW OF FIRST-YEAR OPERATIONS

Any organization will be faced with start-up problems during the implementation of Quality circles. Northrop's first-year activities were very strongly affected by major changes occurring within all three major programs. These operational changes created a significant impact on Circle group activities. New Circle Leaders and Facilitators were required to be trained and Circle members were moved from one area to another. The six Pilot Project Circles experienced 10 changes of Leaders and Facilitators in the first seven months. The message, of course, is that if circles are to be started, every possible effort should be made to introduce them into a stabilized atmosphere.

The first-year activities wee also affected by inadequate support from middle management. Tremendous support was obtained from the top, and from the bottom as the wrokers began to volunteer and became involved, but we did not do a good job of selling and promoting middle management support. Middle management was puzzled and even concerned about Circle activities and therefore not generally supportive, or worse, was pouring cold water on the implementation of Circle suggestions. Today even if top and bottom support of Circles are assured, the chain of command must also be willing to provide support or Circles will not be started.

Another obstacle to Circle progress has been lack of timely response. Workers, unlike management, are not tuned to delays built into the system. A short-circuit system must be implemented to convince people that this program really is supported by management.

Objective evaluation of Circle progress is also a major factor important to the effective development of Circle groups. The training group's energy can be wasted trying to "prop up a dead horse" when, for the same amount of energy, three new Circles can be trained.

I am afraid that Quality Circles is viewed as an instant panacea, a magic potion to sprinkle on the workers to make them, happy, hardworking automatons. It is not. It is a situation where management makes major changes--where management backs off, gives the training and time away from the job, responds positively and gives recognition where it is due. It is an organic change that allows people to "grow and glow!"

In a properly operated program, events will cascade so that the Circle will automatically generate inprovements through involvement. Circle members offer cost-saving ideas, participation develops employee enthusiasm, and from the enthusiasm, real change in people is realized.

The implementation of Quality Circles has provided a very practical means of developing participative management. Many companies have had thousands of people trained in participative management only to find that, in a "theory-X" atmosphere, no one can relate to these types of practices. It is not unusual that, within a week after completion of training, the statement will be made that "it may work in the classroom, but it doesn't work here." The Quality Circles training process hits both top and bottom at the same time, and it works!

OFFICE QUALITY CIRCLE PROJECTS

	YEARLY SAVINGS
• EQUIPMENT/FACILITIES AUTHORIZATION FLOW CHANGE	$ 4,800
• CHANGE IN TIMEKEEPING METHODS	$27,000
• REVISED BILL OF MATERIALS FORM	$19,000
• STANDARD DATA PREPRINTED ON MATERIAL REQUEST FORM	$ 2,000
• REVISED DATA FLOW FOR "CHAIN READING"	$ 2,200
• REVISED PLANNING FORM	$ 600
• EXTENSION PHONE ADDED IN QUALITY ASSURANCE	$ 2,000
• REVISED RECORDING OF MATERIAL REVIEW LISTS	$13,000
• CHANGE IN REQUISITION APPROVAL PROCEDURE	$10,000

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QUALITY CIRCLES -- AN OUTLINE

Dr. Philip C. Thompson
Coordinator
Systems Refinement Teams
Michoud Division
Martin Marietta Aerosapce

The Goal - Our goal is to improve the performance of people at work. To achieve it, we promote quality circles (structures and processes that grant employees greater responsiblity and authority over their tasks), performance feedback (information on the success of their performance) and incentives (tangible rewards for improving their performance). The end results are organizations that are happier, healthier and stronger and produce more and better goods and services, at lower costs.

Elements of a Fully Developed Performance Improvement System - There are at least six major elements to a successful performance improvement system. Three form the core, and three support it.

Core
1. Quality Circles
2. Performance Feedback
3. Incentives

Organizational Supports
4. Quality Circle Office
   a. Facilitators
   b. Training
   c. Special Maintenance Structures
5. Technical Expertise
6. Organizational Culture (beliefs and values)

The Core - 1. Quality Circles - As a structure and a process, the quality circle represents a small but significant change in the power relations of an organization. It grants employees the right to try to solve their work problems rather than have management solve problems for them.

The organization grants time (usually one hour each week, paid), space (a dedicated meeting room), and mandate (identify problems and develop solutions, excluding items subject to labor negotiations or defined by personnel policy). In addition, the organization grants a circle access to all information relevant to the chosen problem, as well as all managers who should hear and evaluate the proposed solution.

Until now, we have viewed quality circle participation as voluntary. This may change. There is ample evidence that circles in the more advanced efforts are developing beyond simple problem-solving groups. They are setting long-term performance improvement goals and regulating their own performance to achieve these goals. To reap the full benefits of this process, all employees of a given work area must participate.

2. Performance Feedback - To set performance goals and to identify problems obstructing the attainment of these goals, the circle requires timely, regular, reliable, relevant and understandable feedback on the performance of the shop or office it represents. Much of this information comes from major functional departments within the organization, such as quality, industrial engineering, finance and safety. But the decision on what data to trend and the definition of what constitutes "timely, regular, reliable, relevant and understandable" is worked out with, if not by the circle. This is crucial not only because each work area, as represented by its circle, "buys into" the performance trends, but also because each work area, from the machine shop to the financial estimates office, requires a different set of performance trends. Each work area has different dimensions to measure.

In addition, circles use these different dimensions to set their own performance goals. For example, while trending ten dimensions of performance, a circle may decide that the defect rate is too high, set a target rate, and work to reach it by identifying and solving problems related to quality. Meanwhile, it continues to track the nine other performance dimensions to ensure that they remain acceptable.

3. Incentives - The organization provides incentives (awards and recognition) to

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improve poor or maintain high performance scores. These are linked directly and visibly to performance trends agreed on by a quality circle, in such a way that employees know beforehand that, if they achieve certain performance levels, they will immediately and with certainty receive the award and/or recognition. To achieve the greatest success, incentives are structured so that they reinforce teamwork in quality circles rather than individual efforts.

Awards and recognitions range from articles on presentations in the company newspaper, to periodic gift awards, to gainsharing. Whichever incentive system is used depends on the age of the circle effort and the type and purpose of the organization. If gainsharing is utilized, it is essential to regulate the amount of sharing at some proportion of the dollar value of the maintained or improved performance, as measured by the performance trending.

The System - Once in place, these three elements form a functional system. At the center of this system is the circle - a cluster of rights and obligations that allows effective involvement, or as some express it, participation. On its own, this innovation produces significant results, at least initially. Circles present improvement ideas, some of which save considerable money. Morale improves. Quality improves. But, without performance feedback, some circles produce only haphazard results, perhaps die, or worse, survive as nonproductive "bull sessions". Performance feedback is equivalent in importance to the circle itself. Without real, reliable, immediate, regular and usable measures of performance, circles cannot choose realistic goals, identify and solve problems that help them to achieve these goals or know when they have achieved them. Good performance information becomes the guidance system. With it, circles can focus on quality, for example, and work at improving it until they reach that "zero defect" objective. Without it, they wander in the dark, fixing this, improving that, saving a little money, but not necessarily improving their work. And without it, management wanders in the dark, feeling that circles improve the organization, but unable to know for sure.

This system requires a third element - energy, something to make it run. The power to change how work is done and the information to show when a change occurs, are necessary but not sufficient components. One needs a reason to engage in this enterprise. Initially, having spent most of their working lives in situations in which they had no voice over how they did their work, most employees find the right to speak motivation enough. As they become more involved, many employees find the process of performance improvement through problem solving a challenge. But, in the long run, most employees need some form of recognition and reward beyond these "intrinsic" ones. They need "extrinsic", tangible rewards in the form of gifts, trips or some type of gainsharing. Any or all of these awards are possible. The only, but essential, criterion is that they be directly linked to the performance measures and are visible and known to all employees beforehand.

Organizational Supports - 4. Quality Circles Office - The quality circle office, composed of administrator and/or coordinator, is responsible for the general promotion and coordination of the quality circle effort. With this as a charter, it usually oversees the provision of a number of subcomponents: training, facilitation and special maintenance structures. The budgets for these subcomponents may reside in other departments or within the office itself, but either way the office coordinates these support elements and is responsible for the circle effort.

Training: All members of the organization (employees, supervisors, middle managers, upper managers and support specialists) receive training in group problem-solving techniques, both elementary and advanced, group decision making, and effective circle leadership. In addition, there is special emphasis on data collection and statistical analysis.

Facilitation: Facilitators are trained in group process and leadership, problem-solving, and most importantly, data collection and statistical analysis. They attend all circle meetings to advise and assist

both leaders and members and to monitor circle activities. In addition, facilitators work behind the scenes with managers and technical specialists to ensure the smooth operation of circles, especially in the early states when members and leaders are unsure of their roles and abilities.

Facilitators can be either paid, full-time specialists or part-time volunteers. Eventually, as circles, managers and technical specialists become more comfortable with the system, the role of facilitator and the number of facilitators, declines.

Special Maintenance Structures:

The quality circle office promotes various organizational structures or processes to enhance the acceptance and operation of quality circles at all levels of the organization. These may include:

a. A steering committee, drawn from the entire organization, to set policy and sponsor and oversee the work of the quality circle office.

b. If the organization is large, advisory and support committees in each of the major departments to oversee the installation of quality circles, advise departmental facilitators and receive and evaluate reports on circle activities.

c. Periodic leader luncheon meetings to recognize the special efforts of circle leaders, discuss common problems and successes and introduce advanced training material.

d. Special groups, such as integrated teams, task teams and management teams, to provide for group problem-solving and statistical analysis at the middle and upper management levels.

5. Technical Expertise - The organization provides technical expertise to circles when needed. It does not force it on circles; it responds when circles request information or help. One means of doing this is through a circle of technical experts who volunteer to review circle needs and organize an effective response.

6. Organizational Culture - The members of an organization acquire a set of values and beliefs that support the quality circle process. These values and beliefs exist in some individuals before circles are introduced, develop in others as the effort expands, blossom in many as circles become institutionalized in the normal management process of the organization and are never felt or thought by a few. The quality circle office promotes these beliefs and values wherever and whenever possible through training, articles and personal conversations. But, in the last analysis, they grow and become the norm as the quality circle process succeeds. Since success can only be demonstrated by performance improvement, regularly measured performance data are crucial to winning the active support of everyone in the organization.

QUALITY IMPROVEMENT

Jerry Robinson
Quality Assurance Specialist
Air Force Space Division
Product Assurance Division

This presentation summarizes the recent quality improvement initiatives within Air Force Systems Command and Space Division. It outlines the Space Division quality improvement program with emphasis on the SD/industrial interface and the results of a recently completed survey of industry executives concerning the causes and cures of the "hidden plant".

1. AFSC QUALITY IMPROVEMENT PROGRAM - In September 1982, General Marsh, Commander of Air Force Systems Command (AFSC), initiated the AFSC quality improvement program. In his letter to the AFSC product divisions the General made the following points:

a. As we implement the President's mandate to modernize our defense force in the face of limited resources, we must seek more efficient ways of acquiring our weapon systems. Air Force acquisition processes and procedures can have a negative impact on the product if not suited to the acquisition or if not implemented properly.

b. One area where we can achieve significant gains with minimum financial investment is quality assurance. The AFSC quality policy as stated in AFSCR 74-1 must be strongly enforced throughout the acquisition cycle to be effective. Quality requirements are expected to be given the same emphasis as cost and schedule requirements.

c. A quality improvement program has been initiated within Headquarters/AFSC to improve the quality and productivity of our methods of acquiring weapon systems. Each product division is strongly encouraged to establish a similar program.

d. We strongly suggest to our major contractors that they voluntarily implement a similar program. One area of improvement which deserves the highest priority is the reduction of the "hidden plant" -- the plant that repairs and reworks the defects, retests the product and handles the scrap. Our estimate is that a minimum of $570 million was spent on scrap, rework, and repair in 1980 in 21 of our largest plants.

2. AFSC PROJECT QUALITY - Project Quality is an AFSC initiative which is part of the AFSC quality improvement program. It is chartered to develop contractual incentives to reduce "hidden plant" costs. An ad hoc group was formed which developed a list of possible approaches or techniques which could be used to effectively reduce "hidden plant" costs on AF contracts.

The list was reviewed by the membership of the Aerospace Industries Association (AIA). The initial reaction was that the list of possible actions developed by Project Quality addressed symptoms rather than causes. AIA also felt that some of the proposals by the ad hoc group infringe upon the right of the contractor to manage his organization and may lead to unnecessary cost with little effect upon the intended goal. A number of proposals were considered worthwhile.

3. PROPOSED SD QUALITY IMPROVEMENT PROGRAM - The objective of the Space Division quality improvement program is to improve the quality of SD acquisition management and thereby improve the quality and affordability of the systems we procure. Quality improvement involves all SD and Aerospace Corporation organizations involved in the acquisition management process. Quality and productivity improvement are viewed as part of an overall, coordinated program of corporate improvement. Within SD the vehicle for corporate improvement is the annual corporate plan and the process used to assemble and implement the plan. Each year quality improvement goals are identified by each SD two letter office. Specific objectives and milestones are established. Each project is reviewed and approved by an executive review board of SD top management. Progress is tracked and periodically reviewed throughout the improvement year as part of the corporate planning and improvement program review cycle.

4. SD/CONTRACTOR QIP INTERFACE - Contractors are being encouraged by AFSC and the product divisions within AFSC to

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voluntarily begin quality improvement programs. Broad quality improvement programs will not be legislated in contracts. Some aspects of quality improvement which are pertinent to individual programs could be required by contracts, however. Contract incentives are being considered by AFSC Project Quality, for instance. If contractors choose to implement broad quality improvement programs, one area of improvement which needs immediate attention is the reduction of the "hidden plant", or the costs associated with scrap, rework, repair and retest. The SD Commander sent a letter to industry executives urging them to begin quality improvement programs and asking their opinion on the root causes and cures of the "hidden plant", as well as what SD could do to reduce "hidden plant" costs on SD contracts.

5. HIDDEN PLANT - As far as we know, the term "hidden plant" or "hidden factory" was coined by Dr. Armand Feigenbaum who is President and Chief Executive Officer of General Systems Co. This term was explained by Dr. Feigenbaum in a speech to the National Conference on Quality in Washington, D. C. in April of 1982. Dr. Feigenbaum says in his speech that based on the quality cost data his company has collected throughout the world, there may exist today even in modern and well organized factories what he calls a "hidden plant" -- both in the factory and in the office -- sometimes amounting to from 15% to as much as 40% of total productive capacity. This is the plant that exists to rework unsatisfactory parts, or to maintain buffered stocks of inventory, or to replace products recalled from the field, or to retest and reinspect rejected units. While Dr. Feigenbaum did not single out any particular industry, such as Aerospace, AFSC figures indicate that approximately $570 million was spent on scrap, rework and repair in 1980 in 21 of our largest contractor plants. General March has since repeatedly stressed the importance of reducing "hidden plant" costs on AF contracts.

6. SPACE DIVISION SURVEY - In connection with the "hidden plant" emphasis, the SD Commander sent letters to a crossection of SD contractors and asked them three questions:

1 - What is your company's experience with the "hidden plant"?

2 - What do your line managers and supervisors feel are the root causes of the "hidden plant" andhow can the causes be eliminated?

3 - Are we, Space Division, encouraging the existance, and possibly the growth of the "hidden plant" through our contracting approach or management practices? If we are, what changes should we consider and why?

The whole point of these questions was to gather some data from our own contractors to better understand the "hidden plant" from their perspective and to get some feedback as to whether SD was somehow contributing to the problem.

7. - 11. RESPONSE TO SURVEY - Eighteen of twenty-three contractors responded to the SD survey letter. Each of the respondees voiced enthusiastic support for the AFSC and SD quality improvement initiatives. While all indicated that they have had systems operating for some time to measure and control "hidden plant" costs, a number of the respondees (General Dynamics, Boeing, Ford, Aerojet, G. E., Rockwell, Vought and Westinghouse) stated that they have established formal quality improvement programs as well. Only a few of the executives gave us quantitative information on the size of their "hidden plant" which ranged from .7% to 2.9% of total sales. (If these numbers seem very small, it's because they are most likely based on only the direct labor costs of scrap, rework and repair and do not include indirect costs which would substantially increase these percentages). Our respondees also indicated that, while these figures are an average over all programs, "hidden plant" costs tend to be much higher for programs in R & D versus programs which are baselined and in production.

As to the root causes of the "hidden plant", one conclusion came through loud and clear. In the opinion of the majority of the executives, the major contributor to "hidden plant" costs is the lack of sufficient schedule and funding to do an

adequate job of design, design validation and process development during the development portion of the program. Coming in a close sedond was the lack of effective producibility reviews during the design and pre-production phases of the program, and overspecification. A number of respondees made the point that, while quality systems can detect, measure and correct the "hidden plant" symptoms, the root causes themselves are management problems which can be prevented only through effective program planning very early in the program. We agree with this conclusion.

As to whether SD is contributing to the "hidden plant" by virtue of our contracting approach or management practices, a number of executives felt that we could do a better job of program planning to eliminate or reduce schedule concurrency and increase development funding. Other complaints included too much micromanagement, overspecification, and not enough emphasis given to quality and producibility design review.

PROPOSED SD QUALITY IMPROVEMENT PROGRAM (QIP)

- OBJECTIVE IS TO IMPROVE SD ACQUISITION MANAGEMENT
- ANNUAL QUALITY IMPROVEMENT PROJECTS
- CORPORATE PLANNING AND IMPROVEMENT PROCESS
  - IDENTIFY GOALS - DEFINE OBJECTIVES
  - TOP MANAGEMENT INVOLVEMENT AND REVIEW
- ACTIVE QIP INTERFACE WITH INDUSTRY
  - MISSION ASSURANCE CONFERENCE
  - SD QUALITY ASSURANCE MANAGERS

SD/CONTRACTOR QIP INTERFACE

- CONTRACTORS ENCOURAGED TO VOLUNTARILY BEGIN QIP'S
- BROAD QUALITY IMPROVEMENT CANNOT BE LEGISLATED BY AF
  - MUST BE A VOLUNTARY CORPORATE EFFORT
  - MUST HAVE FULL COMMITMENT AND INVOLVEMENT OF MANAGEMENT
- AFSC RECOMMENDS EMPHASIS ON REDUCING HIDDEN PLANT COSTS
- SD LETTER TO INDUSTRY EXECUTIVES
  - URGED VOLUNTARY QUALITY IMPROVEMENT PROGRAMS
  - ASKED THREE QUESTIONS ON HIDDEN PLANT
  - INDUSTRY RESPONSE SUMMARIZED

AFSC QUALITY IMPROVEMENT INITIATIVE

- INITIATED IN SEPT '82 BY LETTER FROM AFSC COMMANDER
- OBJECTIVE IS TO IMPROVE AFSC AQUISITION METHODS
- PRODUCT DIVISIONS REQUESTED TO BEGIN QIP'S
- INDUSTRY ENCOURAGED TO VOLUNTARILY BEGIN QIP'S
  - WITH EMPHASIS ON REDUCING HIDDEN PLANT COSTS
- PROJECT QUALITY INITIATED AT AFSC HEADQUARTERS
  - OBJECTIVE TO DEVISE CONTRACTUAL PROCEDURES TO MOTIVATE CONTRACTORS TO REDUCE HIDDEN PLANT COSTS

HIDDEN PLANT

- DR. ARMAND FEIGENBAUM
  NATIONAL CONFERENCE ON QUALITY, 1 APR 1982

  " THERE EXISTS TODAY, EVEN IN MANY MODERN AND WELL-ORGANIZED FACTORIES THROUGHOUT THE WORLD, WHAT OUR GENERAL SYSTEMS ENGINEERS CALL A "HIDDEN PLANT" -- IN THE FACTORY AS WELL AS IN THE OFFICE -- SOMETIMES AMOUNTING TO AS MUCH AS 40 PERCENT OF TOTAL PRODUCTIVE CAPACITY. THIS IS THE PLANT THAT EXISTS TO REWORK UNSATISFACTORY PARTS, OR TO TEST AND RE-INSPECT REJECTED UNITS, OR TO REPLACE PRODUCTS RECALLED FROM THE FIELD."

AFSC PROJECT QUALITY

- DEVELOP CONTRACTUAL INCENTIVES TO MOTIVATE CONTRACTORS TO REDUCE HIDDEN PLANT
- AD HOC COMMITTEE FORMED - APPROACHES EXPLORED
- AIA/NSIA REVIEWED LIST OF 43 SUGGESTED ACTIONS
  - SOME ITEMS CONSIDERED COUNTERPRODUCTIVE
  - SOME CONSIDERED VALID
- INDUSTRY RESPONSE PRESENTED TO AFSC ON 28 JAN '83
- AIA/NSIA PRESENTATION ON PROJECT QUALITY AT THE JUNE MISSION ASSURANCE PROJECT

SPACE DIVISION SURVEY

- WHAT IS YOUR COMPANY'S EXPERIENCE WITH THE "HIDDEN PLANT"?
- WHAT DO YOUR LINE MANAGERS AND SUPERVISORS FEEL ARE THE ROOT CAUSES OF THE "HIDDEN PLANT", AND HOW CAN THE CAUSES BE ELIMINATED?
- ARE WE, SPACE DIVISION, ENCOURAGING THE EXISTANCE, AND POSSIBLY THE GROWTH, OF THE "HIDDEN PLANT" THROUGH OUR CONTRACTING APPROACH OR MANAGEMENT PRACTICES? IF WE ARE ENCOURAGING THE "HIDDEN PLANT", WHAT CHANGES SHOULD WE CONSIDER AND WHY?

RESPONDEES

AEROJET SACRAMENTO	HUGHES (SPACE & COMMUNICATIONS)
AVCO SYSTEMS DIVISION	LMSC (SSD)
BOEING AEROSPACE	MARTIN MARIETTA (DENVER)
CHEMICAL SYSTEMS DIVISION	MC DONNELL DOUGLAS ASTRONAUTICS
DELCO SANTA BARBARA	ROCKWELL (N.A. SPACE OPERATIONS)
FORD AEROSPACE	SYLVANIA SYSTEMS
FAIRCHILD SPACE & ELECTRONICS	TRW
GENERAL ELECTRIC (SSD)	VOUGHT (DALLAS)
HONEYWELL	WESTINGHOUSE ELECTRIC (SPACE DIV.)

PRIMARY CAUSES OF THE HIDDEN PLANT

- o UNREALISTIC DEVELOPMENT SCHEDULES
- o UNDERFUNDING THE DEVELOPMENT EFFORT
- o POOR DESIGN FOR PRODUCIBILITY
- o OVERSPECIFICATION

EXPERIENCE WITH HIDDEN PLANT

- o RANGES FROM 0.7% - 2.9% OF SALES
- o TENDS TO BE HIGHER FOR R & D PROGRAMS THAN FOR PRODUCTION PROGRAMS
- o LEVEL OF TECHNOLOGY AND MATURITY OF PRODUCT LINE INFLUENCE S/RW/R LEVELS
- o OUT-OF-SHOP FACTORS CAN SIGNIFICANTLY EFFECT S/RW/R
- o ALL RESPONDEES ARE AWARE OF HIDDEN PLANT AND HAVE SYSTEMS DESIGNED TO MEASURE AND CONTROL IT
- o SEVEN RESPONDEES INDICATED THEY HAVE FORMAL QUALITY IMPROVEMENT PROGRAMS

GENERAL DYNAMICS	ROCKWELL
BOEING	VOUGHT
FORD AEROSPACE	GENERAL ELECTRIC
WESTINGHOUSE	

S/RW/R = SCRAP, REWORK, REPAIR

HIDDEN PLANT CAUSES

ROOT CAUSES	AEROJET	AVCO	BOEING	CSD	DELCO	FORD	FAIRCHILD	G.E.	HONEYWELL	LMSC	MARTIN	M. DONNELL D.	ROCKWELL	SYLVANIA	TRW	VOUGHT	WESTINGHOUSE
LACK OF DEVELOP. FUNDING		X				X										X	X
LACK OF DEVELOP. SCHEDULE		X				X	X					X				X	X
UNSTABLE PROGRAMS					X		X			X							
OVERSPECIFICATION						X	X					X					X
POOR PRODUCIBILITY DESIGN			X						X	X		X					X
POOR DESIGN		X			X										X		
POOR DESIGN REVIEW							X										X
POOR DESIGN VALIDATION			X						X								
INADEQUATE DESIGN MARGINS																	X
INCORRECT DESIGN TOLERANCES				X			X					X					
LACK OF Q.A. AWARENESS								X				X					
LACK OF MGMT. RESOLVE								X	X			X					
LACK OF MANUFAC. READINESS															X		
POOR WORKMANSHIP					X					X							
POOR PROCESS CONTROL				X			X							X			
OPERATOR ERROR															X	X	
POOR TRAINING										X		X					X
LIMITED TOOLS/TECHNIQUES				X	X			X									
POOR QUALITY PARTS					X									X			X
PART SUBSTITUTIONS						X											
AF MICROMANAGEMENT		X		X													

SIZE OF HIDDEN PLANT

CONTRACTOR

- A - $200,000 MINIMUM IN S/RW/R COSTS IN '82
- B - .5% SCRAP; 1.5% REWORK/REPAIR (% OF SALES) - DIRECT LABOR ONLY
- C - $1.71 PER MANUFACTURING LABOR HOUR
- D - 0.7% OF SALES
- E - 2.9% OF SALES
- F - 1.0% OF SALES
- G - YIELD RATES RANGE FROM 99.9% TO 0.1% DEPENDING ON PRODUCT LINE

S/RW/R = SCRAP, REWORK AND REPAIR

CURES FOR HIDDEN PLANT

- o EARLY AND EFFECTIVE DEVELOPMENT PLANNING (SCHEDULE & FUNDING)
  - o INDEPENDENT SCHEDULE ASSESSMENT
  - o MULTIYEAR FUNDING
- o INCREASE EMPHASIS ON PRODUCIBILITY
  - o PDR, CDR, PRE-PRODUCTION
  - o EARLY INVOLVEMENT OF DESIGN, PRODUCTION & QUALITY ENGINEERING
- o BUILD TEAM RELATIONSHIP BETWEEN PROFESSIONAL AND FACTORY PEOPLE
- o EMPHASIZE COMPREHENSIVE DESIGN VALIDATION DURING DEVELOPMENT
- o AF SHOULD DEMONSTRATE MANAGEMENT COMMITMENT TO QUALITY EQUAL TO COST AND SCHEDULE
- o SCRUTINIZE PERFORMANCE REQUIREMENTS CLOSELY - DON'T OVERSPECIFY
- o ENCOURAGE AUTOMATION AND COMPUTER AIDED DESIGN
  - o CONTRACT INCENTIVES - AWARD FEE
  - o PRODUCIBILITY ENHANCEMENT

ELIMINATE THE HIDDEN PLANT!

William E. Montgomery
General Manager, Space Division
Westinghouse Electric Corporation

and

Harold C. Jones
Senior Advisory Engineer
Westinghouse Electric Corporation

In a speech at the Bottom Line Conference held at Fort McNair, General Marsh coagulated the many costs associated with rework, repairs, quality costs, design correction, low vendor quality, and similar items under the banner of the "hidden plant", a term coined by Dr. Armand V. Feigenbaum. He placed the cost of the "hidden plant" at billions of dollars per year in lost buying power over the entire defense industry. The following are the salient points of why Gen. Marsh feels this "hidden plant" exists.

. Quality is not yet a total committment on the part of major defense contractors.

. The quality of American products is being outpaced by foreign industries, particularly Japan.

. US companies rely too heavily on inspection.

. Major contractors are not managing subtier suppliers to achieve high quality.

. The best workers are utilized in the repair or rework functions, not as leaders in making it right the first time.

One of the strongest points that General Marsh made was the fact that we must do it right the first time and that the USAF is going to structure contracting procedures and decisions to reward those who do so.

In a follow up to General Marsh's speech, General Henry indicated that the Space Division of AFSC shared Gen. Marsh's concerns, and specifically asked the following questions of his contractors:

. "What is your company's experience with the "hidden plant"?"

. "What do your line managers and supervisors feel are the root causes of the "hidden plant", and how can these causes be eliminated?"

. "Are we, Space Division, encouraging the existance, and possibly the growth, of the "hidden plant" through our contracting approach or management practices? If we are encouraging the "hidden plant", what changes should be consider and why?"

These are good searching questions, and this paper will address each one of these in some depth.

Before getting too deeply into details, however, let us attempt to further define the "hidden plant" so that its causes may be more clearly identified. As we see the "hidden plant" it is any effort which is a duplication of previous effort or was never needed in the first place. The most obvious example would be rework and repair. A much more subtle, but no less valid, example is the effort spent in expediting to shore up a poor production system. In a similar vein engineering change notices required to correct the mistakes in the original design are a part of the "hidden plant".

Taken to its logical conclusion, one could say that the entire quality control and inspection effort is a part of the "hidden plant", and we feel that this is indeed true. One of the major functions of quality control and inspection is to detect and reject defects. If they never existed, there would be no need for inspectors and QC. Before any of the qualify professionals explode, let us hasten to differentiate between the Quality Control and Inspection function and Quality Assurance. In our lexicon the people in the Assurance functions are those who function to prevent defects rather than detect them after they exist. It should be the goal of a good quality assurance system to minimize the need for extensive inspection. This entire philosophy applies to the USAF quality function as well as the contractor's.

If we all are able to do an outstanding job of our quality assurance function, the need for routine inspection and surveillance will indeed be minimized.

Now let as turn to the specific questions posed by General Henry.

1. "WHAT IS YOUR COMPANY'S EXPERIENCE WITH THE "HIDDEN PLANT"?"

Every enterprise in the world which produces a tangible output, be it hardware, software, or perhaps even ideas, has some measure of the "hidden plan" existent within its operation. Anyone who seriously thinks about the problem will quickly convince himself that there must be something which can be done to improve acceptable results and reduce unwanted results; i.e., repair, rework and scrap. Many of these thoughts have been wrapped up in a neat package of improving the "quality" of our work; but for this to be meaningful, the word "quality" must be interpreted in its broadest sense, much broader than most people in the industry fully appreciate.

In our opinion, there is no such thing as absolute goodness when it comes to quality in the broadest sense. There are always things that could be done to improve the overall quality level of a given operation. Take scrap rates, for example. Our scrap rates vary from 99.99% (yes, only 0.01% good product is produced) for our most sophisticated advanced VLSI semiconductor fabrication to less than 1.0% for our best automated machining and assembly operations. Rework and repair rates do not cover such a broad spectrum, but the basic problem of setting a standard of goodness remains the same. Yet there remains an inherent resistance to change which dictates the philosoply: "If it ain't broke, don't fix it!" So, once in production, we accept the status quo, or put the pressure on our quality or manufacturing organizations to compensate for problems that they are powerless to correct. The real problems must be fixed at their source -- the design itself. (We mean the word design to include the processes and procedures used to make the product, not just the drawings and specifications which define the output result.)

This ties in very closely with the philosophy being promulgated by the distinguished quality consultant Dr. W. Edwards Deming. One of his most basic messages is to utilize simple, straightforward statistical methods to establish the variability of a process. If the process is statistically in control and is producing too much scrap, the process and/or the design is not capable of producing the parts required. One or the other (or both) must be changed to improve the yield.

In summary, there is definitely a "hidden plant" in the production of aerospace hardware (and software); it is larger than it needs to be, but correcting the situation demands examining the root causes. This brings us to the second question.

2. "WHAT DO YOUR LINE MANAGERS AND SUPERVISORS FEEL ARE THE ROOT CAUSES OF THE "HIDDEN PLANT" AND HOW CAN THE CAUSES BE ELIMINATED?"

To answer this question, we will look at three separate "time blocks" in the life of a program as follows.

2.1 Government/Manufacturer Interface. This is the area of initial specifications of performance, cost, schedule, and quality and takes place predominately in the early phases of the program. Some of the most severe problems in this area are listed below.

2.1.1 Performance Overdesign. It has become almost axiomatic that any new piece of spaceborne equipment will require performance which is beyond the existing state of the art. Concurrent with this the size and weight must be held to a minimum. Trying to improve the performance and pack it into a tight package often results in a design which is immature when the unit is released for manufacture. Problems are often encountered in achieving the required performance, and manufacturability is very difficult, if not impossible. This often requires extensive design revision with its attendant scrap and rework cost. It is, of course, recognized that any new design's reason for being is to advance the state of the art, but great care should be exercised to be sure that the advances required are both necessary and have a reasonably high probability of attainment. This applies to all basic specifications such as performance, size, weight, power consumption, etc.

2.1.2 Unrealistic Schedule. In the area of schedule, the problem is well known. In order to meet the often excessively tight schedules, designs are released to manufacturing which are immature, parts screening is bypassed, and other

risks are taken. The result is again excessive scrap and rework and the attendant lower reliability. This is most surely a joint problem since a great deal of time is often wasted just "spinning wheels" trying to get started on a job. From the government's standpoint it is necessary that the required schedule be reviewed very carefully to assure that it is really achievable. From the manufacturer's point of view, we must be more open in objecting to schedules which can't be met, and at the same time we must develop better methods for shortening the time from "go ahead" to having a fully operating program "up to speed". Finally, in an incentive program we must both be careful that the schedule incentive is not such as to outweigh the quality incentive thereby causing a "schedule over all else" atmosphere to exist.

2.1.3 Cost Problems. In the cost area the major problem seems to be inadequate "front end funding". Too often the initial design phase is underfunded requiring expensive and time consuming redesign when problems are encountered in qualification or production. Another very important contributor to the "hidden plant" is "stop and go funding". When a program is suddenly cut back due to lack of funding, vital trained people must be dispersed to other places. When the program is restarted many of these people cannot be retrieved and a retraining period is encountered. This slows the program down, contributes to rework and reduces efficiency; all of which wastes money.

2.2 Early Manufacturing Phase. Several of the more vexing problems are listed below.

2.2.1 Manufacturability. There is often a basic problem with the manufacturability of the designs which have been generated. As manufacturers we should (and often do) make extensive formal producibility reviews a mandatory part of the design process. The government can also assist in this area by requiring their use and sending representatives to the reviews who really know and understand the problems involved in manufacturing. Consultants should be used if needed to augment this function.

2.2.2 Operator Performance. A pervasive problem which also contributes heavily to the "hidden plant" is poor operator performance in the manufacture of the product itself. This car be caused by many factors, among which are inadequate training, improper matching of operator to job, unclear definition of exactly how to perform the job and poor operator motivation. This problem is primarily in the realm of the manufacturer, but policy guidance to the AFPRO might be appropriate.

2.2.3 Parts Problems. In this phase of the production cycle, parts problems are often encountered. As discussed in the recent IEEE "Spectrum" on Defense, most part manufacturers consider the defense business as less desirable than commercial business due to demands for high quality coupled with relatively low volume. While the AFSC Space Division's efforts in establishing the JANTX, JANTXV and ER level parts has been a major step toward alleviating these problems, we still find a need to screen incoming parts. On the DMSP satellite we used an independent screening laboratory with quite good success. This allowed more rapid acquisition of the parts from the manufacturers and rapid turn around on the screening function.

Eventually it is hoped that we can establish a system similar to the Janapese in making parts suppliers more of a partner, but at the present this is not feasible. We have, however, somewhat alleviated the problem by extensive negotiations with part suppliers to establish mutually acceptable specifications early in the program.

2.3 Late Manufacturing and Deployment Phase. At this phase of a program the problems usually shift from the more obvious to the more subtle. A couple that are worthy of mention are as follows.

2.3.1 Failures due to Inadequate Design Margins. If design margin studies were not performed properly (or at all) and if design margin testing was not utilized during the design phase, it will almost always become apparent during qualification or early deployment. The resulting changes at this level of maturity can be very serious and costly. The remedy is inherent in the problem. Require that a good job of design margin calculation and testing be done and reported at design reviews. This activity should be carefully reviewed by the person assigned by the government to cover the design reviews.

2.3.2 Irrelevant Failure to Meet Specifications. In the myraid of specifications directly applied to the project, specifications referenced in those specifications or referenced in the referenced specification, etc., there are bound to be requirements which have not beem complied with. Mindless enforcement of specifications which do not improve the product is a very real source of the "hidden plant". The remedy is simple to state, but somewhat harder to implement: give the AFPRO representatives the authority to think, rather than blindly enforce the specifications, and be sure that they have the technical expertise to exercise this authority wisely.

This also carries a responsibility for us in industry. In dealing with customer representatives (AFPRO), we must be scrupulously honest and forthright. If a mutual trust and respect is established, then government and industry can truly work together for their mutual benefit.

3. "ARE WE, SPACE DIVISION, ENCOURAGING THE EXISTANCE, AND POSSIBLY THE GROWTH, OF THE "HIDDEN PLANT" THROUGH OUR CONTRACTING APPROACH OR MANAGEMENT PRACTICES? IF WE ARE ENCOURAGING THE "HIDDEN PLANT" WHAT CHANGES SHOULD WE CONSIDER AND WHY?"

The blunt and direct answer to the first question is yes. We would be quick to point out, however, that industry has not overwhelmingly stepped up to the challenge itself, so a repetition of the old adage "people who live in glass houses shouldn't throw stones", would be appropriate.

We believe that a real attack on the problem lies jointly with industry and government -- the government must insist upon improvement, and industry must step up to the challenge. Along these lines, the following suggestions might be considered; some are controversial, but should provide food for thought.

3.1 Improve the Design Review Process. Insist upon detail review of the design margins as well as the manufacturability and producibility of a design early in the development cycle. Insist upon a review of the processes, procedures and tooling that will be used to manufacture the hardware. Insist upon involvement from manufacturing and quality early in the design phase. Provide the up-front funding to accomplilsh this effort. These fundamentals are too often overlooked in the rush to get the development done within the allowed cost and schedule constraints.

3.2 Degrade the Sanctity of the Qual Model. Many of our programs spend exhaustive efforts in the "qualification" of a design through test of a single qualification model built to production drawings, which then serves as a production baseline for subsequent flight models. Change is generally impossible or very difficult once this baseline is established. This philosophy is a major deterrent to any further improvement in manufacturability and a major contributor to the "hidden plant". Would it not be a better alternative to consider a less regimented, but more thorough, development test program which identifies the fundamental technical problems earlier in the program? This data could then be the basis of a well-controlled "test, analyze and fix" program which could be continued into the production of flight hardware. It seems to us that improvements in the "hidden plant" can only occur through the implementation of change. The question is, "How much risk are we willing to take?"

3.3 Encourage Automation and Computer-Aided Design. Recent history has shown that one of the greatest potential sources for reduction of human error and improvement in productvity is the use of computer-aided design and manufacturing techniques. Getting through the problems of implementing these systems can be horribly frustrating, but once implemented, the results can be rewarding. The potential in this field is only beginning to be felt. Government should provide incentives to industry to encourage the use of these techniques.

3.4 Use MIL-STD 1520. MIL-STD 1520 requires the implementation of a system to track the cost of rework, repair, and scrap. Implementation of this standard would provide visibility to the government for what the "hidden plant" is really costing. Its full implementation will initially cost extra dollars over present procedures. Tracking and reporting these costs should be seriously considered and the implementtion costs weighed against the potential benefits.

3.5 Tailor the Specifications to the Real Need. Layers upon layers of standard procurement specifications and "required" contract clauses have built up over the years which often inadvertently lay many unnecessary requirements on system procurements. This is particularly true in the quality and reliability area. Documents which reference other documents, which, in turn reference more documents often inadvertently invoke unnecessary requirements which aggrevate scrap and rework, but go unnoticed for long periods of time. Further, most detailed quality requirements (MIL-STD-883, for example) were derived from a government-industry negotiation process that resulted in criteria that produced an acceptable level of quality for a tolerable level of scrap, rework and repair for the technology in use at the time the document was generated. These criteria are not absolute hard and fast requirements, but standards of comparison — relaxation of some of these requirements to alleviate a particular scrap or rework problem will not necessarily degrade reliability and may significantly improve scrap and rework costs.

Every possible effort should be made to reduce the specificaton requirements (both in number and in difficulty) to the minimum acceptable level for every procurement. Once this is done, a program of visibility into "quality costs" is needed (such as that provided by MIL-STD-1520). And, finally, as the scrap, rework and repair costs are identified, further tailoring of the specifications, the design, or the manufacturing processes should be implemented to fix the problem. Both government and industry must be willing to accept change for this process to take place effectively.

3.6 Use the "Profit Motive". All publicly held corporations are in business to make a profit for their stockholders. Any quality program that does not make quality a more important profit generator than cost and schedule considerations is probably going to fail in the long run. Some bold new ideas are probably in order to challenge the ingenuity of the community to attack the problem. Incentives applied after development is complete are too late. Some profit-generating mechanism needs to be found to elicit the effort needed to reduce the cost of the "hidden plant". Only if government and industry jointly work together in a serious attempt to solve our mutual problems will a solution be found.

3.7 Provide Management Continuity. The United States is a mass of mobile people. The phrase "upwardly mobile" is quite popular, but many of those who aren't going up seem to be going sideways or even downward. But they are moving. This phenomenon is one of our major handicaps in competition with Japan where people are often with a company for life. In that situation managers are far more cognizant of the long term effects of their decisions since they will probably still be around when the "chickens come home to roost". In the quality area of government contracting we have seen many initiatives come with great fanfare only to fade when the officers or civil servants pushing them moved to other jobs. Many of these were very worthwhile, but became orphans when their originators left. We tend to be a nation of innovators — what we badly need is a strong body of implementors and suitable reward and glory for that phase of the effort.

4. SUMMARY. In the foregoing material we have attempted to bring forth some of the factors which are contributing to the "hidden plant" and to suggest a few specific, although not easy, changes which would help to reduce the impact and magnitude of the "hidden plant". Much of what we have said is controversal. Much more needs to be said. If this paper can stir up controversy, which eventually leads to some effective action, our purpose will have been achieved.

Eliminate the Hidden Plant!

by

William E. Montgomery
General Manager, Space Division

and

Harold C. Jones
Senior Advisory Engineer

What Is the "Hidden Plant?"

- Any Action Which Duplicates a Previous Action
- Any Action Which Should Not Be Necessary
- Any Action Dedicated to Finding Errors

According to Gen. Marsh

- The Job Must Be Done Right the First Time
- USAF Is Going To Structure Contracting Procedures and Award Decisions To Reward Those Who Do So

Some Examples of the "Hidden Plant"

- Rework and Repair
- Expediting
- Design Revision Notices
- MRB Actions
- Inspection

Question #1

"What Is Your Company's Experience With the 'Hidden Plant' ?"

Why A "Hidden Plant?"

- Quality Not a Total Commitment
- Japan and Others Outpacing Us In Quality
- Dependence on Inspection
- Not Managing Subtier Suppliers
- Best Workers Used in Repair Function

- It Exists!
- "Quality" Must Be Broadly Defined To Understand the "Hidden Plant" and Eliminate It
- Process Capabilities Must Match Design Requirements

Question #2

"What Do Your Line Managers and Supervisors Feel Are the Root Causes of the "Hidden Plant" and How Can the Causes Be Eliminated."

Late Manufacturing and Deployment The "Pay Me Later" Period

- Inadequate Design Margin Problems
- Part Problems
- Specification Problems

Early Phase

- Performance Overdesign
- Unrealistic Schedule
- Unrealistic Cost Estimates
- Stop and Go Funding

Question #3

"Are We, Space Division, Encouraging the Existence, and Possibly the Growth of the "Hidden Plant" Through Our Contracting Approach or Management Practices? If We Are Encouraging the "Hidden Plant" What Changes Should We Consider and Why?"

Early Production

- Manufacturability
- Parts Problems
- Operator Performance

YES

But

Industry Is Also At Fault!

Some Suggested Changes

- Improve the Design Review Process
- Degrade the Sanctity of the Qual Model
- Encourage Automation and Computer-Aided Design
- Use Mil-Std-1520 Enthusiastically
- Tailor Specifications
- Use the Profit Motive Properly
- Provide Management Continuity

GENERAL DYNAMICS CORPORATE QUALITY IMPROVEMENT PROGRAM

D. J. Talley

Vice President - Quality Assurance

General Dynamics - Fort Worth Division

The General Dynamics Quality Improvement Program (QIP) is a major Corporate commitment to support the Department of Defense Bottomline Initiativies, improve the quality and reduce the cost of delivered products. (This program is the first of its kind in the Defense Industry in response to the challenges put forth by the Bottomline conference.) The policy is to improve systems and processes prior to design release, material acquisition, fabrication, and assembly to assure that quality is built-in, rather than attempting to inspect and test quality into the end products. The QIP will generate increased quality awareness throughout the Corporation to improve the total cost effectiveness of delivered products. The three main features of the QIP approach are: top level management involvement and commitment, annual improvement goals which are measured and reported, and massive training and awareness program. The following paragraphs briefly explain the major elements of the program.

1. Near-Term Elements

In order to capture the earliest benefits of quality and production improvement, early program efforts will be addressed to the near-term program. Those quality and cost detractors which can be managed and controlled immediately to minimize their impact are:

- Scrap
- Rework
- Overtime
- Yield
- Engineering Change Notice
- Product Support
- Material
- Training

Twelve parameters have been established related to the near-term elements with improvement goals, measurement techniques, standardized descriptions, and reporting requirements. The twelve parameters are described in more detail in other sections of this document but are listed here for reference:

- Scrap (labor hours and dollars)
- Rework (labor hours)
- Avoidable Engineering Changes
- Software Change Requests
- Inspection Escapes
- Material Review Board QARs (rejection documents)
- Logistics Response Time
- Deviations/Waivers
- First Time yield
- On-time Delivery of Purchased Material Production Requirements
- Purchased Item Quality
- Overtime

2.0 Long-Term Elements

The best approach to higher quality begins with a disciplined quality attitude at the start of a program before the schedules and design parameters are frozen. To fully address this approach will be the long-term basic program plan. Long-term quality concerns must begin with the initial user requirements and continue

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through the advance development, the program proposal, the program schedule, the program costing, and the program hardware specifications. The selection of suppliers and team members and the ongoing design process, design proofing, and production release with the producibility verification are key milestones to be addressed in the long-term basic program. The long-term areas, which will be expanded as the program develops, are:

- User requirements
- Proposal schedule, cost, and specifications
- Design considerations
- Release to production
- Communication
- Material
- Training
- Facilitization

3.0 Scrap and Rework/Repair

a. Scrap is nonconforming material that is not usable and cannot be economically reworked or repaired. The measurement technique is as follows:

- Determine actual labor hours spent on scrapped hardware and report as a percentage of the actual manufacturing direct labor hours expended monthly.

- Determine the cost of material in scrapped hardware and report as a percentage of total material issued monthly.

The controlling document for scrap accounting is the Quality Assurance Report (QAR) or equivalent rejection document.

b. Rework/repair is labor required to correct a work-in-process nonconformance, labor required for compliance to engineering change, or labor required to correct deficiencies in vendor supplied parts when schedule and economics justify. The measurement technique is to determine actual hours spent on rework/repair as a percent of total actual manufacturing direct labor hours expended monthly. The controlling document for rework/repair accounting is the QAR or equivalent rejection document.

c. Scrap and rework occurrences will be recorded and reported in four principal categories:

(1) Error caused and therefore avoidable
(2) Funded process fallout
(3) Customer furnished material
(4) Change introduction

The major scrap and rework impact falls in category (1), error caused. These errors can be traced to the source and minimized. Source causes could be: errors in manufacturing (workmanship deficiencies), design, inspection, specification, procedure, planning, etc.

In the process fallout category (2) the scrap/rework may be caused by a state-of-the-art capability, performance optimization, or inherent limit. Examples are:

1) Removal and scrapping of electronic components such as resistors or capacitors used for performance tailoring. This tailoring must be

a planned and funded task to be in category (2) and normally occurs in planned original design or a build-to-print second source program.

2) Selective fit assembly such as shims or bearings in mechanisms of a precision nature.

3) Testing of one-shot devices or single-use items such as ignitors, fuses, fuel thermal batteries, etc.

4) Program requirements to conduct periodic environmental or conformance testing of systems or components with the refurbishment and/or scrap/rework of items in the test samples.

5) Proofing loss due to unusable nonconforming material caused by evaluation of tools during the tool inspection cycle.

6) Process yield loss which is the expected amount of unusable nonconforming material resulting from exceeding the capability of existing processes and controls.

Government furnished material. In special cases the component or equipment supplied by the customer may not or cannot consistently meet the application requirement. In these cases the cost and schedule impact on the division operations must be identified, recorded, and reconciled with the customer.

Changes introduction. Obsolete material, or scrap labor and scrap material result when changes are introduced into production or design. These changes can be either division or customer originated. When a change is made to accommodate the customer, the task and division impact is customer funded and should be recorded. When an unplanned change is made to meet the sole definitive company obligations, the material and division impact is to be identified and reported as a category (1) item. When a change is made that a joint responsibility of the customer and the division, the record and reporting shall identify the respective category.

4.0 Inventory Adjustment

Inventory adjustment is loss and gain of material from stock and work-in-process as identified through periodic audit of records and hardware. Actual net hours affected by inventory adjustment will be determined and reported as a percentage of the actual manufacturing direct labor hours expended monthly. The net cost of material affected by inventory adjustments will be determined and reported as a percentage of total material issued monthly.

5.0 Yield

Yield is the measure of the amount of acceptable hardware realized from a manufacturing operation or process, an inspection point, or test operation. Units which fail when presented for first-time acceptance result in added cost due to rework, scrap, retest, and reinspection. The

measurement technique will be to record the number of units accepted for the first time and report as a percentage of the total number of units presented for the first time, on a monthly basis. Units include hardware at all levels of fabrication and assembly which are presented for initial, or first-time acceptance. Separate measurement and reporting will be accomplished for first time yield of assembled hardware at test equipment acceptance points and of fabricated hardware at visual/dimensional inspection points.

6.0 Overtime

Overtime is utilization of an employee more than a normal/planned workweek. The practice is typically employed to regain desired schedule position while not affecting payroll manpower levels. Excessive overtime is mainly caused by schedule problems that can be related, in large part, to scrap and rework. A high level of overtime causes higher energy usage, premium pay, personnel inefficiencies and fatigue, management problems, greater span of control, poor communications, etc., and is therefore, not a quality incentive.

An upperbound of 5% is a good ceiling. A steady level of 5% indicates planned or permissive overtime. The measurement technique will be to determine division-wide direct labor overtime hours and report as a percentage of total division straight time hours (direct and indirect) expended monthly.

7.0 Engineering Changes

The quality of the engineering release to production and the subsequent maintenance and support of that technical data package has a significant impact on product quality, cost, and schedule. In order to measure and improve this element of quality (quality of design), the number of engineering changes that are avoidable changes will be tracked. Avoidable changes (AC) are those changes required due to some inadequacy or fault in the engineering release package; i.e., changes required to make the product work or make it producible on the manufacturing floor.

All active production programs will be measured by the number of ACs per drawing per month. Report as the number of ACs per drawing (active production drawing base) on a monthly basis. The measure will not include changes for cost reduction and customer-directed changes for performance improvement.

8.0 Software Performance

Various methods of measurement of the quality of engineering released software will be utilized, as best fitted to division products and procedures:

a. Software change requests (SCR) are initiated subsequent to release to correct errors found during proofing of the computer program and also for documentation and support software. The number of SCRs per 1,000 Engineering man-hours expended on software, will be reported on a monthly basis.

b. Software quality factor (SQF) of formally released product software is the number of errors reported in the software change requests, excluding SCRs attributed to systems engineering, mechanization, etc., per 1,000 bytes of code in the formally qualified program units. Errors

associated with Software Engineering SCRs written after formal qualification of the software and the number of bytes in the affected program units will be recorded and used as the basis for computing SQF.

c. Errors per thousand lines of code (total lines of source code in the program and data base, including both executable and nonexecutable statement). At each software release subsequent to FQT, the number of errors corrected in the update (if any) and the lines of code in the prior (baseline) release wil be identified for purposes of determining error rate per thousand lines of code.

9.0 On-Time Delivery of Production Requirements

This element measures the efficiency and timeliness of introducing required purchased material to the manufacturing process. Production requirements are those materials incorporated into the end products. Issues are the number of material items released. Manufacturing schedule demands are the number of material items needed to meet factory start dates. Several departments contribute to performance related to this element, including Purchasing, Receiving, Receiving Inspection, Electronic Component Screening, Material Control and Handling, and Kitting. The ratio of on-time issues to manufacturing schedule demands is determined and reported on a monthly basis.

10.0 Quality of Supplier Material

Major impacts on production cost, schedule, and quality can be caused by a relatively small number of purchased item failures and rejections, either upon receipt or after use in higher levels of assembly. The ratio of the number of parts (pieces) received will be determined, and reported on a monthly basis. Acceptance means acceptance by source Inspection, Receiving Inspection, or the user less those subsequently rejected as vendor responsibility after issuance.

In those cases where piece part data is not available, it may be necessary to measure supplier material quality on the basis of purchase order line items received.

11.0 Inspection Escapes

The accuracy of visual/dimensional inspection is critical to ensure that nonconforming hardware is detected at the point of origin. Nonconformances processed to other departments represent added cost and indicate inefficiencies in the inspection process. The measurement technique employed is to determine the number of out-of-department QARs (prior department responsibility) originated as a percentage of the total number of QARs originated on a monthly basis.

12.0 Material Review Board QARs

The volume of rejection documents (QARs) processed in the Material Review Board is a reflection of the amount of nonconforming hardware generated in the manufacturing process. Reduction of MRB documents will reduce the costs involved in material control, handling, MRB labor, repair planning and repair labor, scrap analysis and disposal, and corrective action. MRB actions require customer approval and, thus, provide high visibility of the nonconformance, as well as the effectiveness of the corrective action system. The measurement technique employed is to determine the number of QARs

received in MRB per 1,000 manufacturing direct labor hours, and report on a monthly basis.

13.0 Logistics Performance

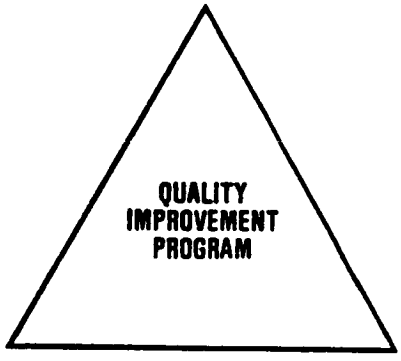
Early resolution of field problems provides for improved customer relations and demonstrates effective support of the product. Customer reports of problems may be in various formats, such as Service Report (SR), Equipment Deficiency Report (EDR), System Hardware Difficulty Report (SHDR), Quality Deficiency Report (QDR), Material Deficiency Report (MDR), and Equipment Performance Report (EPR). The measurement technique employed is to determine the percent of these problem reports answered on time, and report on a monthly basis.

14.0 Deviations/Waivers

Deviations and waivers are initiated to cover departures (including make-it-work fixes) from contract baseline requirements to allow delivery of contract end items. A deviation is written authorization, granted prior to the manufacture of an item, to depart from a particular performance or design requirement of a contract, specification, or referenced document, for a specific number of units or specific period of time. A waiver is written authorization to accept a configuration item or other designated items, which during production or after having been submitted for inspection, are found to depart from specified requirements, but nevertheless are considered suitable for use "as is" or after rework by an approved.

The actual number of deviations/waivers recorded on each contract end item at the time of delivery is determined and reported monthly. This element will be tracked by divisions in summary form (all active production programs combined) and by individual production programs.

General Dynamics Corporation Commitment To Support The DOD Bottomline Initiatives



Corporate Involvement In Quality Improvement, Cost Reduction And Long-Term Education

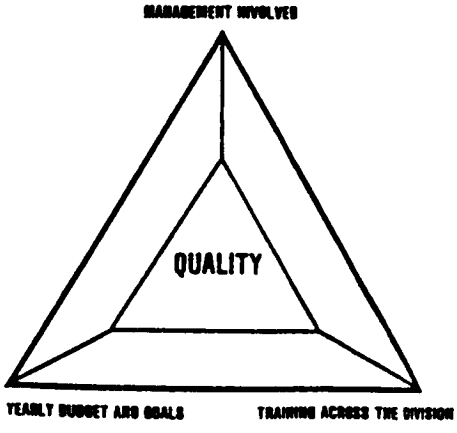
(A) Corporate directives for division plans — addressing quality of work, cost of products and training program.

(B) Corporate targets and measures of division performance.

(C) Continuous aerospace group council performance reviews and improved implementation.

Aerospace Quality Improvement Program

GENERAL DYNAMICS CORPORATION IS MAKING A MAJOR COMMITMENT TO IMPROVE THE QUALITY OF PRODUCTS BEING PRODUCED IN THE AEROSPACE DIVISIONS.



Quality Awareness

- Management has dedicated itself to total quality.
- Formal quality awareness and skill training will be established on a continuing basis.
- QIP will be directed and monitored by top management and will include participation of all employees, particularly executives.
- Each division will implement an expanded QIP that builds on the aerospace QIP.

Agenda
Quality Improvement Program
14-15 September 1982

14 SEPTEMBER 1982

0800	Introduction	— R. E. Adams, General Dynamics Corporation, Executive Vice-President, Aerospace
0810	Quality Improvement	— Dr. J. R. Juran
1000	Break	
1020	Quality Improvement	— Dr. J. R. Juran
1200	Lunch - Buffet	
1300	Quality Improvement	— Dr. J. R. Juran
1430	Break	
1450	Quality Improvement	— Dr. J. R. Juran
1600	Final Comments	— O. C. Boileau, General Dynamics Corporation President R. E. Adams, General Dynamics Executive V-P, Aerospace

15 SEPTEMBER 1982

0800	Introduction	— O. C. Boileau, General Dynamics Corporation President
0830	Speaker	— W. J. Willoughby, Jr., Deputy Chief of Naval Material (RM&QA)
1015	Break	
1030	Speaker	— J. Lavery, Ass't. Product Assurance, AFSC, Andrews AFB
1200	Lunch - Buffet	
1330	Speaker	— S. Lorber, Director Product Assurance and Test, Dept. of the Army, Development and Readiness Command
1415	Break	
1430	Speaker	— R. E. Adams, General Dynamics Executive V-P, Aerospace
1500	Questions and Answers	— O. C. Boileau, General Dynamics Corporation President
1530	Adjourn	

Education — Training and Continuous Application

- EXPANDED TRAINING IS TO BE INITIATED AT:

Top Management Level

Corporate And Division

SEMINARS

Recognized Teachers:	Juran, Deming, Crosby
Government Leaders:	Willoughby, Lavery, Lorber
Government Labs:	ASD, AFSC, NWC, MICOM, ERADCOM,
Military:	Program managers, acquisition leaders

Line Supervisor Level and Hands-On Employees

SEMINARS

Division Specialists:	Vice-President and Directors of Operations, Quality Assurance, Engineering, Purchasing, Contracts, Design Specialists, Industrial Relations, Program Director

Suppliers

DIVISION SEMINARS

Recommitment to Excellence
Critical Component

Quality Improvement Program

- NEAR TERM STRUCTURED TO CAPTURE IMMEDIATE BENEFITS.
- LONG TERM DEVELOPMENT OF THE QUALITY PROCESS THAT PREVENTS ERRORS.

Quality Improvement Program

ELEMENTS

NEAR TERM

- Scrap
- Rework
- Overtime
- Yield
- ECN (engineering change notice)
- Product Support
- Material

LONG TERM

- User requirement
- Proposal schedule, cost, specification
- Design considerations
- Release to production
- Communication
- Material

INTEGRITY

TRAINING

Quality Improvement Program

SELECTED EXAMPLE

Rework/Repair

PARAMETER — **GOAL REDUCTION — %** 1982 1983

- Rework and repair

DESCRIPTION

- Labor required to correct a work-in-process non-conformance when such non-conformance is identified on an inspection rejection document.
- Labor required for compliance to engineering change or to correct vendor supplied parts when schedule and economics justify.

MEASUREMENT TECHNIQUE

- Determines actual hours spent on repair/rework parts and report as a percentage of actual direct labor hours expended monthly.
- Quality assurance report or equivalent inspection rejection documents are used to identify need for rework.

Quality Improvement Program

SELECTED EXAMPLE

Scrap

PARAMETER — **GOAL REDUCTION — %** 1982 1983

- % scrap

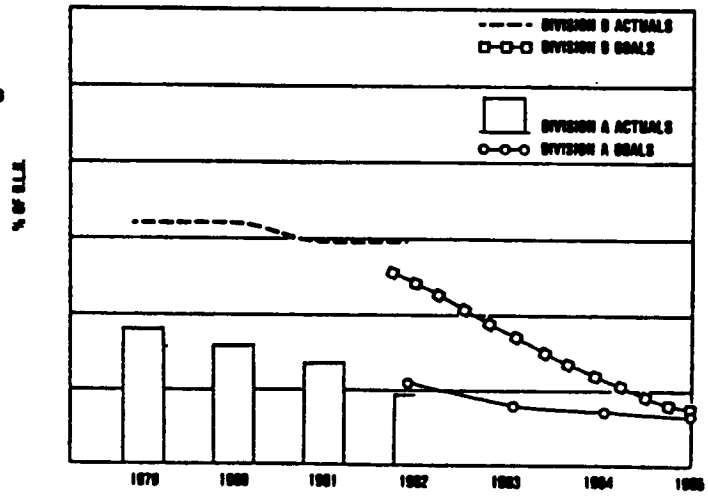
DESCRIPTION

- Nonconforming material that is not usable and cannot be economically reworked or repaired.

MEASUREMENT TECHNIQUE

- Determine actual hours spent on scrapped parts and report as a percentage of the actual direct labor hours expended monthly.
- Determine cost of material in scrapped parts and report as a percentage of total material issued monthly.

General Dynamics Demonstrated Reduction In Scrap And Rework At Divisions A & B

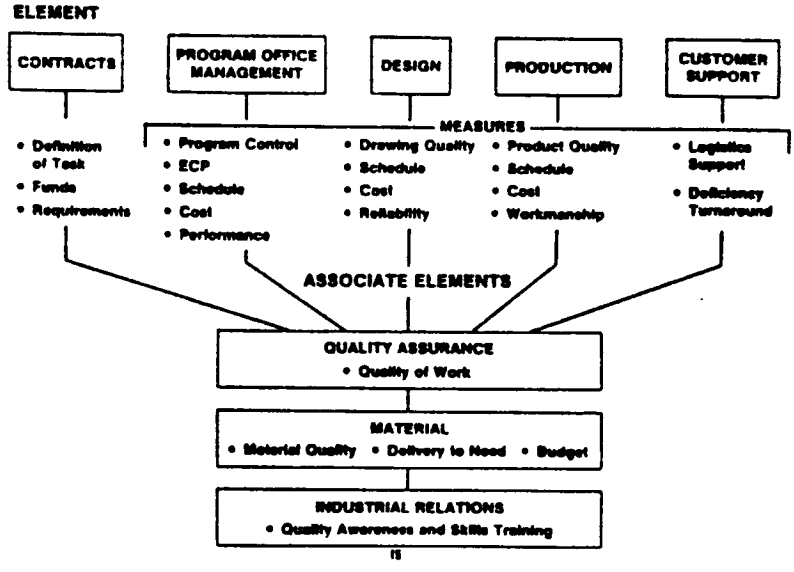


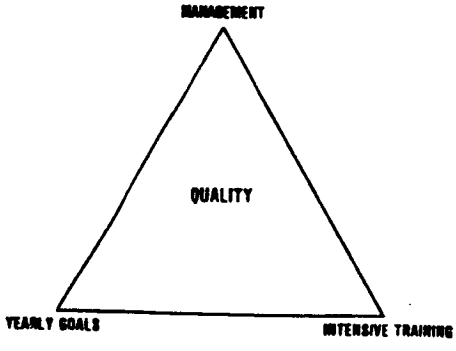
Corporate Aerospace Council

A Corporate Aerospace Council was established in April 1981, chaired by the Corporate Aerospace Vice-President of operations and quality assurance and the Aerospace Divisions' leaders of operation and quality assurance. This council meets every two months to review the production and quality process with the primary goal of reducing scrap and rework/repair.

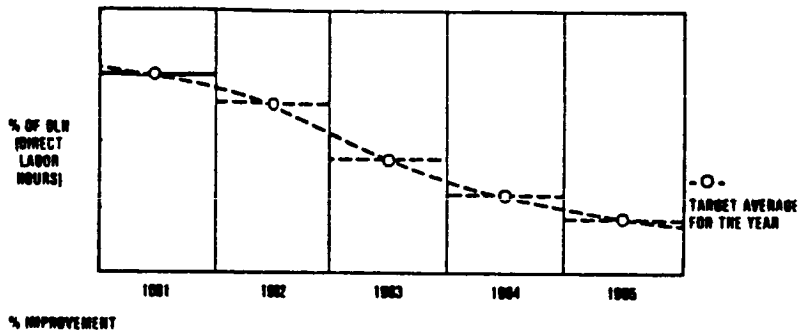
On a semi-annual basis, the Corporate Executive Vice-President Aerospace personally provides the guidance of these meetings.

Basic Elements And Measures





Selected Example of General Dynamics Aerospace QIP Goal Scrap + Rework + Repair



Quality Improvement Program

Performance Recognition

PARAMETER

- Aerospace QIP Targets Objectives

GOAL

- Achieve/Exceed Aerospace Target

DESCRIPTION

- Overtime, ECNs, Software SCRs, Scrap, Rework/Repair, Yield, Material Measure, Material Supplies Acceptance, Inspection Escapes, MRB, SRs, Deviations/Waivers

BACKGROUND

- These measures will be used as a significant factor in incentive compensation, merit reviews, promotions and other award criterion.

VALUE ENGINEERING AS A MOTIVATIONAL PROGRAM

Tony Negrete

Hughes Aircraft Company

4 June 1983

It has been said that the single most useful intellectual tool that man possesses is the ability to classify. This ability however does not develop automatically or uniformally.Although I have been working with Value Engineering (VE) for about 10 years, and my academic background is such as to dispose me to think of VE as motivational, I must confess that I did not think of it as such until I was asked to speak on it in this panel, the theme of which is Motivational Programs. Examining the subject has crystallized some disturbing impressions that have formed through the years.

My conclusions are that in both the sharing clauses in government contracts and in the application of the VE Methodology, the motivational potential does not appear to be what you might expect from the stimuli.

Before I explain my conclusions, I want to say that I am going to be discussing two kinds of VE. Being steeped in VE, or Value Analysis as it was originally called, as a methodology, when I talk or think of VE it is the methodology that I have in mind. I also have to keep in mind the fact that some people who are familiar with the VE clauses in government contracts, but not familiar with the methodology, think that VE refers to the contract clauses. So let's just keep in mind that there are two distinct referents for VE.

Let's consider the results from contract clauses first. The incentives for the contractor certainly are powerful. The Government shares the savings with the contractor. There have been recommended savings in the million of dollars. There have been cases when the contractor earns more from his share of the savings than from the contract.

The incentives for the Government are also equally compelling. [1]

1. Save money
2. Improve schedules
3. Enhance or expand utility
4. Provide politically feasible path to eliminate excessive requirements and upgrade

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Here are the results for a period from 1976 through 1982 [2] of the savings to DoD from the contractor program - a piece of a peanut (.23%) compared to the Total Obligation Authorization (TOA). When we compare the number of Value Engineering Change Proposals (VECPs) to the number of contracts awarded we see that we have at least one whole peanut (1.39%). Imagine what it might be to have at least one VECP per contract. If we look at the data over time we see that there does not seem to be a trend toward improvement. While the dollar savings and TOA are increasing, the percentage of savings to TOA is not increasing.

Let us now consider the application of the methodology. The methodology consists of the step by step application of a collection of techniques for identifying and eliminating unnecessary costs. I don't have the statistics, but from my experience with the methodology I am convinced that to the degree that you apply the techniques rigorously, to that extent you improve the probability of making large cost reductions. There are two motivational aspects to the methodology: first, the increased opportunity for large earnings from savings by the contractor; second, the intrinsic motivation in accomplishing a task competently.

It has been my experience that all who attend Value Engineering workshops appreciate the value of the concepts and the training greatly. There are many people teaching Value Engineering across the country and it has been estimated that between 100,000 and 500,000 people have been trained. These people have worked on projects for which substantial reductions in cost have been proposed both during the workshops and afterwards. While I can't really speak for all of them, it has been my experience that very few changes during or after the workshops stem directly from rigorous application of the techniques. This does not mean that spectacular changes cannot occur without the VE methodology such as this waveguide feedhorn that was changed from a design that required many parts, special processes and close tolerances, to one that is essentially a printed circuit antenna using strip line techniques with the cost reduced by 90%.

I must conclude that while the insights gained in the workshops do carry over to some individual behavior in fragmented or adapted form, the intellectual acceptance of the methodology lacks motivational potential in terms of altering behavior pervasively.

I would like to discuss the motivational aspects of VE using some theoretical structures as a framework: a taxonomy of cost reduction behavior; a motivational paradigm; and a definition of learning.

Sometime ago I started constructing what I call a Taxonomy of Cost Reduction Behavior. The principal categories are:

1. Set
2. Opportunity
3. Awareness
4. Competence
5. Motivation
6. Tools

While it was designed with the individual in mind, we should keep in mind that we are dealing with organizations as well as individuals and that organizational behavior is analogous to individual behavior. If we look at motivation as the impetus to acting, we can look at the other factors as facilitative or constraining. For example, if the opportunity does not exist, is not visible, or the set to restructure the situation to create an opportunity is not in the individual's or organization's repertoire no amount of motivation is going to result in desirable change.

In oversimplified form, the motivational paradigm tells us that we change behavior when we discover that the pleasure from engaging in the new behavior is worth the trouble to make the change or that the current experience is so painful that the only recourse is a new behavior. Learning is defined as the acquisition of new insights that leads to a change in behavior.

The problem that this leads to is:

> Given the substantial number of dollars that are available to the contractor for engaging in behavior that is essentially the same as his everyday behavior and that the contractor is in business to acquire dollars for engaging in his everyday behavior, why is the response to the stimulus so low and not improving?

If we can make what I think is a safe assumption, that money does have motivating potential and that there is motivation in a job well done (intrinsic motivation), we can restate the problem in operational terms:

> What learning must occur to increase the behavior that leads to reduction of costs?

Do not despair at these gloomy conclusions. In the words of Thomas Gilbert, [3] the worse the situation is, the greater the potential for improvement.

It seems to be an established phenomenon that it takes a long time for an idea to catch on. Twenty years between the public exposure of VE by the publication of the Government VE Handbook, and the VE contract clauses is not really too long a time if you look at the history of acceptance of ideas. For comparison think of statistical process control which first got wide publicity through the publication of Dr. Shewhart's book in 1931. [4] It's been used in many places but you can't say it caught on in a big way until the Japanese picked it up in the 1960's. It might be of interest to you that they have picked up VE in the same way, and have a Miles Award for VE similar to the Deming Award for Quality. [5]

We need to influence the rate of acceptance of VE. The customer has a major role in this. The set, or attitude, of the Government contracting people has been ambiguous at best, obscuring the opportunity, diluting the motivation and diminishing the motives to develop awareness, competence, and the use of cost reduction tools. The inhibitions stem from: the attitude that VE is a ripoff; interfering priorities; and lack of competence.

Now that I have aroused your attention with that last statement let me explain it - I mean it in a very narrow sense. I've referred to intrinsic motivation relative to application of the methodology; there is intrinsic motivation in being able to do a job well. [6] It can even be said to be fun. [7] This kind of motivation arises when the job is known so well from successful practice that it is a habit not a chore.

All government and contractor contracting personnel and those who influence contracting should be thoroughly trained in the VE methodology and administration of the contract clauses, and given support and incentives to create the set that will make these practices an integral part of their contracting behavior. One important aspect of support is the transforming of contracting practices to give the effort toward cost reduction the priority that circumstances require. The attitude that VE is a ripoff should be countered with insights into the concept and nature of unnecessary costs. They arise mostly through understandable reasons:

Habit
Budget constraints
Time constraints
Technology

No one starts out to make a poor design. The waveguide antenna that we saw earlier is an excellent design that I am certain the designer and manufacturer are proud of. If you sent out an RFP for a 3 CM microwave test antenna to many reputable contractors you would probably get back a lot of waveguide designs. Given the time and budget constraints it is remarkable that designers come up with one good design let alone several from which they can pick the best.

One objection that we can dismiss without another word is that the contracts and specifications are so perfect that there is no opportunity for improvement.

This is not to say that abuses cannot occur and part of the training that should be instilled in contracting people is how to detect and respond to these competently.

Fortunately there is an encouraging increase in interest on the part of the government. The latest evidence is the strong commitment expressed at the Aeronautical Systems Division Briefing on VE by General McMullen and others. But words, exhortations and commitment are not enough. The tools and the climate to use them must be provided. It must also be demonstrated by actions all the way down the chain of command and through the contractor's organization that cost consciousness and the use of cost reduction tools is a way of life.

When customer barriers to cost reduction proposals are replaced with: responsiveness; contracting practices that facilitate cost reduction efforts; and demand, the contractor is more likely to respond to the motivational aspects of the contract clauses. The increased opportunity may even stimulate interest in training contractor people in VE methodology to maximize the income from VECPs.

The inhibition to apply VE techniques systematically arises from two related phenomena. First what de Bono calls the intelligence trap. [8] The cultural premium placed on being right. [9] If the phenomenon were to be verbalized it might be something like this, "We know how to solve problems why should we go through the tedious filling out worksheets in a step by step way to identify the problem? We can solve the problem without this drudgery." The intelligence trap leads to a problem solving strategy wherein the solution is attempted at the expense of understanding the problem thoroughly. VE is a structured problem solving method which consists of a problem, identification phase, a problem solution phase, and an implementation phase.

The intelligence trap in VE is analogous again to the quality control experience. In the process control view of quality control, the first phase amounts to a problem trend identification phase. If you use this procedural tool as a way of life you do away with the hidden plant [8] that is with inspection, rework and scrap. But it hasn't caught on for the reasons we have discussed. This way of approaching problems becomes a habit what we need is new habits.

The second reason for inhibition of the systematic application of the VE methodology is one we have touched upon before, and that applies to statistical process control also. It is the lack of practice and hence the lack of competence motivation, that is of being able to do something well.

The training to be effective must, as in the case of government personnel, include all the contractor's people who influence the design and the contract. Executives and managers must be conversant with the methodology so that they know what to expect and can manage its application effectively. The training should be such that the concepts, practices, and use of the tools become so internalized that they become a way of life. Alfred North Whitehead said it this way [10]:

> It is a profoundly erroneous truism, ... that we should cultivate the habit of thinking what we are doing. The precise opposite is the case. Civilization advances by extending the number of important operations which we can perform without thinking about them.

Some other tools that may help are: transformation of costing practices to give visibility to costs and to highlight VE targets to facilitate cost reduction; VE plans that identify VE targets, strategies, study programs, provide guidance to contractor personnel etc.; and supplier VE programs. Many ideas can be found in the monthly publication Value Digest published by Tufty Communications Co., Washington, D. C.

To summarize there is a great potential that we can work on at a crucial time but we must act to provide opportunity, facilitate the application of tools, and bring to bear the great motivational potential of the sharing strategy and the methodology.

In closing, let me remind you of a law of nature - change or die. [11]

CONTRACT CLAUSES

HUGHES

1. PROVIDE FOR SHARING SAVINGS
2. THE SAVINGS MAY BE ACHIEVED BY:
   - CONVENTIONAL COST REDUCTION
   - PRODUCIBILITY
   - SERENDIPITY
   - VALUE ENGINEERING

METHOD

HUGHES

A SET OF TECHNIQUES TO REDUCE UNNECESSARY COSTS:

- IDENTIFY FUNCTIONS
- ESTIMATE WORTH
- CREATE ALTERNATIVES

HUGHES

VECP SHARING

HUGHES

TYPE OF CONTRACT	INCENTIVE (VOLUNTARY)		PROGRAM REQUIREMENT (MANDATORY)	
	INSTANT	CONCURRENT AND FUTURE	INSTANT	CONCURRENT AND FUTURE
FIXED-PRICE (OTHER THAN INCENTIVE)	50	50	25	25
INCENTIVE (FIXED-PRICE OR COST)	*	50	*	25
COST-REIMBURSEMENT** (OTHER THAN INCENTIVE)	25	25	15	15

*Same ratio as the contract's cost incentive ratio.
**Includes cost-plus-award-fee contracts.

HUGHES

WHAT DOES VE OFFER THE SPO?

HUGHES

SAVE MONEY
- ABSOLUTE SAVINGS
- MAKE CHANGES AFFORDABLE

IMPROVE SCHEDULE

ENHANCE OR EXPAND UTILITY

PROVIDE POLITICALLY FEASIBLE PATH TO:
- ELIMINATE EXCESSIVE REQUIREMENTS
- UPGRADE PRODUCT CAPABILITY

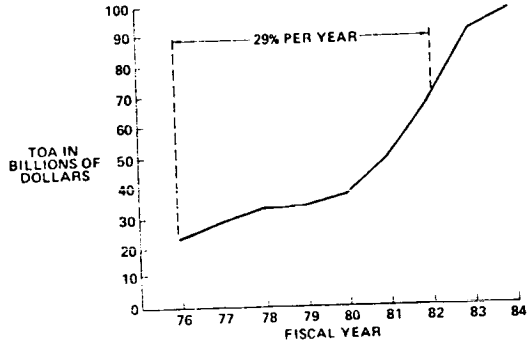
DEMONSTRATE COST AWARENESS

DOD REPORT 1976-1981

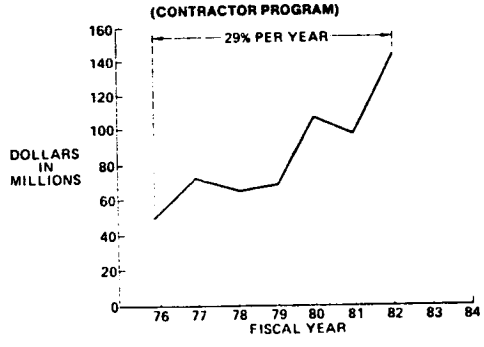
GORDON FRANK — MARCH 23, 1983

PROCUREMENT TOA	$261,581,000,000
CONTRACTOR SAVINGS	$599,900,000
CONTRACTOR SAVINGS/TOA	0.23%
NUMBER OF CONTRACTS AWARDED OVER $100,000	252,114
NUMBER OF VECP'S	3,505
VECP/CONTRACTS	1.39%

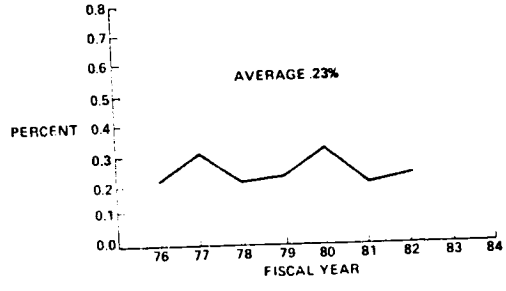
FISCAL YEAR VS. PROCUREMENT TOA



ESTIMATED VECP SAVINGS TO DOD
(CONTRACTOR PROGRAM)

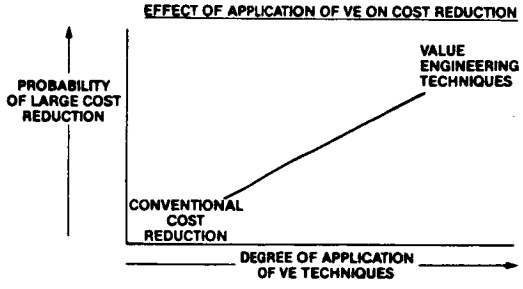


CONTRACTOR DOD SAVINGS VS. TOA



IMPROVE YOUR ODDS

HUGHES



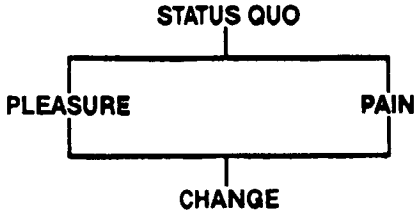
REASONS FOR UNNECESSARY COST

HUGHES

- HABIT:
  - TEMPORARY CIRCUMSTANCES BECOME PERMANENT
  - DESIGNING BY HABIT
- TIME CONSTRAINTS - SCHEDULE
- COST CONSTRAINTS - DESIGN COST
- TIME SPAN - R&D TO PRODUCTION

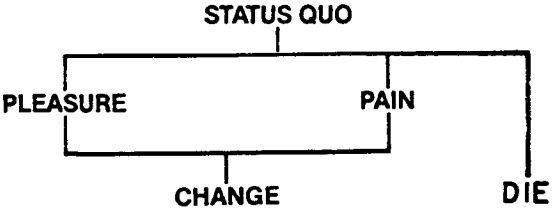
MOTIVATIONAL PROCESS

HUGHES



CHANGE OR DIE

HUGHES



X140

ROADBLOCKS

HABIT

TO CHANGE ONE'S HABITS HAS A SMELL OF DEATH.

—PORTUGUESE PROVERB

A TAXONOMY OF COST REDUCTION BEHAVIOR

1.000 SET
- 1.100 INTERNAL FACTORS
  - 1.110 EXPERIENCE
  - 1.120 AWARENESS
  - 1.130 PERSONALITY
- 1.200 EXTERNAL FACTORS
  - 1.210 ENVIRONMENT
  - 1.220 CULTURE

2.000 OPPORTUNITY
- 2.100 INTERNAL FACTORS
  - 2.110 AWARENESS
  - 2.120 INHIBITIONS
- 2.200 EXTERNAL FACTORS
  - 2.210 VISIBILITY
  - 2.220 INHIBITIONS
  - 2.230 FACILITATION

3.000 AWARENESS
- 3.100 INTERNAL FACTORS
  - 3.111 OF COST ELEMENTS
  - 3.112 OF COSTS
  - 3.113 OF FUNCTIONS
  - 3.114 OF ALTERNATIVES
  - 3.115 OF INCENTIVES
  - 3.116 PERCEPTION
- 3.200 EXTERNAL
  - 3.210 VISIBILITY OF COSTS
  - 3.220 AVAILABILITY OF INFORMATION
  - 3.230 FACILITATIVE RESOURCES

4.000 COMPETENCE
- 4.100 INTERNAL FACTORS
  - 4.110 EXPERIENCE
  - 4.120 ABILITY
  - 4.130 PROBLEM SOLVING
- 4.200 EXTERNAL FACTORS
  - 4.210 OPPORTUNITY

5.000 MOTIVATION
- 5.100 INTERNAL FACTORS
  - 5.110 ATTITUDE
  - 5.120 LANGUAGE
  - 5.130 COMPETENCE
  - 5.140 ACTIVITY
  - 5.150 ACTIVITY LEVEL
  - 5.160 CURIOSITY
  - 5.170 PERSONALITY
  - 5.180 COMMITMENT
  - 5.190 INTERESTS
- 5.200 VALUES
  - 5.210 SATISFACTION/DISATISFACTION
  - 5.220 EXPERIENCE
- 5.300 EXTERNAL FACTORS
  - 5.310 MODELS
  - 5.320 KNOWLEDGE OF RESULTS
  - 5.330 REINFORCEMENT
    - 5.331 RECOGNITION
    - 5.332 AWARDS
    - 5.333 PUBLICITY
    - 5.334 PERSONAL CONTACTS
    - 5.335 WORK ITSELF
    - 5.336 ENCOURAGEMENT
    - 5.337 FLOW
    - 5.338 ADVANCEMENT
    - 5.339 FINANCIAL
    - 5.340 PARTICIPATION
  - 5.350 DEMAND
  - 5.360 INTRINSIC FACTORS

A TAXONOMY OF COST REDUCTION BEHAVIOR

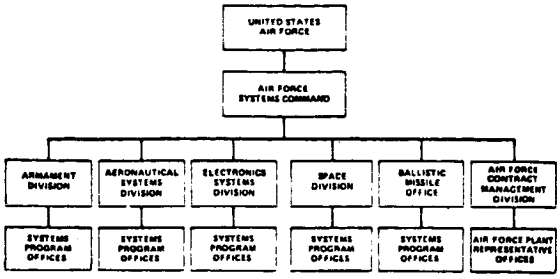
6.000 TOOLS

- 6.100 INTERNAL FACTORS
  - 6.110 CONCEPTUAL/BEHAVIORAL TOOLS
  - 6.111 CONCEPTS
  - 6.112 OBSERVATION
  - 6.113 INVESTIGATION
  - 6.114 DATA COLLECTION
  - 6.115 ANALYSIS
  - 6.116 DECISION MAKING
  - 6.117 CREATING ALTERNATIVES
  - 6.118 SELLING
  - 6.119 PLANS
- 6.200 EXTERNAL FACTORS
  - 6.210 ENVIRONMENT
  - 6.220 AVAILABILITY
  - 6.230 FACILITATION

MANUFACTURING TECHNOLOGY

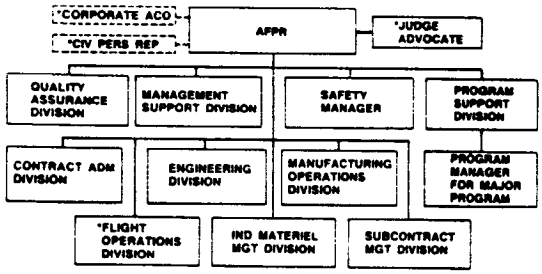
Dr. Gary Denman
AFWAL/Materials Laboratory

ORGANIZATION LEVEL



WHILE THE UNITED STATES LEADS THE WORLD IN PRODUCTIVITY, THE UNITED STATES IS DEAD LAST IN PRODUCTIVITY IMPROVEMENTS AMONG ALL INDUSTRIALIZED NATIONS OF THE WORLD.

AFPRO ORGANIZATION



*NOT PART OF OR COLLOCATED WITH ALL AFPROs

PRODUCTIVITY INITIATIVES AND POLICIES

- ACQUISITION IMPROVEMENT PROGRAM
  - PRODUCTIVITY INITIATIVES
- MANUFACTURING TECHNOLOGY
- TECHNOLOGY MODERNIZATION
- AIR FORCE COMMAND PRODUCTIVITY MOTIVATION
- GET PRICE

OBJECTIVES

- PROMOTE PRODUCTIVITY
  - MAKE IT AN AEROSPACE PHILOSOPHY
- DEFINE INITIATIVES AND POLICIES
- EXPLORE IMPLEMENTING OPTIONS—GOVERNMENT AND CONTRACTOR
  - IMPROVE PRODUCTIVITY
  - MAINTAIN QUALITY
  - MINIMIZE COST

IMPLEMENTATION OF PRODUCTIVITY IMPROVEMENTS INITIATIVES AND POLICIES

- CONTRACTING FOR PRODUCTIVITY
  - MULTIYEAR CONTRACTS
  - CAPITAL INVESTMENT INCENTIVES
  - AWARD FEES
  - INDEMNIFICATION PROVISIONS
- PRODUCTIVITY MEASUREMENT
  - MIL-STD-1567
  - COST SCHEDULE CONTROL SYSTEM CRITERIA (CSCSC)
  - CONTRACT MANAGEMENT SYSTEM EVALUATION PROGRAM (CMSEP)

ORGANIZATION LEVEL AND AFPRO ORGANIZATION

- EXPLANATION OF FUNCTIONS
- MAJOR PROGRAM DESCRIPTIONS

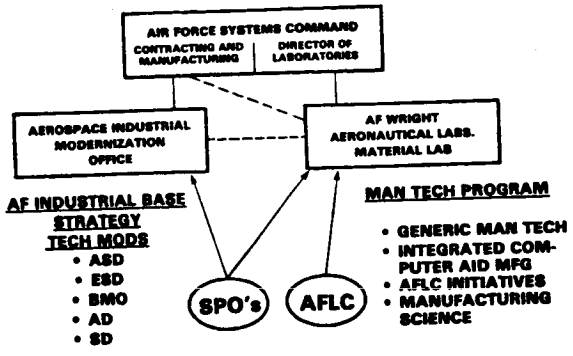
MUTUAL PROBLEMS AND CONCERNS

- GOVERNMENT REVIEWS
  - PRODUCTION READINESS REVIEWS
  - MANUFACTURING CAPABILITY REVIEWS
  - SHOULD COST
  - DESIGN REVIEWS
  - PROGRAM REVIEWS
- WORK MEASUREMENT BENEFITS
- WORK ETHIC—HUMAN BEHAVIOR
- PRODUCTIVITY—A WAY OF LIFE

OVERVIEW OF THE AIR FORCE MANUFACTURING TECHNOLOGY PROGRAM

The A.F. Man Tech program is part of the DOD program managed by OUSDR&E in which the 3 Services provide for their respective missions, improvements in productivity and responsiveness to the industrial base. The program in the Air Force is unique with respect to the other Services in that at W-PAFB the technical effort is centralized at the Man Tech Division of the Materials Laboratory which is the focal point for all Man Tech program. In the other services the of Man Tech effort decentralized in the Army arsenals and various commands in the Navy. At AFSC we promote planning and control necessary for direction and orientation of the program to areas of greatest need and payoff and as you will see in this Man Tech briefing we are dedicated toward transitioning, existing, and emerging technologies into production on the factory floor and encouraging program managers to include new manufacturing technology in their acquisition strategy. The briefing will also display the interactive role of Man Tech and Technology modernization programs.

RELATIONSHIPS



Viewgraph "Relationships"

This viewgraph displays the organizational lines for both Man Tech and Tech Mod. The Man Tech program is functionally aligned under the AFSC Director of Laboratories.

Funding and Program Element management for Man Tech is assigned to the Contracting and Manufacturing office of AFSC. This office also provides funding and direction to the Tech Mod program.

Planning and requirement input for the Man Tech program comes from various sources, most importantly the AFSC Product Divisions and AFLC.

Tech Mod programs are executed by the AFSC Product Division, coordinated by the AIM office.

TERMS

MANUFACTURING TECHNOLOGY

- **CATEGORIES**
  - GENERIC MANUFACTURING TECHNOLOGY
  - INTEGRATED COMPUTER-AIDED MANUFACTURING
  - AIR FORCE LOGISTICS COMMAND INITIATIVE
  - MANUFACTURING SCIENCE
- **FUNDING**
  - PE 7.8011F
- **MANAGEMENT**
  - AFWAL/MLT

TECHNOLOGY MODERNIZATION

- **CATEGORIES**
  - SYSTEM
  - FACTORY
  - SUBCONTRACTOR/VENDOR
- **FUNDING**
  - PE 7.8011F, PRODUCT DIVISIONS AND INDUSTRY
- **MANAGEMENT**
  - AIM OFFICE AND PRODUCT DIVISIONS

It's important to understand the distinction and interrelationships between the Man Tech and Tech Mod programs. The Man Tech program provides the technology base which feeds enabling Manufacturing Technology to Tech Mods for modernization programs at the Aerospace primes and vendors. There are other differences between the two as it relates to funding and management. The Man Tech program categories of effort, which will be discussed later in the briefing, are all funded out of one program element (78011F) budgeted by the Air Staff and AFSC and managed by the Materials Laboratory Manufacturing Technology Division. The Tech Mod program can have funds from a variety of sources including 78011F as well as funds from product divisions and in some cases directly by industry. Management of Tech Mod program is primary to the product divisions and the AFSC Aerospace Modernization Office (AIM) located at Aeronautical Systems Division.

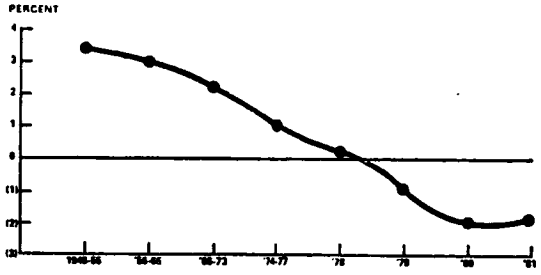
BASIS FOR AF MAN TECH INVESTMENT STRATEGY

- **CONTRIBUTIONS TO PRODUCTIVITY IMPROVEMENT**
- **COST DISTRIBUTION FOR BATCH MANUFACTURED PRODUCTS**
  - **LIFE CYCLE COST DISTRIBUTION**

There are three fundamental areas that we are concerned with in planning the Man Tech program. In a sense it is not only a strategy but fundamental principles against which we construct the program. The first is productivity, which is a straight forward improvement. The second being the projected return on Man Tech investment based on the cost drivers in, what for the most part, is a batch manufacturing environment. Specific consideration is also given to life cycle cost issues both in terms of new manufacturing approvals as well as cost reduction and modernization of our Air Logistic Centers.

PRODUCTIVITY GROWTH RATE IN U.S.

ANNUAL AVERAGE



We are all aware of the productivity situation in the United States and I don't intend to descri to you. Let me just say that the productivity growth rate in the United States has steadily declinec the middle 50s. For the last five (5) years, United States' direct labor productivity has remained unchanged while the rest of the industrialized West has been increasing by from 3% to 9% per year. b believe that the MAN TECH Program coupled with the Tech Mod initiative can change this trend for the aerospace industry and, in fact, be a model for modernization and productive growth for all U.S. industries.

THE EFFECT OF LOW PRODUCTIVITY ON THE US AIR FORCE

- WEAPONS SYSTEMS COST INCREASES
- ERODING PRODUCTION BASE
- LONG REACTION TIMES
- REDUCED QUALITY
- FOREIGN COMPETITION

A strong military cannot exist without a strong economy! Therefore, the productivity of the United States manufacturing industries has far-reaching implications for the continued ability of the Air Force to perform its missions. Some impacts are shown on this chart.

Cost - Declining productivity in the direct labor force translates immediately to increased hardware costs, which in turn impacts our force structure. Declining productivity in the indirect labor force has the same effect through overhead rates.

Production Base - Declining productivity reduces the number of companies capable of delivering critical hardware, most importantly for low volume or high technology products which provide little profit volume. We are increasingly left with one or two sources (for example, jet engine bearings) - little or no competition. The result - higher costs, lower quality, longer lead times, and no surge capability.

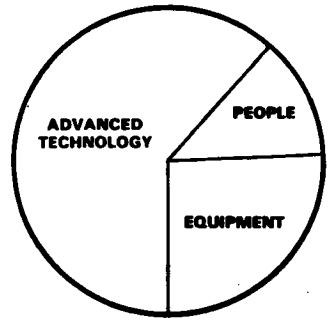
Reaction Times - Declining productivity inherently reduces response to change - even massive dollar infusions cannot totally overcome it.

Quality - Declining productivity reduces quality by both decreasing competition, as I said before, and by increasing the difficulty of meeting delivery commitments. It is also true that many of the causes of low productivity also result in low quality.

Foreign Competition - Most Air Force contractors do significant commercial business. Declining productivity in those firms relative to foreign firms has the effect of seriously degrading their profitability and therefore their ability to make productivity improvements. The net effect is downward spiral of our industrial base.

There can be no doubt that increased productivity within U.S. Industry is by far the most powerful factor in increasing the ability of the Air Force to accomplish its mission.

CONTRIBUTIONS TO PRODUCTIVITY IMPROVEMENT



Numerous studies have been made to determine the most important contributors to improved productivity. While there is disagreement on the relative percentages, all agree on these factors, all agree that advanced technology provides the largest contribution, people the smallest, and all agree that each factor is critical and must be work in common.

Equipment - A worker's productivity obviously depends significantly on the equipment he uses. The vast preponderance of most companies' modernization effort is spent in obtaining the latest state-of-the-art equipment - primarily for replacement and capacity. The Air Force can and should play a major role in incentivizing and rewarding industry for doing this. This is the cornerstone of our Tech Mod Program.

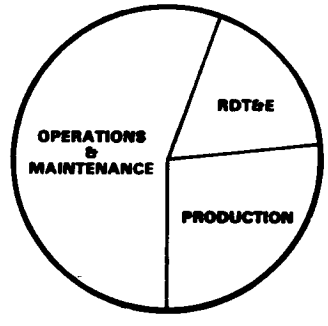
People - A worker's knowledge, skill for doing this, and motivation level is important in how well the job is done - both in productivity and in quality. The Air Force can have relatively little effect here other than a leadership role to encourage labor and management to do a far better job.

Advanced Technology refers to a significant change in methods of or approach to manufacturing, and can be evolutionary or revolutionary. Normally, the closer change approaches being revolutionary - for example, the concept of an assembly line - the greater its effect on productivity. Advanced technology embodies within it appropriate aspects of people and equipment.

It is here that the Air Force, through its Manufacturing Technology Program, plays the major role - not just establishing the advanced technologies but also putting the technology on the factory floor through the close ties between MAN TECH, Tech Mods, SPOs, and industry.

I will give you a few examples of activities which typify the MAN TECH Program. But first, just one example from the past. The Air Force MAN TECH Program is almost single-handedly responsible for today's automation - the widespread usage and the companies which produce the equipment - because in the 50s and early 60s it drove numerical control technology from an idea being toyed with in University Laboratories all the way through industrial application and NC equipment production. Without that pioneering effort, today's automated warehouses, conveyor systems, flexible manufacturing systems, and robots could not exist.

AIR FORCE LIFE CYCLE COST DISTRIBUTION



The MAN TECH Program is aimed at all Air Force activities which are involved in manufacturing or are impacted by the manufacturing process. These activities can be broken down into three general categories which impinge in different ways on the three major life cycle cost elements.

Performance - The ability of a system to perform a critical mission is frequently driven by the capability of specific components to handle a certain demanding environment - for example, the ability of a reentry vehicle to resist rain erosion. These environments are virtually always different - and more demanding - than those which similar commercial systems must withstand. The MAN TECH Program responds to these Air Force peculiar needs by establishing methods by which such components can be built. Such activities support the RDT&E and Production phases.

Cost - The MAN TECH Program aggressively pursues techniques and approaches to reduce system costs across the total spectrum of Air Force systems both in RDT&E and Production. A vital portion of this aspect is Quality Assurance.

Readiness - The MAN TECH Program responds directly to the Operations and Maintenance needs in two ways. First by keeping reliability and maintainability needs as first order priorities in the establishment of methods and systems used in system production. Second MAN TECH commits a substantial portion of its resources to the upgrading and implementation of field and depot inspection and repair techniques as a cooperative venture with AFLC.

MANUFACTURING TECHNOLOGY MAJOR PROGRAM CATEGORIES

- GENERIC MANUFACTURING TECHNOLOGY
- INTEGRATED COMPUTER-AIDED MANUFACTURING
- AIR FORCE LOGISTICS COMMAND INITIATIVE
- MANUFACTURING SCIENCE

There are four basic categories in the Man Tech program namely Generic, ICAM, AFLC, and Manufacturing Science. The relative dollar value of each slice is shown for FY82 and FY83. Note that in FY83 we have created a line called Manufacturing Science. This area provides seed money for precursor research required to show feasibility in selected manufacturing projects. I am going to review each one of these categories with respect to objectives, approaches, and show you some examples of each type of effort.

GENERIC MANUFACTURING TECHNOLOGY

OBJECTIVE

- PRODUCTION PROCESS FOR NEW MATERIALS AND SYSTEM COMPONENTS
- PRODUCTIVITY ENHANCEMENT AND QUALITY

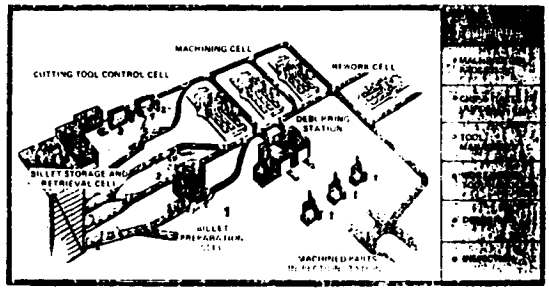
MAJOR THRUSTS

- MACHINING
- COMPOSITES PRODUCTION INTEGRATION
- PROPULSION TECHNOLOGY
- QUALITY MANUFACTURING
- ELECTRONICS PRODUCTION
- CRITICAL/STRATEGIC MATERIALS

The generic MAN TECH Program is the foundation of the Program. It basically provides the enabling manufacturing technology for everything we do, from providing new materials to advanced fabrication processes, to improve productivity and quality. The impact obviously is lower cost materials and components as well as an ability to manufacture complex materials and components. This gives the designer an inventor, of advanced materials from which to choose to design for performance and durability. The underlying theme of the Program is enhancement of productivity. This is done by improving efficiency on the shop floor of advanced processes and equipment. These improvements include automation as well as new concepts in Quality Control. The major thrusts shown are representative of the key Manufacturing Technology Thrusts and will be discussed in further detail beginning with advanced machining.

ADVANCED MACHINING SYSTEMS

FMS/IMS FOR MACHINING

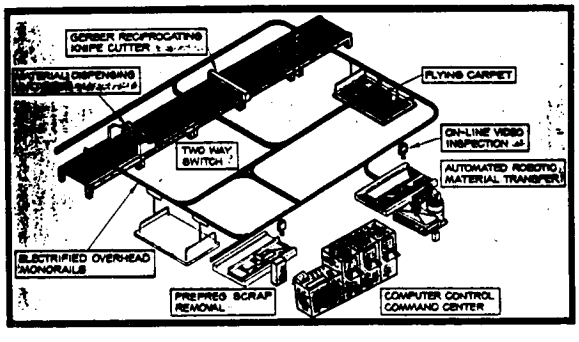


The Advanced Machining Systems Program (AMS) addresses both the near and long term aspects of productivity improvement for aerospace machined parts production. For the near term, the State-of-the-Art in flexible automation is being implemented into existing aerospace machine shops in a manner similar to the artists concept depicted in the viewgraph. In order to achieve maximum productivity, using today's technology, standard single and multi-spindle machine tools will be automated to run unattended on 2nd and 3r shifts. In order to maximize system efficiency and decrease flow time of a part through the shop, other functions required to support a machined component are integrated with the machining cells via automated handling devices. In this example, a robo-carrier is shown as the transfer device. As systems become more automated, quality assurance becomes an important factor.

Inspection of tool and final workpiece may also be included at the machine itself, to account for problems with cutting tool wear and failure. Finally the dimensional inspection of the completed machined part may be automated and included within when economically feasible. When finish machining of airframe aluminum and titanium parts create rough edges, deburring becomes a major cost driver. Automated debur of a part can significantly reduce the time and direct labor hours, thereby achieving significant cost savings. A cutting tool control cell, of some sort, is required to insure that the right tool goes to the right place at the right time.

In summary, the Flexible Machining System (FMS) for the aerospace factory of today is an integration of today's technologies; robotics, machine tools, sensors, etc. to achieve an island of productivity. The factory-of-the-future, though, requires these automation islands of productivity to be integrated into the factory information, scheduling, planning, business and design systems. The Integrated Machining System (IMS will take the FMS (to be demonstrated in 1985) and utilizing new technology in computers and software, and implement it within the factory CAD/CAM structure. The IMS will be a paperless system for the 1990's.

COMPOSITES INTEGRATED FLEXIBLE AUTOMATION CENTER (IFAC)

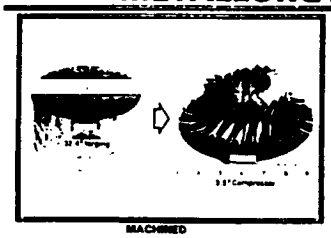


The major focus of recently completed and on-going work for advanced composite structures is to significantly reduce the expensive hand labor operations which until recently was the only available approach to composite fabrication. As industry moves toward the "Factory of the Future" it has become apparent that an automated integrated "center" approach to composite fabrication would be an integral part of the Factory.

To reduce the costs of fabricating relatively flat composite aircraft components, a MAN TECH Program was established with Northrop Corporation for an Integrated Flexible Automation Center (IFAC). The IFAC consists basically of six key individual elements which are integrated to perform the required functions associated with the lamination of a composite structure. These elements include: material dispensing units, Gerber reciprocating knife cutters, cutting/transfer tables, robot transfer mechanism, prepreg scrap removal devices, and associated on-line quality assurance devices. Integrating these key elements forms a completely hands off flexible automated fabrication operation has resulted in significant cost savings and quality enhancement over that provided hand operations.

Composites fabricated by the IFAC will save more than 80% of the labor hours when compared to hand fabrication. In addition, the Center should be more flexible in response to design changes. This will be a result of the concept merging the computer control of the Center with the Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) capabilities being established in most major aerospace companies. The IFAC facility has been placed in operation and is now being used for composites production at Northrop.

TITANIUM POWDER METALLURGY IMPELLER



MACHINED

MANUFACTURING TECHNOLOGY PROBLEM

- HIGH BUY/FLY RATIO (9.3:1)
- DIFFICULT TO MACHINE
- HIGH COST
- LONG LEAD TIMES (52 WKS)

APPROACH

- ESTABLISH NEAR NET SHAPE "AS-HIPED" TI PM PRODUCTION CAPABILITY

ACCOMPLISHMENTS & IMPACT

- COST SAVINGS ($2000/COMPONENT FOR F107) LESS MACHINING LESS INPUT
- LOWER BUY/FLY RATIO (2.6:1)
- SHORTER LEAD TIMES (26 WKS)
- MORE UNIFORM PROPERTIES

The Titanium forging shown on the left is very expensive and takes a long time to obtain. They are especially expensive for centrifugal impellers because of the extensive machining necessary to make the airfoils. In current practice, the impeller is machined from a 32.4 lb forging. The final part weighs only 3.5 lbs. Thus 28.9 lbs (89%) of the original forging has been turned into chips and scrap. In addition to the machining time required, it probably took at least 52 weeks to get the forging blank.

A new MAN TECH process which eliminates much of the machining is shown on the right. In this case we now have the ability to manufacture the impeller by Hot Isostatic Pressing (HIP) in one operation, the near net shape, using only 8.75 lbs of material. This represents a material input savings of 23.65 lbs (82% reduction in scrap material). As a consequence the machining time to a final part is significantly less. In addition, the lead time for the powder metal is only 36 weeks (a 30% reduction) compared to the 52 weeks for the forging blank. More uniform mechanical properties appear to be another benefit derived from prealloyed titanium powder. The resultant new powder process achieves 40% cost savings over the cost of the conventional forged part.

QUALITY ASSURANCE

- A NEW EMPHASIS WITHIN MANTECH
- QC TECHNOLOGY FOCUS
  - NONDESTRUCTIVE EVALUATION
  - PROCESS CONTROL
- PAYOFF FROM MODERNIZATION AND AUTOMATION

Viewgraph - Quality Assurance

Quality Assurance is a new emphasis within the Manufacturing Technology Program. A cornerstone to manufacturing productivity, improved quality assurance technology, provides a focus to the myriad of checkpoints from raw materials to the final manufactured product. Often 30% or more of manufacturing costs are directly linked to assuring quality. Mantech programs are underway to directly attack our quality problem. Activities include advanced automated inspection technology and advanced processing techniques to improve material and component reproducibility. A direct payoff from modernization and automation will bring significant improvements in "built in" quality.

Automation is a key to quality; by this I mean "built-in" quality as a better choice than inspection.

Advanced robotics is the cornerstone of future automation and is an area of intense interest. Robots that can perform the dull, repetitive, dirty and dangerous production jobs are a very attractive prospect because they can remove people from hazardous environments, greatly increase productivity, and at the same time significantly improve quality. The MAN TECH Program and Tech Mod Programs established the first robotics production application in the airframe industry - drilling and routing F-16 fuselage panels. The robot was installed in late 1979 and has yet to have a panel rejected. The installation did so much for productivity that General Dynamics has seven more robots committed to production.

While I've just given an example in the airframe area, robots have the potential for extremely broad application because they can be so flexible: handling of materials and parts ranging from diodes to wing skins performing individual unit processes ranging from trimming resistor leads to painting airframe parts, and assembling units as different as printed wiring boards and jet engine compressors. Robots promise tremendous payoff throughout all of industry and in our Air Logistics Centers as well. The primary emphasis in MAN TECH is the manufacturing of advanced sensors for robotics applicable to aerospace manufacturing operations.

"MANUFACTURING TECHNOLOGY FOR RADIATION HARDENED MICROPROCESSORS"

The availability of radiation hardened electronic devices has been a major problem to all military systems. Also, the production of such devices has required the incorporation of new or improved manufacturing processes and controls and materials.

Commercially available microprocessor circuits are not suitable for military environments with respect to nuclear radiation and wide operating ambient temperature ranges.

Under MAN TECH sponsorship, RCA produced the first high performance microprocessor chip set for military computer applications. The chip set is implemented in silicon-gate CMOS (Complementary Metal Oxide Semiconductor) circuit technology on sapphire substrates and is composed of a number of microcircuits, including the General Processor Unit (GPU), Read Only Memory (ROM), Random Access Memory (RAM) and Gate Universal Arrays (GUAs). Key steps in achieving radiation hardness involves the growth of thin gate oxides to minimize radiation induced charge buildup. Low temperature processing was developed to maintain radiation hardness of these CMOS devices.

Work is ongoing to establish manufacturing processes for increased circuit densities with enhanced functional capabilities and improved performance.

"Critical/Strategic Materials"

The Air Force is currently vulnerable to fluctuation in the availability and price of non-fuel critical and strategic materials. The two major areas of concern are:

(1) Materials which must be imported from politically unstable or hostile areas, and,

(2) Those sections of the U.S. materials processing industrial base which have inadequate capability.

For virtually every weapons system system, the Air Force requires significant amounts of critical/strategic materials. These include elements such as cobalt, tantalum, chromium, columbium, precious metals, titanium, tungsten, and aluminum.

In order to minimize the impact of the critical/strategic metals shortages a focused attack is required to the following technological areas to minimize our dependency:

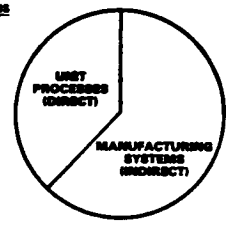
1. Conservation through reclamation and recovery of critical materials.
2. Substitute materials for items with critical/strategic materials content.
3. Productivity which includes efficient mill processing of critical materials to minimize losses.

Substitution includes all those cases in which high critical material content items are replaced with items of low or zero critical material content. With Respect to reclamation, both recycling scrap materials and spent parts are being considered. The arena of efficient processing tackles those portions of the basic metals industry which are characterized by substantial, irretrievable losses of critical materials. Efficient processing is aimed at working those manufacturing technologies which can substantially reduce those losses.

COST DISTRIBUTION FOR BATCH MANUFACTURED PRODUCTS

UNIT PROCESS/OPERATIONS

- MACHINING
- FORMING
- CASTING
- FORGING
- DRILLING
- FASTENING
- INSPECTION
- PAINTING
- SEALING
- COMPOSITE LAY-UP
- ELECTRONIC COMPONENT FABRICATION



MANUFACTURING SYSTEMS

- MATERIAL MANAGEMENT
- INVENTORY CONTROL & ACCOUNTING
- FLOW MONITORING
- PROCESS PLANNING
- SCHEDULING & ROUTING
- ORDER RELEASE
- CAPACITY PLANNING & FORECASTING
- ENGINEERING CHANGE ORDERS
- FACILITIES MANAGEMENT
- DATA COMMUNICATIONS
- PLANT LAYOUT

I've given you a brief summary of some of the initiatives we are taking in MAN TECH to attack the many problems presented by the material processes and shop floor operations. Now I'd like to turn to the management of that shop floor, the area of Manufacturing Systems, which is a major driver of indirect costs.

You will recognize many of these functions. The basic problem of manufacturing management is to insure that the myriad of parts, components and subassemblies all are produced to engineering requirements (which constantly change) and all arrive where they should when they should in order to meet delivery schedule requirements within budget, regardless of anything that may happen along the way. This is a very complex undertaking, the costs of doing it are very high, and they are getting higher all the time.

MAN TECH has mounted a major attack on these costs through its Integrated Computer Aided Manufacturing Program - ICAM.

INTEGRATED COMPUTER AIDED MANUFACTURING (ICAM)

OBJECTIVES

- REDUCE COST (INDIRECT)
  - CUT LEAD TIMES
    - IMPROVE QUALITY
      - ENHANCE SURGE CAPABILITY
        - INCREASE FLEXIBILITY

CONTENT

- GROUP TECHNOLOGY
  - FLEXIBLE INFORMATION MANAGEMENT
    - SHOP FLOOR CONTROL
      - SHEET METAL CENTER DEMONSTRATION

ICAM attacks the fundamental ways in which these manufacturing management functions are performed. Successful application of the technologies ICAM is providing will have enormous benefits.

Total costs can be dramatically reduced. Substantial reductions in various lead times (materials, product forms, tools, detail parts, etc.) and increases in direct labor productivity are worthy goals in and of themselves. But when we couple that with major reductions in the overhead costs of factory management, and now I'm talking about cutting overhead rates by as much as 50% in the long term, we can see truly huge payoffs.

We aren't just talking about cost reduction, though. Many other benefits come from the types of improvements that are possible. Quality increases, for example. Many of today's quality problems stem from poor instructions, unreasonable pressure to meet schedule, and all too often just plain confusion. ICAM is creating manufacturing systems which are lean and mean, and therefore can respond easily and quickly to change.

In our quest for the Factory of the Future, we are concerned with Group Technology which addresses part families that have similar characteristics such that the manufacturing operations can be optimized. The Sheet Metal Center is our shop floor demonstration of the payoffs which can result from these kinds of improvements.

ONE SHEET METAL AEROSPACE FACILITY

1	GENERAL FOREMAN
4	FOREMEN
1	PRODUCTION CONTROL SUPERVISOR
7	PRODUCTION CONTROL PERSONNEL
6	PRODUCTION CONTROL EXPEDITERS
2	QUALITY ASSURANCE PERSONNEL
15	FABRICATION PERSONNEL
36	TOTAL PERSONNEL

VIEWGRAPH "ONE SHEET METAL AEROSPACE FACILITY"

In one major airframe builder there is one department which does the first cut operations on all sheet metal for the company - these operations are sawing, shearing, routing and punch pressing. If you took a tour of this facility and put a job title with everyone you saw, this is how is would break out. All tools are designed and built somewhere else, the work orders are written somewhere else, the raw mater is ordered, received, inspected and stored somewhere else, and the machines are ordered, installed and maintained by someone else. But even at this very lowest level of manufacturing, fully 60% of the people (21 out of 36) are part of the management function - they do not add value to the hardware, they are required primarily to meet schedule and secondly (and it's a distant second) to ensure quality.

In this example, ICAM aims to reduce those production control people from fourteen to one and the foremen from five to three - a total reduction of fifteen of the twenty-one "non-touch" people. When you multiply this impact across the whole factory, make a similar impact in the areas of planning, scheduling, etc., you can see why we are so excited about ICAM and so dead set on continuing the attack on this area to make it happen.

SHEET METAL CENTER MINIMUM REQUIREMENTS

SYSTEMS

INTEGRATED COMPUTER-BASED PLANNING, SCHEDULING, AND CONTROL SYSTEM FOR PRODUCTION AND QA/QC

PROCESSES

AUTOMATED AND CONVENTIONAL
- BLANKING
  - STRAIGHT LINE AND CURVED BENDING
    - QA/QC

CAPACITY

- 450 PARTS/HOUR
- WIDE RANGE OF PART FAMILIES (80% OF TYPICAL AEROSPACE SHEET METAL PARTS)

The final demonstration of the ICAM Program, as currently planned, is an Integrated Sheet Metal Center, or ISMC. As designed, the ISMC demonstration will treat sheet metal production as the entire factory in microcosm, primarily concentrating in the manufacturing systems area. The Center will demonstrate integrated scheduling and control, using the computer as its integration and communication mechanism, with paperless operation as a major goal. These functions include master and production schedule generation, order generation and dispatch and shop floor control of people, machines, material and tools.

The Center is designed to be part of the contractor's factory and will produce production hardware from its start in 1985. It is designed to be expandable in both hardware and software, thereby facilitating technology transfer and fostering the incorporation of new or enhanced capabilities. Shop floor processes will include automated and conventional blanking, straight and curved line bending and material and tool handling and storage.

The Center will have the capacity for at least 450 sheet metal parts per hour, or approximately one million parts per year on a one shift basis. Those parts will represent, by type, 80% of all sheet metal parts produced in the aerospace industry.

Keeping in mind that sheet metal fabrication represents about 8-10% of total airframe cost, this one center alone is expected to generate savings of at least 10 million dollars per year. Rapid transfusion of the demonstrated technology will increase the savings because the technology is applicable to all batch manufacturing. In other words, what works for sheet metal with minimal modification, will work everywhere - airplanes, engines, satellites, electronics - everything we buy.

AIR FORCE LOGISTICS COMMAND INITIATIVES

OBJECTIVE

- MAN TECH FOR REPAIR AND MAINTENANCE PROCESSES
- MODERNIZATION OF AIR LOGISTIC CENTERS
- QUALITY IMPROVEMENT IN REPAIR PROCESSES

CONTENT

- ADVANCED INSPECTION TECHNOLOGY
  - ENGINE REPAIR CENTER
    - ELECTRONICS REPAIR CENTER
      - BONDED STRUCTURE REPAIR

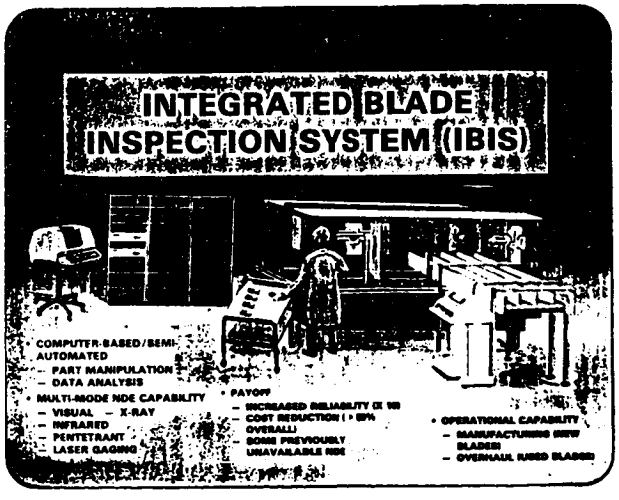
The MAN TECH Program has another major facet in its objective and that is supporting our Air Logistics Centers (ALCs) in providing the latest technology for:

a. Repairing current and future high technology hardware.
b. Establishing automated/modern repair lines for the ALC.
c. Providing the latest in NDI for flaw detection and repair quality control.

We are currently emphasizing the areas shown:

a. Advanced Inspection Technology.
b. Engine Repair Center.
c. Electronics Repair Center.
d. Bonded Structure Repair.

An example of the inspection area of effort is shown in the next viewgraph describing the Integrated Blade Inspection System.



Present inspection of blades at Oklahoma City and San Antonio Air Logistics Centers is a labor intensive operation subject to human error and limited by human visual accuracy and speed. IBIS involves the computer automation of four blade inspection techniques. The Visual Inspection Module (VIM) scans the blade optically to examine for surface defects such as nicks, dents, and scratches. The Fluorescent Penetrant Inspection Module inspects for surface flaws such as cracks. The X-ray Inspection Module (XIM) inspects for internal casting flaws, such as gas porosity, and manufacturing flaws, such as internal hole position and dimensions. The Infrared Inspection Module (IRIM) inspects for internal cooling passage and surface cooling hole blockages. Each module interfaces with Information Computer Systems. The viewgraph shows a visual inspection module. The IBIS System will be installed at San Antonio ALC.

INTEGRATED BLADE INSPECTION SYSTEM

ADVANTAGES

– **RELIABILITY**

HUMAN	COMPUTER
50-70%	99%

– **SENSITIVITY**
BETTER DETECTABILITY AND INTERPRETATION

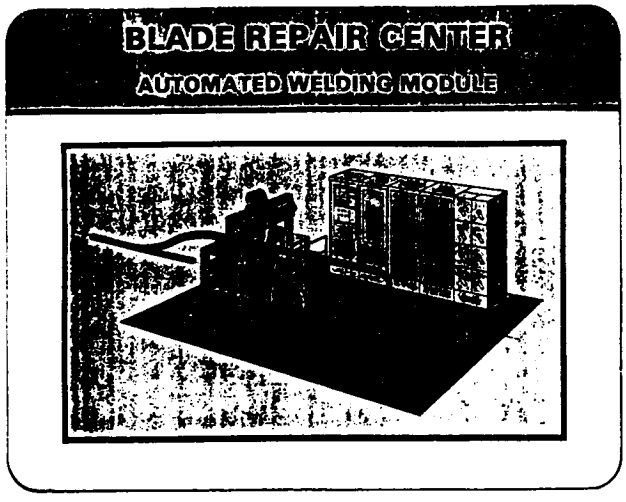
HUMAN	COMPUTER
.015" - .020"	.010"

– **COST**

IMPROVED THROUGHPUT

500 PARTS PER HOUR

The automation of nondestructive evaluation (NDE) processes significantly improves the quality of inspection during production and operational use. The primary benefit to be derived from this modular IBIS system, built to detect abnormal conditions in gas turbine engine airfoils, is the outstanding improvement in inspection quality and reliability, and, flaw detection as a result of computer automation. Clearly, the use of computer technology to replace human judgment and senses provides not only better detectability, but also, nearly a 30 - 50% improvement in inspection reliability. The high inspection rate or throughput capability of each module assures more cost effective and timely inspection.



VIEWGRAPH "AUTOMATED WELDING MODULE IWAG CELL"

The IBIS inspection system I just discussed will ultimately be linked to blade repair modules currently under development.

This a conceptual view of an automated welding module. The welding system is a two station device using Plasma Arc Welding. It will include computer control, a part transfer device (robot) and a material transport system to move parts in carriers to and between the welding and grinding modules.

MANUFACTURING SCIENCE

AN INOVATIVE MANUFACTURING INITIATIVE

OBJECTIVE

ENHANCE THE SCIENCE BASE FOR FUTURE DEFENSE SPECIFIC MANUFACTURING

APPROACH

- ADOPTIVE AUTOMATED PROCESSES
- ADVANCED UNIT PROCESSES
- ARTIFICAL INTELLIGENCE (ROBOTICS)
- INDUSTRY — UNIVERSITY — RESEARCH INSTITUTE TEAMS

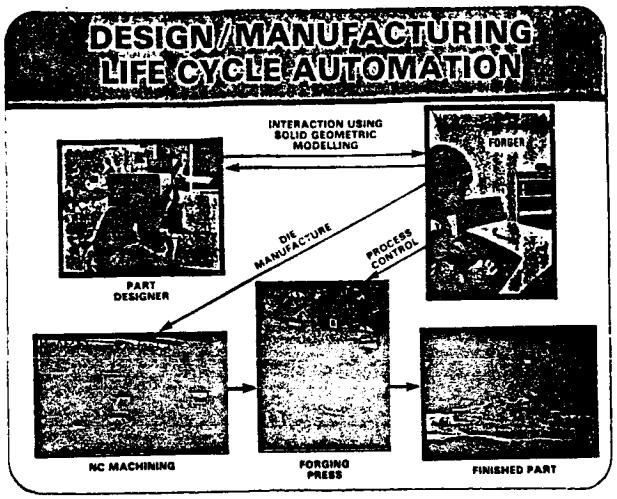
The DoD R&D program on Materials has traditionally addressed the problems of improved materials performance and quality with insufficient attention to manufacturing processes. The Manufacturing Technology program has addressed critical defense manufacturing issues but, by design, builds upon existing and proven technologies. This program organization has left a void in the area of R&D for manufacturing processes and operations. A new Air Force initiative is the Manufacturing Science program being managed by the Materials Laboratory.

The new activity will fund high payoff manufacturing topics to provide the precursor R&D required for future Man Tech programs. A significant involvement by universities will be part of our strategy to assure a rapid transition of technology increase such as microelectronics, computer science and artificial intelligence to new manufacturing processes and operation.

The first Manufacturing Science program to be initiated in September of 1982 and will establish the science base required for flexible automation by sponsoring research on intelligent, adaptable robotics. This cornerstone program has major university participation and has been carefully coordinated with related DARPA and AFOSR activities. The program will address micromanipulators for high accuracy and precision assembly, and versatile fingers with integrated sensing for complex assembly marks.

Additional Manufacturing Science programs are currently in planning and will address such important manufacturing issues as CAD/CAM for forging die design and manufacture to drastically reduce forging die delivery lead times and improve press utilization, smart curing of structural composites to reduce start up costs and provide batch process scheduling capability for the automated composites factories of the future, and enhanced productivity of HgCdTe detector arrays to increase yields by an order-of-magnitude for the coming generation of large area mosaic focal plane arrays.

The Manufacturing Science initiative is an innovative Air Force activity which will provide the solid manufacturing science base required for defense specific manufacturing needs of the future.



Through the use of interactive graphics and computer design the ability to design a structured part and its forging tooling as well as the processing limits, is within our grasp. Our aerospace prime can talk to the forger via the computer and provide the part dimensions and tolerances. At the forge the computer designs the tooling as well as the NC program to machine the forging dies. In the future we hope to automate the forging process itself. The benefits are: forging lead times will be cut in half and realistic manufacturing cost estimates can be readily made.

TECHNOLOGY MODERNIZATION

- ACCELERATED IMPLEMENTATION
- LEVERAGE CAPITAL
- GOALS
  - REDUCED COST
  - ENHANCED PRODUCTIVITY
  - IMPROVED INDUSTRIAL BASE
- THRUSTS
  - SYSTEM
  - FACTORY
  - SUBCONTRACTOR/VENDOR

Viewgraph "Technology Modernization"

The objective of Technology Modernization (Tech Mod) is to accelerate the implementation of advanced manufacturing technology. The process involves the coupling of contractual incentives with technology development and implementation. The goal is to make it attractive for the contractor to increase or accelerate his capital investments over that originally planned for the instant production contract, so that benefits may accrue to the Government and to him. The expected result of enhanced productivity will provide reduced acquisition costs and an expanded industrial base.

When dealing with a prime contractor, the subject of the Tech Mod is typically a single weapon system and there is very little difference between a "system" and "factory" program. However, the idea is to maintain a long-range view so that a balance is struck between short-term benefits and long-term improvement of industrial capability. Experience to date with second and third-tier subcontractors and vendors is limited, but these industrial organizations are critical to the production of defense systems and new ways of incentivitizing this area are being sought.

KEY ELEMENTS OF TECH MOD

TECHNICAL

- STRONG EMPHASIS ON ANALYSIS, PLANNING AND INTEGRATION
  - FOCUS ON MANUFACTURING CENTERS
    - SATISFY MANUFACTURING TECHNOLOGY CRITERIA

CONTRACTUAL INCENTIVES

- INDEMNIFICATION
  - SHARED SAVINGS
    - AWARD FEE
      - SHARED COST
        - ACCELERATED DEPRECIATION
          - OTHER

CREATE A WIN/WIN SITUATION

Experience has shown that vigorous analysis and planning are vital to the success of Tech Mod efforts. While the incentives/benefits are usually tied to a single contract, the improvements made must fit into the production system and be in consonance with long range business and manufacturing plans. Therefore there is emphasis on integration of the improvements into the existing system. That is, there is little point in improving a single manufacturing operation if the result is that other operations will become bottlenecks to smooth and efficient production. While manufacturing centers are the key focus of Tech Mods, other areas of manufacturing must not be overlooked. Manufacturing information systems (MIS) such as planning, scheduling, inventory control and the like can be a fruitful source of benefits when span time and overhead costs can be reduced. Similarly the area of quality control/assurance should be examined for increases in yield and reductions in rework. Where the Government shares the technical and financial risk in technology development, these projects must satisfy manufacturing technology criteria. Simply stated, these criteria are: the technology must be generic, the results must be an advancement in the state of the art, and they must be able to be transferred to other organizations who can or want to benefit from them.

The variety of contractual incentives that can be used are shown here. The key to Tech Mod is the mutually beneficial result: the win/win situation must be real. We ask contractors and Government procurement people to come to the negotiation table with the idea in mind that a reasonable business deal can be achieved. There are no standard forms or pat answers to which incentives are used or what share lines should be. What is important is what makes sense and is profitable to both sides.

ACTIVE AIR FORCE TECH MODS (FY 82-83)

SYSTEM	FACTORY	SUBCONTRACTOR/ VENDOR
F-16	WESTINGHOUSE	F-16 SUBCONTRACTORS
LANTIRN	BMAC	TWT
C-5 WING	PWA	
B-1B	GE	
JTIDS		
SEEK TALK		
E-4B		
MEECN		
AMRAAM		

This chart provides an overview of the scope of Tech Mod activity. As you can see, with respect to systems, we are dealing with aircraft (F-16, B-1B, C-5), electronics (LANTIRN), communications (JTIDS, SEEK TALK, MEECN) and missiles (AMRAAM). The factory types represent those contractors who are producing more than one system. A key point here is that both the Pratt & Whitney and General Electric Tech Mods include second and third tier suppliers in addition to the primes' facilities. The F-16 subcontractor activity is our first effort at reaching beyond the prime contractors; the positive and enthusiastic cooperation of those involved in this activity has been very encouraging, and indicates that the fruitfulness of this area (subcontractors/vendors) must be pursued ever more aggressively.

TECHNOLOGY TRANSITIONED FROM MAN TECH TO TECH MOD

EXAMPLES

MAN TECH	TECH MOD
• ICAM SYSTEMS ENGINEERING METHODOLOGY – ARCHITECTURE – IDEF MODELING – GROUP TECHNOLOGY	ALL
• HERMETIC CHIP CARRIERS	AMRAAM, LANTIRN, ROCKWELL-COLLINS (JTIDS)
• ADVANCED COMPOSITES	F-16
• PRINTED WIRING BOARD PROCESSING TECHNIQUES	WESTINGHOUSE, SEEK TALK, LANTIRN, SINGER
• CAPACITANCE HOLE PROBE	C-5, B-1
• PHOTOGAMMETRY	F-16, B-1

Now turning to a few examples where we have taken MAN TECH Programs and are implementing them in the production environment through the incentives of the Tech Mod Program. This building block approach provides for an earlier return on our technology investment and a continuum for technology implementation.

The systems engineering tools developed under the Integrated Computer Aided Manufacturing (ICAM) Program are being used by industry on all Tech Mod Programs.

The Capacitance Hole Probe (CHP), which for the first time will provide an objective evaluation of airframe fastener hole quality, is being evaluated in the production environment for use during the C-5 Wing Modification Program and on the B-1. This item spent nearly ten years in the Laboratory and now through the Tech Mod Program we are putting it on the shop floor. The Navy, the Air Force ALCs and the aerospace industry in general are poised to use the results of the Tech Mod evaluation before they adopt the CHP for their use.

Other MAN TECH Programs and their related Tech Mod Programs are as shown. The key message is that the thrust of the Tech Mod Program is to implement the technologies demonstrated under the MAN TECH Programs so the Air Force receives an earlier return on its investment in technology and we achieve the critically needed modernization of our aerospace industries.

BENEFITS TRACKING

OBJECTIVE

IDENTIFY AUDITABLE PAYOFF OF MANTECH CONTRACTS

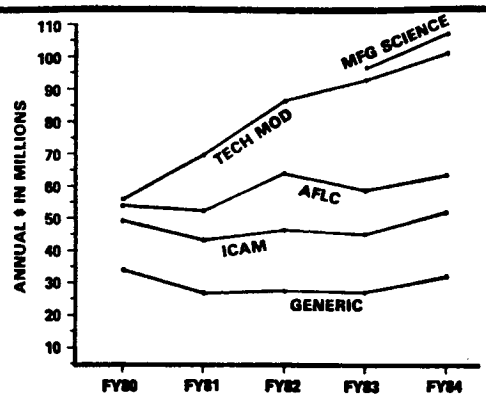
MODIS OPERANDI

- MANTECH CONTRACTUAL REQUIREMENT
  - TECHNOLOGY TRANSFER/USER IMPLEMENTATION PLAN
  - BENEFITS ANALYSIS AND TRACKING
- INDEPENDENT ANALYSIS PRIOR PROJECTS CONTRACTOR - APPLIED CONCEPT

Since FY81, all new start MANTECH contracts have SOW requirement for establishing a plan for technology transfer and user implementation. In addition we require an analysis of benefits expected, plus a plan for tracking benefits for a period of 3 years beyond the end of the contract. Our Objective is to obtain an auditable track of benefits, which we can use to quantify Return on Investment

In order to show our past performance we have initiated a contract to assess 69 MANTECH contracts that were completed in the 1971 - 1981 time frame. Specifically we are going to determine successful/unsuccessful contracts, identify which contracts resulted in implementation of the technology and where implemented, and, finally, an auditable determination of benefits. Our initial focus is on MANTECH programs supporting advanced technology with the turbine engine contractors.

AF MANTECH AND TECH MOD PROGRAM FUNDING (PE7.8011F)



The funding chart shows a number of significant trends. It's clear that Tech Mod is increasing while the Generic Program has been level funded. ICAM funding was fenced for five years and we would expect that in FY85 there will be a decrease in the ICAM effort as the program will have matured.

The AFLC manufacturing support will be level funded at about 20% of the Man Tech program. The Manufacturing Science thrust has just started and we will review its progress to formulate our future plans for expanded activity.

SUMMARY

MANUFACTURING TECHNOLOGY

- TECHNOLOGY FOR SYSTEMS
- SIGNIFICANT COST REDUCTION IMPACT
- AFLC MODERNIZATION INITIATIVE
- MANUFACTURING SCIENCE THRUST
- TECHNOLOGY TRANSFER/BENEFITS TRACKING

TECH MOD

- TECHNOLOGY MODERNIZATION VIA INCENTIVES
- MAN TECH TECHNICAL INTEGRITY RESPONSIBILITY
- INTEGRATION INTO ACQUISITION PROCESS

The Man Tech program is now and always will be responsive to the needs of our SPO directors in providing a technological superiority in our weapons systems that advanced manufacturing can bring. Without Man Tech bridging the gap to full scale production the designer would have few choices. By fulfilling this role Man Tech offers to the aerospace community and others the gateway to benefits such as Performance, Durability, Reliability and Availability. And while we do all this we drive to reduce costs through productivity and manufacturing efficiencies.

Recognizing the technical complexity of our hardware and the difficulty of repair we find that maintenance cost reduction is critical. To drive the cost down we are applying our advanced manufacturing technology to modernize our Air Logistics centers in cooperation with AFLC. This also includes paying attention to repair processes while we establish production processes for technologically complex materials and components. In order to provide a better foundation for our program, a Manufacturing Science program was created. Funds are now available which provide an integration of the R&D base with computer technology, we call it "Smart Processing".

And finally we are sensitive to our performance and track record. We are going to continue to emphasize the importance of production implementation. We intend to show a large ROI on our Man Tech investments. This is a matter of survival in a fierce competition for dollar resources.

It is our intent to accelerate the transition of Man Tech into Tech Mod to provide today's technology on the factory floor. We plan to financially incentivize industry to do this in order to provide the most modern aerospace industrial base in the world. Man Tech expertise is assisting in these efforts, in order to assure that we select those Tech Mod programs with the greatest impact on our industrial base both financially and

QUALITY CIRCLES IN THE UNITED STATES AIR FORCE

Major Russell F. Lloyd

Wright-Patterson AFB

The U.S. Air Force has become intrigued with the concept of Quality Circles as a means of better achieving its organizational mission. Popular management literature contains a large number of anecdotal reports testifying to the value of Quality Circles as an effective management tool. Cost reductions, increased productivity, better product quality and improved employee morale represent only some of the purported benefits of successful Quality Circles programs conducted in the private sector. These often stunning accomplishments attributed to Quality Circles programs have caught the attention of administrators in the public sector. There is a genuine interest within the Air Force in the application of Quality Circles' principles to the special problems encountered by public sector agencies. At this writing, approximately 500 Quality Circles have been initiated throughout most, if not all, Major Air Commands involving a wide diversity of functional areas from aircraft maintenance to chaplain to security police to procurement to health care and to the R&D environments, to name but a few. Circles exist at all levels of the organizational hierarchy; in predominantly military environments, civilian environments, and in the more commonly found mixed environments; and they can be found scattered throughout the world geographically.

The United States Air Force has designated the Air Force Institute of Technology (AFIT) as the principal center for education, consultation, and research on Air Force Quality Circle undertakings. If current trends are any indication, the enthusiasm generated by Quality Circles will soon make our task a formidable one.

The Air Force Institute of Technology (AFIT) is the resident Air Force graduate scool (accredited by the North Central Association) offering masters and doctoral degrees in various engineering and logistics disciplines. In addition to graduate education, AFIT offers an extensive array of professional continuing educaticn in many areas; one of which is Quality Circles (QCs).

The AFIT Quality Circle Program consists of a wide variety of educational, consultative, and research activities on the Quality Circles process. With respect to education, a repertoire of courses and workshop are offered in conjunction with other educational activities. The resident 5-day course, Principles and Techniques of Quality Circle Management, is offered monthly for QC team leaders, facilitators, and/or coordinators. The student is first introduced to the history, concepts, and philosophy of Quality Circle management, and then acquires the principles, tools and techniques necessary to teach Quality Circle coordinators, facilitators, team leaders, and circle members. Students also learn how to introduce, apply and implement, and operate Quality Circles at their installations. This course includes an effective combination of in-depth lectures, guided discussions, case studies, worksnops and experiential learning exercises. Additional topics taught include group processes (e.g., conflict management, trust, listening skills, how to conduct an effective meeting) and evaluation methodology. Upon the completion of the course, students leave with the materials required to implement a Quality Circle program at their installation.

An on-site 1-day course, An Executive Perspective of Quality Circles, is offered quarterly for general/flag officers and civilian Senior Executive Service personnel who either have a Quality Circle program in being or who are contemplating the implementation of one. The executive is first introduced to

the history, concepts and philosophy of Quality Circles, and is then exposed to select principles, tools and techniques utilized by Quality Circle coordinators, facilitators, leaders and circle members. Emphasis is given to the philosophy of Quality Circles and the implementation issues and problems/solutions associated with them. Other topics include: private and federal sector involvement, research findings, evaluation procedures, and an opportunity to interact with peer executives presently involved in Quality Circle programs. Various modes of presentation are utilized, including multi-media lectures, discussions and simulation exercises. Executives gain a thorough appreciation of the Quality Circles concept so as to evaluate its propriety for their organization.

One to three-day Advanced Quality Circles courses are also offered in residence in the area(s) of group process (e.g., the conduct of effective meetings, trust, conflict, listening, communications, etc.), basic statistics, alternative problem-solving methods, advanced Quality Circle tools, and basic statistics. These short courses are designed to meet the needs of Quality Circle practitioners who desire to refine, expand or otherwise improve upon their expertise.

Because of its mission, AFIT is the recipient of useful information from federal sector colleagues both within and without the DOD. As a result, and as part of its education mission, AFIT issues a quarterly Quality Circles Newsletter for distribution throughout the federal sector. Our intent is to publish names of resource personnel; testimonials about practical applications that worked and did not work; evaluation results; commentary from the field on key topics such as implementation, burn-out, union involvement, evaluation, training, etc. The newsletter is free of charge and field input is emphasized.

An additional element of our educational mission is the sponsorship of an Annual Federal Sector Conference on Quality Circles. The first one is scheduled for 23-25 August 1983, and will contain three concurrent tracts including Tutorials, Applications and Paper Sessions. A keynote address, plenary sessions, workshops and a closing address will supplement the tracts.

A final aspect of our educational mission is the offering of executive/management orientation briefings. AFIT/LSB personnel make themselves available to respond to requests from federal sector organizations to give orientation briefings on the QC process to executives, middle and first line supervisory personnel.

In its role as consultant in Quality Circles, AFIT assists federal sector agencies in the implementation and conduct of Quality Circle programs. It is not uncommon for organizations to face thorny issues for which they lack experience in either the implementation of or conduct of a Quality Circle process. Extensive telephonic consultation occurs, and not infrequently, on-site visits are called for.

Last, but not at all least, AFIT is responsible for the design and execution of systematic longitudinal research on the Quality Circle process. The professional literature is ostensibly void of rigorous research in this area. Anecdotal evidence (i.e., testimonials) abounds in Time, Newsweek, The Wall Street Journal and your local newspaper, but little has been done to subject the Quality Circle process to the scrutiny of controlled, field experimental research. As more and more executive managers contemplate the expenditure of literally millions of dollars in initiating a Quality Circle process (or, as bad, in deleting one) they make those decisions void of insight as to what are the critical issues in the start-up phase; where are Quality Circles

vulnerable; what attributes of the Quality Circle process are flexible, rigid; when do Quality Circles perform best; or what are the causes of circle burn-out and how they can be re-energized.

At this writing, AFIT is collaborating with six organizations throughout the DOD in the evaluation of research of their Quality Circle programs. A quasi-experimental design is typically used involving the collection of both affective and objective data at a pre and at least two post measures. In all cases, control groups have been employed. As sufficient post data is received, we expect to submit our findings to refereed journals for publication.

Anyone desiring further information should write or call Maj Russell F. Lloyd, Department of Organizational Sciences, Air Force Institute of Technology, Wright-Patterson AFB, Ohio 45433. Telephone: (513) 255-4549/4529 or AUTOVON 785-4549/4529.

NASA PRODUCTIVITY GOALS AND NASA EMPLOYEE TEAMS

David R. Braunstein
Executive Director, Special Project
with
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National Aeronautics and Space Administration
Washington, D.C.

PRESENTED TO THE
MISSION ASSURANCE CONFERENCE

(June 6-9, 1983)

ABSTRACT

Recognizing that severe budgetary and manpower constraints are likely to become the conditions under which it operates in the years ahead, NASA formed a Productivity Steering Committee to develop an agency-wide approach to productivity and quality. The goal was to provide, in the long term, the best possible work at the highest level of quality under the constraints of a constant work force and tighter budget. The chairman of this committee is the NASA Administrator and the membership includes key Headquarters administrators and all Center Directors.

NASA's agency-wide effort, established less than one year ago, is focused on seven strategic goals. One key goal is to increase the participation of the NASA employee in the decision-making process. No centralized productivity staff is contemplated instead, part-time productivity coordinator networks and working groups have been formed at Headquarters and the centers to begin specific initiatives for the seven goals. Each of the NASA organizational elements have been reviewing the application of each of the goals, and one, employee participation through NASA employee teams, is finding wide acceptance. This is of particular interest because R&D organizations have not historically been attracted to the quality circle approach.

As evidence of management's commitment to productivity, the NASA Administrator recently published its eight top objectives and one prominent one is to "Establish NASA as a leader in the development and application of advanced technology and management practices which contribute to significant increases in both agency and national productivity."

Solving work environment problems is a goal of the NET concept. However participative management is the long range objective. We, at NAS, believe that by involving our employees

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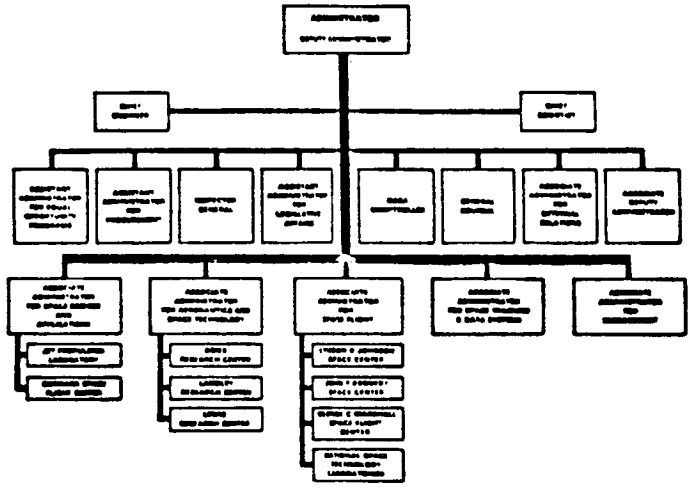
in this management approach will ultimately increase motivation and commitment, develop leadership, resolve work related problems, increase productivity and encourage employees to be more cost effective.

IMPLEMENTATION OF THE QUALITY CIRCLE CONCEPT IN NASA

David R. Braunstein & David J. Austin

Introduction

Mr. James Beggs as the Administrator of NASA has developed an initiative to increase productivity within the agency. In order to fully understand and implement this productivity objective, an overview of the organization is necessary. NASA is made up of Headquarters and nine centers which are semi autonomous. At Headquarters there are ten Associate Administrators (AA) and support offices of the Chief Scientist, Chief Engineer, Inspector General, Comptroller and General Counsel. Three of the AAs are responsible for the nine centers based on predominance of effort. Yet most of the operation has been decentralized with the Center Director basically in charge of the total Center effort.



NASA PRODUCTIVITY STEERING COMMITTEE

NASA Initiatives

The Administrator has created a steering committee made up of the key AAs and Center Directors, with himself as the chairman, for purposes of developing the productivity initiatives. In January of 1983 this group met at the Westinghouse Productivity Center in Pittsburgh in order to review Westinghouse's program and discuss their plan for improving NASA productivity. Seven initiatives resulted from this meeting. One of these was to introduce (implement) NASA Employee Teams (NETs), employing the quality circle process, across the agency.

AGENCY WIDE JANUARY 1983 PLAN

- ESTABLISH NASA GOALS AND SUPPORTING OBJECTIVES
- INTRODUCE NASA EMPLOYEE TEAMS (NETS) ACROSS AGENCY
- PROMOTE OFFICE AUTOMATION
- PLAN FOR COMMON HARDWARE AND SOFTWARE IN ADMINISTRATIVE SYSTEMS
- INITIATE PAPERWORK REDUCTION ACTIVITY
- REDUCE THE PROCUREMENT CYCLE
- IMPROVE SUPPORT CONTRACTOR PRODUCTIVITY
- LECTURES AND WORKSHOPS ON APPROACHES TO MANAGING FOR PRODUCTIVITY

PIQE

The productivity enhancement program is known as PIQE for Productivity Improvement and Quality Enhancement. The intent is to closely align productivity and quality with creativity in the normal NASA R&D environment. In March 1983 the NASA PIQE goals were established. These goals are compatible with the seven initiatives and especially with the NET concept.

MARCH 23, 1983 AGENCY WIDE GOALS

- PROVIDE FOR OUR PEOPLE A CREATIVE ENVIRONMENT AND THE BEST OF FACILITIES, SUPPORT SERVICES, AND MANAGEMENT SUPPORT SO THEY CAN PERFORM WITH EXCELLENCE...
- MAKE THE SPACE TRANSPORTATION SYSTEM FULLY OPERATIONAL AND COST EFFECTIVE...
- ESTABLISH A PERMANENT MANNED PRESENCE IN SPACE TO EXPAND THE EXPLORATION AND USE OF SPACE...
- CONDUCT AN EFFECTIVE AND PRODUCTIVE AERONAUTICS RESEARCH AND TECHNOLOGY PROGRAM ...
- CONDUCT AN EFFECTIVE AND PRODUCTIVE SPACE SCIENCE PROGRAM...
- CONDUCT EFFECTIVE AND PRODUCTIVE SPACE APPLICATIONS AND TECHNOLOGY PROGRAMS...
- EXPAND OPPORTUNITIES FOR U.S. PRIVATE SECTOR INVESTMENT AND INVOLVEMENT IN CIVIL SPACE AND SPACE-RELATED ACTIVITIES.
- ESTABLISH NASA AS A LEADER IN THE DEVELOPMENT AND APPLICATION OF ADVANCED TECHNOLOGY AND MANAGEMENT PRACTICES WHICH CONTRIBUTE TO SIGNIFICANT INCREASES IN BOTH AGENCY AND NATIONAL PRODUCTIVITY.

Recognition of Organization Anxieties

In order to properly gauge the climate for implementation of the seven initiatives, organizational anxieties had to be recognized and addressed. By understanding these anxieties,

which were not unique to NASA or industrial organizations, we were prepared to positively address the initiatives. We recognized that for NASA the key to achieving productivity improvements is through employee involvement, both civil servant and contractor, in all phases of our activities.

ORGANIZATIONAL ANXIETIES CONCERNING PRODUCTIVITY

- ORGANIZATION CANNOT KEEP ADJUSTING TO FADS
- CAN ONLY MEAN MORE PAPERWORK
- ANOTHER PROGRAM WITHOUT MONEY
- NASA ALREADY DOES A GREAT JOB OF MANAGING
- ONLY ENOUGH TIME AVAILABLE TO SPEND ON PROJECTS THAT ARE REALLY IMPORTANT
- WHY PUSH IT, IF YOU CANNOT MEASURE YOUR SUCCESS
- PRODUCTIVITY NOT A NASA RESPONSIBILITY
- GOES WITH THE MANAGEMENT JOB, WHY THE EMPHASIS NEEDED
- SEEMS TO BE MORE POLITICAL THAN REAL
- PROBABLY ANOTHER TECHNIQUE TO RATIONALIZE REDUCTIONS

NETS

The Quality Circle concept has been around for several years now. However, the white collar and government application is relatively new, two to three years. In NASA we elected to call our concept NASA Employee Teams or NETs rather than quality circles, because of the latter's association with manufacturing organizations and because we wanted to focus on the group approach to problem solving. The concept is known by many different terms by various organizations thus we were not unique in our renaming the idea within the NASA.

The philosophy for NETs in NASA is to develop participative management, promote leadership and management development. Our objectives are to involve the NASA employees in resolving problems in the organization, increase motivation and commitment and create an atmosphere of creative management. We believe that there will be a synergistic effect of improving productivity through this concept.

NASA EMPLOYEE TEAMS (NETS)

WHY –	PARTICIPATIVE MANAGEMENT APPROACHES INCREASE PRODUCTIVITY
BENEFITS –	PROMOTE LEADERSHIP AND MANAGEMENT DEVELOPMENT DEVELOP TEAM APPROACH TO PROBLEM SOLVING
ISSUES –	SUPPORTIVE MANAGEMENT CLIMATE LONG TERM REWARDS

Implementation Stragegy

In January 1983 a Headquarters/Agency Advisory Group for NETs was created. This group was made up of members from several Headquarters AAs and their centers. We put this group together to brainstorm appraoches to implementing NETs, and also to develop a plan that could guide the agency. We also interacted with individuals from the NASA field organizations to determine their views and an overall strategic approach to taking the message to the orther parts of the organization.

HEADQUARTERS/AGENCY ADVISORY GROUP

- DAVID BRAUNSTEIN CODE NAD
- DAVID AUSTIN, AGENCY TEAM LEADER, CODE DP
- DALE CROSSMAN, CODE N (TRAINING)
- ELAINE SCHWARTZ, CODE N (PERSONNEL)
- DAVID CUSHING, CODE N (HQ COORDINATOR)
- ELLEN SEARCY, CODE N (TRAINING)
- KAM KERSEY, CODE M (SHUTTLE PROGRAM)
- KEN JEFFRIES, CODE H
- BOB HUFFMAN, LERC
- CLARENCE COLE, LARC
- CHARLIE BOYLE, GSFC

AGENCY IMPLEMENTATION PLAN

• DEVELOP	JAN 1983
• COORDINATOR MEETING	FEB 1983
• BRIEF CENTER DIRECTORS/KEY STAFF	MAR-APR 1983
• BRIEF MIDDLE MANAGERS, STAFF, UNIONS, EMPLOYEES & CONTRACTORS	APR 1983
• COORDINATOR TRAINING SESSION	APR 1983
• FACILITATOR TRAINING	APR & JUNE 1983
• PILOT* NET OPERATION	OCT 1983
• CONFERENCE	DEC 1983
• NASA EMPLOYEE TEAM	

The implementation strategy recognized the decentralization of NASA, lack of a permanent staff for full time duties, use of part time "experts" and emphasis on centralized acquisition of information and subsequent transfer.

IMPLEMENTING STRATEGY

- RECOGNIZE NASA IS DECENTRALIZED
- NO PERMANENT STAFF ASSIGNED TO PRODUCTIVITY DIRECTOR
- USE OF BORROWED PART-TIME "PROJECT MANAGERS"
- EMPHASIS ON TRANSFER OF INFORMATION, MOTIVATION, AND FACILITATING IMPLEMENTATION

Planned Phases

There were four phases of implementation. The first was for members of the advisory group to contact IAQC, the USAF and consultants in order to get first hand knowledge of the NET concept in white collar areas. The advisory group also visited Navy and industry organizations where white collar quality circles were used in research and development or scientific and

engineering operations. Once having convinced the advisory group of the merits of the NET approach, we exposed our findings to Headquarters and Center management. The Headquarters and Center coordinators scheduled NET for their top managers. The briefing consisted of (1) an overview of the what, why and how of NETs, and (2) a testimonial of the results of NETs in practice (since 1980) at the GSFC.

The third phase involved the decision of each Center Director on whether to and how to implement the concept. At this time each center has elected to begin a pilot program. The fourth and final stage is a scheduled follow-up conference in December 1983. This conference will be a "how-goes-it" session with each center to provide a stand-up briefing of their status, problems, benefits, etc. We expect to have a similar meeting, every four months until a final report is provided to the Administrator during the 4th quarter of CY 84.

PLANNED PHASES

- CONTACTED: IAQC
  USAF
  CONSULTANTS
- VISITED: OPERATIONAL CIRCLES
  USN – R&D LABORATORIES
  SEVERAL R&D COMPANIES
- BRIEF NASA MANAGEMENT
  - COORDINATORS TO DC
  - TEAM TO EACH CENTER
- DECISION BY EACH CENTER
- FOLLOW-UP NET CONFERENCE

Basic Implementation Concept

The fact that NASA is decentralized coupled with the fact that for a management initiative to have long-term impact argued strongly that we make any management changes to be completely voluntary on behalf of the Center Directors. This was key to implementation of NETs, and we assidously avoided any suggestion of a Headquarters edict that NETs would be implemented. We merely provided advise, encouragement to explore the benefits that may result from NETs and guidance as to approaches. In addition the concept had to be 100% Voluntary from the Center Director on down. Unions and professional Associations in the government are somewhat different than in industry. However, union acceptance depended on inviting their participation and keeping them informed up-front. This was encouraged by the Advisory Group. In many

centers the union management has been invited to participate as a member of the advisory group/steering communittee. We believe that this will alleviate future problems or concerns on their benalf.

BASIC IMPLEMENTATION CONCEPT

DECENTRALIZED & VOLUNTARY

UNIONS

CONTRACTORS

TABOOS

MANAGEMENT & REWARDS

TRAINING

LERC STEERING COMMITTEE

ANDREW J. STOFAN	CHAIRMAN
PAUL G. ANDERSON	COMPTROLLER
LAWRENCE J. ANDREWS	SENIOR EXECUTIVE VICE PRESIDENT, IFPTE LOCAL 28
MILTON A. BEHEIM	DEPUTY DIRECTOR, ENGINEERING AND TECHNICAL SERVICES
ANDREW J. BENEK	PRESIDENT, AFGE LOCAL 2182
RICHARD D. CLAPPER	CHIEF, TRAINING AND DEVELOPMENT BRANCH
THOMAS A. COZZENS	CHIEF, EMPLOYEE-LABOR RELATIONS BRANCH
ROBERT G. HOFFMAN	QUALITY CIRCLE PROGRAM COORDINATOR
EDWARD A. RICHLEY	DIRECTOR, ADMINISTRATION AND COMPUTER SERVICES
COULSON M. SCHEUERMANN	PRESIDENT, IFPTE LOCAL 28
LEROY G. SIDORAK	EXECUTIVE VICE PRESIDENT, AFGE LOCAL 2182
WARNER L. STEWART	DIRECTOR, ENGINEERING AND TECHNICAL SERVICES

In addition we invited contractor participition. In the Shuttle Program three of the five main prime contractors have a Quality Circle Program. The concept is encouraged contractually. It has proven very successful in improving productivity for the Shuttle Program. In recognition of this success, NASA Manned Flight Awareness Panel had a competition between those

contractors with quality circles and selected one circle for a sponsered trip to witness the launch of STS-5. Currently our centers have been encouraged to include their product and support contractors in the NET process. Early indications are that NSTL, KSC, and JSC may consider combined NETs.

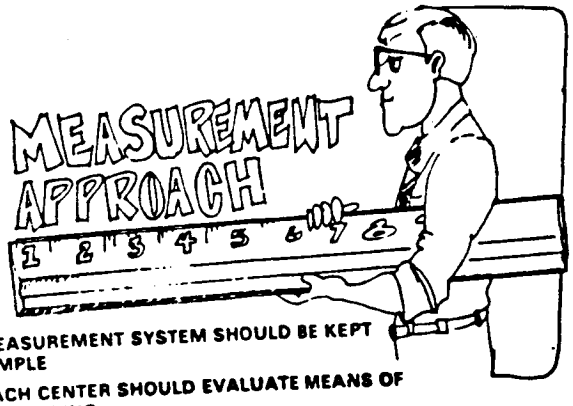
During the advisory groups early research it became apparent that there were several areas that NETs should not contemplate problem solving. These areas were identified in the implemtation plan and briefed to center management.

As described previously the long range objective of NETs is to develop a style of management where each and every employee may participate by being creative/innovative in problem solving. In order to effectively achieve that objective both senior and middle managers had to be convinced that NETs would not present a threat to their positions. Our emphasis was on covincing those groups that their employees would work on solving work related problems that they (senior and middle managers) did not have the time or resources to work on. We also emphasized that recognition and awards primarily consisted of management presentations and the ability to communicate ideas and recommendations to management. However awards may be provided through the normal system such as the suggestion program. Those programs would be used by the NETs when a successful problem solution had been agreed to by managememt.

In the beginning the need for training was recognized. During our disussions with various organizations we realized that there were several ways to go. Since it was NASA's desire to develop a common NET process across the agency, we elected to provide a centralized training course for our coordinators/facilitators early in the planning stage, Our desire to provide this training by an organiation that had both theoretical and practical expertise in the R&D area resulted in asking one of the Shuttls contractors, Martin Marietta, to provide the training. They revised their course to fit our needs and presented it to 25 NASA employees during the week of April 18, 1983. The consensus of the attendees is that this was a very good course and that it was helpful to meet the other agency NET coordinators.

Measurement

In planning the NET process we were conscious of the need for organizational guages to measure NET contributions. However, it is our belief that there are too many variables that will result in both tangible and intangible benefits and by measuring we would fall into a trap by looking only at quantifiable data. Our recommendation to our centers was to develop some measuring system where improved morale, commitment and management enhancements could be detemined. However, we wanted to avoid a numbers accounting as this would ultimately result in comparing organizations and not be truly effective. In the end we believe this would cause the NET process to fail.



- MEASUREMENT SYSTEM SHOULD BE KEPT SIMPLE
- EACH CENTER SHOULD EVALUATE MEANS OF MEASURING
- SHOULD NOT ATTEMPT TO USE QUANTIFIABLE DATA FOR ORGANIZATIONAL RATING FACTORS
  - TANGIBLE
  - INTANGIBLE

The NASA centers have accepted the concept and will begin to implement pilots during 1983. Three centers, LERC, LARC, and GSFC, had quality circles prior to establishment of the Headquarters/Agency Advisory Group. They have had both positive reaction and positive results from the circle concept. It is anticipated that they will be expanding in the near future. Three centers, NSTL, KSC and JSC, may establish integrated NETS with their contractors. This idea has merit but there are several potential areas of conflict that must be resolved. We do not anticipate any serious impediments to this approach. One center has not been briefed but they (JPL) are going ahead with implementing the concept. The Headquarters briefing, to JPL is tentatively scheduled for July 11, 1983.

STATUS

	BRIEFING	DECISION CENTER	PILOT IMPLEMENTATION DATE	ESTIMATE NUMBER OF NETS	COMMENTS
HQ	IN PROGRESS	YES	AUG 83	3-4	
GSFC	MAY 1983	YES	OCT 83	7	MAY BE INTEGRATED
JSC	MAY 1983	YES	AUG 83	4-6	AIRCRAFT MAINT MAY BE JOINT
MSFC	APR 1983	YES	SEPT 83	3-6	WORKING WITH UNION
LeRC	N/A	YES	MARCH 83	6	
LaRC	N/A	YES	SEPT 83	8	MAY BE EXPANDING
GSFC	N/A	YES			
NSTL	MAY 1983	YES	SEPT 83	3	(1) INTEGRATED WITH CONTRACTOR
ARC	MAY 1983	YES	JUN-JUL 83	3-6	
JPL	JUNE 11, 1983	YES	AUG 83	3-6	

The approach to NETS has been to create the proper climate for acceptance. We believe that that has been accomplished. In addition on April 5, 1983 our administrator, Mr James Beggs, signed out a letter, the subject of which is; Productivity Program, Implementation Plan for NASA Employee Teams (NETs). The final paragraph reads, "One of the cornerstones to our productivity program is greater employee involvement in our decision-making. I believe NETs are a positive step in this direction, and fully support their introduction into NASA.

ADMINISTRATOR LETTER TO NASA OFFICIALS IN CHARGE

"ONE OF THE CORNERSTONES TO OUR PRODUCTIVITY PROGRAM IS GREATER EMPLOYEE INVOLVEMENT IN OUR DECISION-MAKING. I BELIEVE NETS ARE A POSITIVE STEP IN THIS DIRECTION, AND I FULLY SUPPORT THEIR INTRODUCTION INTO NASA"

SIGNED BY
JAMES M. BEGGS
APRIL 5, 1983

Our final step as stated earlier will be to review the status of implementation during the scheduled quarterly conferences beginning in December 1983. We believe that, as with other NASA program, this concept will be sucessful in our agency.

NASA MANNED FLIGHT AWARENESS PROGRAM

Darlene Medina
Motivation Administrator
Rockwell International
Space Transportation & Systems Group

MANNED FLIGHT AWARENESS--
The Manned Flight Awareness program is designed by NASA to develop a strong government-industry team spirit. The program's objective is to instill in each worker a sense of personal responsibility for the safety of astronauts and fellow employees, and also a sense of personal involvement with the space hardware and missions.

Since its inception during the pioneering Mercury space flights, the Awareness program has spread to encompass thousands of the aerospace companies that supply hardware and services for NASA's spacecraft, launch vehicles, and support activities. Thus, today Manned Flight Awareness is not just a program, but a way of life for hundreds of thousands of dedicated people who make up the manned spaceflight team.

REQUIREMENTS--
NASA handbook 5300.4 requires the five Space Shuttle element contractors to maintain motivation programs. The handbook states:

> ...the contractor shall maintain a product-oriented motivation (awareness) program planned and implemented as an integral part of, and making maximum use of, the existing motivational effort. The program objective shall be the prevention of human error by instilling in individuals performing on the contract and on critical subcontracts thereunder, an awareness of their personal responsibility for Space Shuttle mission success and motivating the exemplary performance necessary to achieve this success.

ORGANIZATION AND OPERATION--
A Manned Flight Awareness panel comprising the five NASA centers and five element contractors was established to support the program requirements of the NASA handbook. The panel meets at least twice a year to review and implement the policy and operations of the program requirements. The panel evaluates the program effectiveness and recommends changes whenever necessary.

To promote program effectiveness, motivational items and key awards are offered.

MOTIVATIONAL ITEMS:
Posters to reinforce the awareness of the program. These posters reflect messages of concern for quality with pictures and signatures of astronauts and their personal messages to Shuttle employees and subcontractors.

Decals representative of each astronaut's logo. These are distributed to all employees and subcontractors prior to Shuttle launch. A letter from the Quality Division Director accompanies each item with a message of thanks for superior work and dedication to the team effort of producing a quality product.

Astronaut visits, definitely the largest motivators. Shuttle crew members stop by several times a year, speaking to the employees and touring the facility with management and photographers, shaking hands with as many people as possible during the tour time.

KEY AWARDS:
One key award is the Astronaut's Personal Achievement Award, a silver pin/tie tack in the form of a "Snoopy," dressed in space helmet and suit. A letter of appreciation and a certificate signed by the presenting astronaut accompany the Snoopy. The award is presented by the astronaut in the work area to an individual whose job perfomance has been outstanding as well as meaningful in its contributions to mission

success. This recognition may apply to all job qualifications and task assignments.

The Launch Honoree Award is the highest form of recognition given through the Awareness program. It is normally given to employees who have previously received the Astronauts' Personal Achievement Award and have continued with extraordinary and outstanding contributions to mission success. A minimum of one Launch Honoree Program a year is planned.

The total allocation for launch honorees is directed from NASA Headquarters to the NASA centers. The NASA centers then allocate viewing slots to the contractors, who in turn select outstanding subcontractors to be represented. The Launch Honoree Program includes VIP viewing of a Shuttle launch, a tour of the Kennedy Space Center, and an Astronaut reception with top NASA management and contractors in attendance. Astronauts mingle with the honorees for picture taking and autograph signing. Each awardee is also presented a commemorative package displaying motivational items from different contractors along with a commemoration book listing the names of the honorees.

SUMMARY--
Personal recognition has proven to be most effective in motivating employees towards error-free work, as witnessed by the ongoing positive response received from those who have participated. Those employees communicate their enthusiasm about the program to their peers, inspiring other workers and creating an atmosphere of pride and accomplishment.

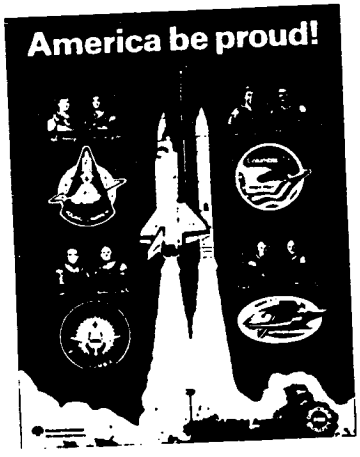
ORGANIZATION AND OPERATION

MANNED FLIGHT AWARENESS PROGRAM

- MFA PANEL
  - NASA CENTERS
  - ELEMENT CONTRACTORS
- PERIODIC REVIEWS
  - POLICY AND OPERATIONS
  - EVALUATE EFFECTIVENESS
  - PLAN AND IMPLEMENT LAUNCH HONOREE PROGRAM

OUTLINE

- NASA MOTIVATION REQUIREMENTS
- ORGANIZATION & OPERATION
- KEY AWARDS
  - ASTRONAUT'S PERSONAL ACHIEVEMENT
  - LAUNCH HONOREE



NASA MOTIVATION REQUIREMENTS

NHB 5300.4

BASIC ELEMENTS

- PRODUCT-ORIENTED MOTIVATION PROGRAM
- MAXIMUM USE OF EXISTING MOTIVATIONAL EFFORT
- PREVENTION OF HUMAN ERROR
- AWARENESS OF PERSONAL RESPONSIBILITY
- MOTIVATE EXEMPLARY PERFORMANCE

LAUNCH HONOREE AWARD

- HIGHEST FORM OF RECOGNITION
- UNUSUAL AND SUSTAINED EFFORTS THAT CONTRIBUTE TO THE SUCCESS OF MANNED SPACE FLIGHT
- ALLOCATION — ABOUT 200 HONOREES — ONE FLIGHT PER YEAR

KEY AWARDS

MANNED FLIGHT AWARENESS PROGRAM

OBJECTIVES

- ELIMINATE HUMAN ERRORS AT ALL LEVELS
- RECOGNIZE OUTSTANDING ACHIEVERS

LAUNCH HONOREE AWARD

NASA ALLOCATION:

HEADQUARTERS
⇩
CENTERS
⇩
CONTRACTORS
⇩
SUBCONTRACTORS

ASTRONAUTS PERSONAL ACHIEVEMENT AWARD

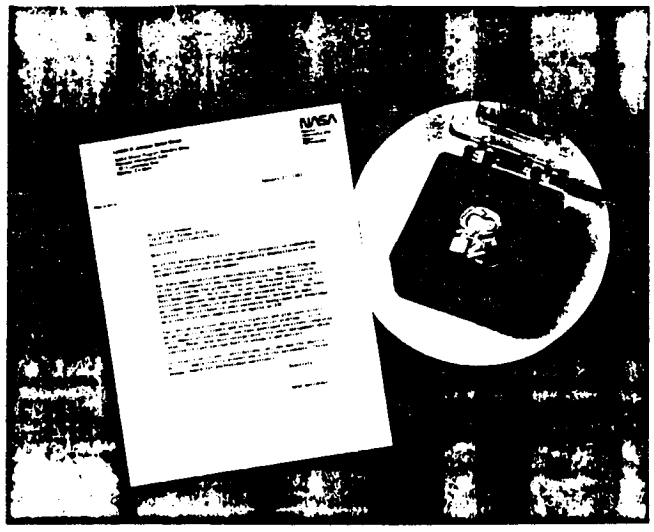
- OUTSTANDING CONTRIBUTION TO MANNED SPACE FLIGHT MISSION SUCCESS

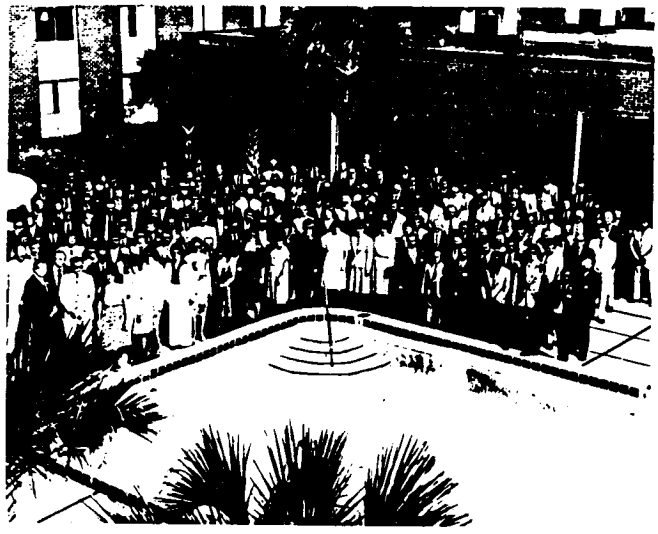
SUMMARY

MANNED FLIGHT AWARENESS PROGRAM

- ON-GOING, POSITIVE IMPACT
- ENTAILS FULL RANGE OF SPACE SHUTTLE WORK FORCES
- EMPLOYEE FEEDBACK TYPIFIED BY:
  - "I AM BOTH PROUD & GRATIFIED FOR THE OPPORTUNITY..."

"THE KEY TO PRODUCTIVITY AND QUALITY IS MOTIVATION AND COMMITMENT; THE PRINCIPLE IS RECOGNITION AND REWARD."
JAMES M. BEGGS





In Recognition

Tommy G. Love

of your dedication and commitment
to excellence on crucial tasks
that made possible the third
Shuttle Mission

Ship: Columbia
John F. Kennedy Space Center

NASA *Manned Flight Awareness*

MARITZ PERFORMANCE IMPROVEMENT MANAGEMENT SYSTEM

The Performance Improvement Management System is based on the concept of a data based process using the principles of positive reinforcement to improve the performance of all employees.

Some basic elements are goals, objectives, incentives (equally shared by team's members earned based on their performance against specific variables), communications, and measurement.

The process:

1) Determine top management's special focus variables, how they measure improvement, and its value in dollars.

2) Cascade the variable down each management level, customizing the measurement to the function and level down to the smallest homogeneous work group...insuring that the member of the group can have a direct impact on the measurement.

3) Obtain agreement on the amount of possible improvement by variable and its total value to the organization.

4) Insure adequate data collection systems and feedback mechanisms for quick turn-around and [illegible].

5) Design an incentive program, as a phase of the system, based on the variables selected insuring an acceptable ROI and cash flow. Incentives could include honor and recognition, cash, merchandise, or travel.

6) Develop and produce communications for the program period, allowing for a two-way process...workers to management; management to workers.

7) Hold regular management reviews to develop action plans for reinforcing success and getting improvement started where appropriate.

8) After the first program is completed as a phase of the system, re-evaluate the variables and objectives and revise where appropriate.

Then, introduce the next phase, much in the same manner as described above.

In addition, a process has been developed for Suggestion programs that has consistently produced from 10 to 40 times the performance reported by the National Suggestions Systems Organization. Based on the same principles as the Maritz Performance Improvement Management System, it approaches the Suggestion opportunity in a pro-active and meaningful way.

J. L. McAdams
Vice President - Planning & Analysis
Maritz Inc.

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PERFORMANCE IMPROVEMENT MANAGEMENT SYSTEMS

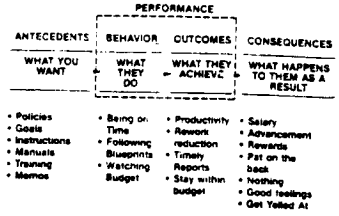
Jerry McAdams

MARITZ INC.

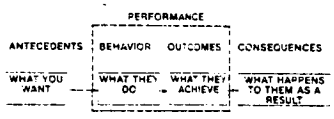
PERFORMANCE IMPROVEMENT MANAGEMENT SYSTEM

- Comprehensive, data based system using positive reinforcement to improve human performance
- Combines
  - Management directed objective and goal setting
  - Measurement systems/evaluation criteria
  - Pinpointing of specific actions leading to desired outcomes
  - Training in management skills
  - Two-way communications
  - Incentives based on performance
  - Self-funding system with planned ROI

THE BEHAVIOR MODEL THAT EXISTS TODAY



THE BEHAVIOR MODEL THAT EXISTS TODAY



- Management spends most of its time managing antecedents
- Behavior is a function of its consequences
- To impact outcomes, managers should focus more on consequences

The performance you are getting NOW is a function of the consequences you've established.

What you are getting NOW is what you are paying for.

MANAGING CONSEQUENCES

POSITIVE (Increases Behavior)	NEGATIVE (Decreases Behavior)
SALARY	SALARY
ADVANCEMENT	TERMINATION
PERQUISITES	FAILURE TO ADVANCE
BONUSES	PUNISHMENT
COMMENDATIONS	REPRIMANDS
PAT-ON-BACK	WITHDRAWAL OF PRIVILEGES
FEEDBACK	
INCENTIVES	
THREATS	

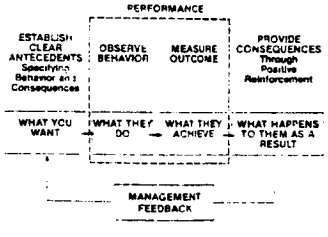
NOT MANAGING CONSEQUENCES
EXTINCTION — DOING NOTHING
(Decreases Behavior)

THE MOST EFFECTIVE WAY TO INCREASE BEHAVIOR IS THROUGH THE CONSEQUENCE OF POSITIVE REINFORCEMENT.

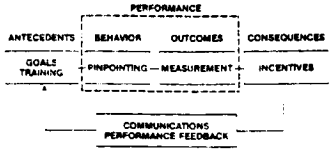
The most effective R⁺ is

- **POSITIVE TO THE INDIVIDUAL**
- **IMMEDIATE**
- **CERTAIN**

HOW MANAGEMENT CAN IMPACT BEHAVIOR



HOW A PERFORMANCE IMPROVEMENT SYSTEM ENHANCES THE BEHAVIOR MODEL



MANAGEMENT TOOLS TO CHANGE BEHAVIOR

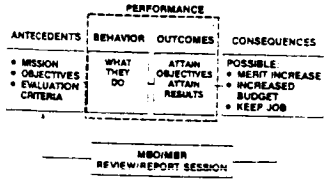
MANAGEMENT TOOLS TO CHANGE BEHAVIOR

MANAGEMENT BY OBJECTIVE OR RESULT (MBO/MBR)
TRAINING
MEASUREMENT — DATA SYSTEMS
JOB ENRICHMENT
COMMUNICATIONS
COMPENSATION
INCENTIVES

HOW WELL EACH WORKS DEPENDS ON HOW CLOSELY IT MEETS THE BEHAVIOR MODEL

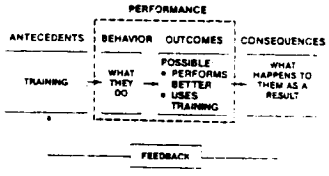
MBO/MBR

- Establishes mission
- Establishes objectives
- Establishes measurements
- Provides opportunity for regular feedback/accountability
- Designed for every level of management



TRAINING

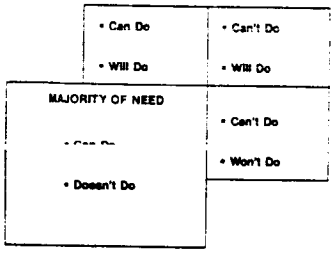
- Teaches Job Skills
- Teaches Management Skills
- Provides Opportunity for Creative Thought
- Concentrates Time and Focus on Limited Subject(s)
- Creates Awareness
- Creates Understanding
- Creates Ownership



TRAINING

• Can Do • Will Do	• Can't Do • Will Do
• Can Do • Doesn't Do	• Can't Do • Won't Do

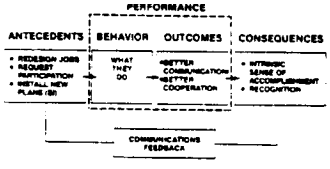
TRAINING



JOB ENRICHMENT

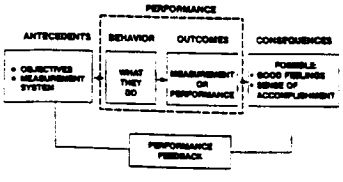
MIGHT INCLUDE:

- Redesign jobs to meet organization's and employee's needs
- Change management style to have more respect for employees and their contributions (Quality of Work Life)
- Participative management (Quality Circles, Task Forces)
- Enhance management and employee communication
- Flextime
- Employee activities (picnics, etc.)



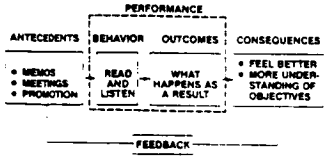
MEASUREMENT — DATA SYSTEMS

- Measures Performance by Objective
- Collects Raw Data from Activity Records or Financial
- Analyzes and Feeds back Performance to groups and/or individuals
- Highlights Opportunities
- Provides Trend Analysis
- Becomes a form of Communications
- Operates in a timely fashion

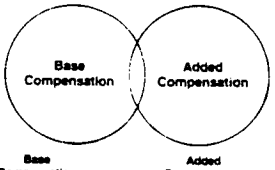


COMMUNICATIONS

- Shares Information, Data, Objectives, Company Needs from top down
- Allows for Input, Recommendations, Questions from bottom up
- Reinforces Image
- Recognizes Outstanding Performance



COMPENSATION



Base Compensation	Added Compensation
• Salary • Fringes • Perquisites • Merit Increases • Cost of Living	• Profit-Sharing • Bonus • Advancement
Fixed	Organizational Performance Generally NOT Individual

COMPENSATION

BASE COMPENSATION

Salary and Fringes	— Terms of Employment
Perquisites	— Car, Country Club, Employee Cafeteria — additional terms of employment
Merit Increases and C.O.L.A.	— Annual Often confused Amount Defined by Policy Distribution system of increases Competitive parity and retention Possible dissatisfaction Questionable Link to Performance

COMPENSATION

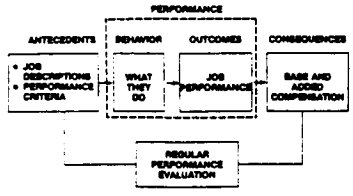
ADDED COMPENSATION

Profit Sharing	— Annual — Profit Sharing Institute considers it fringe benefit — Not perceived as impactable — Confused with salary
Bonus	— Effectiveness depends on size, immediacy and frequency — Confused with salary — Can be objective based
Advancement	— Can improve total fixed and added compensation package — Intrinsically rewarding — Not guaranteed — Individual or organization performance based — Limited opportunity for use

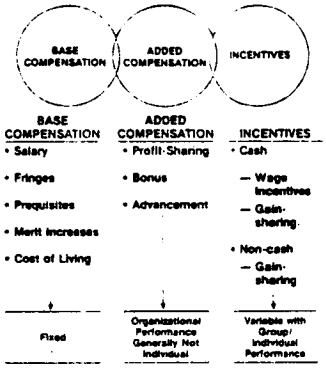
COMPENSATION

Changing Base and Added Compensation

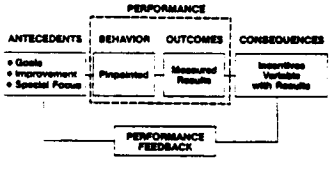
- Tend to become perpetual
- Difficult to use as a tool to change individual behavior for performance improvement



COMPENSATION + INCENTIVES



INCENTIVES



INCENTIVES

- Cash
- Non-cash
  - Social
  - Honor & Recognition
  - Merchandise
  - Travel

INCENTIVES

CASH

Wage Incentives	— Frequent — Generally individual — Based on performance — Generally objective based — High degree of human contingency — Often considered salary. Comfort levels established — Single formula. Single focus, based — Work measurement
Gain-Sharing	— Frequent — Portion of savings generated by group performance improvement shared with employees — Rest of savings retained by organization — Average degree of human contingency — Single formula. Single focus, based — Financially justifiable, good ROI can be designed in — Generally applied in manufacturing (Scanlon, Rucker, improshare)

INCENTIVES

NON-CASH

Gain-sharing	— Frequent — Portion of savings generated by group performance improvement shared with employees — Portion of savings generated goes for system operation, taxes, communications — Rest of savings retained by organization — Average degree of human contingency — Multi-formula, Multi-focus, based — Flexible...Objectives can change — Merchandise, social reinforcement enhance income and provide self-esteem — Not confused with fixed or added compensation

INCENTIVES

CASH AND NON-CASH CONSIDERATIONS

1. Cash and Non-cash reinforcers are positive and change behavior
2. Cash immediately understood and acceptable
3. Formalization of Cash incentives becomes confused with salary, tends to become perpetual
4. Disengagement/change
   - Cash — sensitive — same medium as salary
   - Non-cash — not as sensitive

PERFORMANCE IMPROVEMENT MANAGEMENT SYSTEM

- Comprehensive, data based system using positive reinforcement to improve human performance
- Combines
  - Management directed objective and goal setting
  - Measurement systems/evaluation criteria
  - Pinpointing of specific actions leading to desired outcomes
  - Training in management skills
  - Two-way communications
  - Incentives based on performance
  - Self-funding system with planned ROI

PIMS PROCESS

- Select primary objective and cascade down
- Create groups (teams)
- Develop measurements by objective by group
- Review and confirm
- Develop or refine data collection and feedback system

PIMS PROCESS

- Develop financial rationale
- Design reinforcement system
- Decision training/orientation needs
- Design communication system
- Develop ROI system

PIMS OPERATION

- Management R' Training
- Consultative System launch
- Participant introduction
- Team measurement training
  "What can we do to improve performance on this objective"
- Data collection and feedback
- Reinforcement based on performance
- Team reviews
- Management review with Plan of Action
- Communications and promotion
- Special focus activities
- Refinement

PIMS BENEFITS

- Long-term system that produce short-term results
- Self-funding
- High degree of adaptability to market or organization changes
- Minimum Impowerment threat
- Consultative employee involvement
- Allows special focus
- Improves effectiveness of existing management system
- Taps the behavioral model for management

QUALITY CIRCLES IN A MULTI-CONTRACTOR, MULTI-WORK SITE ENVIRONMENT

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Systems Refinement Teams
Martin Marietta Aerospace
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INTRODUCTION

Every organized human endeavor generates two fundamental and opposing requirements: the division of labor into a variety of individual tasks and the coordination of these tasks to accomplish the overall endeavor. Quite simply, an organization's structure can be defined as the sum total of the ways in which it divides its labor into distinct tasks and then achieves coordination among them. Division of labor is largely dictated by the job to be done and the technical system available to do it.[1] However, coordination seems to be more complicated in that it involves various mechanisms. Some coordination is achieved through direct supervision and through standardization of worker skills, work processes and work outputs. However, these coordinating mechanisms are usually not sufficient for an organization to achieve all of the coordination it requires. After the individual positions have been designed, the superstructure built and the planning and control systems established, important interdepencies remain. The organization must then complete its coordination through the mechanism of mutual adjustment.[2]

Until recently, mutual adjustment was largely a random, informal process that spawned an infrastructure growing up around the formal organizational structures. Two people may decide to hold a five minute meeting in the hall or several people may be called together to respond to an unplanned event. "Stamping out fires" is a well used phrase that describes the crisis management which results when mutual adjustment is left to chance. Recently, organizations have implemented various devices which encourage liaison contacts between people and are incorporated into the formal structure. According to one author, "... these liaison devices represent the most significant contemporary development in organization design, indeed the only serious one since the establishment of planning and control systems..."[3]

This is a conceptual paper which explores the use of quality circles (QCs) as organizational liaison devices. As such, QCs and QC-like structures are viewed not only as improving employee motivation and productivity, but also as lateral linkages between and within organizations purposefully structured to achieve mutual adjustment.

This paper outlines organizational structures which can be implemented at the National Aeronautic and Space Administration's Kennedy Space Center. Quality circles are in their embryonic stage at KSC. Interest has recently been generated by the NASA and several contractors. Only one organization, Martin Marietta, has implemented a QC program. Three variations of the typical quality circle will be explored. Actual examples will be given when possible, however, it should be noted that most of these structures have not yet been implemented at KSC.

THE ENVIRONMENT

Organizational - There are approximately 9000 employees in 40 contractor organizations at KSC responsible for base operations, space shuttle

processing and cargo operations.[4] The NASA employs about 2000 people and has four major departments (Shuttle Management and Operations, Cargo Management and Operations, Engineering Development, Center Support Operations) which administrate and coordinate the contractor organizations.

There are a variety of organizational perspectives one can take when analyzing Kennedy Space Center. The broadest perspective views KSC as one superstructure composed of the NASA and its contractors while the narrowest perspective focuses on a particular sub-unit within one organization. One must adjust and re-adjust the organizational focus when exploring QCs and QC-like structures at KSC. This paper begins with a narrow perspective by addressing typical QCs, then expands in scope with each variation on the QC concept.

Systemic - Obviously, KSC does not operate in a vacuum. Each prime contractor is corporately connected with intracompany organizations. For example, Martin Marietta Corporation (MMC)/KSC currently reports to MMC/Michoud (New Orleans, LA), Rockwell International Corporation (RIC)/KSC reports to RIC/Downey, CA, and United Space Boosters Incorporation (USBI)/KSC reports to USBI/Marshall Space Flight Center (Huntsville, AL). In addition, NASA/KSC is impacted by NASA/Johnson Space Center, NASA/Marshall Space Flight Center, NASA Headquarters, the U.S. Congress and the U.S. Executive Branch. Although many closed systems exist within KSC, the individual organizations represent components of larger systems external to KSC.

Geographical - Kennedy Space Center sits on 84,000 acres of land in central eastern Florida. Launch Complex-39 (LC-39), a part of KSC, includes many work sites necessary for shuttle processing. Each work site has employees from the NASA and at least one prime contractor. These work sites include:

Vehicle Assembly Building (VAB). Low bays: USBI; high bays: MMC, RIC, USBI

Orbiter Processing Facility (OPF). Hangars: RIC

Pad A. Liquid Oxygen system (LOX): MMC; Liquid Hydrogen system (LH2): MMC

Pad A Terminal Control Room (PTCR): MMC

Operations and Checkout Building (O&C): MMC, RIC, USBI

Shuttle Landing Facility (SLF): RIC

Launch Control Center (LCC): MMC, RIC, USBI

Parachute Refurbishment Facility (PRF): MMC, USBI

There are a number of other work sites at KSC which are involved with base operations and cargo operations. These multiple work sites lead to logistical problems when implementing the QC process that are inherent in such a large processing facility that are usually not present in a manufacturing plant. When teams are composed of members from different work sites, meetings are difficult to schedule and attendance may be sporadic. Action items generated by team meetings are more difficult to complete. Coordination within teams as well as between teams and management is not a simple task.

When combining the number of work sites with the number of organizations ast KSC, the implementation and maintenance of the QC process becomes quite complex. A strong, coordinated effort by all organizations is required. In addition, the use of QC-like variations will go a long way to strengthening the process and eliciting commitment from the involved organizations.

VARIATIONS

Typical Quality Circle - The typical QC is composed of 5-12 employees and their supervisor with the same work area interests who voluntarily form a team, receive training in participative problem-solving techniques and meet for one hour each week to identify work-related problems, analyze those problems, recommend solutions to management and monitor the effectiveness of their solutions. Thompson[5] noted that the QC process is political in that employees participate directly in decisions to implement new and better ideas. Circle members gain control over one hour each week, a meeting room of their own, the right to select the problems they will analyze and solve, and access to the relevant decision-makers of the organization. While decision-makers do not abdicate their authority, they do invite employees to participate in decisions on issues about which they have knowledge and interest.

Psychologically, the QC process is also motivational. When employees are allowed to participate in decision-making they will feel like causal agents in the tasks in which they engage. At the heart of employee motivation is a feeling of personal causation, free choice and commitment.In addition to participation in decision-making, the QC process elicits employee motivation through communication of organizational goals, performance feedback and technical information and through recognition of team accomplishments via management presentations and award programs.

Organizationally, the QC serves as a liaison device between employees and management which not only fosters mutual adjustment vertically but also within the QC, itself. With maturity, the circle members begin to gel as a problem-solving team in which an open atmosphere of cooperation, trust and healthy interpersonal relationships is created.

The literature is replete with case studies of effective QCs. At KSC, each contractor organization as well as the NASA have a great many areas which are naturally conducive to the formation of typical QCs. One example of a QC that has been formed at KSC is in the MMC shop in the Vehicle Assembly Building. This team is structurally in the Shuttle Operations Department and is composed of the shop supervisor and his technicians.

Interdepartmental Teams - Classification of KSC as an organization identifies it as a processing facility as opposed to, say, a manufacturing plant or production facility. In a production facility, typical QCs are organized by departments based on work areas within those departments. However, since KSC is a processing facility, work sites are not necessarily contained within a single department. Many work sites are supported by several departments and interdepartmental teams are logically formed in such cases.

For example, MMC is responsible for the Liquid Oxygen (LOX) system, one of the propellants loaded into the space shuttle's external tank. The LOX system is not operated by one

department at MMC. Rather, employees from Safety, Quality, Operations, Engineering and Logistics work together on the system. An interdepartmental team is preferred in this case.

Interdepartmental teams and typical QCs have a few differences. One obvious differences is structural in that typical QCs are organized within one department while interdepartmental teams are organized between two or more departments. As liaison devices, interdepartmental teams by nature provide broader mutual adjustment within their organization. Selection of leaders for interdepart-mental teams is more difficult than for typical QCs since two or more supervisors may work at the same site. The team leader should be selected on the basis of leadership style, the degree of respect granted him by employees of the involved departments, and the amount of desire to participate in the QC process. Other supervisors from the work site can participate as team members and, over time, may be rotated into the team leader position.

Functionally, interdepartmental teams and typical QCs are more similar than different. Voluntarism is the same: no employee at the work site can be forced to join the team nor can anyone be disallowed if they choose to participate. The approximate number of team members is the same; QC training is the same; team operations are the same.

In some cases, interdepartmental teams make more sense based on the geographical distance between work sites. Team meetings should be held as close to one hour as possible. Travel to and from meetings can take as much as an additional half hour (e.g., between Pad 39A and the VAB) thus creating an undesirable situation. Since interdepartmental teams are formed at a particular work site, the only travel necessary is to and from the team meeting room located at the work site.

Typical QCs and interdepartmental teams will predominate within each contractor organization and within the NASA as well. Logic will dictate which kind of team should be formed in any particular work area. The important point is that teams in a processing facility should be structured according to the way in which the work is done. If several departments work together to accomplish the jobs at the particular work site, then interdepartmental teams are indicated. Typical QCs can be formed in areas where employees from a single department work closely together.

Integrated Teams - An integrated team is slightly larger than an interdepartmental team. It is composed of 8-20 people from two or more organizations who meet to identify and solve organizational interface problems. Proposed solutions are presented to their collective management. Primarily, integrated teams are composed of middle managers but may also include employees at the bottom level of the organization. Although integrated teams are not typical QCs, many similarities remain. Team members meet for one hour per week, receive training in QC problem-solving techniques, make management presentations and monitor the effectiveness of their approved solutions.

However, integrated teams differ from typical QCs in two primary ways. Structurally, these teams have members from two or more organizations. As an integrated team matures as a team, cooperation and trust are disseminated beyond one-hour, weekly meetings and begin to affect the involved organiza-

tions. When left to chance, mutual adjustment takes its own random course. As liaison devices, integrated teams offer an opportunity for purposeful mutual adjustment between organizations.

At KSC, the NASA and the contractors work together to achieve successful launches of the Space Transportation System. The opportunity exists for many integrated teams. At the middle management levels, nearly everyone has a counterpart in the other organizations. An example of one proposed team is an Integrated Quality Inspection Team. This team would be composed of two MMC employees (quality inspector chief, quality inspector), two RIC employees (quality inspector manager, quality inspector), two USBI employees (quality inspector manager, quality inspector) and three NASA employees (two quality supervisors, one quality inspector). Other people from these organizations may be added as necessary. At present, decisions in the quality inspection world are made unilaterally by the NASA. By involving all affected parties, there is an increase in commitment to the decision, quality of the decision and ease of implementation of the decision.

The second difference between integrated teams and typical QCs is voluntarism.[5] Among middle managers, most anyone can join if they wish and no one can be forced to participate. However, employees representing the bottom level cannot join at will. Generally, they are invited to join by the middle managers who form the initial core of the team. These employees can also decline if they wish.

An example of an integrated team that has been quite successful is the Integrated Weld Quality Improvement Team at the NASA's Michoud Assembly Facility in New Orleans, LA.[6] This team is composed of 10 Martin Marietta employees (welder, planner, quality control planner, weld development engineer, welding engineer, training instructor, tooling engineer, welding foreman, quality labs chief, quality control manager), two NASA employees (quality, reliability and assurance manager, quality weld engineer [team leader]) and three employees from the Defense Contract Administration Services (two quality control inspectors, quality engineer). One of the problems this team identified waswithin the welder certification system. The system did not allow adequate evaluation of applicants's skills, inhibited skill development and delayed certification. In addition, the recertification system had little content validity and was costly. The team completely revised the welder certification/recertification system: a central control utilizing a certification officer has been incorporated; applicant evaluation is accomplished in shorter time; welders are certified on specific tools; certifcation is now based on performance on production welds; the recertification system is totally oriented to the quality of the welder's performance. These proposed solutions were presented to the team's collective management and all were approved and implemented.

Consider what would have happened if this integrated team had not been formed and one individual had attempted to tackle this system. First, it is somewhat doubtful that one person would have generated all of the problems or solutions identified since groups tend to produce better solutions than individuals working alone. Second, had this person come up with these solutions, he would then have the onerous task of selling his ideas to all the necessary decision makers in his organization. Third, if his ideas were

accepted by his own organization, he would still have two more organizations to convince that his ideas were worthy. The likelihood is that his ideas would have died on the organizational vine.

Joint Teams - A joint team is simply two typical QCs from two organizations who come together to analyze and resolve organizational interface problems, propose solutions to their collective management and monitor the effectiveness of their solutions. Conceptually, joint teams make sense between prime contractors and sub-contractors, between organizations within the same corporation but at different locations, and between government agencies.

One example of a joint team is the Michoud-AVCO Intertank Assembly Joint Team. This team was composed of seven members from MMC/Michoud (New Orleans, LA) and 11 members from AVCO (Nashville, TN), one of MMC's exteral tank suppliers. Meetings were held through the teleconferencing phone system. In this case, the MMC team identified three problems: damage to the thrust panel interface flanges during shipment; epoxy paint peeling from panels and fasteners during removal of the protective coating; difficulty of removing protective coating from rivet heads. These problems were communicated to the AVCO team who then developed solutions. These solutions included protecting the corners of the thrust panels in shipping; various precautions to ensure a clean surface prior to epoxy paint application; laying strips of protective coating over rivet heads prior to spraying. This joint team was formed to deal with these problems, then disbanded as a joint team. However, each individual QC remained intact.

As mentioned earlier, at KSC each prime contractor operates in a corporate system. The opportunity exists for the formation of joint temas within each corporation but between locations. For example, one possible joint team could be composed of the MMC/KSC Mechanical Engineering Team and the MMC/Michoud Design Engineering Team. This joint team could come together on an "as needed basis," i.e., when engineering interface problems are identified. The other prime contractors also have the opportunity to form such teams. The NASA/KSC may form joint teams with the NASA/JSC or with other NASA centers. Again, as liaison devices, joint teams offer yet another method for achieving purposeful mutual adjustment.

Summary - There is little reason why quality circles cannot be adapted to the processing environment at KSC. Multiple contractors and multiple work sites call for more advanced QC-like structures, such as interdepartmental and integrated teams. Of course, there will also be ample opportunity for the formation of typical QCs within individual organizations.

To the extent that the prime contractors and the NASA continue to show interest, implementation of the QC process can be more easily accomplished through a concerted, coordinated effort among all organizations. The work processes at KSC are constant and complicated. RIC has two orbiters in flow and will soon have two more; MMC currently has four external tanks in flow; USBI refurbishes several solid rocket boosters simultaneously; there are two mobile launch platforms in use; Pad B is currently under construction. As the shuttle launch rate increases, so will the amount and complexity of the work. Implementation of the QC process must be flexible enough to accommodate

the increasing complexity of the work at KSC. QC orientations and leader training can be conducted conjointly so that people from the various organizations can attend when time allows. In addition, top management must be committed enough to allow time for the QC process.

Today, the NASA is not in danger of competition for the commercial launch business. But in a very short tomorrow, that competition will grow and will come from many corners: the French Ariane program, the Russians, the Japanese, and American private enterprise. Presently, everyone is concerned with reducing shuttle turnaround time as well as cost per flight. The QC process allows for new and better ways of accomplishing the multitude of tasks carried out at KSC and can provide a very necessary competitive edge.

Notes and References

1. Although division of labor within and among the organizations at KSC is highly complex and technical, it will not be addressed.

2. Mintzberg, H. The Structuring of Organizations, New Jersey: Prentice - Hall, 1979.

3. Ibid.

4. This paper will deal with only three prime contractors in space shuttle processing. These three contractors are responsible for the three major components of the Space Transportation System and include Rockwell International Corporation (orbiter), Martin Marietta Corporation (external tank), and United Space Boosters, Inc. (solid rocket boosters).

5. Thompson, P.C. Participation - The key to middle management support. The Quality Circle Journal, V5.4, November, 1982, pp. 12-18.

6. Ibid.

A VIEW OF MOTIVATION AND PRODUCTIVITY IMPROVEMENT

by

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INTRODUCTION

Improvements in productivity in the Defense industry directly benefit the taxpayer by lowering the costs for producing quality products, Which are essential to our national defense. Since we are all taxpayers we are also, in a sense, working on the same team -- Government and Contractor -- with a common goal to promote productivity improvement as a philosophy of operation in the Aerospace industry. The objectives of this discussion are to define initiatives and policies related to productivity improvement which affect the Air Force and to explore ways in which the Government can help the contractor improve productivity, maintain quality in production and minimize costs. The Air Force has the obligation to assure that the Statement of Need (SON) for a weapons system is met at the lowest possible overall cost to the Government. Productivity has become one of our critical national issues. In a report to Congress made by the Defense Industrial Base Panel of the Committee of Armed Services, House of Representatives, in December, 1980 this statement appears:

> "While the United States leads the world in productivity, the United States is dead last in productivity improvements among all industrialized nations of the world."

We all should be concerned about the adverse impact of this situation on our defense industrial base and our national security and each of us has the opportunity in some measure to influence a reversal of this trend.

INITIATIVES AND POLICIES GUIDING PRODUCTIVITY IMPROVEMENT

Let's look at some of the action programs to enhance productivity that have been initiated by the Department of Defense and are being developed and implemented throughout the military services. The first of these is the Acquisition Improvement Program Action 5. The final report of the DOD Acquisition Improvement Ask Force, December 23, 1981, addresses 32 actions that make up the DOD Acquisition Improvement Program and includes specific recommendations to achieve implementation of these actions. One of the main thrusts of the program is Action 5 to improve productivity on individual contracts by encouraging capital investment. This involves eight different subactions or initiatives which include depreciation legislation, return on investment, progress payments, profit policy, economic price adjustment, patents and data rights, manufacturing technology, and excess profits

legislation. The second action program addresses industrial preparedness and emerged from a DOD task force formed May 20, 1981, by the Under Secretary of Defense for Research and Engineering, Dr. Richard D. DeLauer. This task force developed the Industrial Responsiveness Improvement Program and recommended 12 actions. Seven of these actions aim to integrate industrial base and responsiveness issues into the defense acquisition process. These provide guidance on improving productivity in defense contracting; major systems acquisitions and procedures; defense production management; selection of contractual sources for major systems; defense acquisition regulations; and manufacturing technology. An eighth action was added later by Dr. DeLauer when he established a tri-service committee to prepare a proposed unified DOD policy on "technology modernization." On April 21, 1982, the committee submitted a draft DOD instruction for a DOD productivity enhancement program. Dr. Andrew P. Mosier who is a professor of Acquisition/Program Management at the Defense Systems Management College (DSMC) has an excellent discussion of these action programs in a special issue of "Concepts" published in the summer of 1982. It is not the intent here to go into detail on each of the initiatives and actions of these programs. Rather, this discussion is for reference only and to illustrate two things : first, the relative "recency" of addressing the concept of productivity improvements and secondly, the intensity with which this subject is being pursued throughout the military services. A third subject area which we can discuss is more detail was initiated by the Air Force in the 1970s. Manufacturing Technology (MANTECH) and Technology Modernization (TECHMOD) is a melding of two Air Force productivity enhancing approaches. MANTECH is the development of new manufacturing technology at the Wright Aeronautical Laboratory/Materials Laboratory Manufacturing Technology Division (AFWAL/MLT) and TECHMOD, developed by the Air Force Systems Command's Aeronautical Systems Division (ASD), is a partnership approach between a contractor and the Air Force which provides the capital investment structure and expertise to bring new and existing technologies into being at the contractor's production facility. The term "Tech Mod" was first used to describe the approach to productivity enhancement developed for the F-16 Program. In the mid 70s, the F-16 contractor, General Dynamics, developed a strategy for technology and facility improvement. The plan was presented to and accepted by the Air Force in 1977. It established a framework for a cooperative Air Force - contractor venture to systematically enhance productivity and reduce acquisition costs. As the concept evolved, investments and incentives were defined and mutual risk benefit sharing goals were established. In 1979, ASD developed the regulatory guidance (ASDR 800-4) to implement MANTECH on all of its major systems which brought the MANTECH and TECHMOD concepts together. The Tech Mod approach is integrated into the Industrial Responsiveness Improvement Program (IRIP) through funding. It is a three phase effort. Phase I is a "top down factory analysis" which evaluates the needs of the overall facility and identifies candidate manufacturing technologies modernization opportunities. Phase I results in a negotiated "business deal" between the Air Force and the Contractor and establishes ground rules for Phases II and III. Considerations include incentives, benefit sharing arrangements, mutual investments, and return on investment. Phase II is the development of enabling technologies and design and fabrication of the factory modernization enhancements. Phase II also identifies implementation plans, specifies hardware/software

operational requirements and validates specific applications through method demonstrations. Phase III is implementation of the Tech Mod, including contractor purchase and installation of capital equipment to implement those Phase II candidates. The primary objective of Tech Mod is to improve the overall health of the industrial base through implementation of manufacturing technology and increased capital investment. There are two sources of funds to support Tech Mods. One is the Industrial Preparedness Program Element dollars labeled "Industrial Productivity and Responsiveness" and the other is the System Program Office (SPO) dollars. Tech Mods, like other investment opportunities, must compete for available funding.

IMPLEMENTATION OF PRODUCTIVITY IMPROVEMENT INITIATIVES AND POLICIES

How are these initiative and policies implemented and productivity measured? Implementation of these strategies calls for a departure from some long held Government practices toward contracting methods which are more in tune with long range business goals. This is the concept of contracting for productivity which uses both the traditional and innovative contracting techniques. Included in the concept are multi-year contracting for major weapons systems, capital investment incentives, award fees and special indemnification provisions. These are contractor motivational incentives and we are now looking specifically at the Technology Modernization approach. The Tech Mod programs are aimed at counteracting several existing DOD contracting processes which depress the level of aerospace industry investment such as: annual buys that increase uncertainty and therefore financial risks; the tendancy of the Government to negotiate away savings that result from productivity investments of follow-on contract buys; contract awards based on criteria which do not recognize past investments; and lack of price competition which dulls contractor sensitivity to cost reduction. Capital investment incentives are written into the contract in the form of increased percentage of profit for capital investments, complementary investment and shared savings. Award fees are based on the contractors performance according to criteria contained in the contract which also establishes the amount of the incentive award fee. The contractor is evaluated against this criteria such as the development of a comprehensive modernization plan; ingenuity in the utilization of total resources; commitment of corporate resources (both manpower and capital) to the plan, and implementation of the modernization effort in a timely manner. There are also special indemnification provisions which provide liability protection in the event the contract is terminated. This transfers to the Government some of the risk associated with the acquisition costs on a pre-determined schedule should the contract be terminated.

What are some of the tools used in productivity measurement? Shown here are three of the tools most often discussed with the contractor. First, Military Standard 1567, Work Measurement, which provides performance reporting, problem identification and cost control using labor time standards. Labor time standards are developed by industrial engineers to define the time required by a qualified worker to perform a specified amount of work, working at a normal pace under capable supervision. The techniques used to develop these standards are methods-time measurement, engineered time study and work sampling. The objectives of this system are: to determine the proper cost of doing business; provide means of reducing costs; measure performance against

proper cost and determine areas for improvement; and to provide appropriate allocation (capital and time management) systematically and to the area of highest return. A second tool used in productivity measurement is the Cost/Schedule Control System Criteria (C/SCSC). The objectives of this system are to provide data which indicates work progress; properly relates costs schedule and technical performance; and is valid, timely and auditable. The system also aims to assure that contractors use effective management control systems. By analyzing schedule status, budgets. actual costs and technical performance, variances - their causes and impacts, problems can be identified and corrective action taken. A third productivity measurement tool is the Contract Management Systems Evaluation Program (CMSEP). This program is a means of assessing the effectiveness of the contractor in using the management controls and systems required by the contract. It is an AFPRO management technique directed toward the prevention of program problems through the early detection of management system defeciencies. The contractor is not contractually required to participate but is encouraged to do so since CMSEP addresses many of the subjects and requirements of special reviews of the contractor's performance which are dictated by regulatory guidance. Again, it is not the purpose here to define these tools in detail but only to propose these as subject for discussion during the workshop session.

ORGANIZATION LEVEL AND AFPRO ORGANIZATION

Mentioned earlier is the fact that we all have the opportunity to influence the reversal of the downward trend of our nation's productivity improvements. The following organizational charts show the relationship of the Air Force Plant Representatives Office to the Air Force Systems Command. The Manufacturing Support Branch performs five essential functions on several major weapons systems programs and as you can see there is abundant opportunity to assist the contractor enhance productivity.

SUMMARY OF ISSUES AND RECOMMENDATIONS

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Quality Circles and Motivation

Issue

Lack of team approach for fostering productivity improvements for Aerospace (NASA, DoD, contractors, subcontractors).

Recommendations

A joint NASA, DoD, and contractors team be established to develop and recommend general guidelines for productivity improvement programs and initiate, develop, and exchange information. The necessary subgroups should be formed to support this effort, for example, a panel on quality circles which will:

a) Meet periodically

b) Produce, distribute, and update a directory of quality circle coordinators and facilitators in Aerospace (NASA, DoD, contractors, subcontractors, and suppliers) to include brief program descriptions

c) Sponsor a subconference on quality circles in Aerospace at the IAQC annual conference

d) Disseminate information (conference papers, bibliographies, etc.)

Suggested OPR

Office of Productivity - NASA and DoD

2. Quality Circles and Motivation

Issue

Productivity improvement has not been properly focused within the Aerospace industry.

Recommendations

AIA institutionalize a formal subpanel on productivity improvement.

Suggested OPR

Mission Assurance Conference - AIA

3. Quality Circles and Motivation

Issue

Lack of incentives on some contracts to develop motivational/productivity programs.

Recommendations

Develop a contract device that provides for allowable costs on productivity/motivation programs and encourages the development of these programs.

Suggested OPR

DoD and NASA

4. Quality Circles and Motivation

Issue

NASA has a manned flight awareness program. DoD has no equivalent activities.

Recommendations

Air Force should allocate resources for:

a) Manned Flight Awareness

b) Unmanned Programs

Suggested OPR

DoD

5. Quality Circles and Motivation

Issue

Group achievement recognition by NASA/DoD for quality circle type team efforts.

Recommendations

NASA should continue and Air Force should implement a system to identify and recognize the superior quality circle teams' efforts in Government and industry and provide appropriate rewards for their efforts (e.g., launch honoree award and group achievement award).

a) Separate launch identified for the program

b) Teams selected from government and industry

c) Programs for unmanned activities

Suggested OPR

NASA and DoD

6. Quality Circles and Motivation

Issue

NASA, DoD and industry have recently begun to emphasize the value of the quality circle concept as an effective element of productivity improvement through employee involvement.

Recommendations

The Mission Assurance Conference endorses the quality circle concept and the efforts of industry, NASA, and DoD to increase awareness of the concept.

Suggested OPR

Mission Assurance Conference

7. Quality Improvement and Productivity Enhancement

Issue

At present there is no assurance that Quality Improvement, Productivity Enhancement and Manufacturing (Producibility) subjects are properly included in RFPs. This can ultimately have a negative impact on overall program costs when the subjects are not included early in the acquisition process. With the AFSC encouragement for the use of draft RFPs to obtain industry comments, it would be beneficial to have either the Government provide Quality/Productivity/Manufacturing (Producibility) subjects included in the draft RFP for industry comments. If this does not occur, industry should take the responsibility for recommending the inclusion of these subjects in the RFP.

Recommendations

Government and Industry should, as a matter of policy, assure that quality productivity and manufacturing (producibility) requirements are in draft RFPs for all acquisition phases.

Suggested OPR

AFSC/SD/NSIA/AIA

8. Quality Improvement and Productivity Enhancement

Issue

As part of the Defense Acquisition Improvement Program, HQ AFSC has established a policy for ranking quality and productivity at the same level as technical and management in the source selection process. At present, implementation procedures and regulations have not been established throughout the AFSC organization to implement the above policy. This situation can result in lack of consideration of quality and productivity in source selection process for programs at various acquisition phases.

Recommendations

Government should change implementing procedures and/or regulations to assure compliance with quality/productivity/producibility at the same level as technical and management in source selection.

Suggested OPR

AFSC/SD

9. Quality Improvement and Productivity Enhancement

Issue

To emphasize the importance of Quality and Productivity in the Air Force and NASA it seems appropriate to include these subjects as standard subjects for review at all management levels in both Government and industry. In this way the emphasis at top levels of management and the recognition of the emphasis at the lower levels of management will prevail throughout the contract and/or program period.

Recommendations

Quality/productivity must be reviewed at all levels of management during contract/program period (Government/Industry).

Suggested OPR

NASA/AFSC/SD/NSIA/AIA

10. Quality Improvement and Productivity Enhancement

Issue

At present there is no indication the Government or industry program managers have any real training in the appreciation and benefits of productivity and quality matters as an integral part of a program. Also there is no assurance that program managers will seriously consider the need for improving quality and productivity in their program(s) unless their program is measured against these factors as well as the other important factors of their performance.

Recommendations

Training and performance measurement of program managers should include productivity and quality factors.

Suggested OPR

NASA/AFSC/SD/NSIA/AIA

11. Quality Improvement and Productivity Enhancement

Issue

Both DoD and NASA have similar specifications and standard regulations which are applied to various programs. Often a contractor will have to comply with two different requirements on the same product line when providing products for NASA and DoD. Also, the interpretation of the compliance of contractors with their various regulation documents often varies when reviewed by different Government organizations. This creates confusion and often unnecessary duplicative actions by a contractor are made to satisfy the different Government reviewing agencies. Further, companies having multidivisions will often operate differently regarding various requirements documents levied on subcontractors. Again, the interpretations of compliance with requirements made by various divisions of the same company can cause problems with subcontractors.

The conditions are unproductive and time-wasting on the part of both Government and subcontractors. This situation exists in many places and does not help assure proper mission performance.

Recommendations

Need for standardization of DoD/NASA requirements and interpretation thereof to eliminate duplication and improve productivity (multidivision corporations should do likewise).

Suggested OPR

NASA/AFSC/SD/NSIA/AIA

WORKSHOP C

SPACE STATION

Chairmen:

Dr. Kevin Forsberg
Program Manager, Space Station Program, LMSC

Richard Kline
Director of Shuttle Applications, Grumman Aerospace

John Hodge
Director of Space Station Task Force, NASA

Coordinators:

Donald Stein
Grumman Aerospace

William James
LMSC

SESSION 1 — OVERVIEW

Mission Assurance Philosophy	John Hodge, Nasa Headquarters
Integrated Requirements for a Space Station	Brian Pritchard, LARC
Trade Studies	Charles Darwin, MSFC
The Role of the Crew	Col. Jack Lousma, USAF/JSC

SESSION 2 — QUALITY ASSURANCE, SAFETY, PLANETARY EXPERIENCE

Quality Assurance	T. J. Adams, JSC
Crew Safety Requirements	Bob Witcofski, LARC
Mission Assurance from a Ground Processing Perspective	John Oertel, KSC
Payload Safety Policy and Requirements	Paul Davis, NASA Headquarters
Applicable Planetary Experience	Bill Shipley, JPL

SESSION 3 — RELIABILITY-MAINTAINABILITY

NASA Preliminary Approach to Space Station Reliability-Maintainability	Joe Levine, JSC
Mission Assurance Design for Maintainability	Harry Wolbers, McDonnell Douglas
On-Orbit Maintenance/Servicing	Tom Fisher, Lockheed
Space Platforms	Bob Sharples, TRW
OTV	Otto Steinbronn, General Dynamics
EVA Systems Maintainability	Al Brouillet, Hamilton Standard

WORKSHOP C

SESSION 4 — LESSONS LEARNED

Stan Marcus, Rockwell International

Dick Kline, Grumman Aerospace Corp.

S. Schrock, Martin Marietta

Lars Tedman, European Space Agency

SPACE STATION

MISSION ASSURANCE PHILOSOPHY

JOHN D. HODGE
MISSION ASSURANCE CONFERENCE
JUNE 1983

MISSION ASSURANCE IS THE RESULT OF GOOD MANAGEMENT OF A BROAD SPECTRUM OF ACTIVITIES OVER A LONG PERIOD OF TIME

- PROGRAM PHASES
  - CONCEPT DEFINITION
  - DESIGN DEFINITION
  - MANUFACTURING/FABRICATION
  - TEST AND ANALYTICAL VERIFICATION
  - OPERATIONS

- ACTIVITIES/DISCIPLINES
  - REQUIREMENTS DEFINITION/SPECIFICATIONS
  - CONTRACTING/ACQUISITION
  - DETAIL DESIGN
  - SAFETY
  - RELIABILITY
  - QUALITY ASSURANCE/CORRECTIVE ACTION
  - MAINTAINABILITY
  - INVENTORY MANAGEMENT/LOGISTICS
  - CONFIGURATION MANAGEMENT/CHANGE CONTROL
  - TEST PLANNING/TEST OPERATIONS
  - SIMULATIONS/ANALYTICAL VERIFICATION
  - GROUND OPS PLANNING/GROUND PROCESSING
  - MISSION PLANNING/FLIGHT OPERATIONS

BOUNDARY CONDITIONS

MANNED/ACCOMPANIED BY SEVERAL FREE FLYERS

LONG LIFE, SAFE, RELIABLE

FLEXIBLE/VERSATILE

BUILT IN CAPABILITY FOR EVOLUTIONARY GROWTH

"USER FRIENDLY"

COMPATIBLE WITH SHUTTLE/ORBITER

LOW COST

NASA'S OUTSTANDING RECORD OF MISSION ASSURANCE HAS BEEN BASED ON:

CONSERVATIVE DESIGN/THOROUGH DESIGN ANALYSIS
- CONSERVATIVE DESIGN MARGINS/TIGHT SPECIFICATIONS
- PROVIDE REDUNDANCY WHERE FEASIBLE
- SYSTEMATIC IDENTIFICATION/DISPOSITION OF FAILURE MODES & HAZARDS

THOROUGH VERIFICATION PROGRAMS
- DEVELOPMENT TEST/QUALIFICATION TEST
- PIECE PARTS/BLACK BOX/SUB-SYSTEM/SYSTEM
- PRE-LAUNCH PROCESSING/CHECK-OUT
- TEST ARTICLES/TEST FACILITIES
- SYSTEMATIC PLANNING/DOCUMENTATION (TEST SPECS/TEST PLANS/TEST RESULTS)

THOROUGH QUALITY ASSURANCE PROGRAM
- MANUFACTURING PLANS/PROCESSES
- TIGHT SUPPLIER CONTROLS
- QUALITY INSPECTION PROGRAM
- QUALITY ASSURANCE RECORDS/CONFIGURATION RECORDS
- FAILURE ANALYSIS/CORRECTIVE ACTION

THOROUGH OPERATIONS PROGRAM
- MISSION PLANNING
- PROCEDURES/CONTINGENCY PROCEDURES DEVELOPMENT
- SIMULATIONS/OPS TRAINING
- INTERACTION WITH DESIGN/VERIFICATION ACTIVITIES
- OPERATIONS FACILITIES

SPACE STATION MISSION ASSURANCE PHILOSOPHY

THOROUGH DEFINITION DURING CONCEPTUAL PHASE

MINIMIZE DEVELOPMENT RISK

AVOID STOPS, STARTS, SUPRISES, COURSE-CHANGES

FACILITATE PLANNING/ ORDERLY DEVELOPMENT

MINIMIZE TEMPTATION TO TAKE SHORT CUTS WHEN SUPRISES OCCUR

MISSION ASSURANCE PHILOSOPHY/DESIGN

- COMBINED DESIGN/MAINTENANCE CHARACTERISTICS WILL BE CONSISTENT WITH DESIGN LIFE REQUIREMENTS, ie 10 YEARS TO INDEFINITE
- PRESSURE VESSELS:
  STANDARD MARGINS/LEAK BEFORE BURST/REPLACEABILITY
- SAFETY CRITICAL COMPONENTS, SUBSYSTEMS, SYSTEMS:
  FAIL OPERATIONAL/FAIL SAFE /RESTORABILITY
- OTHER HARDWARE
  FAIL SAFE/RESTORABLE

SPACE STATION SAFETY PROGRAM/BASIC ELEMENTS

- DESIGN REQUIREMENTS
  - CRITICAL HARDWARE: FAIL OP—FAIL SAFE—RESTORABLE
  - OTHER HARDWARE: FAIL SAFE—RESTORABLE
  - SPACE STATION PAYLOADS: TBD
  - COMPATIBLE WITH SHUTTLE-ORBITER SAFETY REQUIREMENTS:
    - INSIDE ORBITER
    - DOCKED ON ORBIT
    - PROXIMITY OPERATIONS
- PROCEDURAL REQUIREMENTS
  - HAZZARD IDENTIFICATION AND DISPOSITION
  - CONCURRENCE BY SAFETY/ORGANIZATION OF HAZARDOUS OPERATIONAL PROCEDURES
- OPERATIONAL CONSIDERATIONS
  - EVA IS CONSIDERED ROUTINE OPERATIONAL PROCEDURE
    - ASSEMBLY/BUILD-UP/ACTIVATION ACTIVITIES
    - MAINTENANCE/REPAIR ACTIVITIES
  - TRAINING REQUIREMENTS FOR HAZARDOUS OPERATIONS --- TBD

EVOLUTIONARY SPACE STATION/ A NEW DIMENSION IN DESIGN

WE NEED TO DESIGN TWO SPACE STATIONS:

- A COMPREHENSIVE/EXHAUSTIVE DEFINITION OF THE INITIAL SPACE STATION
- A CLEARLY DEFINED CONCEPT AND PLAN FOR THE ORDERLY GROWTH/EVOLUTION OF THE INITIAL SPACE STATION.
- WE MUST ASSURE THAT THE INITIAL SPACE STATION IS COMPATIBLE WITH THE PLANNED EVOLUTION.

DEFINITIONS

FAIL OPERATIONAL:

THE ABILITY TO SUSTAIN A FAILURE AND RETAIN FULL OPERATIONAL CAPABILITY FOR SAFE MISSION CONTINUATION

FAIL SAFE:

THE ABILITY TO SUSTAIN A FAILURE AND RETAIN THE CAPABILITY TO SUCCESSFULLY TERMINATE THE MISSION

LONG LIFE CONSIDERATIONS

- GOAL IS INDEFINITE LIFE IN ORBIT/NOMINALLY 10 TO 20 YEARS
- WE ASSUME THAT OVER A 20 YEAR OPERATIONAL PERIOD THAT ALL ON BOARD EQUIPMENT (EXCEPT STRUCTURES) WILL REQUIRE SERVICING, REPAIR, AND/OR CHANGE-OUT
- BASIC APPROACH TO LONG LIFE/RELIABILITY:
  - BUILD SIMPLE, RUGGED HARDWARE
  - BUILD MODULAR SYSTEMS CAPABLE OF BEING RETURNED TO EARTH
  - PROVIDE CAPABILITY FOR CREW TO ACCOMPLISH ON-ORBIT SERVICING/REPAIR/CHANGE-OUT
  - FAIL OPERATIONAL—FAIL SAFE DESIGN FOR CRITICAL HARDWARE

MISSION ASSURANCE FACTORS TO BE CONSIDERED WHEN EVALUATING COMPETING DESIGN OPTIONS

- ESTIMATED OPERATIONAL LIFE
- MAINTENANCE/SERVICING/REQUIREMENTS
- RELATIVE RELIABILITY (IN QUALITATIVE TERMS)
- PERFORMANCE REQUIREMENTS/MARGINS
- HAZARDOUS FAILURE MODES/AVAILABLE CONTINGENCY PROCEDURES
- OPERATIONAL HAZARDS/AVAILABLE CONTINGENCY PROCEDURES

DEFINE AND INITIATE PHASED MAINTENANCE PROGRAM

TASKS TO BE ADDRESSED EARLY IN PROGRAM

- RELIABILITY/REDUNDANCY/ MAINTAINABILITY TRADES
- USEFUL LIFE OF PARTS, COMPONENTS, ETC ESTIMATES
- DETERMINATION OF ORBITAL REPLACABLE UNITS
- IDENTIFICATION OF SPECIFIC MAINTENANCE TASKS
- ESTABLISH ACCESS REQUIREMENTS
- IDENTIFY SUPPORT EQUIPMENT / TOOLS
- DETERMING ON-BOARD SPARES/ STORAGE REQUIREMENTS
- DEVELOP PROCUREMENT PLAN/ PROCEDURES
- DEVELOP PLANS/REQUIREMENTS FOR GROUND MAINTENANCE AND REFURBISHMENT

FUTURE ACTIVITY AREAS

- PROVIDE FOR GSE STORAGE, SPACE STATION DATA BASE MAINTENANCE, SUSTAINING ENGINEERING

ESTIMATED OPERATIONAL LIFE

ITEM	OPERATIONAL LIFE	SERVICING REQTS
PUMPS	TBD	TBD
REGULATORS	↓	↓
BATTERIES		
PRESSURE VESSELS/ LINES-FITTINGS		
HARNESSES/ INSULATION		
EEE PARTS		
SEALS		
COMPUTERS/ SOFTWARE		

SPACE STATION RELIABILITY PROGRAM

- FMEAS / DESIGN AND OPERATIONAL
  - IDENTIFICATION OF FAILURE MODES / DEFINITION OF FAILURE EFFECTS
  - CATAGORIZATION OF FAILURE MODES BY CRITICALITY
  - CRITICAL ITEM CONTROL PROGRAM
- INDEPENDENT RELIABILITY ASSESSMENT OF SELECTED RELIABILITY ISSUES

OBSTACLES TO MISSION SUCCESS

- LONG PROGRAM
- TIGHT BUDGET
- WHEN FUNDING SQUEEZES OCCUR, THERE WILL BE A STRONG TEMPTATION TO REDUCE, POSTPONE OR ELIMINATE
  - MAINTENANCE CAPABILITY
  - SPARES
  - SUPPORT EQUIPMENT

MISSION ASSURANCE REQUIREMENTS
DISPOSITION AND CONTROL OF SINGLE FAILURE POINTS

CRITICALITY		FUNCTIONAL AREAS				
SFP	CATEGORY	DESIGN	QUALITY	TEST & CHECKOUT	OPERATIONS	SAFETY
1	CREW SAFETY	•ELIMINATE SFP's IF POSSIBLE •RETENTION RATIONALE FOR REMAINING SFP's •CCB CONTROL OF SFP's •PROVIDE DETECTION METHOD	•MANDATORY INSPECTION POINTS •FAILED PARTS ANALYSIS	•VERIFY BY TEST IF POSSIBLE •EXPLICIT TEST RQMTS FOR EACH SFP	•PROVIDE CONTINGENCY PLAN & PROCEDURES IN EVENT OF OCCURRENCE	•CONCUR WITH RETENTION RATIONALE & RELATED CONTINGENCY PROCEDURES
1S	SAFETY SYSTEM & HAZARD MONITOR SYSTEMS					
2A	PRIMARY MISSION OBJECTIVES, IMMEDIATE MISSION TERMINATION	•ELIMINATE SFP's (IF FEASIBLE). •MINIMIZE IMPACT •RETENTION RATIONALE •CCB CONTROL OF SFP's •PROVIDE DETECTION METHOD IF FEASIBLE	•MANDATORY INSPECTION POINTS •FAILED PARTS ANALYSIS	•VERIFY BY TEST OR ANALYSIS •EXPLICIT TEST RQMTS FOR EACH SFP	•PROVIDE CONTINGENCY PLAN & PROCEDURES IN EVENT OF OCCURRENCE	•REVIEW FOR SAFETY IMPLICATIONS INCLUDING COMBINED FAILURES
2B	LAUNCH SCRUB					
3	LAUNCH DELAY SECONDARY MISSION OBJECTIVES	•MINIMIZE IF FEASIBLE •PROVIDE BUILT IN HOLDS	•SELECTED KEY INSPECTION POINTS	•VERIFY BY ANALYSIS •SELECTED TEST RQMTS	•PROVIDE PROCEDURAL WORK-AROUNDS	•NONE
4	ALL OTHERS	•NO SPECIFIC RQMTS	•ROUTINE INSPECTION	•NO SPECIFIC RQMTS	•ROUTINE PROCEDURE	•NONE

SPACE STATION SAFETY PROGRAM/BASIC ELEMENTS

- DESIGN REQUIREMENTS

  CRITICAL HARDWARE: FAIL OP—FAIL SAFE—RESTORABLE
  OTHER HARDWARE: FAIL SAFE—RESTORABLE
  SPACE STATION PAYLOADS: TBD
  COMPATIBLE WITH SHUTTLE-ORBITER SAFETY REQUIREMENTS:
  INSIDE ORBITER
  DOCKED ON ORBIT
  PROXIMITY OPERATIONS

- PROCEDURAL REQUIREMENTS

  HAZARD IDENTIFICATION AND DISPOSITION
  CONCURRENCE BY SAFETY/ORGANIZATION OF HAZARDOUS OPERATIONAL PROCEDURES

- OPERATIONAL CONSIDERATIONS

  EVA IS CONSIDERED ROUTINE OPERATIONAL PROCEDURE
  ASSEMBLY/BUILD-UP/ACTIVATION ACTIVITIES
  MAINTENANCE/REPAIR ACTIVITIES

  TRAINING REQUIREMENTS FOR HAZARDOUS OPERATIONS --- TBD

SPACE STATION QUALITY ASSURANCE

PROGRAM DEFINITION PHASE

DEVELOP PROGRAMMATIC QUALITY ASSURANCE REQUIREMENTS

SPACE STATION NEEDS

- GROUND
- FLIGHT

DEVELOPMENT PHASE

- ASSURE THAT INSPECTION REQUIREMENTS ARE REFLECTED IN DESIGN
- ASSURE COMPLIANCE WITH SPECIFICATION REQUIREMENTS DURING:

  SUPPLIER ACTIVITIES

  MANUFACTURING/FABRICATION/ASSEMBLY
  TEST/VERIFICATION
  TRANSPORTATION/STORAGE

- ASSURE IMPLEMENTATION OF FAILURE REPORTING/CORRECTIVE ACTION/RECURRENCE CONTROL PROGRAMS
- ASSURE COMPLIANCE WITH CONFIGURATION MANAGEMENT RECORD KEEPING REQUIREMENTS

OPERATIONS PHASE

TBD

PHILOSOPHY

- MAIN THEME OF QUALITY ASSURANCE ACTIVITIES:

  ELIMINATE NON-CONFORMANCES

- QUALITY ASSURANCE IS EVERYONE'S BUSINESS

APPROACH TO MEETING LOW COST OBJECTIVES

STEPS REQUIRED TO GET SPACE STATION APPROVED AS NEW PROGRAM

- MUST SHOW NEED FOR SPACE STATION
  - (I.E., ATTRACTIVE SCIENCE/ TECHNOLOGY/ APPLICATIONS MISSIONS WHICH REQUIRE A MANNED SPACE STATION)
- MUST CONVINCE CONGRESS THAT WE KNOW HOW TO BUILD A SPACE STATION THAT CAN ACCOMMODATE MISSIONS
- MUST BE VIABLE LOW COST PROGRAM

SPLIT PERSONALITY

- ON THE ONE HAND, WE FACE A STERN AND DIFFICULT CHALLENGE TO MEET MISSION ASSURANCE OBJECTIVES; i.e., TO DESIGN, BUILD, AND OPERATE A SPACE STATION IN SUCH A WAY THAT IT WILL FUNCTION AS INTENDED FOR UP TO 20 YEARS
- ON THE OTHER HAND, WE MUST ADOPT LOW COST WAYS OF DOING BUSINESS ACROSS THE BOARD, INCLUDING LOW COST APPROACHES TO MISSION ASSURANCE

CANDIDATE AREAS FOR COST SAVINGS/COST AVOIDANCE

- REDUCE SPECIFICATION REQUIREMENTS WHICH ARE OVERLY TIGHT/OVERLY CONSERVATIVE
- INCREASE ON-BOARD AUTONOMY/REDUCE GROUND MONITORING, GROUND CONTROL
- DESIGN SIMPLE/RUGGED SYSTEMS EMPHASIZING MODULARITY AND COMMONALITY
- USE EXISTING SYSTEMS/FACILITIES
- DEVELOP/IMPLEMENT OPTIMIZED ACQUISITION/ PROCUREMENT STRATEGY AND INVENTORY CONTROL
- REDUCE DOCUMENTATION REQUIREMENTS

SPECIFICATION REQUIREMENTS

SOME SPECIFICATIONS ARE UNNECESSARILY TIGHT

- WHICH SPECIFICATIONS? WHICH REQUIREMENTS?
- HOW DO WE INTELLIGENTLY "EASE-OFF"

THE TIME HAS COME TO AGGRESSIVELY "ATTACK" THIS AREA. THE OBJECTIVE IS TO RELAX OVERLY RESTRICTIVE REQUIREMENTS WHERE IT CAN BE ESTABLISHED THAT

- SIGNIFICANT COST SAVINGS WILL RESULT
- MISSION ASSURANCE/SAFETY WILL NOT BE UNDULY COMPROMISED

HOW MUCH GROUND MONITORING/GROUND CONTROL

- INTUITIVELY, WE WOULD LIKE TO CUT BACK IN THIS AREA, i.e. LESS GROUND MONITORING AND CONTROL
- HOWEVER WHEN PROBLEMS OCCUR — AS THEY INEVITABLY WILL — CREW WILL NEED EXPERT ASSISTANCE FROM GROUND TO ANALYZE/RESOLVE PROBLEMS
- WE NEED TO DEFINE OUR NEEDS IN THIS AREA AND DEVELOP AN OPTIMIZED APPROACH

SIMPLE RUGGED SYSTEMS

- ENVIRONMENT:
  - RELATIVELY EVENTLESS, BENIGN
- DESIGN CHARACTERISTICS:
  - RELATIVELY LESS EMPHASIS ON WEIGHT SAVING, HIGH PERFORMANCE
  - MODULAR/REDUNDANT
  - MAINTAINABLE IN EVENT OF FAILURE
  - FAILURES CAN GO UNATTENDED FOR RELATIVELY LONG PERIODS WITHOUT CREATING HAZARDS
- CONSEQUENT COST REDUCTION OPPORTUNITIES
  - POSSIBLE TO BUILD RUGGED SYSTEMS WITH REDUCED LEVEL OF REDUNDANCY RESULTING IN
    - LOWER INITIAL COSTS
    - LOWER OPERATING COSTS

EXAMINE USE OF EXISTING FACILITIES/SYSTEMS, SUCH AS:

GROUND PROCESSING FACILITIES
DOCKING HATCHES
LATCHES, FITTINGS
EVA EQUIPMENT
SCIENTIFIC AIR LOCK
PALLETS
PRESSURE VESSELS
INSTRUMENT POINTING SYSTEM
REMOTE MANIPULATOR SYSTEM
ETC.

COMMONALITY OF HARDWARE

- MODULES/STRUCTURES
- INTERFACES
- SUPPORT EQUIPMENT
- COMPONENTS/BLACK BOXES/SUB-SYSTEMS

MISSION ASSURANCE PHILOSOPHY

SPACE STATION FAIL SAFE/FAIL OPERATIONAL/ RESTORABLE DESIGN PROVIDES US WITH OPPORTUNITY TO RELAX (TO SOME DEGREE) VERIFICATION REQUIREMENTS — — — PARTICULARLY IN NON-SAFETY CRITICAL AREAS

HOW MUCH GROUND VERIFICATION?

- DEVELOPMENT TESTING
- QUALIFICATION TESTING
  - LIFE TESTING
  - ENVIRONMENTAL OVERSTRESS
- FUNCTIONAL/OPERATIONAL SIMULATION
  - INITIAL DESIGN
  - ON-ORBIT REPAIRS/MODS
- HOW MANY TEST ARTICLES
- HOW MUCH ACCEPTANCE TESTING
- WHAT IS PHILOSOPHY OF PRE-LAUNCH CHECK-OUT?
  - HOW DO WE VERIFY:
    - INITIAL BUILD-UP/ASSEMBLY/ACTIVATION

SPARE PARTS

INVENTORY CONTROL/OPTIMIZED PROCUREMENT STRATEGY

- HOW DO WE ASSURE THAT SPARE PARTS WILL BE AVAILABLE OVER A 25 YEAR PERIOD?
  - — WHAT ARE OUR LONG TERM NEEDS?
  - — WHAT PROBLEMS CAN WE ANTICIPATE?
  - — WHAT IS OUR APPROACH TO LOGISTICS MANAGEMENT?

SOFTWARE SYSTEM DEVELOPMENT/MANAGEMENT

- SPACE STATION FLIGHT SOFTWARE SYSTEM WILL PERFORM NUMEROUS VEHICLE SYSTEMS MANAGEMENT AND MONITORING FUNCTIONS AND PROVIDE VEHICLE TO CREW AND VEHICLE TO GROUND INTERFACE
- SOFTWARE/SOFTWARE SYSTEM WILL BE A MAJOR COST/RISK FACTOR IN THE PROGRAM
- DEFINING AND VALIDATING GOOD SOFTWARE/SOFTWARE SYSTEM REQUIREMENTS IS CHALLENGING, DIFFICULT TO MANAGE—CRUCIAL TO PROGRAM SUCCESS
- MANY (TBDs) AT PRESENT TIME
- ISSUES: HOW MUCH AUTOMATION
  HOW MUCH ON-BOARD AUTONOMY
  HOW MUCH FAULT TOLERANCE.

REDUCE DOCUMENTATION/ REPORTING REQUIREMENTS

- COMMON PERCEPTION THAT NASA REQUIRES A CONSIDERABLE AMOUNT OF UNNECESSARY/ MARGINALLY USEFUL DOCUMENTATION IN THE FORM OF REPORTS, ANALYSES, ETC.
- WE ARE LOOKING INTO THIS AREA AND INTEND TO DO SOMETHING ABOUT IT

MISSION ASSURANCE IS THE RESULT OF GOOD MANAGEMENT OF A BROAD SPECTRUM OF ACTIVITIES OVER A LONG PERIOD OF TIME

- PROGRAM PHASES
  - CONCEPT DEFINITION
    - DESIGN DEFINITION
      - MANUFACTURING/FABRICATION
        - TEST AND ANALYTICAL VERIFICATION
          - OPERATIONS

PLUS: GOOD PEOPLE GOOD TEAM WORK

- ACTIVITIES/DISCIPLINES
  - REQUIREMENTS DEFINITION/SPECIFICATIONS
    - CONTRACTING/ACQUISITION
      - DETAIL DESIGN
        - SAFETY
          - RELIABILITY
            - QUALITY ASSURANCE/CORRECTIVE ACTION
              - MAINTAINABILITY
                - INVENTORY MANAGEMENT/LOGISTICS
                - CONFIGURATION MANAGEMENT/CHANGE CONTROL
                - TEST PLANNING/TEST OPERATIONS
                - SIMULATIONS/ANALYTICAL VERIFICATION
                - GROUND OPS PLANNING/GROUND PROCESSING
                - MISSION PLANNING/FLIGHT OPERATIONS

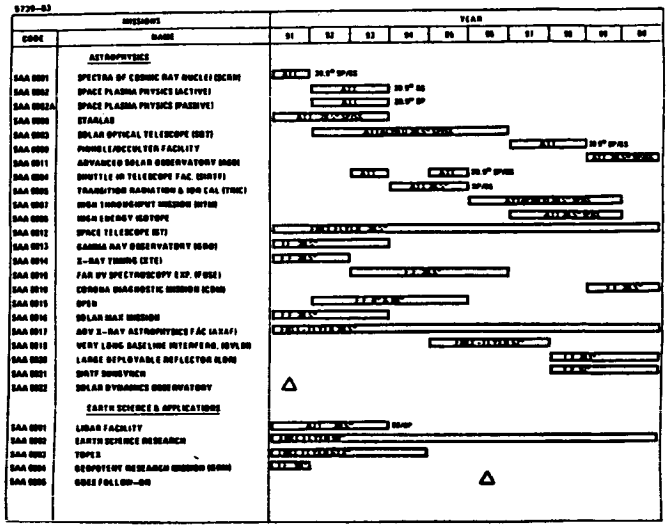
INTEGRATED REQUIREMENTS FOR A SPACE STATION

E. BRIAN PRITCHARD

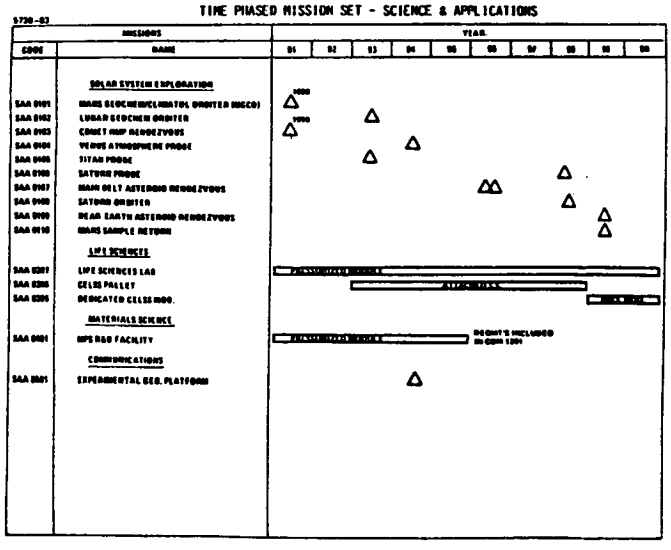
NSIA/ AIA/ AF-SD/ NASA
CONFERENCE and WORKSHOP
on MISSION ASSURANCE

7-8-9 JUNE 1983 / LOS ANGELES

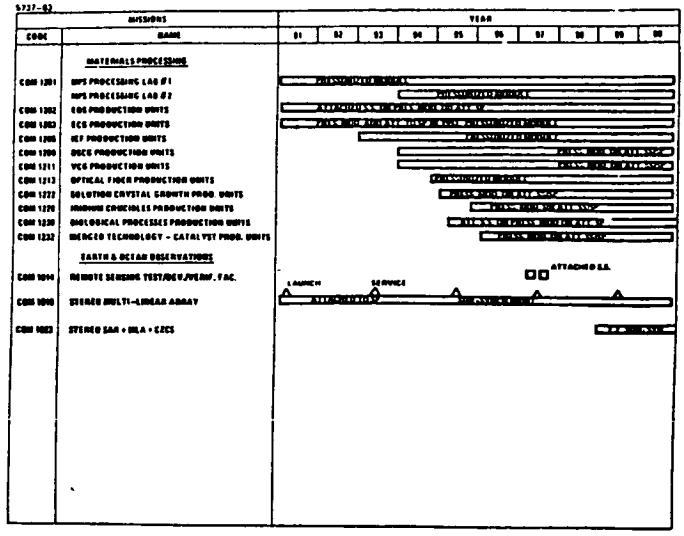
TIME PHASED MISSION SET - SCIENCE & APPLICATIONS



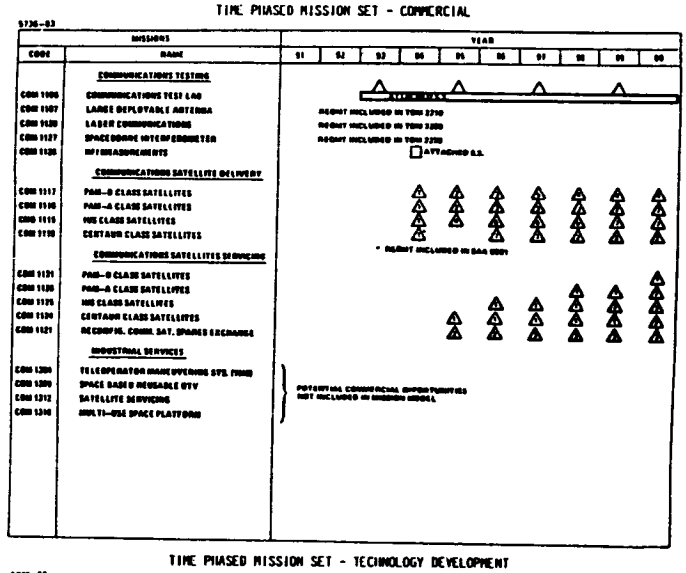
TIME PHASED MISSION SET - SCIENCE & APPLICATIONS



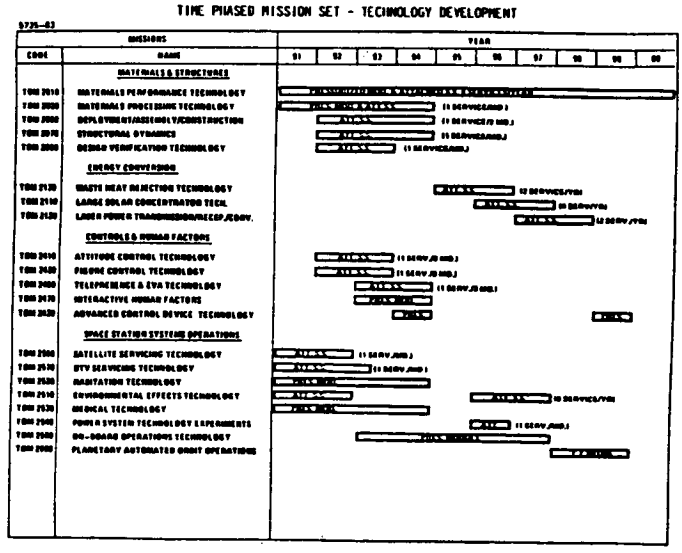
TIME PHASED MISSION SET - COMMERCIAL



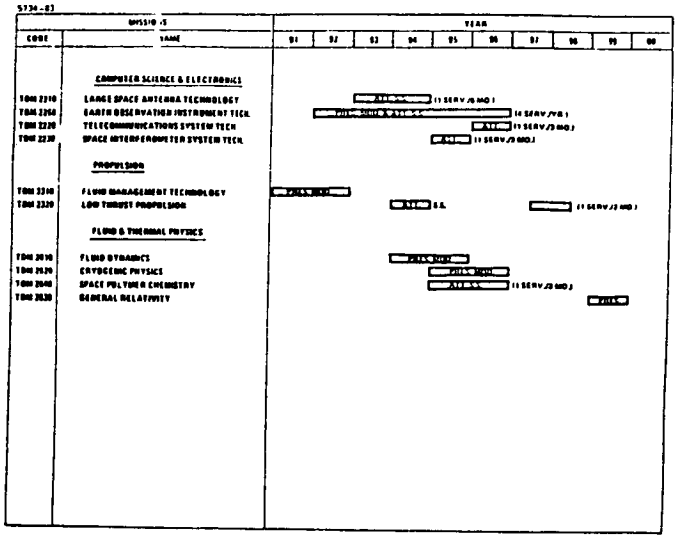
TIME PHASED MISSION SET - COMMERCIAL



TIME PHASED MISSION SET - TECHNOLOGY DEVELOPMENT



TIME PHASED MISSION SET - TECHNOLOGY DEVELOPMENT



ESA SPACE UTILIZATION

(128 PAYLOADS)

- o MATERIAL SCIENCE AND SPACE PROCESSING
  - AUTOMATED PROCESSING FACILITY (20 KW)
  - MANNED R&D FACILITY (10 KW)
- o LIFE SCIENCES
  - FREE FLYER (EURECA)
  - MANNED R&D FACILITIES (SHORT AND LONG MODULES)
- o SPACE SCIENCES AND APPLICATIONS
  - EARTH OBSERVATIONS FREE FLYERS AND PLATFORM (57° TO POLAR)
  - ASTRONOMICAL OBSERVATIONS FREE FLYERS AND PLATFORM (LOW AND HIGH INCL.)
- o TECHNOLOGY AND OPERATIONS
  - ASSEMBLY/CONSTRUCTION
  - SATELLITE SERVICING
- o NEW FIELDS
  - CALIBRATION LAB
  - MODULAR OTV
  - SOLAR ENERGY TRANSMISSION
  - SPACE PROPULSION SYSTEM DEVEL.
  - SPACE DEBRIS REMOVAL

28.5° SPACE STATION

U.S. SUMMARY REQUIREMENTS

YEAR	MASS KG	PRESSURIZED VOLUME M^3	POWER KW	IVA HRS	EVA HRS	# PRESSURIZED MODULES	# ATTACHED PAYLOADS / # PORTS	# FF SERVICING	# TRANS-PORTATION EVENTS
1991	35900	195	55	12300	830	4(2)[2]	6/2	3	-----
1992	49900	195	60	12900	1450	4(2)	13/3	3	-----
1993[1]	55000	215	63	16600	1520	5(3)	12/4	3	-----
1994	61000	275	88	24800	1330	8(5)	11/4	2	4
1995	101000	275	101	25200	230	11(8)	7/4	2	6
1996[1]	107000	310	106	29500	160	14(10)	10/4	2	12
1997	101000	305	121	30200	150	14(10)	8/4	1	10
1998	99000	305	112	27400	140	14(10)	5/4	2	13
1999[1]	96000	370	130	27500	110	15(10)	2/2	2	14
2000	94000	365	129	26900	70	15(10)	2/2	2	14

NOTES: (1) EEG PRODUCTION FACILITY ADDITIONAL UNITS BROUGHT ON LINE IN 1993, 96, AND 99 ARE ASSUMED TO BE CO-ORBITING FREE FLYERS.

(2) NUMBER IN PARENTHESIS IS THE NUMBER OF COMMERCIAL PRODUCTION UNITS PROVIDED BY INDUSTRY.

JAPANESE SPACE UTILIZATION

- o MATERIAL SCIENCE AND SPACE PROCESSING
  - MANNED R&D FACILITY
  - PROCESSING FACILITY
- o LIFE SCIENCES
  - MANNED R&D FACILITY (BIOLOGY, SPACE MEDICINE, CELSS)
- o SPACE SCIENCES AND APPLICATIONS
  - EARTH OBSERVATIONS MANNED AND UNMANNED FACILITIES (NEAR POLAR)
  - ASTRONOMICAL OBSERVATIONS FREE FLYERS/PLATFORM (LOW AND HIGH INCL.)
- o TECHNOLOGY AND OPERATIONS
  - FREE FLYER FOR SPACE PLASMA, ADVANCED PROPULSION, MICROWAVE ENERGY TRANS., SOLAR ARRAYS AND CONCENTRATORS
  - ATTACHED MODULE FOR LARGE STRUCTURES, LONG DURATION EXPOSURE, ZERO GRAVITY LIQUID HANDLING
- o COMMUNICATION TECHNOLOGY
  - LARGE ANTENNAS CONSTRUCTION
  - SATELLITE ASSEMBLY AND TEST
  - MAINTENANCE

28.5° PLATFORM

SUMMARY REQUIREMENTS

YEAR	POWER KW	RECORDING DATA RATE MBPS	# ATTACHED PAYLOADS	PAYLOAD MASS KG	# SERVICINGS
1991	2.5	16	2	6400	2
1992	3.1	66	3	11500	3
1993	4.7	67	4	18500	2
1994	1.9	50	2	12400	3
1995	3.2	51	3	19400	2
1996	3.3	51	2	16600	3
1997	2.6	2	3	16600	3
1998	2.6	2	3	16600	2
1999	4.9	44	3	25500	3
2000	2.6	42	1	12500	2

CANADIAN SPACE UTILIZATION

(37 PAYLOADS)

- o MATERIAL SCIENCE AND SPACE PROCESSING
  - MANNED R&D FACILITY
  - AUTOMATED PROCESSING FACILITY
- o LIFE SCIENCES
  - MANNED R&D FACILITY
- o SPACE SCIENCES AND APPLICATIONS
  - EARTH OBSERVATIONS FREE FLYERS/PLATFORM (SUN SYNC., 4-7 KW, 120-240 MBPS)
  - ASTRONOMICAL OBSERVATIONS FREE FLYERS/PLATFORM (LOW AND HIGH INCL.)
- o TECHNOLOGY AND OPERATIONS
  - LARGE STRUCTURES CONSTRUCTION/ASSEMBLY
  - SOLAR CELLS/ARRAYS
  - SENSOR DEVEL.
  - OTV SRM
  - MAINTENANCE, SERVICING, REPAIR

INTERNATIONAL SPACE UTILIZATION SUMMARY

Mission Area	U.S.	ESA	JAPAN	CANADA
Material Science and Space Processing				
Manned R&D Lab	✓	✓	✓	✓
Attached Processing Facility	✓			
Co-orbiting Processing Facility	✓	✓	✓	✓
Life Science				
Manned R&D Lab.	✓	✓	✓	✓
Co-orbiting Res. Facility				
Space Sciences and Applications				
Earth Observation				
High Incl. F.F./P	✓	✓		✓
Attached Res.	✓			
Manned High Incl.			✓	
Astronomical Observation				
Attached Obs.	✓			
Low Incl. FF/P	✓	✓	✓	✓
High Incl. FF/P	✓	✓	✓	✓
Technology and Operations				
Large Structures	✓	✓	✓	✓
Energetics	✓	✓	✓	✓
Sensor Development	✓			✓
Maintenance/Service/Repair	✓	✓	✓	✓
OTV	✓	✓		✓

SPECIAL REQUIREMENTS

SCIENCE AND APPLICATIONS
- CONTAMINATION CONTROL
- HIGHLY ACCURATE POINTING AND STABILITY

COMMERCIAL
- PHYSICAL AND COMMUNICATIONS SECURITY FOR PROPRIETARY PROCESSES/EXPERIMENTS
- ON-ORBIT STORAGE OF COMPLETE SPACECRAFT
- STORAGE FOR RAW MATERIALS AND EQUIPMENT

TECHNOLOGY DEVELOPMENT
- HIGH LEVEL OF EVA

SPACE STATION FUNCTIONAL CHARACTERISTICS

INITIALLY: 28.5° SPACE STATION
- o RESEARCH LABORATORY (SCIENCE, APPLICATIONS, TECHNOLOGY, INDUSTRIAL)
- o OBSERVATORY
- o SATELLITE/PLATFORM SERVICE CENTER (TMS)
- o COMMUNICATIONS AND DATA PROCESSING NODE
- o LOW AND HIGH INCLINATION PLATFORMS

MIDTERM: ADD
- o TRANSPORTATION NODE TO HIGHER ENERGY ORBITS (SBOTV)
- o STORAGE FACILITY IN SPACE
- o CONSTRUCTION/ASSEMBLY DEPOT

FINALLY: ADD
- o ENHANCED CAPABILITY IN ALL AREAS
- o MODEST REPLICATION IN POLAR ORBIT

USER CONCERNS

- o HOW WILL NASA INSURE "USER FRIENDLINESS?"
  - RAPID AND GUARANTEED ACCESS
  - ADEQUATE RESOURCES (INCLUDING STORAGE)
  - MINIMUM "RED TAPE"
  - SECURITY FOR PROPRIETARY EXPERIMENTS, PROCESSES, AND DATA
  - CONTAMINATION AND POINTING CONTROL
  - REASONABLE USER CHARGE POLICY
- o HOW COST EFFECTIVE ARE:
  - SATELLITE/PLATFORM SERVICING
  - SPACE BASED OTV
- o WILL SPACE STATION DEVELOPMENT REDUCE FUNDING AVAILABLE FOR TRADITIONAL SPACE SCIENCE AND APPLICATIONS DISCIPLINES?

SPACE STATION CHALLENGES

THE USER VIEW

- o INTERFACE PHILOSOPHY--KEEP IT STANDARD AND SIMPLE.
- o USER CHARGE POLICY--ESTABLISH IT EARLY AND STICK TO IT.
- o ESTABLISH A USER COUNTERBALANCE TO THE DESIGNERS/BUILDERS--DON'T WEAKEN THE USER ACCOMMODATION IMPETUS.
- o EVA IS NECESSARY--ESTABLISH THE EQUIPMENT, TOOLS AND TECHNIQUES EARLY AND GET ON WITH DEVELOPMENT, TEST AND TRAINING ON SHUTTLE.
- o HIGH PRODUCTIVITY IS THE KEY TO COST EFFECTIVENESS--EXCESSIVE MANAGEMENT AND GROUND CONTROL IS THE ENEMY OF PRODUCTIVITY.
- o THE RIGHT MIX OF AUTOMATION AND CREW IS ESSENTIAL AND MUST BE ESTABLISHED EARLY.
- o TO ATTRACT BUSINESS THE SPACE STATION MUST BE RESOURCE RICH.
- o SATELLITE/PLATFORM SERVICING AND OTV OPERATIONS MUST BE COST EFFECTIVE.
- o ONBOARD RESEARCH LABS SHOULD BE EQUIPPED AND OPERATED LIKE GROUND RESEARCH LABS.
- o SPARE PARTS MUST BE AVAILABLE WHEN NEEDED.

MISSION REQUIREMENTS SUMMARY

- o SECOND ITERATION ONLY
- o MISSIONS ARE:
  - PROGRAMMATICALLY REALISTIC
  - SCIENTIFICALLY VALID
  - TECHNOLOGICALLY FEASIBLE
- o COMMERCIAL MATERIALS PRODUCTION
  - CURRENT BEST GUESS (HAMPERED BY LACK OF MICROGRAVITY RESEARCH EXPERIENCE)
  - EXTENSIVE SHUTTLE SORTIE RESEARCH REQUIRED PRIOR TO 1991

ELEMENTS OF COST EFFECTIVE MISSION ASSURANCE

- TESTING
- CHECKOUT
- HARDWARE DEVELOPMENT
- OFF-THE-SHELF HARDWARE
- REDUNDANCY
- MAINTAINABILITY

TESTING

- TEST PROGRAMS ARE LARGE COST DRIVERS (HARDWARE, FACILITIES, AND MANPOWER)
- EARLY TESTING VS. LATE TESTING (APOLLO VS. SHUTTLE)
- FLIGHT TEST VS. GROUND TEST
  - MAN RATING (SHUTTLE VS. OTHER MAN PROGRAMS)
  - THERMAL VACUUM (SHUTTLE VS. OTHER MAN PROGRAMS)

CHECKOUT

- INFLIGHT CHECKOUT VS. GROUND CHECKOUT
  SOME PAYLOADS HAVE USED THIS

HARDWARE DEVELOPMENT

- USE OF FLIGHT-TYPE HARDWARE
  DEVELOPMENT OR QUAL HARDWARE

REDUNDANCY

- TRADE-OFF OF REDUNDANCY VS. CHECKOUT COST VS. DEVELOPMENT COST VS. COST OF UNIQUE HARDWARE

OFF-THE-SHELF HARDWARE

- THE USE OF OFF-THE-SHELF HARDWARE VS. COST OF DEVELOPING UNIQUE HARDWARE

MAINTAINABILITY

- THE COST OF PROVIDING INFLIGHT MAINTAINABILITY

SPACE STATION SYSTEM TRADE STUDIES

Presented to Space Station Workshop at 1983 Conference on Mission Assurance by Charles R. Darwin-MSFC

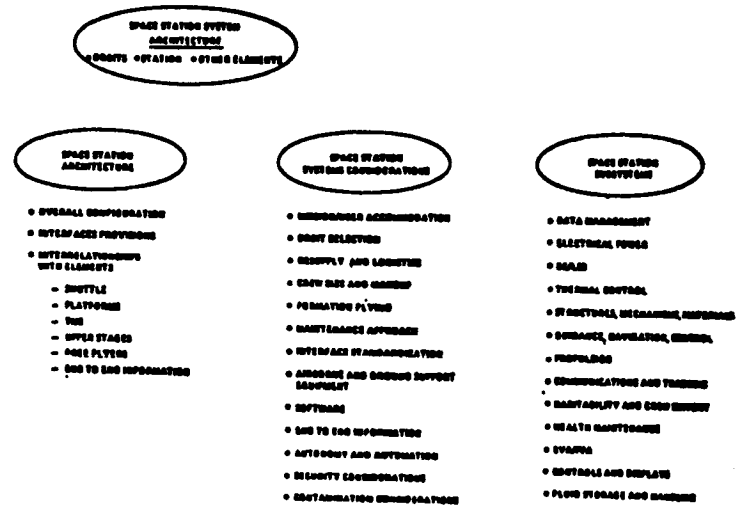
The Space Station System Architecture and Space Station Design Architecture have been the subject of system trade studies over the past year and also serve to partially describe the type characteristics expected in a station and related system. Most of these trades have a relationship with Mission Assurance. Selected summary findings from a number of these preliminary trade findings have been included in this discussion and are reflected in the following charts.

MISSION ASSURANCE

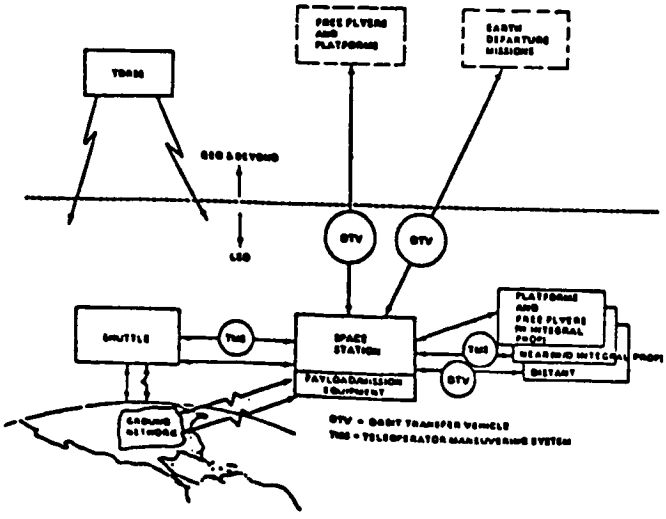
ENNOBLED IN AND PERMEATES

- BASIC SYSTEM ARCHITECTURE
- STATION DESIGN ARCHITECTURE
  - BASIC INITIAL SYSTEM
  - ABILITY TO PROVIDE GROWTH FLEXIBILITY
- STATION SUBSYSTEMS IMPLEMENTATION
- STATION DELIVERY/ASSEMBLY/RESUPPLY/ON-ORBIT OPERATIONS
- STATION INTERFACE/OPERATIONS RELATION TO "MISSIONS"
- APPROACHES TO SAFETY/RELIABILITY/MAINTAINABILITY/RECOVERY
- EFFECTIVE CREW PROVISIONS/UTILIZATION DESIGN AND OPERATIONS
- END TO END INFORMATION SYSTEM
- IMPLEMENTATION AND OPERATIONS COSTS
  - STATION
  - INFLUENCE ON RELATED SYSTEMS

SPACE STATION SYSTEM DEFINITION CONSIDERATIONS



ELEMENTS OF SPACE STATION SYSTEM ARCHITECTURE



SPACE STATION AND SYSTEM SELECTED ISSUES

- SPACE STATION CAPABILITY LEVEL VS EFFECTIVE MISSION ACCOMMODATION CAPABILITY AND SYSTEM COST
  - INITIAL STATION/MISSIONS
  - GROWTH STATION/MISSIONS
- SPACE STATION GROWTH ON ORBIT OVER TIME
  - GROWTH IN CAPABILITY (EVOLUTION AND/OR REPLICATION)
  - TECHNOLOGY GROWTH
- ORBIT SELECTION AND FORMATION FLYING
- DEGREE OF AUTONOMY/AUTOMATION
- APPROACHES TO SAFETY, RELIABILITY, MAINTAINABILITY
- STATION ARCHITECTURE
  - DISTRIBUTION OF FUNCTIONS
  - STANDARD INTERFACES
  - DESIGN COMMONALITY

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SPACE STATION CAPABILITY LEVEL

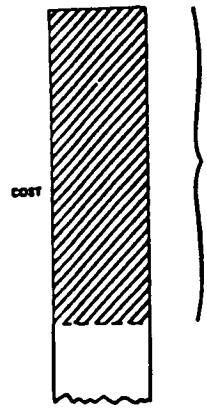
VS

EFFECTIVE MISSION ACCOMMODATION CAPABILITY

AND

SYSTEM COST

POTENTIAL WAYS TO REDUCE COST



- UTILIZATION OF COMMON HARDWARE
  - STRUCTURE
  - BERTHING INTERFACES
- UTILIZE EXISTING HARDWARE – LOWER TECHNOLOGY
  - ORBITER RADIATOR PUMPS
  - LANDSAT K_u BAND
- TRADE LOWER INITIAL COST FOR HIGHER OPERATING COST
  - OPEN LOOP ECLS VS. CLOSED LOOP
- LOWER INITIAL CAPABILITY AND ADD'T GROWTH STEPS
  - POWER LEVEL (15KW VS 30 KW)
- INCREASE SAFETY FACTOR AND REDUCE TESTING
  - STRUCTURE SAFETY FACTOR (2.5 VS 1.4)
- PROTOFLIGHT RATHER THAN PROTOTYPE HARDWARE

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INITIAL SPACE STATION FUNCTIONS/FACILITIES/SERVICES

INITIAL STATION MINIMUM CAPABILITY

- GENERAL RESOURCES TO PLDS.
  - 5 KW AVG. TO USERS
  - PAYLOADS PROVIDE OWN HEAT REJECTION
  - LOW COMM. & DATA
  - COARSE POINTING (ARC MIN – DEG)
  - MIN. ORIENTATION FLEX.
  - PLD. WT./VOL.: TBD
- CREW SUPPORT
  - 3 MAN CREW
  - 90 DAY RESUPPLY
  - OPEN LOOP ECLS
- SCIENCE/APPLICATIONS/COMMERCIAL/DOD/TECHNOLOGY
  - SMALL INTERNAL VOLUME FOR EXPERIMENTS (2 RACK EQUIV)
  - 2 EXTERNAL PORTS OR ATTACH ZONES
- OPERATIONS SUPPORT CAPABILITY.
  - MAINT/SERV OF STATION & INTERNAL PAYLOADS
  - CREW SUPPORT TIME: TBD
- MISCELLANEOUS
  - CURRENT TECHNOLOGY

INITIAL STATION MODERATE CAPABILITY

- GENERAL RESOURCES TO PLDS.
  - 10 KW AVG. TO USERS
  - STATION PROVIDES 50% PAYLOAD HEAT REJECTION
  - MOD. COMM. & DATA WITH INFRASTRUCTURE
  - MODERATE POINTING (ARC MINUTES)
  - MOD. ORIENTATION FLEX.
  - PLD. WT./VOL.: TBD . --
- CREW SUPPORT
  - 4 MAN CREW
  - 90 DAY RESUPPLY
  - PARTIALLY CLOSED ECLS (WATER)
- SCIENCE/APPLICATIONS/COMMERCIAL/DOD/TECHNOLOGY
  - MODERATE INTERNAL VOLUME FOR EXPERIMENTS (4 RACK EQUIV)
  - 4 EXTERNAL PORTS OR ATTACH ZONES
- OPERATIONS SUPPORT CAPABILITY
  - MAINT/SERV OF STATION, INTERNAL, & EXT PAYLOADS
  - CREW SUPPORT TIME: TBD
  - MAINT/SERV OF FF & PLATFORMS
  - TMS BASE
- MISCELLANEOUS
  - MODERATELY ADVANCED TECHNOLOGY

INITIAL STATION SIGNIFICANT CAPABILITY

- GENERAL RESOURCES TO PLDS.
  - 20 KW AVG. TO USERS
  - STATION PROVIDES 80% PAYLOAD HEAT REJECTION
  - SIG. COMM. & DATA WITH INFRASTRUCTURE
  - MODERATE POINTING (ARC MINUTES)
  - SIG. ORIENTATION FLEX.
  - PLD. WT./VOL.: TBD
- CREW SUPPORT
  - 6 MAN CREW
  - 90 DAY RESUPPLY
  - CLOSED LOOP ECLS
- SCIENCE/APPLICATIONS/COMMERCIAL/DOD/TECHNOLOGY
  - INCREASED INTERNAL VOLUME FOR EXPERIMENTS (6 RACK EQUIV.)
  - 6 EXTERNAL PORTS OR ATTACH ZONES
- OPERATIONS SUPPORT CAPABILITY
  - MAINT/SERV OF STATION, INTERNAL & EXT PAYLOADS
  - CREW SUPPORT TIME: TBD
  - MAINT/SERV OF FF & PLATFORMS
  - TMS BASE
  - ON-BOARD MANIPULATOR FOR ASSY. SUPPORT
  - ATTACHMENT/ASSY-SPACE
- MISCELLANEOUS
  - SIGNIFICANTLY ADVANCED TECHNOLOGY

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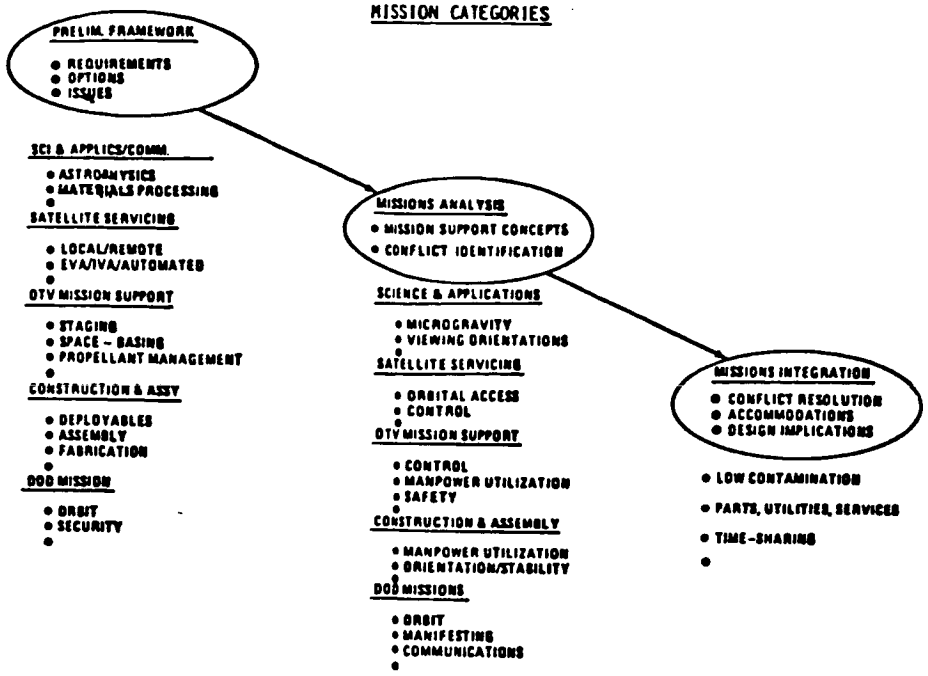
ACCOMMODATION APPROACH FOR MISSION CATEGORIES



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SS SYSTEM SUPPORT OPERATIONS

SUMMARY IMPACTS/CONSIDERATIONS

MISSION CLASSES	SS IMPACTS/CONSIDERATIONS
• SCIENCE & APPLICATION/COMMERCIAL	• ROTATING PORTS
ASTROPHYSICS	• UTILITY SUPPORT (POWER, THERMAL, DATA, . . .)
EARTH SCIENCES	• PRESSURIZED MODULES
MATERIALS R&D, PROCESSING	• AIRLOCKS, HATCHES
LIFE SCIENCES	• INTERNAL RACKS/CARRY-ON SUPPORT
GENERAL R&D	• EXTERNAL PALLETS/UMBILICALS
• UPPER STAGE SUPPORT	• EXPERIMENT CONTROL, CREW SKILLS
• SPACECRAFT SERVICING	• CONTAMINATION, ATMOSPHERE MAKEUP, ECLSS BURDEN
• LARGE STRUCTURES	• BERTHING & HANDLING SYSTEMS
• DOD	• C^3 SUPPORT
• TECHNOLOGY DEVELOPMENT	• REFUELING SYSTEMS
	• EVA SUPPORT PROVISIONS & TOOLS
	• LIGHTING, VIEWING, VOICE SYSTEMS
	• MATING ORIENTATIONS, CLEARANCES

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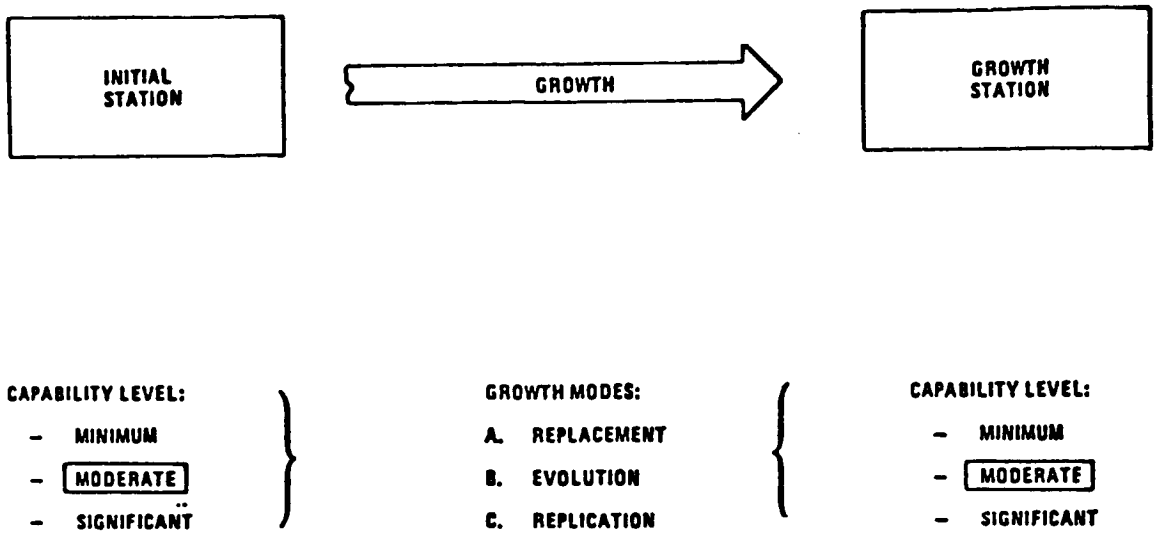
TRADE P-6 EVOLUTIONARY GROWTH MODES



TECHNOLOGY EVOLUTION

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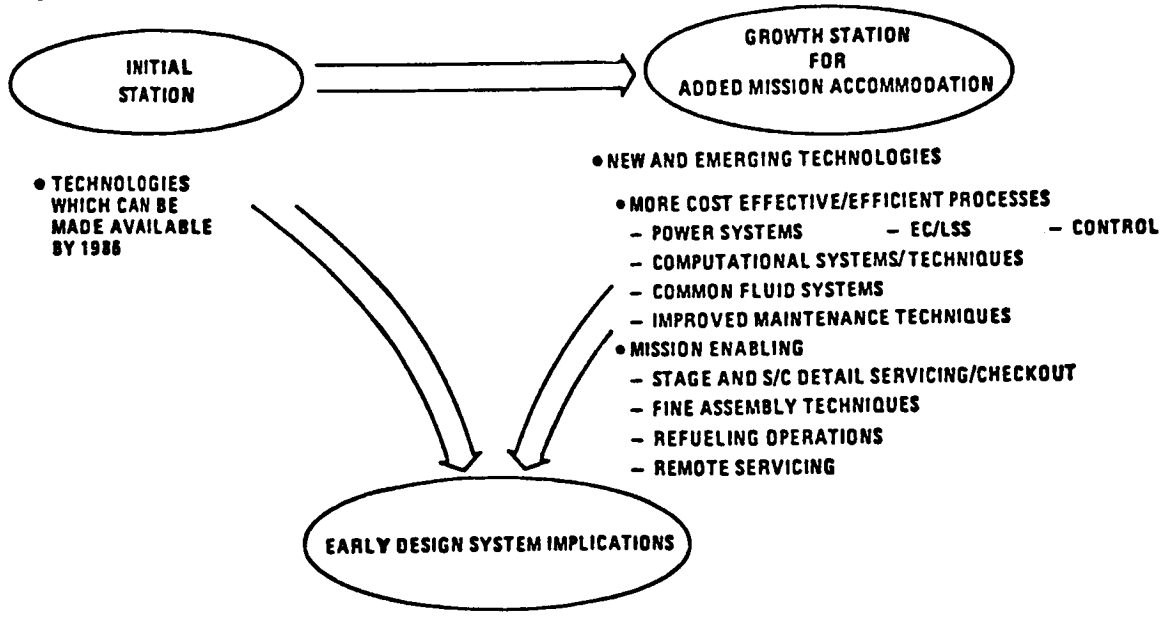

- STANDARDIZE INTERFACES FOR ADD ON AND REPLACEMENT
- DESIGN TO ALLOW ASSEMBLY REPLACEMENT ON ORBIT
  - SOLAR ARRAY
  - COMPUTERS
  - EC/LSS COMPONENTS
- INTRA SYSTEM DATA AND POWER DISTRIBUTION NETWORK SIZING
- CONTROL ADAPTABLE TO ADD ON ACTUATORS
- CONFIGURE ARCHITECTURE ALLOWING FLEXIBILITY IN GROWTH FOR ADDITIONAL ELEMENT AND MISSION EQUIPMENTS/FUNCTIONS

ORBIT SELECT.

AND

FORMATION FLYING

0861-83

ORBIT SELECTION CONSIDERATIONS

ALTITUDE

- STS LAUNCH CAPABILITY, COST
- ATMOSPHERIC DRAG
- RADIATION ENVIRONMENT
- METEOROID/DEBRIS ENVIRONMENT
- MISSION REQUIREMENTS
- STS AVAILABILITY FROM NON-STATION FLIGHTS

INCLINATION (S)

- MISSION NEEDS/ TRAFFIC
- NUMBER OF STATIONS/ COST
- STS PERFORMANCE

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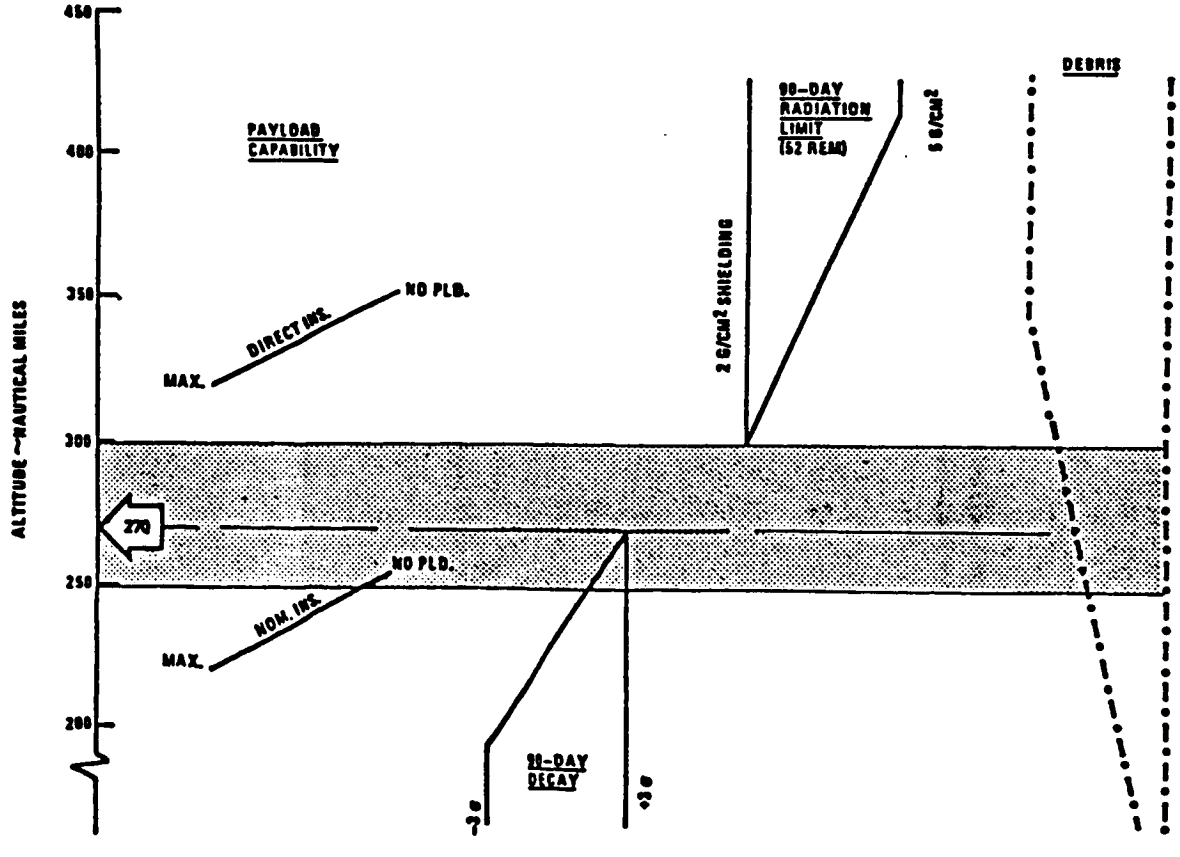
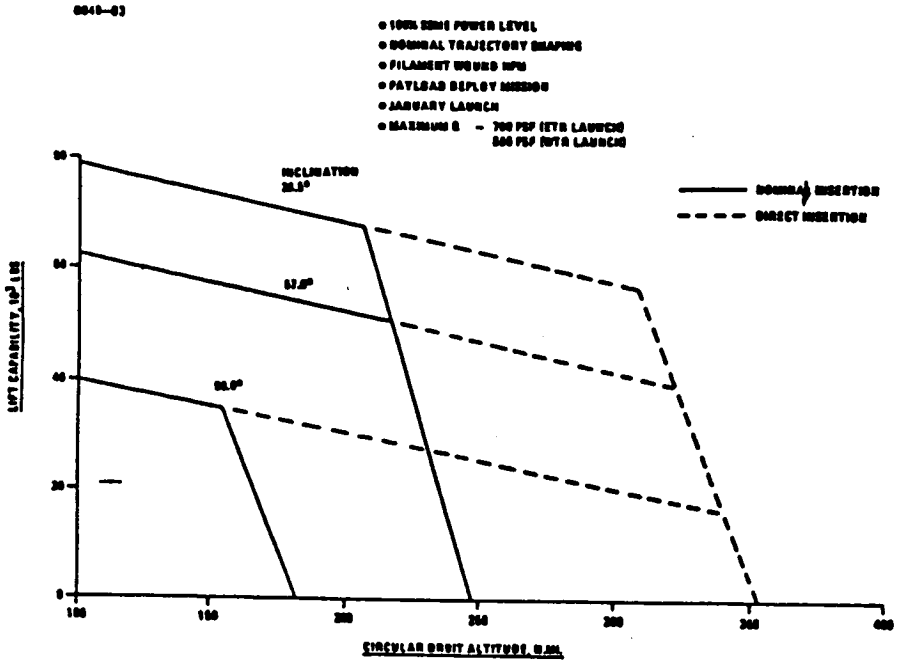
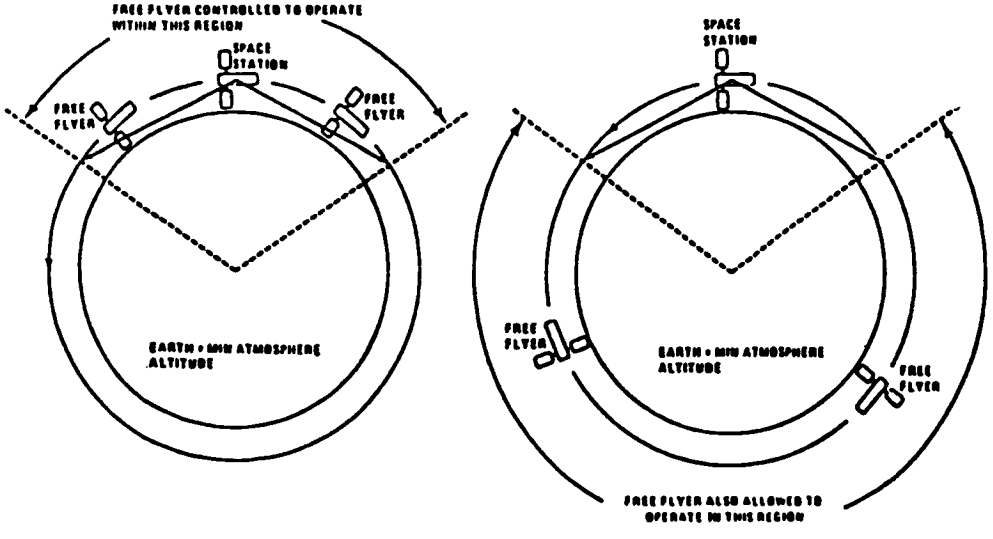
ALTITUDE CONSTRAINTS



PROJECTED STS LIFT CAPABILITY



FORMATION FLYING
RENDEZVOUS COMPATIBLE ORBITS



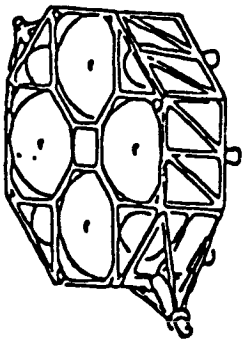
CONSTRAINED TO LINE-OF-SIGHT

UNCONSTRAINED TO LINE-OF-SIGHT

TMS

RECOMMENDED USES WITH SPACE STATION

USE	TYP. PROPELLANT RANGE (LBS)	TYP. NO. USES/YR.
STATION		
• REBOOST	150–600	4–8
• DEORBIT	6000–8500	– ? –
• SPECIAL LOGISTICS FROM LOWER ALTITUDE STS.	750–5000	0–10
MISSION SUPPORT		
• FORMATION FLYING PLATFORMS • CHANGEOUT PAYLOADS • RETRIEVE/REPOSITION FOR SERVICING • REBOOST	100–1400	5–10
• FREE FLYING SPACECRAFT • RETRIEVE/REBOOST FOR SERVICING • REMOTE SERVICING	3000–7000	1–4
• UPPER STAGES • RETRIEVE	300–1000	0–4

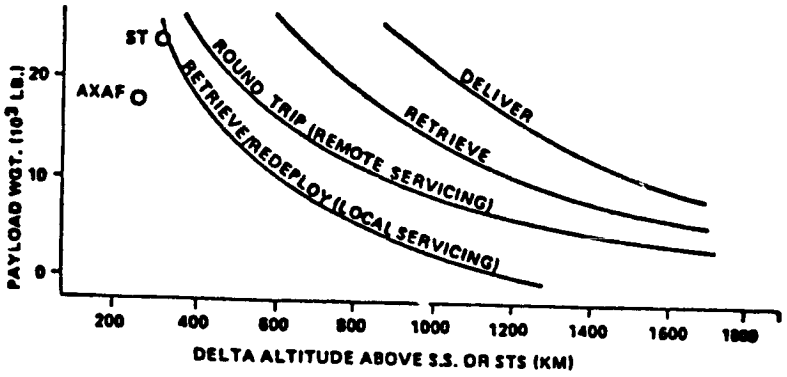


TYPICAL CONCEPT
BIPROP OR MONO
$W_p \approx 7000$ LB.

RECOMMENDATION

- PLAN AS ADJUNCT TO INITIAL STATION
  - SINGLE UNIT INITIALLY
  - EVOLVE TO MULTIPLE UNITS
- SIZE 5000 – 7000 LB. MONO OR BIPROPELLANT

TYPICAL ALT. CHANGE CAPABILITIES



SPACE SHUTTLE UTILIZATION

- SHUTTLE COMPATIBILITY AND INTERACTIONS IS BEING TREATED AS A PRIORITY TRADE.
- NUMEROUS SPACE STATION/STS INTERFACES
  - SPACE STATION ELEMENT LAUNCH AND ASSEMBLY
  - SPACE STATION RESUPPLY AND SERVICING
  - CREW RESCUE OPTIONS
  - RETURN OF SPACE STATION ELEMENTS TO EARTH
    - WASTE PRODUCTS AND MATERIALS
    - EXPERIMENT/MISSION PACKAGES
    - MODULES (?)
    - FAILED ELEMENTS THAT ARE NOT REPAIRABLE AT STATION
  - PROPELLANT SCAVENGING (POTENTIALLY)
  - RENDEZVOUS AND DOCKING OPERATIONS

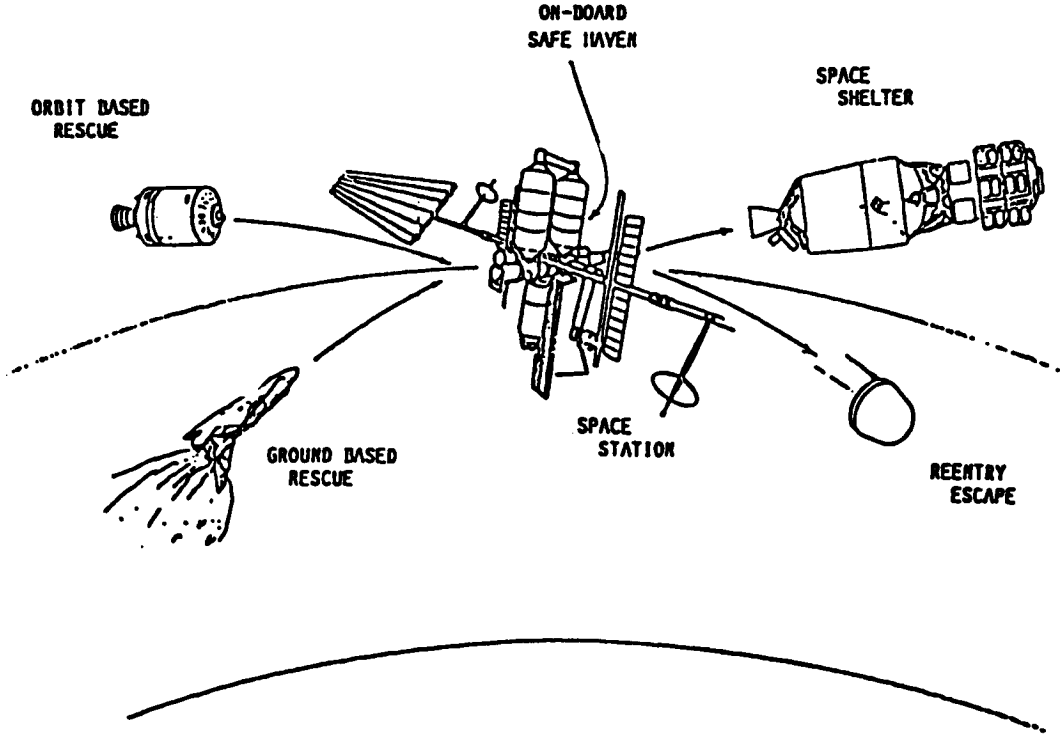
SAFETY/RELIABILITY/MAINTAINABILITY

TRADES AND CONSIDERATIONS

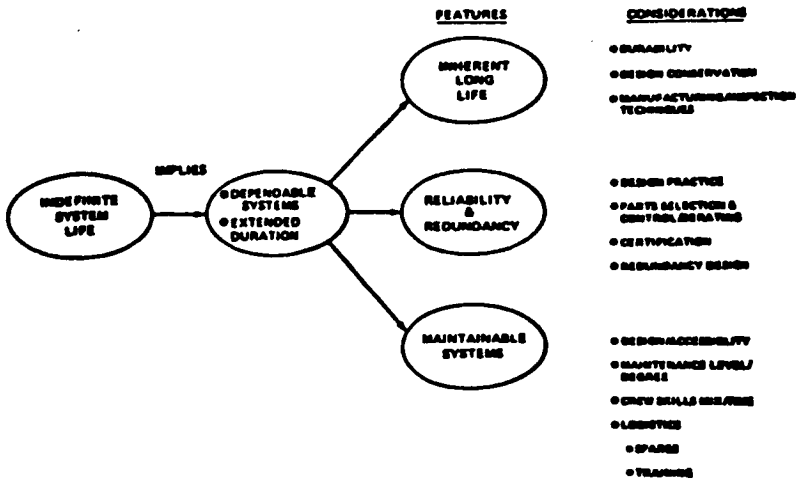
SAFETY KEY ISSUES

- CAUTION & WARNING LEVELS, ALARM/ANNUNCIATOR METHODS, CENTRALIZED VS. DECENTRALIZED CAUTION AND WARNING COMMAND AND CONTROL
- SAFE HAVEN OPTIONS AND APPROACHES
- HAZARDOUS MATERIAL IDENTIFICATION, HANDLING, AND PARTITIONING
- SHUTTLE RESCUE REACTION TIME AND METHODS, INCLUDING MULTIPLE SHUTTLE LAUNCHES

THE OPTIONS



LONG-LIFE, RELIABLE AND MAINTAINABLE SYSTEMS



MAINTAINABILITY KEY ISSUES

- CREW TIME ALLOCATED TO MAINTENANCE
- ALLOWABLE DOWN TIME
- ORU DEFINITION

  EVA ORU'S - EORU
  IVA ORU'S - IORU

- EVA TO IVA TRANSLATION FOR SHIRTSLEEVE CREW ACCESS TO IORU'S
- COMMONALITY OF PARTS
- ON-BOARD SPARES SET, TOOLS, AND REPAIR CAPABILITY
- ACCESS TO SYSTEMS AND SYSTEM DESIGN FOR EASE IN DISASSEMBLY
- SHARED FLIGHT/GROUND DATA BASE FOR MAINTENANCE AND RETEST
- REDUNDANCY/SYSTEMS SEPARATION WITHIN CRITICAL SYSTEMS TO ALLOW SAFE MAINTENANCE
- MAINTAINABILITY REQUIREMENTS FOR ATTACHED INSTRUMENTS, FREE FLYERS AND PLATFORMS

SPACE STATION MAINTENANCE AND SERVICING SCOPE

OBJECTIVES
- SURVIVAL
  - CREW
  - SYSTEM
- OPERATIONS
  - RESTORATION
  - CONTINUITY

ACTIVITIES
- DIAGNOSIS
- ANALYSIS
- CALIBRATION
- ADJUSTMENT
- REPLENISHMENT
- CHANGEOUT
- REPLACEMENT
- REPAIR

APPROACH
- IVA
- EVA
- TELEOPERATION
- AUTONOMOUS

LEVEL
- PIECE-PART
- COMPONENT
- SUBASSEMBLY
- ASSEMBLY
- SUBSYSTEM
- MODULE

POLICY
- SCHEDULED
- UNSCHEDULED
- CONTINGENCY

LOCATION
- INBOARD
- OUTBOARD

RESOURCES
- SKILLS
- TOOLS
- TIME

SUPPORTING

FACILITIES
- PORTS
- HANGARS
- EQUIP. STORAGE
- SPARES STORAGE
- WORKBENCH

EQUIPMENT
- RMS/ORBITER
- SE MANIPULATORS
- TMS/SERVICER
- MMU
- CHERRY PICKER
- EVA SUPPORT EQ.

SYSTEMS
- COMMUNICATIONS
- INFORMATION DISPLAY
- EXPERT OPINION SOFTWARE
- SUSTAINING ENGINEERING

SPACE STATION MAINTENANCE/SERVICING

COST	BENEFITS
• MAINTENANCE DESIGN	• LESS REDUNDANCY
• SUPPORT EQUIPMENT	• LONGER LIFETIME
• SPARES MANAGEMENT	• SYSTEM UPGRADING

SPACE STATION AUTONOMY GOALS

- IMPROVE MAN'S PRODUCTIVITY IN SPACE
- REDUCE GROUND SUPPORT COSTS
- ALLOW COMPLEX, CONCURRENT OPERATIONS
- IMPROVE SAFETY, SECURITY, AND SURVIVABILITY
- MINIMIZE HUMAN ERROR
- ALLOW SPACE OPERATIONS WITHOUT CREW
- PROVIDE REAL-TIME SHORT RESPONSE CONTROL
- INVOLVE FEWER AND SIMPLER INTERFACES

POTENTIAL GUIDELINES/ISSUES FOR AUTONOMY

- AN IMPLEMENTATION OF AUTONOMY SHOULD PROVIDE FOR GROWTH OF SPACE STATION CAPABILITY AND PROGRESSIVE ONBOARD AUTONOMY
- SHOULD BE DESIGNED TO ENABLE OPERATION OF THE SPACE STATION WITHOUT GROUND CONTROLLER OR FLIGHT REAL-TIME INTERVENTION
- SHOULD ALLOW STATION TO OPERATE IN UNMANNED MODE (IN LIMITED MANNER)
- STATION AUTONOMY SHOULD SUPPORT IN-FLIGHT, SUPERVISORY CONTROL BY GROUND CONTROLLERS AND THE FLIGHT CREW AND EASY SOFTWARE MODIFICATION BY FLIGHT CREW
- AUTONOMOUS ACTIVITIES SHOULD BE VISIBLE TO THE GROUND CONTROLLERS AND THE FLIGHT CREW AND HAVE ADEQUATE INSTRUMENTATION TO ALLOW FULL AUTOMATION
- AUTONOMY FEATURES SHOULD RECOGNIZE MISSION CONSTRAINTS AND PAYLOAD OPERATION, PROVIDING A USER FRIENDLY OPERATIONAL AND SOFTWARE INTERFACE
- AN IMPLEMENTATION OF AUTONOMY SHOULD BE HIERARCHIAL
- SELECTED DESIGN FEATURES
  - ENHANCE CREW SAFETY
  - REDUCE GROUNDS OPS
  - ADVANCED DISPLAYS/CONTROLS
  - TOLERANT OF TRANSIENT ERRORS
  - NOT INTRODUCE SINGLE POINT FACTORS
  - OTHER

TRADE S-19 SYSTEM INTERFACE STANDARDIZATION

OBJECTIVE

- TO PROVIDE GENERAL INSIGHT (PRELIMINARY TRENDS) INTO INTERFACES SINCE INTERFACE STANDARDIZATION OFFERS POTENTIAL WEIGHT AND COST SAVINGS AND ENHANCED POTENTIAL FOR EVOLUTION AND ORBITAL MAINTENANCE/SERVICING

OPTIONS

- TYPE INTERFACES FOR POTENTIAL STANDARDIZATION
  - A. ELEMENT-TO-ELEMENT
  - B. MODULE-TO-MODULE
  - C. SYSTEM/SUBSYSTEM
  - D. ORBITAL REPLACEMENT UNIT (ORU'S)
- EARLY EMPHASIS ANALYSIS AREAS
  - A. ELEMENT-TO-ELEMENT
  - B. MODULE-TO-MODULE

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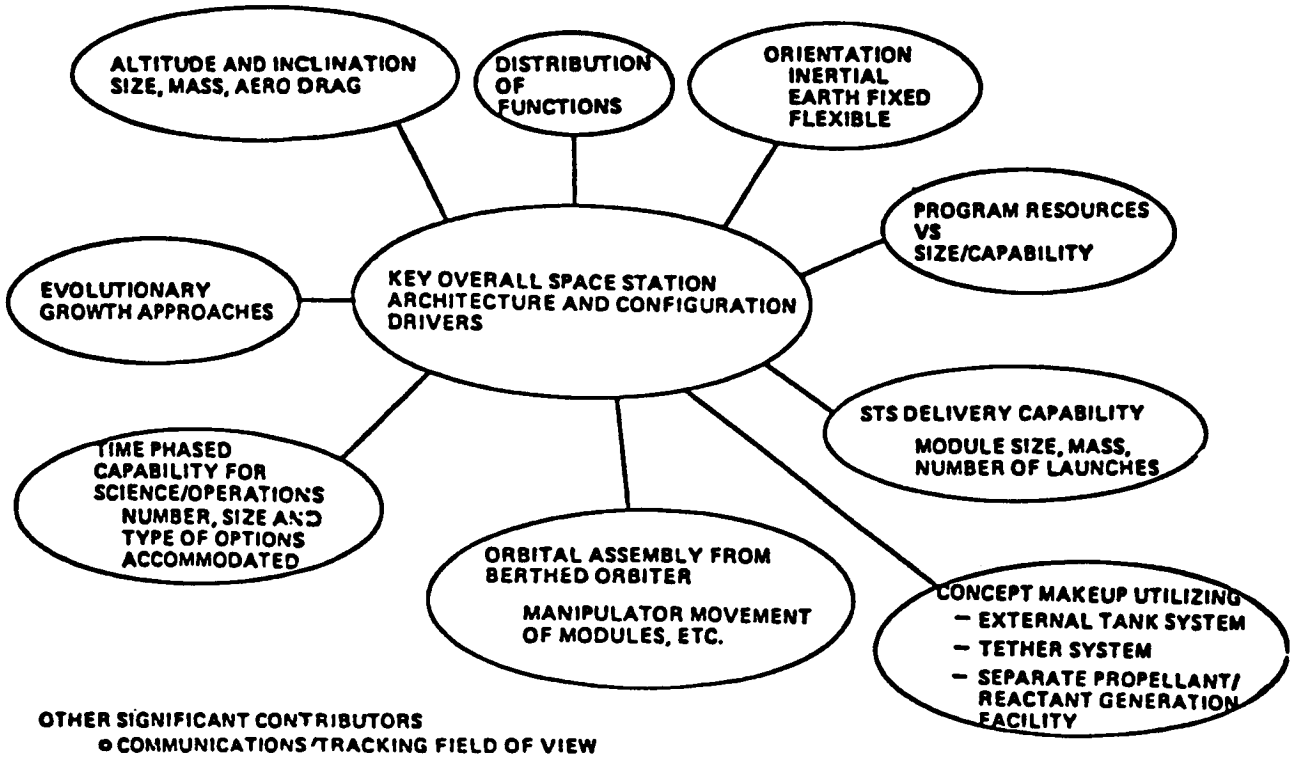
SPACE STATION SYSTEM INTERFACES

	SHUTTLE	SPACE STATION	TMS	OTV	PLATFORM	FREE-FLYER	MODULES/PALLETS
SHUTTLE		X	X	X	X	X	X
SPACE STATION	X		X	X	X	X	X
TMS	X	X		?	X	X	X
OTV	X	X	?			X	
PLATFORM	X	X	X				X
FREE-FLYER	X	X	X	X			
MODULES/PALLETS	X	X	X		X		

ADDITIONAL OPERATIONS PHILOSOPHY KEY ISSUES

- CREW SKILL MIX
- MULTI-SHIFT OPERATIONS
- CREW TIME ALLOCATION
- INITIAL STATION ACTIVATION AND TEST
- SIZE, SCOPE, AND TIME PHASING OF GROUND CONTROL
- SEPARATION OR INTEGRATION OF STATION AND PLATFORM GROUND CONTROL CENTERS
- NEAR TERM VS. FAR TERM GENERATION AND EXECUTION OF PROCEDURES AND TIME LINES
- REQUIREMENTS FOR PROXIMITY VEHICLES
- SECURITY REQUIREMENTS

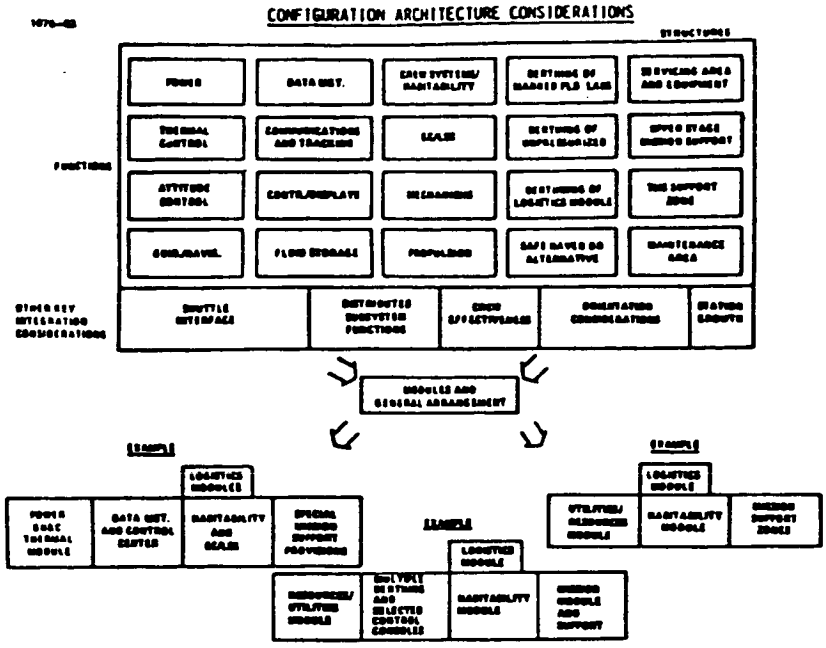
SPACE STATION ARCHITECTURE/CONFIGURATION DRIVERS



OTHER SIGNIFICANT CONTRIBUTORS

- COMMUNICATIONS/TRACKING FIELD OF VIEW
- LARGE SIZE OF SOLAR ARRAYS
- THERMAL HEAT REJECTION SYSTEM (CENTRALIZED, DECENTRALIZED)
- ATTITUDE CONTROL SYSTEM (RCS, CMG'S)
- SAFETY CONSIDERATIONS
- SERVICING AND MAINTENANCE REQUIREMENTS
- TECHNOLOGY STATUS
- CREW CONSIDERATIONS

CONFIGURATION ARCHITECTURE CONSIDERATIONS



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SPACE STATION INITIAL YEAR
GENERALIZED CAPABILITY TRENDS - PRELIMINARY

- POWER TO PAYLOADS: 12KW (MIN.) — 15 KW (NOM.) — 20 KW (MAX.)
- CREW SIZE: 3 — 4 — 8
- CREW TIME AVAILABLE TO PAYLOADS (MAN HOURS/DAY): 24 — 32 — 64
- INTERNAL LAB EQUIVALENT RACKS FOR PAYLOADS: 2 — 4 — 8
- EXTERNAL BERTHING FOR PAYLOADS – PRESSURIZED: 1 — 2 — 3
  - UNPRESSURIZED: 2 — 3 — 4
- OPERATING ALTITUDE (N.MI.): 200 — 270 — 300
- BODY POINTING ACCURACY (DEG.): ±0.1 — 0.5 — 1.0
- RESUPPLY INTERVAL (DAYS): 30 — 90 — 120
- RESUPPLY AVAILABLE TO PAYLOAD
  - WEIGHT (K): 30 — 35 — 40
  - LENGTH (FT): 30 — 35 — 40
- TDRSS AVAILABILITY (MIN. PER ORBIT): 20 — 40 — 90
- COMMUNICATION SUPPORT TO PAYLOADS
  - ATTACHED (BASICALLY AS REQUIRED)
  - FREE FLYING (TBD)
- DATA STORAGE/ANALYSIS SUPPORT TO ATTACHED AND FREE FLYING PAYLOADS: NONE — MINIMAL – BASICALLY PAYLOAD PROVIDED — EXTENSIVE
- STATION BASED TELEOPERATOR PROPULSIVE SYSTEM AVAILABILITY: NONE — ONE — MULTIPLE
- SPACE PLATFORMS IN "FORMATION": NONE — 1-3 — 3-5
- OPERATIONS SUPPORT TRENDS: NONE — LIMITED — EXTENSIVE
  - SERVICING SUPPORT TO FREE FLYERS
  - SERVICING SUPPORT TO PLATFORM
  - LIMITED LARGE STRUCTURE ASSEMBLY
  - LIMITED UPPER STAGE MISSION SUPPORT

0870-83

GENERAL APPROACHES/PHILOSOPHIES EMERGING

- INITIAL STATION EXPECTED TO BE CAPABLE OF EVOLVING ON ORBIT AND/OR REPLICATING FOR ALTERNATE ORBIT OR APPLICATION
- ACCOMMODATIONS OF MULTIPLE TYPE USERS, CAPABILITY TO EVOLVE ON ORBIT, AND MINIMIZATION OF COST ARE COMBINING TO EFFECT A MAJOR SYSTEM CHALLENGE
- DESIGN COMMONALITY BETWEEN STATION/PLATFORM AND BETWEEN STATIONS AT VARIOUS ORBITS EXPECTED TO BE PRACTICAL TO REASONABLE DEGREE
- MANY OPTIONS EXIST FOR EACH SUBSYSTEM RANGING FROM EXISTING EQUIPMENT TO ADVANCED TECHNOLOGIES – SOLUTIONS DEPEND ON TRADES OF TIMEFRAME, TECHNOLOGY MATURITY, AND BENEFIT VS COST
- PHILOSOPHY PREVELANT FOR SUBSTANTIAL AUTONOMY, ORBITAL MAINTENANCE, AND EFFECTIVE LIFE CYCLE COST

5186-83

SELECTED PERVADING ISSUE AREAS

- GROWTH AND EVOLUTION ON-ORBIT – TYPE PROVISIONS AND INTERFACES TO ENSURE PRACTICALITY
- APPROPRIATE UTILIZATION OF CREW IN STATION OPERATION – DESIRE FOR TIME TO BE APPLIED TO MISSION ACCOMMODATIONS/CREW LIMITATIONS/PLANNED ACTIVE USE OF EVA
- UNMANNED OPERATION OF STATION – AS MINIMUM, MAINTAIN ORBIT/ATTITUDE/SYSTEMS AND CONTINUE ESSENTIAL SERVICES TO PAYLOADS
- SAFETY – MAINTAIN ESTABLISHED LEVELS OF CREW AND SYSTEM SAFETY?
- RELIABILITY/MAINTAINABILITY
  - RELIABILITY GOALS VS MAINTAINABILITY POTENTIALS
  - CAPTURING ADVANTAGE OF "FORGIVING TIME/CRITICALITY" OF ON ORBIT FAILURE OR DEGRADED MODE OPERATION
  - BALANCE OF INITIAL COST, SYSTEM EFFECTIVENESS, LIFE CYCLE COSTS
- AUTONOMY – CHARACTER AND DEGREE OF AUTONOMY ON ORBIT AND COMPLEMENTARY GROUND INVOLVEMENT WITH PHASING CONSIDERATIONS?
- USER INTERFACE – APPROPRIATE AND EFFECTIVE TO PROVIDE SIMPLE, STANDARD INTERFACES, MINIMUM REQUIREMENTS ON USER, BASICALLY INDEPENDENT USER OPERATION OF PAYLOADS?
- CHECKOUT/VERIFICATION
  - INITIAL GROUND SYSTEM LEVEL TESTS REQUIRED
  - EVOLVING SYSTEM NEED FOR GROUND SYSTEM LEVEL VERIFICATION

MAN'S ROLE IN SPACE

Col. Jack Lousma
USAF/JSC

MAN'S ROLE IN SPACE

MAN'S CAPABILITIES

- O VERSUS UNMANNED
- O INTELLIGENCE
- O VISION
- O MANUAL FUNCTIONS
- O RELATED TO PAST SYSTEMS

MAN'S ROLE IN SPACE

CAPABILITIES ALREADY DEMONSTRATED BY MAN IN ZERO-GRAVITY

- O EVA
- O REPAIR
- O PAYLOAD SERVICING
- O PRECISION POINTING
- O SCIENCE AND APPLICATIONS
- O EARTH OBSERVATIONS
- O MANIPULATOR SYSTEMS
- O MEDICAL/PHYSICAL

CONCLUSION TO DATE: GIVEN PROPERLY DESIGNED EQUIPMENT, TRAINING, MOBILITY DEVICES, AND STABILIZATION, MAN HAS SUCCESSFULLY ACCOMPLISHED ALL ZERO-G TASKS AND HAS PERFORMED PRODUCTIVELY FOR LONG DURATION MISSIONS.

MAN'S ROLE IN SPACE

CAPABILITIES YET TO BE DEMONSTRATED BY MAN IN ZERO-GRAVITY

- O MANNED MANEUVERING UNIT (MMU)
- O PAYLOAD/FREE FLYER SERVICING
- O PROPELLANT/CRYO HANDLING
- O CONSTRUCTION
- O TELEOPERATOR MANEUVERING SYSTEM (TMS)
- O ORBIT TRANSFER VEHICLE (OTV) PREPARATION AND OPERATIONS

PREDICTION: MAN WILL SUCCESSFULLY DEMONSTRATE NEW CAPABILITIES REQUIRED FOR A SPACE STATION PROGRAM IF PRINCIPLES LEARNED IN THE PAST ARE NOT COMPROMISED.

QUALITY ASSURANCE ROLE IN THE SPACE STATION ERA

Thomous J. Adams
NASA, Johnson Space Center

The Space Station era, which will soon become a reality, will offer a new set of challenges for the quality assurance community. This new adventure is based on our continuing efforts as well as achievements in past space programs. You may be interested in some facets of NASA's quality assurance policies and how those viewpoints have developed from the Apollo Program through the Shuttle and into the coming age of the Space Station.

The Apollo Program was marked by the development of many flight products that had to be regarded as state-of-the-art hardware, notably in the area of microcircuitry and thermal insulation. Dealing with state-of-the-art tasks generally drove up costs and forced extensive ground test programs, whose results were also used to verify the adequacy of the quality levels. There was more of an R&D flavor on the Apollo Program than on the Shuttle Program and hence allowed the final QA buyoff to be further downstream and to ferret out many manufacturing defects through the use of ground test programs. This, coupled with the large amount of redundancy, intricate subsystems designed for one-time use, and the short flight durations, made the effects of inflight anomalies caused by manufacturing defects minimal. Also, with the fairly large quantity of hardware procured from subtier suppliers, NASA and its prime contractors were able to impose Apollo QA requirements on the suppliers with minimum perturbation. One more characteristic of the Apollo era that probably helped considerably to enhance the workmanship and tender loving care, was the fact that not only was there a better national economic climate but there was also national commitment, pride, and patriotism. These emotions could not help but make us, in the field of quality assurance, the beneficiary.

Around 1971 the Space Shuttle concept began to eclipse the Apollo launches and quality assurance was called on to display sufficient flexibility to shift gears from a one-shot philosophy to that of contending with multi missions which had the capability of returning to earth and being launched

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again. New QA requirement documents had to be generated. However, these requirements, in reality, were upgraded Apollo requirements with one major difference. That difference was the encouragement of the use of an MV (manufacturing verification) system -- quality assurance designees from manufacturing who performed selected inspection functions in addition to their production tasks. However, the overall program compared to Apollo was quite different. Much less hardware was being procured, ground test programs were reduced, and multi-flight vehicles with longer flight durations were planned. This, coupled with the economic climate existing in the Shuttle era, made it imperative that we relook at the way we were doing business. Some of the contractors implemented the quality designee system inhouse and at many of their suppliers. Other contractors and suppliers implemented a mandatory inspection point system in lieu of 100 percent inspection.

A new recognition is beginning to surface in the Space Shuttle Program that "Quality is everyone's business." Hopefully this will be carried over to the Space Station Program. The quality organizations are becoming team members with engineering and manufacturing, with one theme in mind -- to eliminate nonconformances.

For example, Rockwell International, on the Orbiter Program, has implemented a concept involving establishment of groups called "Product Quality Improvement Councils." These councils are made up of management people from engineering, manufacturing, procurement and quality. The council's role, in selected areas, is to examine parts scheduled for the next month's production, examine the nonconformance history of the hardware to identify repetitive offenders and implement changes prior to start of manufacturing process. This may result in drawing changes, tooling improvements, planning changes or simply better instructions for the operators. The council's actions have resulted in cost savings of several million dollars in the limited time they have been functioning. Similar activities are being implemented by other contractors.

With the above in mind, I would like to give you my thoughts on some of the areas that need to be explored by the quality assurance community as part of the overall development effort.

LESSONS LEARNED FROM OTHER PROGRAMS

After each major NASA program, such as Apollo and Skylab, a series of experience documents, consisting of lessons learned, were produced. The documents were well done; but, unfortunately, no specific mechanism existed to assure that these experiences were factored into the Shuttle Program requirements. It is our plan to develop a mechanism to review, analyze, and assure that the applicable lessons learned are incorporated into the requirements for the Space Station. It is also intended that a review be made of quality implementation on some Earth-bound, remote locations, such as offshore drilling rigs, submarines, and Antarctic stations, for application to Space Station. In addition to the Earth-bound lessons learned experience, Department of Energy activities will be reviewed. Their quality experience may apply to the Space Station.

By using the lessons learned from the Space Shuttle and other entities, we would hope that costly errors will not be repeated. This will reduce costs and assure timely progress in the Space Station effort. Our future plans are to develop a quality assurance requirements document patterned after our current Space Shuttle Program document, with separate sections for Earth-bound and on-orbit quality requirements. During this search and review, some of the data will not be applicable to just quality. This data will be passed on to the other applicable disciplines for use in their areas.

We also plan to revise the way we have conducted contractor/subcontractor surveys. Our surveys and those of our contractors are too procedurally oriented. This is a good approach early in the program to assure that all facets of the contractor's QA program are adequately covered. Once this is done, however, the surveys should be restructured to be more hardware oriented -- to look in-depth at such things as process controls; recurrence control of nonconformances; and fabrication, assembly, test and inspection planning. Process and inspection requirements imposed on contractors have not always been transmitted to and implemented by the technician on the floor, even though a system was in place to accomplish this. Therefore, parts were produced that did not comply with requirements. The requirement omission was not discovered until an investigation was conducted following

a failure. We plan to emphasize evaluation of on-the-floor implementation of requirements, by completely reorienting our checklists and providing more training for the surveyors. This will assure that the technician is being informed and implementing the correct requirements. Hopefully, the products manufactured will experience fewer problems.

NONDESTRUCTIVE EVALUATION IN SPACE

Long term exposure of hardware in space will, in all probability, dictate the need for an NDE (nondestructive evaluation) capability. This need should be addressed by the subsystem/system study groups with quality assurance playing a supporting role. Maintainability considerations of the primary space structures will probably drive this need to a great degree. Two distinct approaches are thought to be of importance with respect to Space Station application:

1. In-place NDE for primary space structures, particularly those manufactured of advance composite materials.
2. Compact and portable NDE equipment that can be used in both habital and extravehicular environments. This equipment could be used for both routine and investigative-specific contingency inspection.

Many of our current NDE methods may not function or be appropriate to use in the anticipated environment. For example, dye penetrant and radiography probably could not be used in habitable areas. We must consider the health and safety of the crew in addition to the practicality of applying scientific NDE in space.

A study is to be initiated shortly to evaluate the applicability of current NDE technology to a Space Station environment. Emphasis will be placed on state-of-the-art research currently in progress within NASA. Advanced ultrasonic testing technology appears to be one good candidate for Space Station use; with the widespread use of microelectronics, such devices could probably be used with little or no training.

HARDWARE FABRICATION AND ASSEMBLY INSPECTION PLANNING

I'm sure that most of you have read in the paper recently that our first EVA (extravehicular activity) test of the space suit had to be aborted during the STS-5 mission due to the failure of a regulator. Failure analysis revealed that a significant component was inadvertently omitted during the assembly of the regulator. Needless to say, the poor company inspector was severely chastised for allowing that to happen. The facts of the matter were that the planning documents were so general and the inspection points selected so vaguely, that it's no wonder he missed the item. I only mention this to illustrate that we must rethink the way we do our inspection planning for the Space Station Program.

We must be sure that fabrication and assembly planning papers have received detailed review by knowledgable people from engineering, manufacturing, and quality assurance so that critical items are identified and subjected to the necessary inspections. These critical items must be identified using all available data such as FMEA/CIL, and engineering drawings or specifications.

With the austere economic climate that we will be operating in during the Space Station Program, we can only assume that less funds will be available for inspection activities. We must, therefore, rely more heavily on the MV system (quality designee) and put the inspection points performed by quality personnel where they will count the most -- on the critical items. The floor inspectors and MV's must be made aware of the significance of their inspections. In addition to doing a better job of providing more detailed fabrication and assembly planning documents, we must assure that manufacturing verifiers are trained and qualified to perform those designated inspection functions.

CONTAMINATION CONTROL

Another area of concern which must be dealt with is contamination. This includes control of particulate and chemical/molecular contamination. Three general areas of concern are associated with the Space Station:

1. Internal environment
2. External environment
3. Fluid systems

Contamination of the internal environment inhabited by the crew must be controlled for the well-being of the crew and to minimize malfunctions of critical Space Station hardware and experiments. Onboard detection equipment must be developed. We have developed experience in controlling the internal environment from Apollo, Skylab, and Shuttle Programs which should be applicable to the Space Station.

Contamination of the external environment may be produced by the operation of MMU's (manned maneuvering units), Orbiters, and other sources as yet undefined. This contamination could adversely affect optical experiments, etc. Controlling the external environment will enhance the scientific value of the station.

Also, valuable information was obtained during STS-2, -3, and -4 using the IECM (induced environment contamination monitor) experiment to analyze contamination resulting from RCS (reaction control system) thruster firings.

Assuring the purity of fluid systems throughout the life of the Space Station is very important. Methods must be developed to assure contaminants are not introduced into the systems by degradation of filters or by filter changes.

CONFIGURATION MANAGEMENT

A well-controlled system of configuration management exists today on the Space Shuttle Program. This system provides for: (1) a flight and ground support hardware nomenclature and status system; (2) an interface control system for hardware-to-hardware, hardware-to-GSE, hardware-to-test equipment, and hardware-to-inspection equipment interface
recording, storage and retrieval system for rapid access to configuration details; and (4) a ground-based management system for authorizing changes to hardware.

Basically, the Space Shuttle configuration management system provides a firm base for Space Station configuration management development. The Space Station long term space operations environment requires adding a degree of sophistication to configuration management. As viewed at this point in time, we anticipate the need to have a controlled hardware interchangeability capability on-orbit. We also expect to see an expansion of the information and data recording, storage and retrieval system to include accurate details of all hardware nomenclature, status, and change activities on-orbit, including modifications, rework and repair, and replacements. Mockups will probably be fairly sophisticated to a high-fidelity level so that they may be used as ground-based verifiers of all hardware interfaces, including test equipment/ground support equipment, and inspection equipment interfaces with hardware. I would also expect high-fidelity mockups to demonstrate accessibility of hardware for inspection, test, changeout, and verification that electrical and mechanical configuration parameters are compatible. Finally, the requirement for an on-orbit bonded storage capability to assist in controlling configuration of spares and equipment not in use, seems to me to be needed.

PRACA (PROBLEM REPORTING AND CORRECTIVE ACTION) SYSTEM

The Space Shuttle problem reporting and corrective action system has evolved from the system used for Apollo and Skylab. Improvements were necessary with the advent of a reusable space vehicle. The Space Station adds new complexity with its long term use without return to Earth. This poses new challenges for a PRACA system; therefore, the Space Shuttle PRACA will have to be enhanced for use on the Space Station. For example, some of the failure analysis effort will probably be done in orbit. However, after troubleshooting to a component/board level, some components will be replaced and returned to ground operations for further analysis. This will be heavily dependent on the availability of diagnostic equipment onboard. Some sparing to the component/board level will be necessary for this to be effective. It is also envisioned that not all problems will require component replacement and failure analysis, but that some low criticality problems will simply be monitored inflight to see if further degradation develops. In order to assist the crew in problem troubleshooting or failure analysis, the problem

reports will be entered directly into the PRACA system via data link to allow technical personnel to evaluate and assist the crew with the failures. Furthermore, a direct onboard link with the PRACA data base will allow a search for the previous failure history of a suspect unit such that the findings and actions under similar situations could be evaluated and duplicated, if appropriate.

MAINTAINABILITY

Another area that I see QA involvment in is maintainability. It's important that the equipment be designed for ease of inspection as well as maintenance. QA should concentrate a major effort during the inception and design phase to accomplish these goals. QA needs to assure that measurable parameters such as identification of critical items, inspection characteristics and limited life are established. Flight crews must have access to hardware to be able to repair, replace, maintain or inspect it during operation. Also, a concerted effort should be exerted early to use as much common hardware as possible. Not only am I talking about items like fasteners, quick disconnects, switches, and black boxes, but other functionally similar hardware that can be interchanged throughout the Space Station. The correct tools and fixtures must be used during manufacturing and inspections to assure interface tolerances between parts are maintained. Finding out that a replacement part does not fit while in orbit is too late. We currently are participating with our design groups to support this activity.

QUALITY CONTROL --- ON-ORBIT

In all past NASA programs, quality control has included all activities associated with hardware from design through launch; after launch, minimal activity resulted. In Apollo, some quality functions were necessary after vehicle recovery; and Shuttle required tight quality control as soon as the Orbiter landing was completed until the vehicle was launched again. Now, Space Station poses a whole new challenge to quality control --- providing a quality function on-orbit.

I would be facetious at this point in time if I told you that part of the crew for Space Station must be made up of inspectors. I doubt if we can afford that luxury. However, there will be inspections needed, and it is going to be important to keep good records of all on-orbit activities, including quality related ones.

A study task will be necessary to determine the type of quality training needed by a crew so that they may perform on-orbit inspection functions. A Space Station crew should be able to perform quality functions on-orbit similar to inspectors in a manufacturing facility. Fabrication, assembly, test, repair and nondestructive evaluation are some of the anticipated on-orbit functions which require inspection and verification. In support of on-orbit inspection, it will be necessary to develop planning and requirements which will not necessarily have a direct relationship with similar functions performed on Earth.

Records will need to be maintained of limited life components to assure their timely replacement. We also need to develop workmanship standards for special processes being performed in space (i.e., soldering, welding, assembling, etc.).

One area that I would like to touch on briefly is quality involvement, of both NASA and its contractors, in software. To date, there has been little to no involvement by the quality organizations in this area other than to perform an accountability function. Software will be a significant activity in the Space Station era and Quality plans to participate to a larger extent. As I am sure you are aware of, DOD has several specifications and handbooks dealing with both contractor and Government roles in software development. Under the sponsorship of NASA Headquarters, a draft specification on software has been issued and is being reviewed by the NASA Centers.

The Space Station Program, like previous programs, has been divided into four major phases. These phases consist of (1) the program definition phase, (2) the development phase, (3) the production phase, and (4) the operational phase. Our plans are to take an active role in all phases of the program.

QUALITY PARTICIPATION IN PROGRAM DEFINITION AND DEVELOPMENT PHASES

The program definition phase will develop the architecture, configuration, system and interface requirements and specifications; perform system evaluation studies; and define the programmatic requirements. This will be ongoing through fiscal year 1985. As I mentioned earlier, we will be taking a look at the lessons learned from other programs, and writing new preliminary quality assurance requirements and specifications applicable to the Space Station. We will continue to review the Space Station development documentation and participate in engineering team activities.

The next step in the program is the development phase. This phase is expected to commence during fiscal year 1986 and last for several years. We will be involved here in much the same manner and doing the same kinds of quality functions as we did with the Shuttle Program. We must be able to design a Space Station with the concept that it must be inspectable and provide for ease of maintenance.

At the same time, we will finalize the programmatic quality assurance requirements for production of hardware. We will also be initiating development of requirements for utilization in space that I mentioned earlier (i.e., inspection techniques, problem reporting, configuration management, nondestructive evaluation, and contamination control).

The third phase of the program is the production phase. During this phase the Space Station is manufactured, integrated, tested, delivered, and checked out. This phase is expected to last from fiscal year 1986 through fiscal year 1990, and will overlap the development phase.

The Quality approach will generally be the same that we have applied in previous programs. In addition to continuing to support design reviews and other milestone activites, we will implement the quality assurance program at the contractors' facilities based on the requirements developed earlier. We will also refine the requirements for quality assurance applications in space in anticipation of the operational phase.

The first launch will be in 1990, with subsequent flights building the Space Station into an initial operational capability by 1991. The operational phase will consist of the operations support throughout the life of the program. Requirements for the quality assurance applications in space will be implemented along with crew training.

In conclusion, there is a lot of work to be done in the quality assurance area to ready ourselves for the Space Station. We look forward to it.

I appreciate the opportunity to share my thoughts with you on this subject.

Thank you.

QUALITY ASSURANCE ROLE IN SPACE STATION DEVELOPMENT

LESSONS LEARNED FROM OTHER PROGRAMS

- REVIEW HISTORICAL DATA FROM PAST PROGRAMS AND DEVELOP LESSONS LEARNED.
- RESEARCH EARTH-BOUND REMOTE "FACILITY" QUALITY PROGRAMS.
  - SUBMARINES
  - OFFSHORE OIL EXPLORATION AND DRILLING
  - ANTARCTIC GEOLOGICAL BASES
- UTILIZE DATA TO DEVELOP SPACE STATION REQUIREMENTS.
- LESSONS LEARNED ARE APPLICABLE TO OTHER DISCIPLINES (ENGINEERING, MANUFACTURING, ETC.) AS WELL AS QUALITY.

QUALITY ASSURANCE ROLE IN SPACE STATION DEVELOPMENT

CONTAMINATION CONTROL

- CONTROL OF CONTAMINATION DURING DESIGN, MANUFACTURING, ASSEMBLY, PRELAUNCH, AND OPERATIONAL PHASES IS ESSENTIAL. THREE AREAS OF CONCERN ARE:
  - AREAS INHABITED BY THE CREW
  - THE EXTERNAL INDUCED ENVIRONMENT SURROUNDING THE SPACE STATION ITSELF
  - FLUID SYSTEMS
    - INTEGRITY OF FLUID PURITY
    - LIFE LIMITATIONS OF BOTH SYSTEM AND COMPONENT FILTERS
    - MAINTAINABILITY OF FILTERS (E.G., REPLACEMENT)
- MINIMUM EQUIPMENT FOR MEASUREMENT/DETECTION OF CONTAMINATION IN SPACE MUST BE DETERMINED.

QUALITY ASSURANCE ROLE IN SPACE STATION DEVELOPMENT

NDE (NONDESTRUCTIVE EVALUATION) IN SPACE

- DETERMINATION OF NEED FOR NDE IN SPACE SHOULD COME FROM SUBSYSTEM AND SYSTEM STUDY GROUPS.
- TWO APPROACHES MAY BE OF SIGNIFICANCE:
  - IN-PLACE NDE OF PRIMARY SPACE STRUCTURES.
  - COMPACT AND PORTABLE NDE EQUIPMENT THAT CAN BE USED IN BOTH HABITAL AND EXTRAVEHICULAR ENVIRONMENTS.
- MANY NDE METHODS USED IN GROUND-BASED OPERATIONS MAY NOT FUNCTION OR BE APPROPRIATE TO USE IN A SPACE ENVIRONMENT. TECHNIQUES/METHODS EVENTUALLY USED SHOULD NOT CAUSE/PRODUCE CONTAMINATION OR POSE A HEALTH/SAFETY CONCERN FOR CREW.
- NDE METHODS USED TODAY, OR IN DEVELOPMENT, SHOULD BE EVALUATED FOR POSSIBLE USE IN SPACE.
- ADVANCED ULTRASONIC TECHNOLOGY MAY BE MOST APPROPRIATE FOR SPACE STATION USE.

QUALITY ASSURANCE ROLE IN SPACE STATION DEVELOPMENT

CONFIGURATION MANAGEMENT

- A SYSTEM MUST BE DEVELOPED TO VERIFY THAT PART AND SERIAL NUMBERS OF INTERCHANGEABLE HARDWARE ARE MAINTAINED.
- INTERCHANGEABILITY OF HARDWARE IN SPACE STATION WILL BE A CONTROLLING FACTOR. ACCURATE TRACKING OF STATUS, PART AND SERIAL NUMBERS, AND LOCATION OF THIS HARDWARE IS ESSENTIAL.
- KNOWLEDGE OF INTERCHANGEABLE HARDWARE LOCATION AND USE IS REQUIRED.
- DEVELOP REQUIREMENTS FOR AN INTERFACE CONTROL SYSTEM TO ASSURE INTERFACE COMPATIBILITY OF DRAWINGS, HARDWARE, TEST EQUIPMENT, ETC.
- HIGH-FIDELITY MOCKUP SHOULD BE CONSIDERED.

QUALITY ASSURANCE ROLE IN SPACE STATION DEVELOPMENT

FABRICATION AND ASSEMBLY INSPECTION PLANNING

- MOST OF CURRENT SHUTTLE CONTRACTOR INSPECTION SYSTEMS ARE BASED ON 100 PERCENT INSPECTION OR SERIES OF INSPECTION POINTS BASED ON THE LAST TIME SOMETHING CAN BE SEEN. SOME "IN-BETWEEN" STEPS COULD BE CRITICAL BUT CRITICALITY IS NOT KNOWN BY INSPECTORS.
- INSPECTION SYSTEMS NEED RESTRUCTURING FOR SPACE STATION; EMPHASIZE MORE DETAILED FABRICATION AND ASSEMBLY PLANNING.
  - JOINT ENGINEERING/QUALITY ESTABLISHMENT OF CRITICAL ITEMS TO BE INSPECTED UTILIZING FMEA/CIL, DRAWINGS, SPECIFICATIONS, ETC.
  - CRITICAL ITEMS UNIQUELY IDENTIFIED IN PLANNING DOCUMENTS.
  - INCREASED USE OF A MANUFACTURING VERIFICATION SYSTEM FOR CERTAIN DESIGNATED INSPECTION FUNCTIONS.

QUALITY ASSURANCE ROLE IN SPACE STATION DEVELOPMENT

CONFIGURATION MANAGEMENT

- A SYSTEM MUST BE DEVELOPED TO VERIFY THAT PART AND SERIAL NUMBERS OF INTERCHANGEABLE HARDWARE ARE MAINTAINED.
- INTERCHANGEABILITY OF HARDWARE IN SPACE STATION WILL BE A CONTROLLING FACTOR. ACCURATE TRACKING OF STATUS, PART AND SERIAL NUMBERS, AND LOCATION OF THIS HARDWARE IS ESSENTIAL.
- KNOWLEDGE OF INTERCHANGEABLE HARDWARE LOCATION AND USE IS REQUIRED.
- DEVELOP REQUIREMENTS FOR AN INTERFACE CONTROL SYSTEM TO ASSURE INTERFACE COMPATIBILITY OF DRAWINGS, HARDWARE, TEST EQUIPMENT, ETC.
- HIGH-FIDELITY MOCKUP SHOULD BE CONSIDERED.

QUALITY ASSURANCE ROLE IN SPACE STATION DEVELOPMENT

PRACA (PROBLEM REPORTING AND CORRECTIVE ACTION) SYSTEM

- THIS SYSTEM WILL MONITOR THE VARIOUS PROBLEMS THAT ARISE, THE ANALYSIS, AND THE CORRECTIVE ACTION TAKEN.
- DETERMINE UNIQUE REQUIREMENTS FOR IDENTIFICATION, REPORTING, ANALYSIS AND CORRECTIVE ACTION OF HARDWARE PROBLEMS OCCURRING IN SPACE.
- COMMUNICATION LINK TO RESOLVE ON-ORBIT CONCERNS NEEDED.

QUALITY ASSURANCE ROLE IN SPACE STATION DEVELOPMENT

MAINTAINABILITY

- INSPECTABILITY OF SPACE STATION HARDWARE AND FACILITIES SHOULD BE DESIGN CONSIDERATION.
- ACCESSIBILITY OF SPACE STATION HARDWARE FOR INSPECTION/REPAIR/REPLACEMENT MUST BE ASSURED IN THE DESIGN PHASE.
- COMMON-USE HARDWARE SHOULD BE CONSIDERED IN DESIGN.

QUALITY ASSURANCE ROLE IN SPACE STATION DEVELOPMENT

CONTROL ------ ON-ORBIT

- SPACE STATION PERSONNEL ON-ORBIT WILL PERFORM QA FUNCTIONS.
- INSPECTION METHODS AND TECHNIQUES ARE NEEDED.
- A SYSTEM IS NEEDED FOR MAINTAINING RECORDS OF LIMITED LIFE COMPONENTS USED IN SPACE STATION.
- WORKMANSHIP STANDARDS FOR ELECTRICAL AND MECHANICAL FABRICATION/ASSEMBLY, SUCH AS NEW JOINING TECHNIQUES, ELECTRICAL CABLE REPAIR, ETC., SHOULD BE PROVIDED.

QUALITY ASSURANCE ROLE IN SPACE STATION DEVELOPMENT

QUALITY PARTICIPATION IN PROGRAM DEFINITION AND DEVELOPMENT PHASES

- PROGRAM DEFINITION PHASE
  - REVIEW LESSONS LEARNED FROM OTHER PROGRAMS
  - INITIATE DEVELOPMENT OF PROGRAMMATIC QUALITY ASSURANCE REQUIREME
  - REVIEW SPACE STATION PROGRAM REQUIREMENTS DOCUMENTS
  - PARTICIPATE IN ENGINEERING TEAM ACTIVITIES
- DEVELOPMENT PHASE
  - CONTINUED PARTICIPATION IN ENGINEERING TEAM ACTIVITIES
  - COMPLETE PROGRAMMATIC QA REQUIREMENTS
  - SUPPORT DESIGN REVIEWS
  - INITIATE DEVELOPMENT OF SPECIFIC REQUIREMENTS FOR QUALITY APPLICATIONS IN SPACE
    - INSPECTION TECHNIQUES
    - PROBLEM REPORTING
    - CONFIGURATION MANAGEMENT
    - NONDESTRUCTIVE EVALUATION
    - CONTAMINATION CONTROL

QUALITY ASSURANCE ROLE IN SPACE STATION DEVELOPMENT

QUALITY PARTICIPATION IN PRODUCTION AND OPERATIONAL PHASES

- PRODUCTION PHASE
  - PARTICIPATE IN MILESTONE REVIEWS
  - IMPLEMENTATION OF QUALITY PROGRAM AT CONTRACTOR FACILITY
    - INSPECTION PLANNING
    - CLEANLINESS/CONTAMINATION CONTROLS
    - PROCESS CONTROLS
    - WORKMANSHIP STANDARDS
  - REFINING QA APPLICATIONS IN SPACE INITIATED IN DEVELOPMENT PHASI
- OPERATIONAL PHASE
  - IMPLEMENTATION OF REQUIREMENTS FOR QA APPLICATIONS IN SPACE
  - CREW TRAINING FOR ASSEMBLY, INSPECTION, REPAIR, AND MAINTENANCE

SPACE-STATION CREW-SAFETY REQUIREMENTS

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INTRODUCTION

Crew safety has historically been a prime requisite of the U.S. Space program. Whereas crew fatalities have occurred during training (the Apollo fire on the pad and several T-38 accidents), no fatalities have occurred during an actual space mission. U.S. astronauts have suffered only trivial injuries while in space, but there have been anxious moments such as John Glenn's Mercury-Atlas 6 flight during which a telemetry fault indicated that the spacecraft's heat shield was no longer locked into position. Of the small number of truly life-threatening system failures, one example is the Gemini 8 mission during which a jammed thruster caused uncontrolled tumbling and spinning (a roll rate of up to 360°/sec.) of the spacecraft. The astronauts were finally able to gain control of the spacecraft by deactivating the thrusters and firing up their reentry control system. Because the reentry system had been activated, mission rules stipulated a return to Earth, and the mission was terminated 2 days early. Another example of a truly life-threatening system failure is the Apollo 13 mission during which an oxygen tank on the service module exploded when the spacecraft was 205,000 miles from Earth and on its way to the Moon. By improvising a do-it-yourself air conditioner to prevent carbon-dioxide poisoning and by firing the lunar module's descent engines, the command module and its crew were safely returned to Earth.

The operation of a space station presents many new issues for flight crew safety. A broad range of potential crew activities including construction, maintenance and repairs of spacecraft, and scientific and applications experiments, greatly expands man's role in space but also significantly increases the range and potential level of exposure to risks by space-flight crews. A comparison of some of the crew-safety-related factors of a space station as opposed to the previous U.S. space program are presented in Fig. 1. The 90-day resupply missions to a space station by the Space Shuttle Orbiter, as currently envisioned in NASA's space-station studies, would imply stay times for the space-station crews which are similar to the 84-day Skylab 4 mission. Potentially longer stay times might result for a number of reasons, including the conduction of biomedical research on prolonged weightlessness or, in the case of a space station with more than eight crew members, the current capacity of the orbiter to carry eight people plus a crew of two. This limitation is brought about by the number of hard points available for seats onboard the orbiter. Passengers could be carried within the cargo bay provided some appropriate type of crew-housing volume is developed to fit into the cargo bay.

Skylab holds the functional endurance record in the U.S. space program for a manned spacecraft, logging a total of 171 days during Skylab 2, 3, and 4. Unless it is determined to be prudent to periodically replace specific space-station modules, the modules or at least major components of those modules may be expected or required to have functional lives of 10 years or more, a sharp departure from previous manned spacecraft. Systems and subsystems maintenance and repair by the space-station crew becomes an increasingly important factor.

As the scope of crew activities increase, so do the chances of error and the likelihood of threats to crew safety. To date, the majority of the U.S. astronauts have been experienced test pilots who were capable of immediate and dispassionate response to emergency situations. The advent of a space station brings with it the likelihood of crews with a variety of backgrounds and skills which, with the probable exception of the mission commander, will not necessarily include those of a pilot.

The previous U.S. manned space program has included meticulous training of the crew for specific tasks to be performed during the mission. As the breadth of crew activities increase, exhaustive training for each specific task becomes less practical, thus increasing the likelihood of crew errors.

Around-the-clock support by a plethora of highly-skilled ground support team members may not be economically tolerable. It is further possible that space-station crews will not have an around-the-clock work effort. Both darkness and quiet have been found to be prime ingredients to restful sleep in space. This introduces the possibility of a small groundbased monitoring team during sleep periods on the station.

All previous manned U.S. space missions have had the ability to abort the mission and return the crews to Earth. Mercury had its reentry capsule, Gemini had its reentry module, Apollo had its command module, Skylab had an Apollo command module onboard, and the Shuttle orbiter provides return capability. Whether emergency return-to-Earth capability must be provided by the Space Shuttle or by a space-station-based entry device is a moot question at this time.

It is essential that the issue of crew safety be addressed early in the development of the space station, since the requirements for crew safety may effect the basic design features of the space station and its operational characteristics as well. Space-station crew-safety studies are currently being conducted in-house by NASA and under Contract NAS1-17242, "Space Station Crew Safety Alternative Strategies Assessment" with Rockwell International in Downey, California. The objectives of the studies (Fig. 2) are to assess space-station crew-safety requirements and to assess the alternative strategies for meeting those requirements. Sub-objectives are: (1) to develop a crew-safety philosophy and criteria; (2) to assess potential threats to crew safety, potential space station design and operational concepts, and the range of potential space activity scenarios in order to identify key crew-safety issues; and (3) to assess the potential for various crew-safety

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strategies to meet desired criteria. The primary guidelines, assumptions, and range of data for the study are also listed in Fig. 2. Although the studies are in their early stages at the time of this writing, many potential threats to crew safety have been identified, as have a number of possible strategies to counteract those threats. Also identified is the impact of those strategies on space station design features. This paper presents an overview of the preliminary findings of the studies. Cost analyses, though planned, are not available at this time.

STUDY VARIABLES

Assessment of the requirements for space-station crew safety requires the consideration of a number of variables. The relevance of the variables noted in Fig. 3 are discussed briefly in this section of the paper and selected variables are discussed in more depth in later sections.

Threats - An assessment of threats must include consideration of the reality of those threats and the probability of their occurrence. Thus, consideration must be given to the tasks to be performed on the space station and the potential physical makeup of the space station itself. The severity of the threats, such as the degree to which the crew might be injured or incapacitated, may tend to dictate how the consequences of the threats are handled.

Time- Being forewarned of a threat, and the time between the warning and the actual occurrence of the threat, will affect the crew's ability to react and their options for handling the situation. The threats and options for handling those threats will vary during the various stages of space-station growth such as its initial construction, initial operation, follow-on construction, and/or additions or possibly the existence of two space stations.

Number of: - The number of crew members onboard the space station and the number of habitable modules and volumes onboard will have a strong effect on the crew's ability to handle threats and the type of action required. The ability of the crew to retreat from a hazardous volume to one or more functional and safe volumes is an important factor.

Crew-Safety Strategies - The potential strategies for providing crew safety vary. One extreme would be a space station with sufficient integrity and redundancy to preclude any damage to the space station or injury to the crew. The other extreme would accept the debilitation or loss of the space station and provide for crew survival. The appropriate set of strategies probably lies near the middle ground of these two extremes. The effectiveness of a particular strategy in handling more than one or a multiplicity of threats is a potentially important factor. The complexity of a strategy must also be considered, since complexity can often introduce additional monitoring and maintenance requirements.

Dependence - The degree to which the safety strategies are dependent upon actions taken by ground-based personnel as opposed to the space station crew must be considered, since this factor will affect both the ground requirements (around-the-clock for 20 years?) and the duties, training requirements, and possibly the reaction time of the crew.

Status of Required Technologies - Each potential strategy must be evaluated from the standpoint of the technologies required to bring the strategy into service, and the cost and risk associated with that technology development.

Impact on Space-Station Concepts - Depending upon the crew safety strategies which are ultimately selected, crew-safety requirements may have a profound effect upon the basic design and operational characteristics of the space station. For example, if it is determined that a requirement for safety is a space-station-based device to permit the crew to return to Earth in time of dire emergency, the number of devices required and provisions for gaining access to those devices may affect the geometry of the space station.

Dollar Cost - Space-station crew-safety must be provided at a tolerable cost. Some strategies can be cast aside immediately. One of those is a Space Shuttle sitting on the pad, dedicated to and awaiting the call for rescue of a space-station crew. The cost of providing levels of redundancy as opposed to the option of repair-in-space by the crew must be considered as well.

Psychological - Psychological health is an important factor in providing crew safety. Crew members cannot be expected to live in a cramped, noisy, drab environent for extended periods of time and still be expected to react quickly and decisively to emergency situations. Good food, private communications with their families, windows for viewing, physical exercise equipment, and leisure-time activities are positive factors for good psychological health. Perceived safety (the level of safety perceived by the crew) may also be an important factor in the psychological health of the crew and thus their productivity.

Crew-Safety Philosophy - Because of the expected long life of a space station, it seems appropriate to review the crew-safety philosophy of the previous manned U.S. space program to determine from whence it evolved, its compatability with the goals of the space station, and what appropriate modifications can be made while still providing adequate crew safety. Analogous operations such as submarines, off-shore oil rigs, and Arctic posts may provide useful information regarding crew-safety philosophy. A list of the options for space-station crew-safety philosophy which has evolved from the aforementioned Rockwell study is shown in Fig. 4. The candidate baseline philosophy selected for that study is representative of middle-ground position mentioned under the section entitled "Crew-Safety Strategies."

THREATS

A list of typical threats to space-station crew safety is shown in Fig. 5. Fire, injury/illness, and abandonment of space station will be addressed herein.

Fire

Three lines of defense against the threat of fire are shown in Fig. 6. The first is to design to preclude the threat of fire. In order for a fire to occur three elements must be present: fuel, an oxidizer, and an ignition source. Design to preclude implies the breaking of two legs of the fire triangle. If only one leg is broken the space station is still only one failure away from a fire. A good design practice would be to store all propellants outside of the space station, at least to the extent possible.

The second line of defense is to design to control the fire should one occur. Methods for doing so include smoke-, temperature-, and toxicity- sensing devices which would trigger alarms and automated fire-suppression systems. It would be desirable for each module to have the capability of monitoring the sensing devices in the other modules. Dual egress routes from each volume or module would assure the crew of an escape route from the fire zone. A requirement for dual egress routes would have a profound effect upon the architecture of the space station in that each module or volume would have to be connected at both ends to either another volume, module, or a tunnel leading to another volume or module. A requirement for dual egress may not be appropriate for a space station consisting of relatively short modules for which the distance to the nearest egress hatch is but a few steps away.

Automated control of hatch actuation may also be desirable. Such automation might range from merely relieving an injured crew member from the task of manually closing the hatch to a hatch closure sequence triggered by the smoke-, temperature-, and toxicity-sensing devices. In the engine room of some military ships it is a common practice to have automated control of the exit hatch. In the event of a fire, sensing devices trigger an alarm. The occupants of the engine room have perhaps 20 to 30 seconds to egress through the exit hatch before it is automatically closed and the engine room filled with an inert gas.

Fire suppression might consist of a number of options or combinations of options. One possibility is the use of Halon 1301 which is to be used in the Spacelab fire-suppression system. A disadvantage of this method is that toxic gases are produced in the process of extinguishing the fire. Another potential option for extinguishing a fire is to seal off the fire zone and vent the fire zone to the vacuum of space. This introduces several interesting possibilities. Evolving from the Rockwell study is a concept whereby deployable bulkheads are placed within each module. These deployable bulkheads (possibly inflatable) would serve several purposes. They would seal off the fire zone and prevent the spread of fire, smoke, and toxics. They would also permit the venting of the fire zone, thus ridding the fire zone of smoke and toxic gases, and would minimize the volume of air required to repressurize the fire zone. Such deployable bulkheads could also be utilized to seal off a portion of a module punctured by a meteorite. Preliminary calculations have indicated that inflatable bulkheads would be able to withstand the 14.7 psi associated with venting a volume of a module. If the space station is to be constructed from "off-the-shelf" systems which produce heat, those systems would likely require either cold plates or deactivation during the venting to prevent overheating. Deactivation of some systems or subsystems may not be tolerable. Also, if the environmental-control system (ECS) within a module consists of a ducting system, automated controls would be required to shut off the fire zone from the ECS.

The third line of defense against fire would be to retreat to another functional habitable volume or module and either continue the mission until the damaged volume or module is repaired or replaced or abandon the space station should such action be required.

Injury/Illness

Both injuries and illness will occur on a space station. An interesting set of collected health data from 10 years of Polaris submarine patrol activities (an activity somewhat analagous to space station) is presented in Ref. 1. The major malady requiring general surgery was an appendicitis, 70 cases over a 10-year period with an average of 2096 men involved in the statistics each year, or 70 cases per 20,960 man years (0.00334 per man year). For a space station with a crew of 10 people, these statistics indicate that an appendicitis would occur on the station once every 30 years.

Resolution of the requirements for a space station regarding the handling of injuries and illness must eventually be resolved through trades (Fig. 7) between what can be done onboard the space station by crew members with medical training and experience as opposed to transferring the injured or ill crew member to Earth for subsequent treatment. Regarding the ground-oriented solution to medical problems, one possibility is to screen potential space-station crew members more thoroughly and perhaps rule out anyone who still has an appendix or other health history items of question.

If a crew member must be returned to Earth for medical attention, the method of return is a potentially important factor. As will be discussed later, a 12- to 18-day wait may be required before a Space Shuttle mission could be sent to retrieve a crew member. The wait time for a space-station-based reentry device (Ref. 2) is less than one day. Though beyond the scope of this paper, medical researchers (Ref. 3) have pointed out that acceleration/deceleration loads and durations for the crew patient should not be harmful to his or her ailment. The maximum g

force a nominal Space Shuttle Orbiter currently experiences on reentry is around 1.6 g's over a duration of around 10 minutes. On the other hand, a ballistic reentry device (Ref. 2) would experience 1.6 g's for perhaps 3 minutes, 3 g's for perhaps 1.5 minutes, and between 7 and 8 g's for several seconds. Subjecting a crew member with a cardiovascular ailment or a fracture of a major bone to high g forces may be out of the question.

Regarding medical capabilities onboard a space station, Ref. 1 describes a sequential buildup of medical capability onboard a space station. The first phase of the buildup addresses a single habitable work area for two persons on a short-duration mission, with the Shuttle Orbiter docked or in a nearby orbit. One or more of the orbiter's crew would be trained as an emergency medical technician (EMT). Medical supplies would be primarily those onboard the orbiter. The second phase includes an increased space-station size, a four-person crew occupying the station for 90 days, and medical equipment similar to that onboard the orbiter plus equipment and supplies necessary to care for the crew for 90 days would be on the station. One crew member would be a trained EMT with extensive experience as a medical assistant. The orbiter would return to Earth after deposition of the space-station crew and supplies, and emergency rescue would be provided by the Space Shuttle with possibly a 14 to 21 day wait. The third phase includes a crew of eight or more. Dedicated medical facilities would resemble those available in a physicians office, clinic, or two-bed field hospital. The crew would include a trained research physician whose primary duty would be the health care of the crew. Emergency rescue capability would remain at 14 to 21 days maximum wait time. Finally, a dedicated life sciences medical research module is addressed. Such a facility would be attended by a physician who would both conduct medical and biological research and provide for the health care of the crew.

Abandonment of Space Station

If, despite all precautions, it becomes necessary to essentially abandon the space station for a period of time or return the crew to Earth in a major emergency situation, several alternatives (Fig. 8) must be considered. For the sake of definition these alternatives have been divided into two categories, escape and rescue. Escape is defined herein as steps taken by the space-station crew to leave the threat location. Rescue is defined herein as steps taken by other than the crew to leave the threat location. Some actions by the crew may be required or desirable during a rescue operation.

Escape - One approach to crew escape is to provide a dedicated onboard safe haven (Fig. 9). If the space station proper must be abandoned, the crew would retreat to the safe haven and await either return to the space station after the crisis has passed or rescue by the Space Shuttle or some other source. The dedicated safe haven would require accommodations for the entire space-station crew. Environmental control and life support (ECLS) and provisions would be required to sustain the crew until they could either return to the space station proper or be rescued. The amount of radiation protection required for a safe haven must be determined. Communications between the space-station crew, the ground, and rescue vehicle would be required, as would the capability of monitoring the status of the space-station proper. Power must be provided for the safe haven (probably batteries). Whether provisions should be made for extravehicular activities (EVA) through an external egress route and therefore not requiring the crew members to reenter the space-station proper to perform EVA is a moot question.

There are disadvantages associated with an onboard safe haven. If the crew must be rescued from the distressed space station and the station is tumbling or out of control, or if debris or radiation hazards are in close proximity to the space station, docking by the Shuttle Orbiter or some other rescue vehicle could be both difficult and dangerous. A potential alternative to the onboard safe haven is a bail-out-and-wait device (Fig. 10) of the type cited in Ref. 4. This concept is basically a safe haven and would provide all the advantages of a safe haven, but it would also have the capability of detaching itself from the space station and moving to a safe location to await rescue. The requirements would be basically those of the safe haven except minimal propulsion and altitude control would be required.

Another concept cited in Ref. 4 is that of a bail-out-and-return device (Fig. 11). This device is similar in concept to the bail-out-and-wait device except it would have propulsion and docking modules which would permit it to return to the space station after the crisis had passed. By sizing the propulsion module, the device might also be utilized to rendezvous and dock with another nearby space station. A special requirement of this concept would be the guidance and navigation equipment.

If the space station must be abandoned and the crew returned to Earth, one option is that of a space-station-based entry device. The major advantage of such as approach is the short time required prior to departing the space station and returning to Earth, typically less than 21 hours for a continental United States recovery. One concept (Fig. 12) is the manned orbital space escape system (MOSES) of Ref. 3, which was mentioned earlier under "Injury/Illness." This concept is based upon a reentry system developed by the General Electric Company (GE) for retrieving payloads from orbit. Hundreds of flights and successful payload recoveries have been achieved with this system with improvements in reliability and accuracy carried to a point of 100 percent over the past decade. As applied to space station, the concept would consist of one or more reentry capsules which would be based at the station. If return to Earth became necessary, the crew would don space suits and enter the capsule. On command from within the MOSES vehicle, the capsule is ejected from the space station, stabilizes itself, and aligns properly for retro

fire. Ground tracking initiates the retro fire, and a three-axis attitude control system maintains pointing accuracy. A final pitch maneuver is performed to achieve nose-first entry altitude and then a slow spin rate (5-10 rpm) is initiated to compensate for minor c.g. offset. Although the low spin rate may present few problems, an upgrading of the control and retro system should nullify the need for spin. The deorbit module (Fig. 13) is then jetisoned and atmospheric reentry commences. When the vehicle is slowed to approximately Mach 1, the heat shield and its substructure are pyrotechnically severed, and a drogue chute is deployed to further slow the capsule and assist in discarding the spent heat shield. The main chute is then deployed, and locator equipment and a landing shock attenuation system are activated. Although the present GE satellite recovery system utilizes an "air-snatch" recovery system enolving a trapeze trailing from an Air Force C-131 aircraft, it appears that a "CONUS" landing, assisted by glide chutes and autohoming on a beacon would assure prompt recovery of the vehicle, enhance the pinpointing of the landing point, and decrease the descent rate. The glide chute descent rate is currently 24 feet per second. The goal which GE has established for its system is 5 feet per second.

GE has developed concepts for 1 to 4 crewmen. Also, although the concept of Ref. 2 addresses a vehicle which would require the donning of space suits, the GE concept has been utilized in a recovery mission which included an onboard ECS. On June 28, 1969, the Bios 3 (Ref. 5) satellite was launched from Cape Canaveral, containing the "Astromonk Bonny." The MOSES concept was used for recovery. The capsule was equipped with an ECS. The Apollo command module was docked at the Skylab as a return-to-Earth vehicle and has been given consideration for a similar application on the space station. The Apollo capsule was an extremely sophisticated vehicle compared to the MOSES concept. Cost comparisons are not available at this time.

Rescue - The baseline system for rescue of a space-station crew is usually considered (Ref. 1) to be an unscheduled mission by the Space Shuttle. The time between the determination of the need for a rescue mission by the Space Shuttle and the arrival of the orbiter at the space station will be a function of the stage of readiness of an available Shuttle system. Ref. 6 addresses the projected turnaround times for Space Shuttle and the maximum launch rate per year as currently envisioned. Space Shuttle (STS) turnaround time capabilities (Ref. 6) are shown in Fig. 14. The turnaround times show with regard to the times allotted to the Orbiter Processing Facility (OPF), the Vehicle Assembly Building (VAB), pad processing, Solid Rocket/External Tank (SRB/ET) stacking, pad refurbishment, and Mobile Launch Pad (MLP) refurbishment. Three turnaround time goals are listed. One is the STS-14, one for the STS-30 timeframe as projected by the Shuttle Turnaround Analysis Report (STAR), and a 25-day turnaround which reflects a number of product improvements. The reader is referred to Ref. 6 for details. The chart at the lower portion of Fig. 14 represents a recent STS traffic model which provides a time reference for the STS-14 and STS-30 missions.

The maximum launch-rate capability for the Kennedy Space Center for the 35-day and 25-day turnaround are shown in Fig. 15 for the capabilities which may be functional by FY '85 and FY '87. The reader's attention is called to the footnotes which qualify the assumptions upon which the figure is based. Included in the figure are the reaction times for rescue or the maximum time the space station might have to await a rescue by Space Shuttle. These estimates have been derived from the data of Ref. 6. The reaction-time estimates do not include the time required to make the necessary software and hardware changes required to reconfigure to a rescue mission and assumes three orbiters at the Kennedy Space Center and no assistance from the Vandenberg facility. Rescue of crews from space stations placed in orbit by STS launches from KSC cannot, based on present STS capability, be performed by launches from Vandenberg. Assuming that turnaround times of from 25 to 35 days can be achieved during the space station era, the reaction time or time to wait for rescue by STS should be on the order of from 12 to 18 days.

Other options for the rescue of a space-station crew include the use of a manned or unmanned device launched via an expendable booster, with the device carrying either a capsule to provide Earth reentry capability or carrying supplies to sustain the crew until they can be rescued by the Shuttle. Rescue by another space station in a nearby orbit has been discussed previously. The capability of foreign nations to aid in the rescue of a U.S. space-station crew would depend upon their willingness to do so, their capabilities, capacities and status of their spacecraft, and the commonality between the docking and berthing hardware.

CONCLUDING REMARKS

Evolving from the space-station crew-safety studies are some key issues regarding threats, the options for handling the threats, and the potential impact on a space station as shown in Fig. 16. Fire, injury/illness, and abandonment of space station have been discussed earlier. The issues regarding radiation are the amount of protection required, the best way to provide the protection, and where the radiation protection should be placed. Regarding placement of the radiation protection, it may be sufficient to provide radiation protection for just one volume, to which the crew could retreat if radiation threats occur. Impact or penetrations by meteoroids or debris should be detected and damage repaired if possible. Detection methods must be investigated. Materials and structural concepts for providing protection must also be investigated.

As the study of space-station crew safety continues, the requirements for providing adequate crew safety will become more clear, as will the impact of those requirements on space-station architecture and operations. As the space station, its operational aspects, and crew tasks become more clearly defined, new threats to crew safety may surface.

Perhaps the most challenging task associated with selecting the appropriate provisions for crew safety is the trade between reliability, redundancy, maintainability, and cost. Although the current studies will provide some rough-order-of-magnitude costs, far more work must be done in this area, and it should be done in the early phases of space-station planning.

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[1] Johnson, Philip C. and Mason, John A.: "Medical Operations and Life Sciences Activities on Space Station," NASA TM 58248, October 1982.

[2] Mayer, Roland T.: "MOSES (Manned Orbital Space Escape System) - A Hypothetical Application," Journal of Spacecraft and Rockets, Volume 20 Number 2, March-April 1983, pp 158-163.

[3] Life Sciences Considerations for Space Station," a publication by the Life Sciences Division of NASA Headquarters in Washington, DC, September 14, 1982.

[4] "Space Rescue Operations," Volume II, NASA CR-121869, May 12, 1971.

[5] Turnill, Reginald: "The Observers Spaceflight Directory," Frederick Warne (publishers) Ltd., London, 1978.

[6] Smith, R.G.: "Shuttle Ground and Turnaround Launch Projections," AIAA-82-1791, October 1982.

FACTOR	PREVIOUS	SPACE STATION
MAN IN SPACE	SKYLAB 4 --- 84 DAYS	90 DAYS
EQUIPMENT IN SPACE	SKYLAB ----- 171 DAYS	10 OR MORE YEARS?
CREWS	EXPERIENCED PILOTS	MOSTLY SCIENTISTS, ENGINEERS, TECHNICATIONS/ NON-PILOTS
TASKS	WELL PRACTICED	MANY UNPLANNED
GROUND SUPPORT	ABUNDANT	LIMITED ?
RETURN-TO-EARTH CAPABILITY	YES	TBD

Fig. 1 - Safety-related factors; the previous U.S. space program versus a space station.

CURRENT OPTIONS	COMMENTS
● CAUSE NO DAMAGE WHATSOEVER TO SPACE STATION AND NO INJURY TO CREW	DESIRABLE: COST TRADE
● CAUSE NO DAMAGE TO SPACE STATION BEYOND ROUTINE MAINTENANCE CAPABILITY	COST TRADE
● CAUSE NO DAMAGE TO SPACE STATION OR INJURY TO CREW WHICH WILL RESULT IN A A SUSPENSION OF OPERATIONS	BASELINE PHILOSOPHY
● SPACE STATION REPAIRABLE AND OPERATIONAL WITHIN A SPECIFIED PERIOD OF TIME	MAY REQUIRE ESCAPE/RESCUE
● CREW SURVIVAL AT EXPENSE OF THE SPACE STATION	IMPLIES EVACUATION AND RESCUE, AS A MINIMUM

Fig. 4 - Space station safety philosophy options.

OBJECTIVES
- ASSESS CREW SAFETY REQUIREMENTS AND ALTERNATIVE STRATEGIES

GUIDELINES
- DEFINE ADEQUATE EMERGENCY STRATEGIES AT A TOLERABLE COST

ASSUMPTION
- SPACE STATION IOC IN 1990

RANGE OF DATA FOR STUDY
- PAST HISTORY OF SPACE PROGRAM
- EMERGENCY STRATEGIES FOR ANALAGOUS ACTIVITIES: SUBMARINES, OFF-SHORE OIL RIGS, ARCTIC POSTS
- PRIOR SPACE RESCUE AND ESCAPE CONCEPTS
- PRIOR AND ONGOING STUDIES OF SPACE STATION CONCEPTS

Fig. 2 - Space station crew safety study profile.

- ✓ FIRE
- LEAKAGE
- TUMBLING/ LOSS OF CONTROL
- BIOLOGICAL OR TOXIC CONTAMINATION
- ✓ INJURY/ILLNESS
- GRAZING/COLLISON
- CORROSION
- MECHANICAL DAMAGE
- EXPLOSION
- LOSS OF PRESSURIZATION
- RADIATION
- OUT-OF-CONTROL IVA/EVA ASTRONAUT
- INADVERTENT OPERATIONS
- LACK OF CREW COORDINATION
- ✓ ABANDONMENT OF SPACE STATION
- METEOROID PENETRATION
- STORES/CONSUMABLES DEPLETION
- STRUCTURAL EROSION
- ORBIT DECAY
- LOSS OF ACCESS TO A HATCH
- TEMPERATURE EXTREMES
- DEBRIS

Fig. 5 - List of typical threats to space station crew safety.

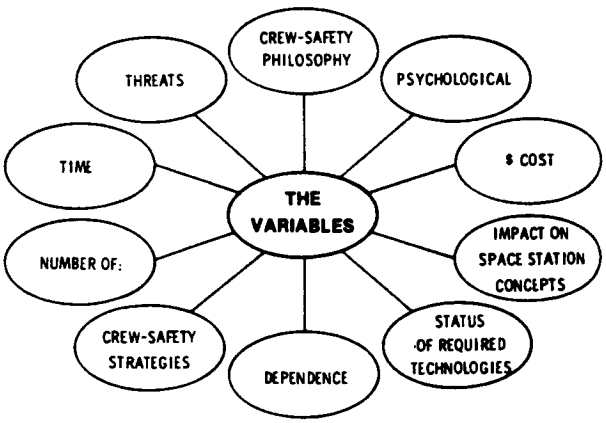
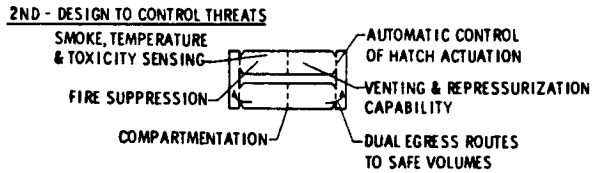


Fig. 3 - Variables effecting the requirements for space station crew safety.

1ST - DESIGN TO PRECLUDE THREATS

- BREAK TWO LEGS OF THE TRIANGLE
- ISOLATE ELEMENTS OF COMBUSTION

2ND - DESIGN TO CONTROL THREATS



3RD - RETREAT TO FUNCTIONAL VOLUMES AND CONTINUE MISSION UNTIL
- DAMAGED VOLUME IS REPAIRED OR REPLACED
- ABANDONMENT OF THE SPACE STATION IS REQUIRED

Fig. 6 - Lines of defense against fire.

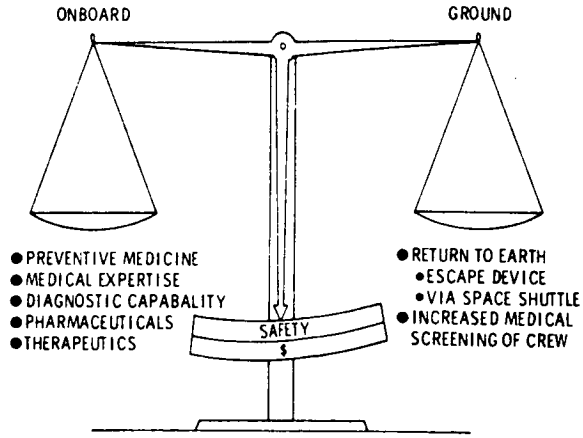


Fig. 7 - Trade elements regarding the handling of injury and illness.

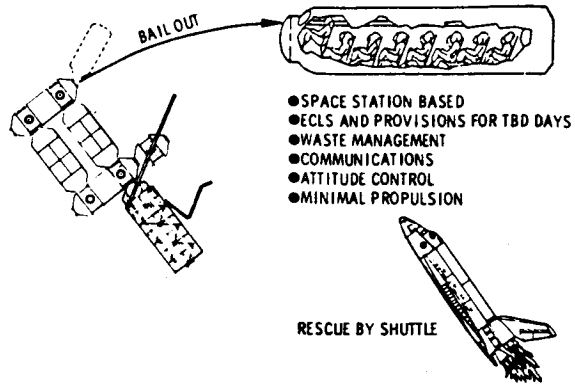


Fig. 10 - A bail-out-and-wait device concept.

ESCAPE (STEPS TAKEN BY SPACE STATION CREW TO LEAVE THREAT LOCATION)

- TO REMAINING HABITABLE VOLUME(S)
- TO DEDICATED ONBOARD SAFE HAVEN
- TO BAIL-OUT-AND-WAIT DEVICE (WAIT FOR RESCUE)
- TO BAIL-OUT-AND-RETURN DEVICE (RETURN TO SPACE HAVEN)
- TO BAIL-OUT-AND-RETURN-TO-EARTH DEVICE

RESCUE (STEPS TAKEN BY OTHER THAN SPACE STATION CREW)

- BY REMOVAL OF CREW BY UNSCHEDULED SHUTTLE MISSION
- BY UNMANNED BOOSTER SENDING UP
  - ENTRY CAPSULE TO RETURN CREW TO EARTH
  - CONSUMABLES TO EXTEND LIFE OF STRANDED CREW
- BY ANOTHER SPACE STATION
- BY FOREIGN NATIONS

Fig. 8 - Space station escape and rescue options.

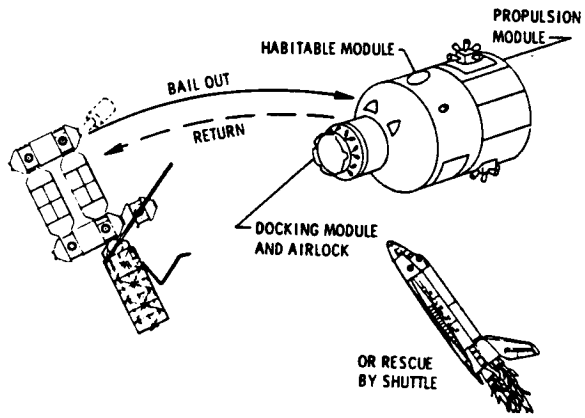
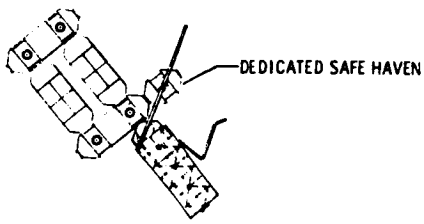


Fig. 11 - A bail-out-and-return device concept.



FUNCTIONS/ BENEFITS	REQUIREMENTS
●HOUSE CREW UNTIL •RETURN TO SPACE STATION PROPER •RESCUE ●QUIET/ ALONE PLACE •PERSONAL COMMUNICATIONS •WITH EARTH (HOME)	●ACCOMODATIONS FOR ALL CREW MEMBERS ●ECLS PLUS PROVISIONS FOR TBD DAYS ●RADIATION PROTECTION?

Fig. 9 - A dedicated onboard safe haven.

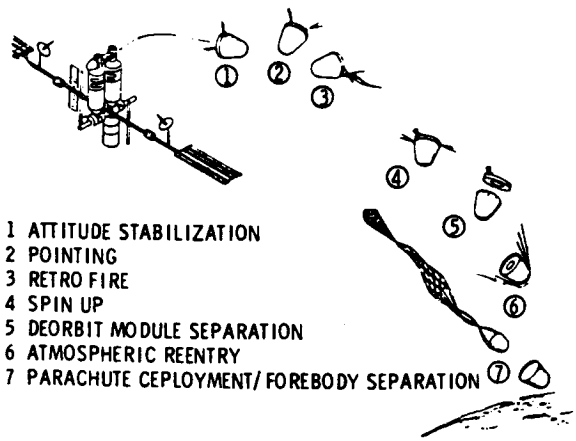


Fig. 12 - Operational aspects of General Electric's manned orbital space scape system (MOSES) concept.

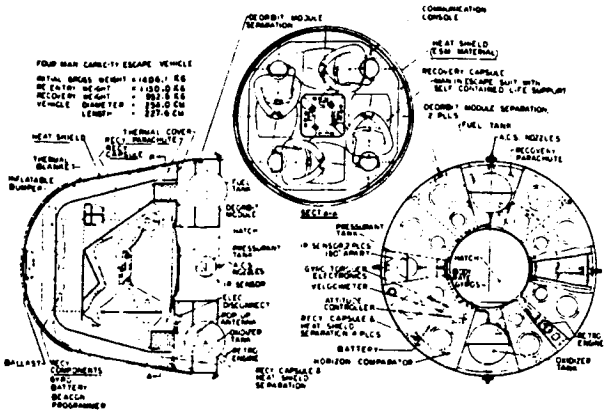


Fig. 13 - Details of General Electric's MOSES concept; four man capacity.

	35-DAY TURNAROUND (STAR 022, STS-30 TIMEFRAME)	25-DAY TURNAROUND
ON-LINE IN FY 87:		
3 ORBITERS AT KSC 2 VAB INTEGRATION CELLS 2 PADS 3 MLPS 2 OPF HIGH BAYS	19.8 FLIGHTS/YR. (LIMITED BY 2 VAB INTEGRATION CELLS) 18 DAY REACTION TIME[B]	29.7 FLIGHTS/YR (LIMITED BY 3 ORBITERS AT KSC) 12 DAY REACTION TIME[B]

A CRITICAL PATH REQUIRES 6-DAY/3-SHIFT WORKWEEK; MLP REFURBISHMENT REQUIRES 7-DAY/3-SHIFT WORKWEEK; MEAN MISSION DURATION IS 5 DAYS

B DOES NOT INCLUDE TIME REQUIRED FOR STS SOFTWARE, ETC. CHANGES

Fig. 15 - Projected Space Shuttle launch rate capabilities and reaction time for space station rescue missions from the Kennedy Space Center.

	TURNAROUND TIMES[A], DAYS		
	STS-14	STAR 022 (STS-30 TIMEFRAME)	25-DAY TURNAROUND
OPF PROCESSING	17	15	9
VAB INTEGRATION	7	7	6
PAD PROCESSING	18	13.3	10.3
SRB/ET STACKING	17	15.5	10
PAD REFURBISHMENT	7	5	4
MLP REFURBISHMENT	5	4	2
TOTAL ORBITER PROCESSING	42	35.3	25.3

A IN 3-SHIFT WORKDAYS

STS TRAFFIC MODEL

FISCAL YEAR	83	84	85	86	87	88	89	90	MAX RATE
KSC FLIGHT RATE	5	10	13	15	16	18	20	24	30

Fig. 14 - Projected Space Shuttle turnaround times at the Kennedy Space Center: flight timeframe reflected in space shuttle traffic model.

THREAT	ISSUE RE SPACE STATION
• FIRE	• PREVENTION, CONTROL, SUPPRESSION, AND EGRESS
• INJURY/ILLNESS	• ONBOARD VERSUS GROUND CARE • EMERGENCY RETURN-TO-EARTH ?
• RADIATION	• AMOUNT OF PROTECTION REQUIRED • HOW TO BEST PROVIDE IT • WHERE
• ABANDONMENT OF SPACE STATION	• ONBOARD SAFE HAVEN • BAIL-OUT-AND-WAIT OR RETURN • REENTRY CAPSULE • SPACE SHUTTLE RESPONSE
• METEOROID PENETRATION • DEBRIS	• DETECTION • PROTECTION • REPAIR • RE-PRESSURIZATION

Fig. 16 - The relevance of threats to space station concepts.

SPACE STATION — KSC — FUTURE PROJECTS TECHNOLOGY

JOHN OERTEL

JUNE 8, 1983

MISSION ASSURANCE FROM A
GROUND PROCESSING PERSPECTIVE

SPACE STATION — KSC — FUTURE PROJECTS TECHNOLOGY

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GROUND PROCESSING MAJOR TEST PHASES FOR SS ELEMENTS

- 0 PHASE 1 : ELEMENT CHECK OUT
  - NO SHIPMENT DAMAGE
  - ALL SUBSYSTEMS AND SYSTEMS HEALTHY
- 0 PHASE 2 : ELEMENT TO ORBITER (SIMULATED)
  - I/F V TESTS - FORM, FIT, AND FUNCTION
  - INTEGRATION TESTS - ALL SYSTEMS 'GO'
- 0 PHASE 3 : ELEMENT TO SS
  - I/F V TESTS - ASSEMBLY OPERATIONS, FIT, FUNCTIONS
  - INTEGRATION TESTS - ALL SS SYSTEMS TESTS 'GO'
    - o ACTUAL (IOC)
    - o SIMULATED (FOLLOW-ON)

SPACE STATION — KSC — FUTURE PROJECTS TECHNOLOGY

AGENDA

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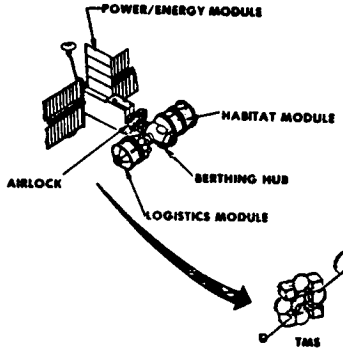
- 0 PURPOSE
- 0 GROUND PROCESSING PHASES
- 0 THE INITIAL OPERATIONAL SPACE STATION
- 0 O&C FACILITY CAPABILITY FOR SS BASIC ELEMENTS
- 0 SS CARGO MANIFEST FOR THE INITIAL CAPABILITY
- 0 FOLLOW-ON PHASE OPERATIONS AND GROUND PROCESSING
- 0 SS ENGINEERING MODEL ROLE
- 0 MISSION ASSURANCE-GROUND PROCESSING-AND SSEM
- 0 SUMMARY

SPACE STATION INITIAL CAPABILITY



INITIAL SS ELEMENTS

- POWER/ENERGY MODULE
- HABITAT MODULE
- BERTHING HUB & AIRLOCK
- LOGISTICS MODULE
- UNMANNED SPACE PLATFORM
- TELEOPERATOR MANEUVERING SYSTEM

SPACE STATION — KSC — FUTURE PROJECTS TECHNOLOGY

PURPOSE

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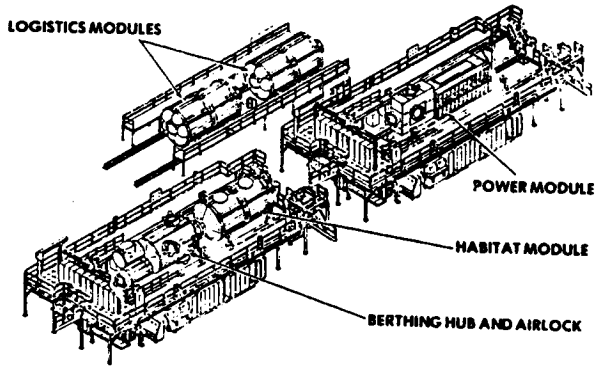
TO PROPOSE CONCEPTS OF WHAT CAN BE DONE FROM A GROUND PROCESSING PERSPECTIVE TO INCREASE THE ASSURANCE THAT

- o THE IOC SS WILL BE SUCCESSFULLY ASSEMBLED ON ORBIT AND BROUGHT TO ON-LINE OPERATIONS
- o THE FOLLOW-ON SS GROWTH, EXPANDED CAPABILITIES, AND NEW MISSIONS WILL BE SUCCESSFUL

SPACE STATION ELEMENT CHECKOUT



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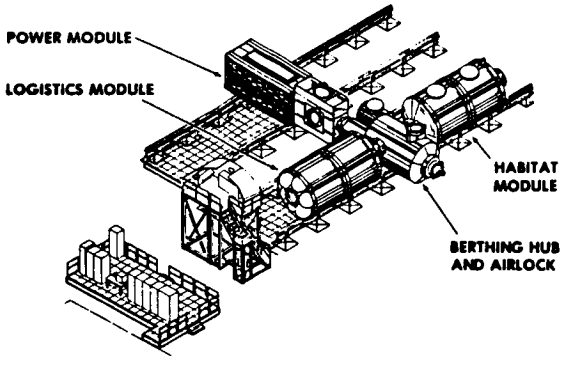
IOC INTEGRATED TESTING



SPACE STATION KSC FUTURE PROJECTS TECHNOLOGY

FOLLOW-ON PHASE

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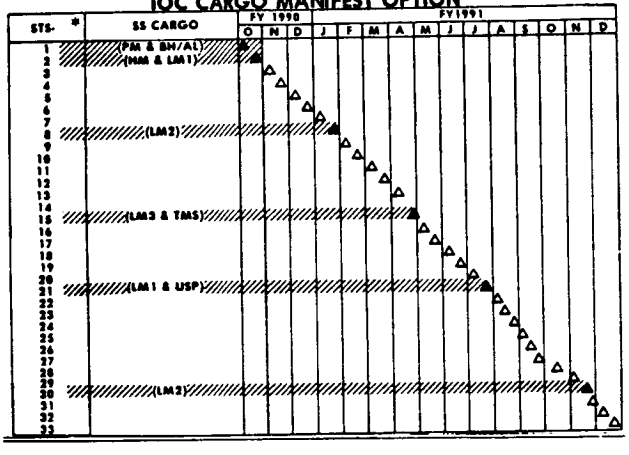
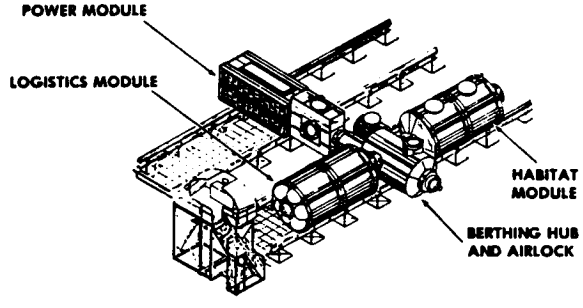
- O POTENTIAL REQUIREMENTS FOR THE SPACE STATION ENGINEERING MODEL (SSEM)
  - o ON GROUND VERIFICATION OF FORM, FIT AND FUNCTIONAL INTERFACES WITH THE ON-ORBIT SS
  - o PRE-LAUNCH SUPPORT FOR INITIAL OPERATIONS BUILD-UP
  - o GROUND SUPPORT TO THE BASIC ON-ORBIT SS
  - o PRE-LAUNCH TESTING OF FOLLOW-ON SS ELEMENTS
  - o SOFTWARE DEVELOPMENT & VALIDATION
  - o FOLLOW-ON ENGINEERING DESIGN AND DEVELOPMENT SUPPORT
  - o PAYLOAD INTERFACE SIMULATIONS
  - o SS DATA COMMUNICATIONS AND COMMAND/CONTROL LINK SIMULATIONS
  - o GROUND SUPPORT FOR ON-ORBIT MAINTENANCE
  - o SS MODIFICATIONS VALIDATION
  - o SHORT TERM SPARES AND CONSUMABLES SOURCE (CANNIBALIZATION)
  - o SAFETY, EMERGENCY AND CONTINGENCY ON-ORBIT SUPPORT
  - o MAINTENANCE PROCEDURES DEVELOPMENT AND VALIDATION
  - o DEPLOYABLE SPACECRAFT INTERFACE PLANNING AND ON-ORBIT SUPPORT

IOC CARGO MANIFEST OPTION



ENGINEERING MODEL OPERATIONS



SPACE STATION KSC FUTURE PROJECTS TECHNOLOGY

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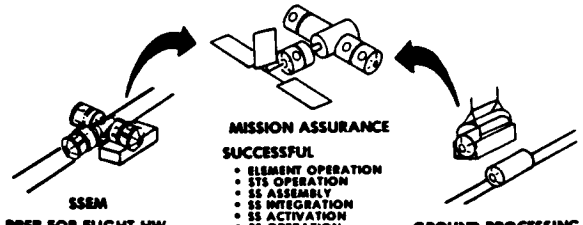
FOLLOW ON PHASE SPACE STATION MISSION ASSURANCE

- O INTERFACE VERIFICATION IS PERFORMED AT KSC TO BRING OUT ANY FORM, FIT, OR FUNCTIONAL COMPATIBILITIES IN FLIGHT HARDWARE/SOFTWARE
- O THE FOLLOWING SPACE OPERATIONS ACTIVITIES HAVE INCREASED MISSION ASSURANCE BECAUSE OF ON-GROUND INTERFACE VERIFICATION TESTING
  - - EXPANSION OF BASIC SS BY ADD-ON OF REPEAT ELEMENTS
  - - EXPANSION OF BASIC SS BY ADD-ON OF NEW TYPE ELEMENTS
  - - SATELLITE SERVICING
  - - SYSTEM MODIFICATION
  - - OTV OPERATIONS

MISSION ASSURANCE FROM A GROUND PROCESSING PERSPECTIVE



SSEM

PREP FOR FLIGHT HW
- FACILITY/GSE C/O
- HANDLING, PROCESSING
- SOFTWARE DEVELOPMENT

MISSION ASSURANCE SUCCESSFUL
- ELEMENT OPERATION
- STS OPERATION
- SS ASSEMBLY
- SS INTEGRATION
- SS ACTIVATION
- SS OPERATION
- SS EXPANSION

GROUND PROCESSING AND OPERATIONS
- R&I ELEMENTS
- A&I ELEMENTS
- PREPARE FOR & C/O ELEMENTS
- CITE
- FULL-UP IOC SS
- TRANSPORT
- INSTALL IN ORBITER
- CLOSEOUT

ON-ORBIT
- ON-GROUND VERIFICATION OF SS FORM,FIT,FUNCTION
- PRE-LAUNCH C/O FOLLOW-ON SS ELEMENTS
- GROUND SUPT FOR ON-ORBIT MAINTENANCE,SAFETY, CONTINGENCY,EMERGENCY
- MODIFICATION/PROCEDURE VALIDATION

SPACE STATION — KSC — FUTURE PROJECTS TECHNOLOGY

SUMMARY

JOHN OERTEL

CONCEPTS FOR DISCUSSION

- 0 FULL UP INTEGRATED TEST FOR SS IOC ELEMENTS
  - VERIFY INTERFACES
  - VERIFY SYSTEM/SUBSYSTEM OPERATION
- 0 HIGH FIDELITY ENGINEERING MODEL
  - VERIFY FOLLOW ON ELEMENT INTERFACES & OPERATION
  - VERIFY MODIFICATIONS/PROCEDURES
  - VERIFY PAYLOAD INTERFACES

SPACE STATION — KSC — FUTURE PROJECTS TECHNOLOGY

LESSONS LEARNED

JOHN OERTEL

- 0 VALUE OF ENGINEERING MODELS/INTERFACE VERIFICATION
- 0 CITE ANALOGY

SPACE STATION — KSC — FUTURE PROJECTS TECHNOLOGY

MISSION ASSURANCE CONFERENCE
SPACE STATION WORKSHOP

JOHN OERTEL

JUNE 9, 1983

LESSONS LEARNED

SPACE STATION — KSC — FUTURE PROJECTS TECHNOLOGY

LESSONS LEARNED

JOHN OERTEL

CITE ANALOGY

- 0 CITE TESTING IS A RELATIVELY SMALL PORTION OF OVERALL FLOW
- 0 PHILOSOPHY OF MINIMIZING ON-LINE PROBLEMS BY PERFORMING OFF-LINE TESTING HAS PRODUCED POSITIVE RESULTS
- 0 STS - 5/6/7
  - 392 HRS ADDED
  - 869 HRS (EST) SAVED

SAFETY POLICY AND REQUIREMENTS

FOR PAYLOADS USING THE

SPACE TRANSPORTATION SYSTEM

PAUL DAVIS
NASA HEADQUARTERS

STS PAYLOAD SAFETY

- NHB 1700.7A SAFETY POLICY & REQUIREMENTS FOR PAYLOADS USING THE SPACE TRANSPORTATION SYSTEM
- PROVIDES POLICY AND REQUIREMENTS APPLICABLE TO ALL STS PAYLOADS
  - TECHNICAL
  - SYSTEM SAFETY

NASA OBJECTIVES

- PROVIDE EASIER ACCESS TO SPACE
- EXPAND THE RANGE OF POTENTIAL USERS
- REDUCE COSTS OF SPACE RESEARCH AND APPLICATION OF SPACE TECHNOLOGY
- TAILOR SAFETY REQUIREMENTS FOR PAYLOADS TO HAZARD POTENTIAL

SAFETY IMPLEMENTATION RESPONSIBILITIES

- PAYLOAD ORGANIZATION
  - ASSURE SAFETY OF PAYLOAD
  - IMPLEMENT SAFETY REQUIREMENTS
  - VERIFY COMPLIANCE WITH REQUIREMENTS
  - INTEGRATED SAFETY ON MULTIPLE PAYLOADS
  - PRESENT APPROVED FORMS AND SUPPORT DATA AT STS SAFETY REVIEWS
  - MAINTAIN SAFETY COMPLIANCE DATA PACKAGE FOR SHIPMENT WITH PAYLOAD

SAFETY IMPLEMENTATION RESPONSIBILITIES (CONT)

- JOHNSON SPACE CENTER (JSC)/SAMSO
  - RESPONSIBLE FOR FLIGHT SYSTEMS & FLIGHT OPERATINS
  - REVIEW PAYLOAD FOR COMPLIANCE WITH NHB 1700.7A
  - INTERPRETATION OF REQUIREMENTS
  - REVIEW & DISPOSITION OF WAIVERS
  - ASSURE INTER-ACTION AMONG MIXED PAYLOADS AND BETWEEN PAYLOADS & STS DOES NOT CREATE HAZARDS
- KENNEDY SPACE CENTER (KSC)/VAFB
  - RESPONSIBLE FOR PAYLOAD GSE & GROUND OPERATIONS
  - CORRESPONDING ROLE FOR PAYLOAD GROUND SAFETY

STS PAYLOAD SAFETY REVIEW PANEL

- AUTHORITY ESTABLISHED BY CENTER DIRECTOR
  - MEMBERSHIP
    - PROGRAM OPERATIONS OFFICE - CHAIRMAN
    - STS OPERATIONS PROGRAM OFFICE
    - SAFETY, RELABILITY, AND QUALITY ASSURANCE OFFICE
    - FLIGHT OPERATIONS DIRECTORATE
    - SPACE AND LIFE SCIENCES DIRECTORATE
    - ENGINEERING AND DEVELOPMENT DIRECTORATE
    - SPACE SHUTTLE PROGRAM OFFICE
    - SAFETY R&QA AND PROTECTIVE SERVICES
    - CARGO PROJECTS OFFICE (KSC)
- RESPONSIBILITIES
  - REVIEW AND EVALUATE HAZARD REPORTS AND WAIVERS SUBMITTED BY PAYLOAD ORGANIZATION
  - PROVIDE TECHNICAL INPUTS AT THE PHASE SAFETY REVIEWS
  - CHAIRMAN PROVIDES CONCURRENCE/APPROVAL OR OTHER DISPOSITION OF HAZARD REPORTS AND ACTION ITEMS

SAFETY REVIEWS

- FORMAL MEETINGS WITH PAYLOAD ORGANIZATION TO ASSESS COMPLIANCE WITH THE REQUIREMENTS OF NHB 1700.7A
  - PAYLOAD DESIGN AND FLIGHT OPERATIONS - JSC PANEL
  - GSE DESIGN AND GROUND OPERATIONS - KSC PANEL
- DEPTH AND NUMBER OF REVIEWS DETERMINED BY PAYLOAD HAZARD POTENTIAL
- SCHEDULE FOR REVIEWS
  - ESTABLISHED BY PAYLOAD ORGANIZATION (TENTATIVE)
  - COORDINATED WITH JSC PAYLOAD INTEGRATION OFFICE OR KSC CARGO PROJECTS OFFICE
- DATA SUBMITTED TO JSC/KSC
  - REVIEWED BY PANEL
  - ACTUAL REVIEW DATE ESTABLISHED

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INITIAL CONTACT MEETING

- INITIAL MEETING WITH PAYLOAD ORGANIZATION
  - PROVIDE SAFETY DOCUMENTS
    - NHB 1700.7A - "SAFETY POLICY AND REQUIREMENTS FOR PAYLOADS USING THE SPACE TRANSPORTATION SYSTEM"
    - JSC 13830 - "IMPLEMENTATION PROCEDURE FOR STS PAYLOADS SYSTEM SAFETY REQUIREMENTS"
    - JSC 11123 - "STS PAYLOAD SAFETY GUIDELINES HANDBOOK"
    - JSC 09331-1 AND - 2 - "THE PREVENTION OF ELECTRICAL BREAKDOWN AND ELECTROSTATIC VOLTAGE PROBLEMS IN THE SPACE SHUTTLE AND ITS PAYLOADS." PART I AND PART II
  - BRIEFING ON IMPLEMENTATION PROCEDURE AND SAFETY REVIEWS
  - SCHEDULE PHASE 0

STS PAYLOAD SAFETY

- CATASTROPHIC HAZARDS CONTROL
  PARA- 201
  - NO COMBINATION OF TWO FAILURES, OPERATOR ERRORS OR RF SIGNALS SHALL RESULT IN THE POTENTIAL FOR PERSONNEL INJURY, LOSS OF THE ORBITER, GROUND FACILITIES, OR STS EQUIPMENT.
- FUNCTIONS RESULTING IN CATASTROPHIC HAZARDS
  PARA 202-2
  - A FUNCTION THAT COULD RESULT IN A CATASTROPHIC HAZARD MUST BE CONTROLLED BY A MINIMUM OF THREE INDEPENDENT INHIBITS, WHENEVER THE HAZARD POTENTIAL EXISTS.
- CATASTROPHIC FUNCTIONS
  - THREE INDEPENDENT INHIBITS
  - MONITORING OF TWO OF THREE INHIBITS – GND OR FLT CREW
  - MINIMUM OF ONE SHALL BE FAIL SAFE

SUMMARY OF SAFETY REVIEW PROCESS

PHASE	TIMING	PAYLOAD ORGANIZATION'S SAFETY EFFORTS	PURPOSE OF REVIEW
0	Conceptual Design Established	1. Perform preliminary system level safety analysis.	1. Identify potential hazards and applicable safety requirements.
I	Preliminary Design Established	1. Define and expand safety analysis. a. Define hazards b. Define hazard causes c. Evaluate options for reducing or controlling hazards d. Identify approach for safety verification 2. Prepare a mission scenario. 3. Determine compliance with NHB 1700.7A.	1. Update safety analysis to reflect preliminary design. 2. Evaluate preliminary hazard controls and safety verification methods.
II	Final Design Established	1. Define and expand safety analysis. a. Evaluate interfaces and mission procedures/timelines. b. Update hazard descriptions, causes, and controls. c. Finalize test plans, analysis procedures, or inspections for safety verification. 2. Determine compliance with NHB 1700.7A.	1. Update safety analysis to reflect final design. 2. Concur on specific hazard controls and safety verification methods.
III	Delivery to Customer	1. Complete safety analysis. 2. Prepare safety assessment report. 3. Complete all safety verification tests, analyses, and/or inspections. 4. Prepare safety compliance data package.	1. Approval of safety assessment report. 2. Review of safety compliance data package 3. Identify open safety items.

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

DEPLOYMENT AND/OR SEPARATION

- PREMATURE DEPLOYMENT OR SEPARATION TO CONDITION WHICH CANNOT WITHSTAND STS INDUCED LOADS (INCLUDING LANDING) OR PREVENT SAFE ORBITER ENTRY IS CATASTROPHIC HAZARD
- THREE INDEPENDENT INHIBITS TO FUNCTION MUST REMAIN SAFE UNTIL FUNCTION IS NOT HAZARD TO ORBITER OR CREW
- DESIGNED TO PRECLUDE INADVERTENT MECHANICAL OPERATION IN INDUCED ENVIRONMENTS
- PYRO DEVICES MUST MEET SPECIAL REQUIREMENTS
- ADDITIONAL REQUIREMENTS FUNCTION OF PLANNED OPERATIONS
  - FUNCTION PERFORMED AFTER FINAL SEPARATION FROM ORBITER
    - FUNCTION NOT PERFORMED UNTIL PAYLOAD AT SAFE DISTANCE
    - FLIGHT OR GROUND CREW MONITOR OF TWO INHIBITS IN NEAR REAL TIME
  - FUNCTION PERFORMED BEFORE FINAL SEPARATION FROM ORBITER
    - THREE INHIBITS SAFE FOR BOOST AND ENTRY
    - REMOVED ONLY BY CREW COMMAND TO PERFORM FUNCTION
    - COMMAND AND MONITOR OF INHIBITS AVAILABLE TO FLIGHT CREW
    - ABILITY TO RETURN TO SAFE STATUS AVAILABLE TO FLIGHT CREW

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

FAILURE TOLERANCE (201)

- PAYLOAD MUST TOLERATE MINIMUM NUMBER OF CREDIBLE FAILURES AND/OR OPERATOR ERRORS FOR HAZARDOUS FUNCTIONS
- APPLICABLE TO LOSS OF FUNCTION OR INADVERTENT OCCURRENCE WHICH RESULTS IN HAZARDOUS EVENT

  CRITICAL HAZARD. NO SINGLE FAILURE OR ERROR SHALL RESULT IN DAMAGE TO STS EQUIPMENT OR CONTINGENCY OR EMERGENCY PROCEDURES

  CATASTROPHIC HAZARDS. NO COMBINATION OF TWO FAILURES, ERRORS, OR RADIO FREQUENCY SIGNALS SHALL RESULT IN THE POTENTIAL FOR PERSONNEL INJURY, LOSS OF THE ORBITER, GROUND FACILITIES, OR STS EQUIPMENT

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

- RETRIEVAL OF PAYLOADS (203)
  - CAPABILITY TO RETURN SYSTEMS TO A SAFE CONDITION
  - VERIFICATION OF SAFE CONDITION TO ORBITER OR GROUND CREW WHILE STILL A SAFE DISTANCE
  - VERIFICATION MUST ESTABLISH AT LEAST SINGLE FAULT TOLERANCE
- HAZARD DETECTION AND SAFING (204)
  - MINIMIZE BY DESIGN THE REQUIREMENT FOR TIME-CRITICAL FLIGHT CREW MONITORING AND CONTROL OF HAZARDOUS FUNCTIONS/SYSTEMS
  - WHEN USED PROVIDE GROUND CHECKOUT CAPABILITY
- CONTINGENCY RETURN OF PAYLOADS (205)
  - DEPLOYABLE PAYLOADS MUST PROVIDE CAPABILITY TO RETURN TO SAFE CONDITION AT ALL TIMES PRIOR TO SEPARATION
  - SAFE CONDITION MUST MEET REQUIREMENTS OF PARAGRAPH 202, "CONTROL OF HAZARDOUS FUNCTIONS"

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

- STRUCTURAL (208)

STRUCTURAL DESIGN

- ULTIMATE FACTOR SAFETY ≥ 1.4 FOR ALL PHASES EXCEPT EMERGENCY LANDING
- DESIGN BASED ON FRACTURE CONTROL PROCEDURES FOR CATASTROPHIC HAZARD

EMERGENCY LANDING LOADS

- DESIGN SHALL COMPLY WITH EMERGENCY LANDING LOAD FACTORS SPECIFIED IN VOLUME XIV, ATTACHMENT 1.

STRESS CORROSION

- MATERIALS MUST COMPLY WITH MSFC - SPEC - 522
- WAIVER REQUIRED FOR CASES WHEN MSFC - SPEC - 522 REQUIRES MATERIAL USEAGE AGREEMENT

PRESSURE VESSELS

- DESIGN TO ASME BOILER AND PRESSURE VESSEL CODE OR MIL-STD-1522 OR NSS/NP 1740.1 WITH F.S. ≥ 1.5
- QUAL. TEST TO NO FAILURE AT DESIGN BURST FOR MIL-STD-1522 OR NSS/NP 1740.1
- QUAL. TEST TO DEMONSTRATE 2 TIMES PREDICTED LIFE CYCLES FOR ASME CODE OR MIL-STD-1522
- FLUID COMPATIBILITY FOR CLEANING, TEST AND OPERATION

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

- STRUCTURAL (208) (CONT'D)

PRESSURIZED LINES AND FITTINGS

- FITTINGS AND LINES < 1.5 INCHES INSIDE DIA. SHALL HAVE FACTOR OF SAFETY ≥ 4.0
- FITTINGS AND LINES > 1.5 INCHES INSIDE DIA. SHALL HAVE FACTOR OF SAFETY ≥ 1.5
- OTHER COMPONENTS SHALL HAVE FACTOR OF SAFETY ≥ 2.5

DECOMPRESSION

- PAYLOADS IN MANNED VOLUMES DESIGNED FOR DECOMPRESSION AND REPRESSURIZATION MUST WITHSTAND DIFFERENTIAL PRESSURE WITHOUT RESULTING IN A HAZARD
  - AIRLOCK IS AN EXAMPLE

SEALED CONTAINERS

- ANALYSED TO ESTABLISH HAZARD POTENTIAL
- PROOF TEST 1.5 NOMINAL DIFFERENTIAL IF A HAZARD

SAFETY POLICY AND REQUIREMENTS TECHNICAL REQUIREMENTS

- MATERIALS (208)
  - TEST DATA FOR HAZARDOUS FLUID COMPATIBILITY, FLAMMABILITY, AND OFFGASSING IN JSC 02681
  - JSC 09604 PROVIDES "ACCEPTABILITY" RATING FOR MATERIALS CHARACTERISTICS

HAZARDOUS MATERIALS

- HAZARDOUS MATERIALS SHALL NOT BE RELEASED OR EJECTED IN OR NEAR ORBITER
- MUST CONTAIN HAZARDOUS FLUIDS AFTER EXPOSURE TO ALL STS ENVIRONMENT UNLESS VENTING NEGOTIATED WITH STS OPERATOR
- MATERIALS IN OXYGEN SYSTEMS, EITHER DIRECT CONTACT OR A SINGLE BARRIER FAILURE, MUST MEET NHB 8060.1 FOR TYPE D MATERIALS AT MAX TEMPERATURE AND PRESSURE
- USE OF NEACHMY SHALL BE MINIMIZED; WHEN USED, SPECIFIC DATA DOCUMENTED PRIOR TO NASA APPROVAL
- MATERIALS IN OTHER HAZARDOUS FLUID SYSTEMS, EITHER DIRECT CONTACT OR A SINGLE-BARRIER FAILURE, MUST MEET NHB 8060.1 FOR TYPE J MATERIALS AT MAX TEMPERATURE AND PRESSURE

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

- MATERIALS (CONT'D)

ORBITER CABIN MATERIALS

- MUST MEET REQUIREMENTS OF NHB 8060.1 AND SE-R-0006 OR EQUIVALENT
- VOLUMES OTHER THAN ORBITER CABIN NOT REQUIRED TO MEET NHB 8060.1

FLAMMABLE MATERIALS

- OTHER THAN ORBITER CABIN GOOD PRACTICES ARE REQUIRED
  - FLAMMABLE MATERIALS SEPARATED TO PREVENT FLAME PROPAGATION
  - SEPARATE FLAMMABLE MATERIALS FROM IGNITION SOURCES TO MAX. EXTENT PRACTICABLE
  - MINIMIZE FLAMMABLE MATERIALS PREFERRED APPROACH
    - MATERIALS WHICH MEET 8060.1 CONSIDERED NONFLAMMABLE
    - JSC 02681, JSC 09604, AND JSC 11123 PROVIDE TEST DATA, MATERIAL SELECTION LISTS AND GUIDELINES
    - USER OR NASA TESTS FOR OTHER MATERIALS

MATERIAL OFFGASSING

- AVOID MATERIALS WITH TOXIC OFFGASSING IN HABITABLE AREAS
- OFFGASSING TESTS FOR SAFETY VALIDATION PRIOR TO STS INTEGRATION
- RIGOROUS MATERIAL SELECTION NEGOTIABLE ALTERNATIVE
- NHB 8060.1 OR STS OPERATOR APPROVED EQUIVALENT TESTS

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

- FAILURE PROPAGATION (206)
  - DESIGN SHALL PRECLUDE PROPAGATION OF FAILURES FROM THE PAYLOAD TO THE ENVIRONMENT OUTSIDE THE PAYLOAD
- REDUNDANCY SEPARATION (207)
  - SAFETY CRITICAL REDUNDANT SUBSYSTEMS ARRANGED SO THAT PROPAGATION OF FAILURE FROM ONE TO THE OTHER IS MINIMIZED

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

LIQUID PROPELLANT PROPULSION SYSTEMS

- PREMATURE FIRING OR ADIABATIC DETONATION IS A CATASTROPHIC HAZARD
- MINIMUM OF THREE MECHANICALLY INDEPENDENT FLOW CONTROL DEVICES IN SERIES AND REMAIN CLOSED UNTIL PAYLOAD AT SAFE DISTANCE
- FLOW CONTROL DEVICE TO ISOLATE TANK(S) FROM DISTRIBUTION SYSTEM - MAY NOT BE OPENED UNDER CERTAIN PROVISIONS
- MIN. OF ONE FLOW CONTROL DEVICE "FAIL SAFE"
- OPENING OF ANY FLOW CONTROL DEVICE SHALL NOT RESULT IN ADIABATIC DETONATION
- SAFE DISTANCE IS 200 FT FOR THRUST ≥ 10 POUNDS
- SAFE DISTANCE CASE-BY-CASE > 10 POUNDS THRUST
- FOR BI-PROPELLANT SYSTEM DEVICES MUST PREVENT PROPELLANT MIXING AND EXPULSION THRU THRUST CHAMBERS
- ELECTRICAL INHIBITS, MONITORING AND SAFING REQUIREMENTS FUNCTION OF PLANNED OPERATION

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

DEPLOYMENT/EXTENSION PREVENTING PAYLOAD BAY DOOR CLOSURE

- HAZARD CONTROLLED BY INDEPENDENT PRIMARY AND BACKUP METHOD
- COMBINATION MUST BE TWO FAILURE TOLERANT

RF ENERGY RADIATION

- CARGO RADIATION IN EXCESS OF "DOORS OPEN" LEVELS IN VOLUME XIV, ATTACHMENT 1 IS CATASTROPHIC
- THREE INDEPENDENT INHIBITS TO RADIATION
- NO COMMAND AND MONITORING REQUIREMENTS FOR THESE INHIBITS

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

- PYROTECHNICS (210)
  - ALL PYRO SUBSYSTEMS AND DEVICES SHALL MEET MIL - STD - 1512

  CATASTROPHIC HAZARDS
  - SPECIAL SAFETY REQUIREMENTS TO DEMONSTRATE THAT DEVICES ARE NOT SUSCEPTIBLE TO PREMATURE FIRING FROM ELECTROSTATIC DISCHARGE
  - EXCEPTION WHEN SAFE AND ARM REMAINS SAFE UNTIL PAYLOAD IS A SAFE DISTANCE

  NASA STANDARD INITIATORS
  - FULLY COMPLY WITH SPECIAL REQUIREMENTS AND REQUIRE NO FURTHER DEMONSTRATION

  TRANSITION PAYLOADS
  - NSI PREFERRED
  - EQUIVALENT CRITERIA AND DEMONSTRATION REQUIREMENTS FOR ALTERNATE INITIATORS
    - EACH INITIATOR MUST PASS MIL-STD-1512 ELECTROSTATIC DISCHARGE TEST WITHOUT A RESISTOR IN FIRING CIRCUIT
    - ANY FAILURE REJECTS ENTIRE LOT UNLESS SHOWN TO BE AN ISOLATED CASE (WAIVER REQUIRED)

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

- PYROTECHNICS (CONT'D)

  TRANSITION PAYLOADS (CONT'D)
  - SINGLE BRIDGEWIRE CONFIGURATION PREFERRED
  - DUAL BRIDGEWIRE REQUIRES ELECTROSTATIC TESTS BETWEEN BRIDGEWIRES AS WELL AS BRIDGEWIRES TO CASE
  - PREFER ELECTROSTATIC PROTECTION FEATURE BE HERMETICALLY SEALED TO INSURE STABILITY IN ALL ENVIRONMENTS
  - IF NOT HERMETICALLY SEALED, TEST TO DEMONSTRATE STABILITY IN ALL ENVIRONMENTS INCLUDING VACUUM
  - DEMONSTRATE ACCEPTANCE DOES NOT DEGRADE ELECTROSTATIC PROJECTION

  NEW PAYLOADS
  - USE NSI INITIATORS OR STS APPROVED ALTERNATIVE

  ELECTRICAL CONNECTION OF PYRO DEVICES
  - IF HAZARDOUS FUNCTION, DESIGN TO BE ELECTRICALLY CONNECTED AFTER INSTALLATION IN ORBITER AND ELECTRICAL INTERFACE VERIFICATION COMPLETED
  - EXCEPTIONS REQUIRE SPECIFIC LAUNCH SITE SAFETY OFFICE APPROVAL

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

- DESTRUCT SYSTEMS (211)
  - USE ONLY WHEN APPROVED BY STS OPERATOR
  - MUST COMPLY WITH HAZARD CONTROL AND HAZARD DETECTION AND SAFING REQUIREMENTS
- RADIATION (212)

  IONIZING RADIATION
  - ALL PAYLOADS THAT CONTAIN, USE, OR GENERATE IONIZING RADIATION SOURCES REQUIRE APPROVAL PRIOR TO USE
  - DATA PER JSC 13830
  - APPROVAL VIA NASA COORDINATOR TO INTERAGENCY NUCLEAR SAFETY PANEL
  - DOD USES THEIR OWN PROCEDURES
  - MUST COMPLY WITH LICENSE REQUIREMENTS AT LAUNCH SITE

  NONIONIZING RADIATION
  - PAYLOADS SHALL NOT EMIT ELECTROMAGNETIC RADIATION (INCLUDING X-RAYS) WHICH PRESENT A HAZARD
  - MAX. ACCEPTABLE CARGO-PRODUCED FIELDS PER VOLUME XIV
  - COMPATIBLE WITH INDUCED ENVIRONMENT PER VOLUME XIV
  - TRANSMITTERS OFF DURING BOOST AND ENTRY

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

- ELECTRICAL SYSTEMS (213)
  - ELECTRICAL POWER DISTRIBUTION DESIGNED SO THAT FAULTS INTERNAL TO PAYLOAD DO NOT DAMAGE STS CIRCUITS
  - DESIGN SO THAT FAULTS DO NOT CREATE IGNITION SOURCES FOR PAYLOAD OR ORBITER MATERIAL
  - WHEN LIGHTNING PROTECTION REQUIRED FOR CATASTROPHIC HAZARD USE JSC 0P530 AS DESIGN GUIDE
- VERIFICATION REQUIREMENTS (214)
  - SAFETY ASPECTS OF HAZARDOUS PAYLOAD EQUIPMENT SHALL BE SATISFACTORILY VERIFIED
  - TEST, ANALYSES AND INSPECTION ARE TECHNIQUES
  - METHODS DOCUMENTED IN SAFETY REVIEWS
- HAZARDOUS PROCEDURES (215)
  - POTENTIALLY HAZARDOUS OPERATIONS SHALL BE IDENTIFIED AND OPERATING PROCEDURES PREPARED FOR ASSEMBLY, TEST AND USE
  - PROCEDURES SHALL BE VERIFIED TO DEMONSTRATE CONTROL OF THE HAZARD

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

- REFLOWN HARDWARE (216)
  - HARDWARE TO BE REFLOWN SHALL BE REVIEWED FOR:
    - CORRECTION OF ANY SAFETY DEFICIENCY ON PREVIOUS MISSIONS
    - SAFETY IMPACT OF ANY CHANGES TO HARDWARE OR PROCEDURES
    - MAINTENANCE AND/OR REFURBISHMENT AFFECTING SAFETY
    - APPROPRIATE DESIGN AND VERIFICATION FEATURES FOR REUSE
    - SAFETY OF REUSE IN VIEW OF WEAROUT OR SUBTLE DEGRADATION (INCLUDING FATIGUE) IN PREVIOUS USE
    - ANY LIMITED LIFE ITEMS THAT MAY AFFECT SAFETY
- EXTRAVEHICULAR ACTIVITY (217)
  - PAYLOADS WHICH PLAN EVA SHALL COMPLY WITH DESIGN REQUIREMENTS OF JSC 30615

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

- SERIES PAYLOADS (218)
  - SERIES PAYLOADS SHALL BE REVIEWED FOR:
    - SAFETY IMPACT OF ALL CHANGES INCLUDING MODIFICATION OF HARDWARE OR PROCEDURES
    - CORRECTION OF ANY SAFETY DEFICIENCIES ON PREVIOUS MISSIONS
    - ANY LIMITED LIFE ITEMS WHICH AFFECT SAFETY
- FLAMMABLE ATMOSPHERES
  - DURING ENTRY, LANDING, OR POSTLANDING (PLANNED OR CONTINGENCY) NORMAL PAYLOAD FUNCTIONS SHALL NOT CAUSE IGNITION OF A FLAMMABLE PAYLOAD BAY ENVIRONMENT THAT MAY RESULT FROM LEAKAGE OR INGESTION OF FLUIDS

SAFETY POLICY & REQUIREMENTS TECHNICAL REQUIREMENTS

SUMMARY

- BASIC APPROACH
  - ESTABLISH FAILURE TOLERANCE FOR HAZARDOUS EVENTS/FUNCTIONS BY INDEPENDENT INHIBITS/DEVICES TO PROTECT AGAINST OCCURRENCE
    - ONE FAILURE TOLERANCE FOR CRITICAL HAZARDS
    - TWO FAILURE TOLERANCE FOR CATASTROPHIC HAZARDS
  - FOR CATASTROPHIC HAZARDS ESTABLISH MONITORING TO ASSURE KNOWLEDGE OF SINGLE FAILURE TOLERANCE TO PERMIT CORRECTIVE ACTION
  - FOR PASSIVE CATASTROPHIC HAZARDS SUCH AS STRUCTURAL FAILURE, FIRE, OR TOXICITY ESTABLISH DESIGN CRITERIA AND MARGIN REQUIREMENTS WHICH PRECLUDE THEIR OCCURRENCE
  - DESIGNED TO MINIMIZE NASA PARTICIPATION IN THE PAYLOAD DEVELOPMENT PROCESS AND STILL PROVIDE CONFIDENCE IN THE SAFETY OF FLIGHT
- LIMITATIONS
  - REQUIREMENTS ARE BASED ON NASA EXPERIENCE WITH CURRENT SPACE DESIGN TECHNOLOGY AND TYPICAL SYSTEMS/SUBSYSTEMS
  - SAFETY ANALYSIS BY THE PAYLOAD DEVELOPER IS REQUIRED TO IDENTIFY AND CONTROL HAZARDS IN ANY SPECIFIC PAYLOAD

PLANETARY PROJECT ASSURANCE

APPLICABILITY

TO SPACE STATION

W. S. SHIPLEY

JUNE 8, 1983

COMMON REQUIREMENTS

- LONG LIFE
- AUTONOMOUS OPERATION
- ENVIRONMENT

LONG LIFE

- CONTROLLED PARTS, MATERIALS & PROCESSES
- REQUIRED MARGINS
- SINGLE FAULT TOLERANT

CONTROLLED PARTS
(ELECTRONIC)

- o SELECTION - STANDARDIZATION
- o CONTROLLED (CONSOLIDATED) PROCUREMENT
- o TRACEABILITY - SCREENING - ΔS
- o FAILURE ANALYSIS

PARTS RADIATION

- o TOTAL DOSE
  - o SELECTION - REQUIREMENT
  - o SURVEILLANCE
- o SINGLE EVENT UPSET
  - o COSMIC RAY, HEAVY IONS, PROTON
  - o ENV. MODELS - DEVICE MODELS
    - o SELECT DEVICES
    - o DEVICE GUIDELINES
    - o ERROR DETECTION, CORRECTION

MIGRATED-GOLD RESISTIVE SHORTS
(MGRS)

- REACTIVE CHEMICAL + WATER + BIAS + TIME = MGRS
- FAILURE MECHANISM DISCOVERED DURING VIKING TESTS
- FAILURE WAS EXPERIENCED IN 0.5% OF THE ICs
- THREE SCREENS WERE REVISED AND APPLIED
  - OUTLIER ANALYSIS OF LEAKAGE CURRENT Δ - VALUES ACROSS BURN-IN,
  - BURN-IN FOR 400 HOURS AT 6°C
  - MAXIMIZE PRELAUNCH OPERATING TIME OF THE HARDWARE
- PRELAUNCH FAILURE EXPERIENCE FOR VOYAGER WAS 0.01%
- EACH VOYAGER HAS 3272 54L ICs
- NO FAILURES HAVE BEEN DETECTED IN MORE THAN 5 YEARS OF FLIGHT

MARGINS

- WORST-CASE CIRCUIT ANALYSIS - VARIABILITY, AGING, RADIATION AND TEMPERATURE
- POWER SUPPLY ANALYSIS
- STRESS RATIOS, MARGINS FOR BOTH ELECTRICAL & MECHANICAL
- TIMING ANALYSES
- VERIFICATION-VOLTAGE/TEMP MARGIN TESTS
  SUBSYSTEM/SYSTEM QUAL & ACCEPTANCE TESTS
  ANALYSIS COMPLETION STATEMENTS

SINGLE FAULT TOLERANCE

- REDUNDANCY - BLOCK
  FUNCTIONAL
- CONTROL SINGLE FAILURE POINT THRU WAIVERS
- VERIFICATION: FMEA
  ELECTRICAL
  PRODUCT

MECHANICAL FMEA
(PRODUCT ANALYSIS)

- USED FOR MECHANICAL DEVICES
- TYPICALLY SINGLE FAILURE POINT
- ACCOUNT FOR EVERY FAILURE MODE TO LOWEST LEVEL OF HARDWARE (FAULT TREE)
- VERIFY AT LEAST ONE INSPECTION TEST OR ANALYSIS AS A PREVENTIVE MEASURE

MECHANICAL FMEA

(EXAMPLE)

ASSEMBLY	SPIN BEARING ASSEMBLY
COMPONENT	ROTARY TRANSFORMER
FAILURE MODE	JAMS
SUB FAILURE MODES	DEBRIS GAP CLEARANCE FERRITE CRACKS
CAUSE OF FAILURE	DEBRIS SILVER SLIVERS BROKEN WIRE CLIPPINGS CLEARANCE RADIAL MISALIGNMENT PART TOLERANCES FERRITE CRACKS PROCESS/MATL AGING BONDING

GALILEO AUTONOMY

- FOCUSED ON ORBITER HEALTH - FAULT PROTECTION
- SYSTEM LEVEL FAULT PROTECTION
  - EMPHASIS ON PROTECTION OF MAJOR SPACECRAFT FUNCTIONS UPLINK, DOWNLINK, POWER STABILITY
- SUBSYSTEM LEVEL FAULT PROTECTION
  - EMPHASIS MAINLY ON MAINTAINING HEALTHY HARDWARE AND SOFTWARE COMPONENTS/SUBASSEMBLIES
- AUTONOMOUS MANAGEMENT DESIGN FEATURES
  - FUNCTIONAL REDUNDANCY
  - BLOCK REDUNDANCY
  - HYBRID (PART CENTRALIZED, PART DISTRIBUTED) CONTROL
  - MISSION PHASE DEPENDENT RESPONSES
  - CRITICAL SEQUENCE ROLL BACK
  - TRANSIENT INPUT FILTERING
  - GRACEFUL DEGRADATION OF SPACECRAFT PERFORMANCE
  - DATA RELATIVE TO PERFORMANCE OF AUTONOMOUS CONTROL PROVIDED FOR GROUND ANALYSIS

AUTONOMOUS OPERATION

- FAULT PROTECTION
  - GROUND-CREW INDEPENDENT FOR X DURATION
  - HARDWARE PROVIDES POTENTIAL TO BE AT LEAST SINGLE FAILURE POINT TOLERANT
  - REALIZATION OF THIS POTENTIAL REQUIRES GROUND INTERVENTION OR ON-BOARD INTELLIGENCE
  - PLANETARY OPS COSTS PRECLUDES 24-HR COVERAGE
  - ON-BOARD INTELLIGENCE SUPPLANTS GROUND
- AUTONOMY - ABOVE, + ANY ON-BOARD CONTROL CAPABILITY ENABLING PERFORMANCE ENHANCEMENT

ASSURANCE PROBLEM

- CORRECT UTILIZATION OF HARDWARE IN RESPONSE TO A FAULT
- FREE FROM SOFTWARE INTRODUCED FAULTS
- RELIABILITY FMEA OF FP ALGORITHM
  - EXAMINE EACH PATH OF ALGORITHM
  - VERIFY H/W CONSTRAINTS NOT VIOLATED
  - VERIFY SYSTEM STATE CONSTRAINTS NOT VIOLATED

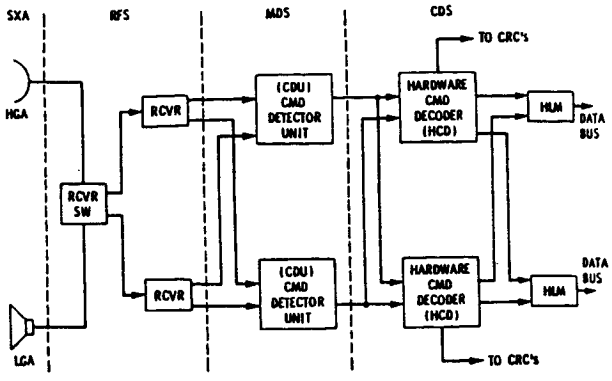
HISTORY OF AUTONOMOUS FEATURES

- EARLY MARINER SPACECRAFT (1960's)
  - DISTRIBUTED CONTROL OF REDUNDANT ELEMENTS
  - CONTROL IN HARDWARE
  - AUTOMATIC ATTITUDE REFERENCE ACQUISITION
  - AUTOMATIC MISSION
- MARINER 9 (1971)
  - EXTENSIVE COMPUTER CONTROLLED SEQUENCING
- VIKING ORBITERS (1975)
  - CENTRALIZED CONTROL OF REDUNDANT ELEMENTS
  - ACCESS TO SPACECRAFT TELEMETRY STREAM
  - AUTONOMOUS FEATURES ENHANCE MISSION AND REDUCE OPERATIONS COSTS

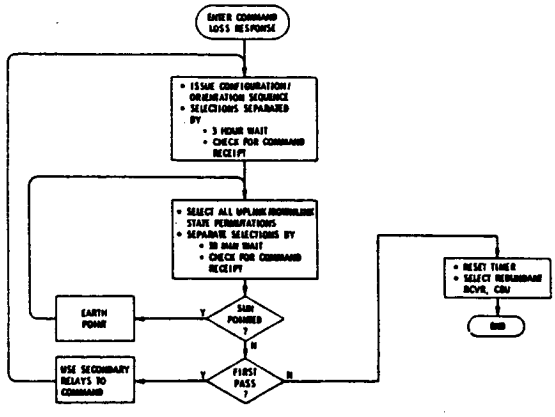
COMMAND LOSS RECOVERY ALGORITHM

- <u>FAULTS PROTECTED</u>
  - FAILURE TO RECEIVE GROUND COMMANDS
    - H/W FAILURES IN RFS, MDS
    - ORIENTATION ANOMALIES
- <u>CONSEQUENCES IF NOT PROTECTED</u>
  - LOSS OF UPLINK. CATASTROPHIC
- <u>SUSCEPTIBILITY</u>
  - ANYTIME DURING MISSION

COMMAND FLOW BLOCK DIAGRAM



COMMAND LOSS RESPONSE SUMMARY FLOWCHART



COMMAND LOSS RECOVERY

MONITOR

FUNCTION: MONITOR OCCURRENCE OF UPLINK ACTIVITY

- CDS H/W
  - UPLINK MESSAGES DECODED BY HARDWARE COMMAND DECODERS (HCD)
    - MESSAGES STORED IN COMMAND BUFFERS
    - STATUS FLAGS SET
- CDS S/W
  - S/W DETERMINES RECEIPT OF VALID COMMANDS
  - SENDS INDICATION TO F/P
- F/P
  - "TIMER" RESET TO A GROUND-SUPPLIED VALUE UPON COMMAND RECEIPT (VALUE IN HOURS FOR GROUND CONVENIENCE)
  - IF TIME "ELAPSES" INITIATE RESPONSE

COMMAND LOSS RECOVERY

RESPONSE

- OVERVIEW

  ALGORITHM AUTOMATICALLY:
  - SELECTS A H/W CONFIGURATION OR A S/C ORIENTATION
  - WAITS FOR A PRE-SPECIFIED PERIOD
  - CHECKS FOR COMMAND RECEIPT
    - IF A VALID COMMAND IS RECEIVED, TERMINATE RESPONSE
    - IF NO COMMAND RECEIVED, SELECT NEXT CONFIGURATION
- APPROACH
  - SELECT MOST LIKELY FAILURES/MOST BENIGN RESPONSES FIRST
  - CERTAIN CLASSES OF "MULTIPLE FAILURES" COVERED

COMMAND LOSS RECOVERY

RESPONSE (CONT'D)

PART I: ORIENTATION AND CONFIGURATION SEQUENCE:

ALG. ACTION	RATIONALE
1) TURN OFF AUXILIARY FUNCTIONS (DOR, X-BAND UPLINK, S-, X- RANGING, TWNC)	o MINIMIZE INTERFERENCE WITH UPLINK SIGNAL
2) SELECT LGA	o LARGER BEAM WIDTH TO CORRECT ORIENTATION PROBLEMS
3) SUN POINT	o ORIENTATION ANOMALIES CORRECTED
4) SELECT CDU-B	o H/W FAILURE
5) SELECT RCVR-2	o H/W FAILURE
6) SELECT REDUNDANT S-EXC, X-EXC, TMU	o RECEIVER LOCKED ON A DOWNLINK SIGNAL

- 3 HOUR WAIT BETWEEN SELECTIONS

COMMAND LOSS RECOVERY

RESPONSE (CONT'D)

PART II: "MULTIPLE FAILURE" PROTECTION

ALG SELECTS ALL UPLINK STATE PERMUTATIONS FOR EACH DOWNLINK STATE PERMUTATION

UPLINK STATES	DOWNLINK STATES
1) HGA SELECT	1) NO OP (DUMMY COMMAND)
2) CDU-A SELECT	2) USO OFF
3) LGA SELECT	3) TMU OFF
4) RCVR-1 SELECT	4) S-BAND LOW PWR SELECT
5) HGA SELECT	5) X-BAND LOW PWR SELECT
6) CDU-B SELECT	6) S-BAND TWTA OFF X-BAND TWTA OFF S-BAND EXC OFF
7) LGA SELECT	7) S-BAND EXC ON S-BAND TWTA ON X-BAND TWTA ON
8) RCVR-2 SELECT	
9) HGA SELECT	

NOTE: 9 x 7 SELECTIONS @ 30 MIN. EACH

COMMAND LOSS RECOVERY

RESPONSE (CONT'D)

PART III. ALGORITHM:

- o CHANGES FROM SUN POINT TO EARTH POINT
  REPEATS UPLINK AND DOWNLINK CYCLING
- o REPEATS ENTIRE RESPONSE USING SECONDARY RELAYS
- o FINALLY, ALGORITHM:
  - o SELECTS RCVR-2 AND CDU-B
  - o SETS TIMER TO GROUND SUPPLIED VALUE
  - o EXITS RESPONSE
    - o RESPONSE RE-ENTERED IF NO MESSAGE RECEIVED AFTER A FULL CYCLE

COMMAND LOSS RECOVERY

S/C IMPACT

- o RADIOMETRIC COMMUNICATIONS OFF AND/OR
- o CHANGE IN S/C ORIENTATION AND/OR
- o EXTENSIVE CYCLING OF UPLINK AND DOWNLINK ELEMENTS
  - o NOTE: DOWNLINK LOSS KEPT TO A MINIMUM

GROUND IMPACT/RESPONSIBILITIES

- o CHANGE THE "TIMER" VALUE WHENEVER NECESSARY
- o UPDATE ALGORITHM FOLLOWING COMPONENT FAILURES

MISSION PHASE DEPENDENCY

- o NONE

F A U L T P R O T E C T I O N

SOFTWARE ASSURANCE

S/W FMEA AND DESIGN REVIEW OF FP ALGORITHMS

- CORRELATE CRITICAL S/C FUNCTIONS & OPERATIONAL MODES WITH DESIGN APPROACH OF FP ALGORITHMS
- VERIFY FP ALGORITHMS ARE CONSISTENT WITH PROJECT AND SYSTEM REQUIREMENTS, INCLUDING S/S REDUNDANCY
- VERIFY FP ALGORITHMS DO NOT INTRODUCE POTENTIALLY CATASTROPHIC FAILURE MODES
- EXAMINE THE FAILURE MODES OF THE FP SOFTWARE

EXAMINATION PROCEDURE (1)

INPUT DATA

FP ALGORITHM DESCRIPTION
625-205 GLL FUNCTIONAL REQUIREMENTS
H/W FMEA
RELATED SUBSYSTEM AND FUNCTION DOCUMENTATION
VERBAL EXPLANATIONS AND DESCRIPTIONS

EXAMINATION PROCEDURE (2)

DETERMINE THE PROTECTED FUNCTION'S CHARACTERISTICS

- INPUTS (NORMAL)
- PROCESSES
- OUTPUTS (NORMAL)

TABULATE POSSIBLE FUNCTION FAILURES AND APPARENT FAILURES

- CAUSE
- SYMPTOM
- LOCAL IMPACT
- MISSION IMPACT

DETERMINE F-P RESOURCES

- REDUNDANT H/W
- F-P H/W (SWITCHES, SENSORS)
- ALGORITHM
  SCOPE TBDs AND MISSING ITEMS
  WALK THROUGH THE STEPS

EXAMINATION PROCEDURE (3)

SUMMARIZE INTO REPORT

- H/W
- NORMAL FUNCTION
- FAILURES
- FP H/W
- FP ALGORITHM
- FP FAILURES

FAILURE MODES AND EFFECTS ANALYSIS

REVIEW THE REPORT WITH H/W ENGINEERS

AMEND AND ISSUE REPORT

REPORTABLE ITEMS

- O IMPROPER IDENTIFICATION OF AND/OR RESPONSE TO A SINGLE POINT FAILURE
- O ANY DANGEROUS RESPONSE
- O FORMAL VIOLATION OF REQUIREMENTS
- O UNNECESSARY DEGRADATION OF S/C PERFORMANCE
- O INCORRECT OR INCONSISTENT STATEMENTS IN F-P DOCUMENTATION
- O RISKY DESIGN/CODING PRACTICES
- O IMPROPER DOCUMENTATION PRACTICES

EXAMPLES OF PROBLEMS DETECTED (1)

IMPROPER IDENTIFICATION/RESPONSE - OVERPRESSURE

- o A TEMPERATURE RISE CAN CAUSE AN IMPROPER IDENTIFICATION OF A RPM REGULATOR LEAK FAILURE AND THE SUBSEQUENT IRREVOCABLE FIRING OF A PYRO.

DANGEROUS RESPONSE - OVERPRESSURE

- o IF THE OVERPRESSURE RESPONSE OCCURS DURING LAUNCH (IMMEDIATELY AFTER BEING ENABLED), IT WILL TURN OFF PSU-1. THE LAUNCH SEQUENCE WILL ASSUME PSU-1 IS STILL ON.

REQUIREMENT VIOLATION - CMD LOSS

- o THE COMMAND LOSS FP ALGORITHM IS REQUIRED TO PROVIDE UPLINK IF THERE IS ANY CHAIN OF COMPONENTS AND RELAYS THAT WILL ALLOW IT. SOME QUADRUPLE-POINT (!) FAILURES ARE NOT PROTECTED AGAINST.

EXAMPLES OF PROBLEMS DETECTED (2)

DEGRADATION OF PERFORMANCE - UNDERVOLTAGE

- o THE DIODE UNSHORT ROUTINE OF UNDERVOTAGE RECOVERY DOES NOT SHORT OUT THE DIODES ASSOCIATED WITH THE GOOD RTG IN SOME CIRCUMSTANCES.

INCONSISTENT DOCUMENTATION - RF LOSS

- o IN DOWNLINK, THE CHART RESPONDS ON FOURTH INSTANCE OF BAD STATUS, THE TEST RESPONDS ON THE THIRD. THE CHART COUNTS THE NUMBER OF TIMES A RESPONSE APPEARS TO BE NEEDED, THE TEXT COUNTS THE NUMBER OF TIMES A BAD STATUS EVENT WAS DETECTED.

RISKY CODE - CMD LOSS

- o THE PARAMETER CMDRST OF COMMAND LOSS IS USED FOR 2 POSSIBLY DISTINCT PURPOSES.

DOCUMENTATION PRACTICES - ALERT CODES

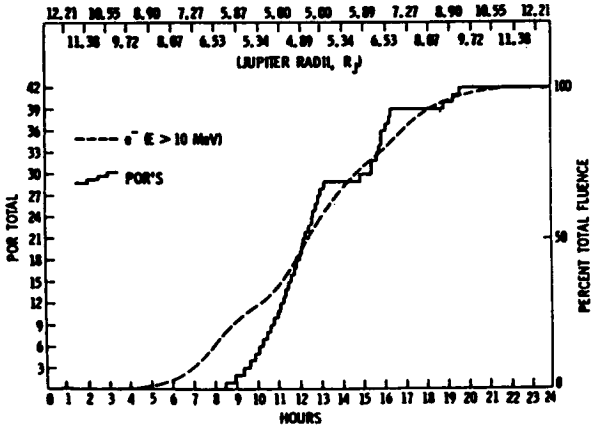
- o THE INTEGRATION AND INTERACTION OF AACS ALERT CODES MONITOR WITH OTHER FP ALGORITHMS IS NOT STATED. THE BIT FLIP ALERT CODE RESPONSE IS TBD.

ENVIRONMENT

ELECTRICAL INTERACTIONS

- ATS EXPERIENCE
- VGR DISCHARGE PROTECTION
  - CONDUCTIVE COATINGS
  - GROUND ALL BODIES 3 MILI JOULES
  - FARADAY CAGE FOR AVIONICS
  - FILTER SUBSYSTEM/SUBSYSTEM INTERFACE AND LINES TO TRANSDUCERS

CORRELATION OF POR'S WITH HIGH ENERGY ELECTRON FLUENCE



VOYAGER-GALILEO

ESD HERITAGE

- MULTIPOINT - LOCAL BLANKET TO STRUCTURE GNDS
- CONDUCTIVE COATINGS FOR CHARGE BLEED OFF
- LOCAL GNDING SUBSYSTEMS TO STRUCTURE
- DOUBLE AND TRIPLE SHIELDED WIRING & GROUNDING
- GNDING SHIELDS AT ENTRANCE TO BUS CAVITY
- FILTER SENSITIVE CIRCUITS
- SPATIAL SEPARATED CABLING FOR INTERNAL AND EXTERNAL FUNCTIONS
- ADEQUATE BLEED PATHS FOR TRACES & SPOT SHIELDS

ELECTRICAL INTERACTIONS FOR SPACE STATIONS

- LARGE, MANNED STRUCTURES - COMPLEX INTERACTIONS WITH THE ENVIRONMENT.
- NO ADEQUATE TECHNOLOGY BASE CURRENTLY EXISTS FOR EVALUATING MANY OF THESE INTERACTIONS.
- KEY TECHNICAL AREAS OF CONCERN ARE:
  - SPACE VEHICLE STATIC CHARGE BUILDUP (INTERNAL/EXTERNAL)
  - EXPOSED, HIGH POTENTIAL SURFACE INTERACTIONS
  - LONG TERM CHANGES IN ELECTRICAL PROPERTIES DUE TO RADIATION DAMAGE
  - LOGIC UPSETS/RESETS
  - ENHANCED ARTIFICIAL CONTAMINATION RATES DUE TO CHARGING
  - INDUCED ELECTRIC FIELDS IN LARGE STRUCTURES
- PROGRAMMATIC CONCERN:
  - UNIFORM DESIGN AND QUALIFICATION PROGRAM CROSS ALL CENTERS

NASA
National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston Texas 77058

JSC 18981

NASA Preliminary Approach to Space Station Reliability-Maintainability

JOSEPH H. LEVINE

Presented at Mission Assurance Conference and Workshop, Los Angeles Airport, Hyatt Hotel, June 7-9, 1983

Scope of Paper

- SPACE STATION STUDY CONTRACTS
- TRADE DRIVERS
- COMPARISON BETWEEN SPACE SHUTTLE (RELIABILITY-MAINTAINABILITY) REQUIREMENTS AND PROPOSED SPACE STATION RELIABILITY-MAINTAINABILITY REQUIREMENTS
- SPACE STATION RELIABILITY-MAINTAINABILITY STATE-OF-THE-ART
- SPACE STATION RELIABILITY-MAINTAINABILITY DISCIPLINE IMPLEMENTATION
- CONCLUSIONS

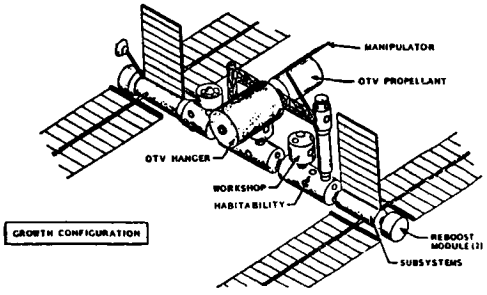
Mission Analysis Studies

- EIGHT $787,500 STUDIES TO ANALYZE THE SCIENCE, APPLICATIONS, TECHNOLOGY DEVELOPMENT, NATIONAL SECURITY AND SPACE OPERATIONS MISSIONS THAT REQUIRE OR WOULD MATERIALLY BENEFIT FROM A PERMANENT SPACE STATION IN LOW EARTH ORBIT
- CONTRACTORS: BOEING, GENERAL DYNAMICS, GRUMMAN, LOCKHEED, McDONNELL DOUGLAS, MARTIN MARIETTA, ROCKWELL, AND TRW
- EMPHASIS ON USER COMMUNITIES, ARCHITECTURE NOT CONFIGURATION
- SCHEDULE

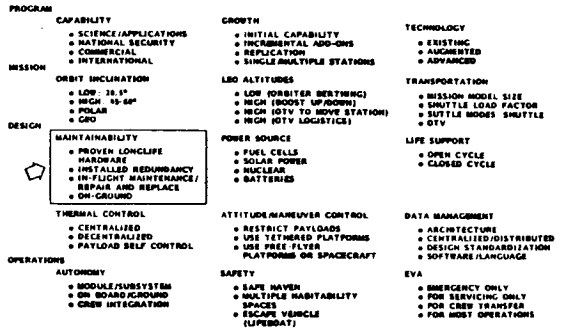
RFP RELEASED	JUNE 20, 1982
CONTRACTS SIGNED	AUGUST 20, 1982
MID-TERM BRIEFINGS	NOVEMBER 15-18, 1982
FINAL BRIEFINGS	RESCHEDULED FOR APRIL 5-8, 1983
FINAL REPORTS	APRIL 22, 1983

- PARTICIPATION BY DOD
- SIMILAR STUDIES BY ESA, JAPAN, AND CANADA
- STUDIES WILL BE INTEGRATED BY NASA INTO SINGLE SET OF TIME-PHASED MISSION OBJECTIVES AND CORRESPONDING SPACE STATION REQUIREMENTS, FROM WHICH ARCHITECTURAL OPTIONS WILL BE DERIVED

Space Station Concept



Trade Drivers



Reliability-Maintainability Requirements Comparison Between Space Shuttle and Proposed Space Station

Space Shuttle Reliability-Maintainability Requirements

- INFLUENCED BY PREVIOUS MANNED SPACE PROGRAMS AND FIVE IMPORTANT POINTS:
  - THE SPACE SHUTTLE PROGRAM WAS DESIGNED TO BE AN OPERATIONAL PROGRAM, FOLLOWING THE COMPLETION OF FOUR SUCCESSFUL TEST FLIGHTS
  - MOST OF THE HARDWARE WAS DESIGNED FOR REUSE FOR UP TO 100 MISSIONS AND 10-YEAR LIFE REQUIREMENTS WITH THE EXCEPTION OF THE EXTERNAL TANKS AND THE SOLID ROCKET BOOSTERS, THE LATTER OF WHICH HAVE A 20-MISSION LIMITATION.
  - THE PREVENTION OF FLIGHT FAILURES WAS GIVEN THE SAME EMPHASIS AS IT WAS IN THE PREVIOUS MANNED SPACECRAFT.
  - THE GROUND TEST AND ANALYSIS PROGRAM WAS ALSO DESIGNED TO PROVIDE MAXIMUM CONFIDENCE FOR EACH MANNED FLIGHT AS IT WAS IN THE PREVIOUS MANNED SPACECRAFT PROGRAMS.
  - ALTHOUGH IN-FLIGHT MAINTENANCE WAS CONSIDERED IN THE DESIGN OF THE SPACE SHUTTLE, IT WAS DISCARDED MAINLY FOR REASONS SIMILAR TO THOSE NOTED IN THE PREVIOUS MANNED SPACECRAFT PROGRAMS: I.E., EQUIPMENT COMPLEXITY AND ADDED CREW TASKS.
  - SPACE SHUTTLE REDUNDANCY REQUIREMENTS FAIL-SAFE AS MINIMUM WITH THE EXCEPTION OF AVIONICS WHICH HAS A REQUIREMENT OF FAIL-OPERATIONAL/FAIL-SAFE.

Space Shuttle Reliability Specification

- PERMITTED THREE-PHASE RELIABILITY APPROACH
  - PREVENTATIVE DISCIPLINES (PLANS, TRADE STUDIES, FAILURE MODES AND EFFECTS ANALYSIS; PARTS AND MATERIALS; AND LIMITED LIFE CONTROLS)
  - APPRAISAL DISCIPLINES (TESTS AND MILESTONE REVIEWS)
  - REMEDIAL DISCIPLINES (PROBLEM REPORTING AND CORRECTIVE ACTION AND GIDEP ALERTS)
- BASIC REQUIREMENTS DESCRIBED IN SAFETY, RELIABILITY, MAINTAINABILITY AND QUALITY PROVISIONS FOR THE SPACE SHUTTLE PROGRAM. RELIABILITY AND QUALITY ASSURANCE PUBLICATION, NASA NHB 5300.4(1D-2), OCTOBER 1979

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Space Shuttle Reliability-Maintainability Requirements

- RELIABILITY REQUIREMENTS - IN ACCORDANCE WITH NHB 5300.4(1D-2)
  - REDUNDANCY REQUIREMENTS
    - ALL VEHICLE SUBSYSTEMS NOT LESS THAN FAIL SAFE
    - EXCEPT PRIMARY STRUCTURE, THERMAL PROTECTION, PRESSURE VESSELS - COVERED BY DESIGN FEATURES
- MAINTAINABILITY REQUIREMENTS - IN ACCORDANCE WITH NHB 5300.4(1D-2)
  - ACHIEVE 160-HOUR TURNAROUND CAPABILITY THROUGH MAINTAINABILITY DESIGN AND EVOLUTION OF OPERATIONAL TECHNIQUES
- DEFINITIONS
  - FAIL SAFE - THE ABILITY TO SUSTAIN A FAILURE AND RETAIN THE CAPABILITY TO SUCCESSFULLY TERMINATE THE MISSION
  - FAIL OPERATIONAL - THE ABILITY TO SUSTAIN A FAILURE AND RETAIN FULL OPERATIONAL CAPABILITY FOR SAFE MISSION CONTINUATION
  - USEFUL LIFE - THE SHUTTLE SYSTEM SHALL OPERATE FOR A MINIMUM OF 10 YEARS

Space Station Reliability-Maintainability Requirements

- SPACE STATION RELIABILITY-MAINTAINABILITY REQUIREMENTS INFLUENCED BY THE PREVIOUS MANNED SPACECRAFT REQUIREMENTS
- SPACE STATION RELIABILITY-MAINTAINABILITY REQUIREMENTS INFLUENCED BY FIVE IMPORTANT POINTS:
  - THE SPACE STATION IS A LOW-EARTH ORBIT FACILITY THAT WILL OPERATE WITH COMPLEMENTARY, INTERFACING SPACE SYSTEM THAT WILL SUPPORT VARIOUS MANNED AND UNMANNED SPACE OPERATIONS
  - THE SERVICES AND EQUIPMENT PROVIDED BY THE SPACE STATION WILL INCLUDE PROVISIONS FOR THE MAINTENANCE, CHECKOUT, AND STORAGE OF SPACE HARDWARE AND CONSUMABLES
  - THE SPACE STATION REQUIREMENTS WILL INCLUDE INTERFACES WITH THE SPACE TRANSPORTATION SYSTEM, ORBIT TRANSFER SYSTEMS, UNMANNED PLATFORMS, FREE-FLYING SATELLITES, AND OTHER RELATED ELEMENTS
  - THE SPACE STATION WILL BE ASSIGNED AN INDEFINITE OPERATIONAL LIFETIME; I.E., ITS PROVISIONAL AND CHANGEOUT CAPABILITY WILL ALLOW IT TO REMAIN OPERATIONAL INDEFINITELY AS NEEDS DEMAND
  - PAYLOADS WILL BE OPTIMIZED IN TERMS OF CREW INVOLVEMENT

Space Station Reliability-Maintainability Requirements

- RELIABILITY REQUIREMENTS - IN ACCORDANCE WITH NHB 5300.4(TBD)
  - REDUNDANCY REQUIREMENTS
    - ALL VEHICLE SUBSYSTEMS NOT LESS THAN FAIL OPERATIONAL/FAIL SAFE
    - OPERATIONAL STATUS OF REDUNDANT FUNCTIONAL PATHS OR SUBSYSTEMS CAN BE VERIFIED WITHOUT REMOVAL OF ORU's (ORBITAL REPLACEMENT UNITS)
- MAINTAINABILITY REQUIREMENTS - IN ACCORDANCE WITH NHB 5300.4(TBD)
  - CAPABILITY TO PERFORM MAINTENANCE AND REPAIR ON-ORBIT
  - OVERALL OPERATIONS NOT SUBSTANTIALLY DEGRADED BY SELECTED REPAIR MODES
  - FAILURE MODES AFFECTING CREW SAFETY OR STATION SURVIVAL CONTROLLED BY CREW PREVENTIVE OR CORRECTIVE MAINTENANCE
  - PROVIDE ONBOARD CRITICAL SPARES AND HARDWARE MAINTENANCE CAPABILITY
- DEFINITIONS
  - FAIL SAFE - THE ABILITY TO SUSTAIN A FAILURE AND RETAIN THE CAPABILITY TO SUCCESSFULLY TERMINATE THE MISSION
  - FAIL OPERATIONAL - THE ABILITY TO SUSTAIN A FAILURE AND RETAIN OPERATIONAL CAPABILITY FOR SAFE MISSION CONTINUATION
  - SYSTEM LIFE - AN INDEFINITE OPERATIONAL LIFETIME WITH PROVISIONAL AND CHANGEOUT CAPABILITY. INDIVIDUAL SUBSYSTEMS DESIGNED FOR A LIFE (WITHOUT MAINTENANCE) OF TBD YEARS

Space Station Program Description Documents "Yellow Books"

BOOK 1 - INTRODUCTION/SUMMARY
BOOK 2 - MISSION DESCRIPTION
BOOK 3 - SYSTEM REQUIREMENTS AND CHARACTERISTICS
BOOK 4 - TECHNOLOGY OPTIONS
BOOK 5 - SYSTEM DEFINITION
- SYSTEM TRADES AND PERFORMANCE ENVELOPE
- ARCHITECTURE
- CONFIGURATIONS

BOOK 6 - SYSTEMS OPERATIONS
BOOK 7 - PROGRAM PLAN
- MANAGEMENT STRUCTURE
- PROCUREMENT
- COST/SCHEDULE

Space Station Reliability-Maintainability State-of-the-Art Major Technology Drivers

- RELIABILITY-MAINTAINABILITY INTEGRATION
- LONG-LIFE ASSURANCE REQUIREMENTS
- EEE (ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL) PARTS CONTROL REQUIREMENTS

Reliability-Maintainability Integration

- RELIABILITY-MAINTAINABILITY BE CLOSELY INTEGRATED FOR SPACE STATION DESIGN
- MAJOR CONCERN FOR SPACE SHUTTLE MAINTAINABILITY IS ACHIEVING TURNAROUND GOAL IN CONTRAST TO SPACE STATION REQUIREMENTS FOR ON-ORBIT MAINTENANCE AND REPAIR AND CONTINUED OPERATIONS OF CRITICAL SPACE STATION SUBSYSTEMS DURING MAINTENANCE AND REPAIR
- CHALLENGE AHEAD IS TO DEVISE RELIABILITY-MAINTAINABILITY TECHNIQUES TO RESPOND TO SPACE STATION RELIABILITY-MAINTAINABILITY NEEDS
- SOME EXPERIENCE AVAILABLE FOR EVALUATION AND APPLICATION (E.G., SPACE TELESCOPE)
- SOFTWARE RELIABILITY TECHNIQUES NEEDED

Long-Life Assurance Requirements

- SYSTEM LIFE IS AN IMPORTANT FACTOR IN SPACE STATION DESIGN INDEFINITE OPERATIONAL LIFETIME SPECIFIED FOR SPACE STATION
- LONG-LIFE NEEDED FOR SUBSYSTEMS TO PERMIT FLIGHTCREW NOT TO BE BURDENED WITH MAINTENANCE
- SOME STUDIES ACCOMPLISHED IN DETERMINING LONG-LIFE APPROACHES - UPDATE REQUIRED SINCE PERFORMED IN 1972 IN FIVE VOLUMES
  - VOLUME I - SUMMARY OF LONG-LIFE ASSURANCE GUIDELINES
  - VOLUME II - LONG-LIFE ASSURANCE STUDIES OF EEE PARTS AND PACKAGING
  - VOLUME III - LONG-LIFE ASSURANCE STUDIES OF COMPONENTS
  - VOLUME IV - SPECIAL LONG-LIFE ASSURANCE STUDIES
  - VOLUME V - LONG-LIFE ASSURANCE TEST AND STUDY RECOMMENDATIONS

Summary of Long-Life Assurance Study

- PURPOSE
  - TO ESTABLISH COMPREHENSIVE GUIDELINES FOR ACHIEVING LONG-LIFE RELIABLE HARDWARE (1972 STUDY)
- SCOPE
  - A DETAILED REPORT ON EACH OF THE FOLLOWING
    - INTEGRATED CIRCUITS
    - HYBRID CIRCUITS
    - TRANSISTORS
    - DIODES
    - RESISTORS
    - RELAYS
    - SWITCHES
    - CIRCUIT BREAKERS
    - TRANSDUCERS
    - BATTERIES
    - MOTORS
    - TEMPERATURE CYCLING
    - BEARINGS
    - ACCELEROMETERS
    - GYROSCOPES
    - TAPE RECORDERS
    - VALVES
    - PRESSURE VESSELS
    - PUMP AND COMPRESSORS
    - ELECTRONIC PACKAGING
    - SYSTEMS DESIGN USAGE FACTORS
    - ACCELERATED TESTING
    - SCREENING
    - DERATING

Summary of Reliability-Maintainability Discipline Potential Changes for Space Station

RELIABILITY-MAINTAINABILITY DISCIPLINES	RELIABILITY-MAINTAINABILITY POTENTIAL CHANGES FOR SPACE STATION
• RELIABILITY MANAGEMENT	• INCORPORATE PLANNING TO INTEGRATE MAINTAINABILITY IN RELIABILITY APPROACH; i.e., ONE RELIABILITY-MAINTAINABILITY PLAN, AND A SOFTWARE RELIABILITY APPROACH
• NUMERICAL TRADE STUDIES	• INCORPORATE RELIABILITY-MAINTAINABILITY IN ALL TRADE STUDIES AS REQUIRED. USE NUMERICAL PROBABILISTIC APPROACHES WHERE CREDIBLE
• FMEA (FAILURE MODES AND EFFECTS ANALYSIS)	• MODIFY THE FMEA AND CRITICAL ITEMS LIST TO INCORPORATE MAINTAINABILITY REQUIREMENTS AND RETENTION RATIONALE
• PARTS CONTROL	• CONDUCT TRADE STUDY AS TO LEVEL OF PARTS REQUIRED AND APPROPRIATE PROCUREMENT APPROACH
• MATERIALS CONTROL	• CONDUCT TRADE STUDY AS TO TECHNIQUE NEEDED TO CONTROL FLAMMABLE MATERIALS FOR SPACE STATION
• MAINTAINABILITY ANALYSES	• PREPARE SPECIAL MAINTAINABILITY ANALYSES INTEGRATED WITH THE RELIABILITY ANALYSES
• LIMITED LIFE CONTROL	• INCORPORATE THIS TASK INTO THE MAINTAINABILITY APPROACH
• TEST CONTROL	• CONDUCT TRADE STUDY TO EVALUATE OVERALL TEST APPROACH FROM ORU ACCEPTANCE TO INTEGRATED MODULE PREFLIGHT AND IN-FLIGHT CHECKOUT INCLUDING SIGNIFICANCE
• MILESTONE REVIEWS	• EVALUATE PRESENT METHOD OF CONTROLLING MILESTONE REVIEWS AND INCREASE MODE PARTICULARLY AT CONTRACTOR SUPPLIER REVIEWS
• PROBLEM REPORTING AND CORRECTIVE ACTION	• MODIFY PROBLEM REPORTING AND CORRECTIVE ACTION FORMAT TO ASSURE MAINTAINABILITY CORRECTIVE ACTION AS APPROPRIATE
• CHIEF ALERTS	• OBTAIN MORE RAPID RESPONSE ON ALERTS WHERE POTENTIAL USAGE IS INVOLVED

EEE Parts Control

- SPACE SHUTTLE DESIGNED WITH EEE PARTS TECHNOLOGY OF 1970'S - HYBRIDS, DISCRETES, SOLID-STATE RELAYS, IC'S (INTEGRATED CIRCUITS), AND REDUCED USE OF ELECTROMECHANICAL RELAYS
- SPACE STATION TO BE DESIGNED WITH EEE PARTS TECHNOLOGY OF 1980'S-HYBRIDS, LARGE SCALE IC'S, SOLID-STATE RELAYS, FEWER DISCRETES, REDUCED USE OF ELECTROMECHANICAL RELAYS
- PROCUREMENT APPROACH REQUIRES CAREFUL CONSIDERATION AS TO LEVEL OF PARTS AND CONTROL TECHNIQUES

Results of Visits to Space Station Study Contractors

- VISITS MADE TO THE MAJORITY OF SPACE STATION STUDY CONTRACTORS TO ATTEMPT TO ESTABLISH THE STATE-OF-THE-ART IN RELIABILITY-MAINTAINABILITY INTEGRATION
- SEVERAL OF THE STUDY CONTRACTORS HAD BEEN INVOLVED IN SPACE VEHICLE STUDIES AND PROGRAMS WHERE ON-ORBIT MAINTAINABILITY WAS AN UP-FRONT REQUIREMENT (e.g., SPACE TELESCOPE, ORBITAL TRANSFER VEHICLE)
- THE CONSENSUS FROM ALL SPACE STATION STUDY CONTRACTORS IS THAT THE RELIABILITY-MAINTAINABILITY CONSIDERATIONS AND REQUIREMENTS BE FORMULATED EARLY AND BECOME UP-FRONT REQUIREMENTS
- STUDIES ARE NEEDED TO ASSURE OPTIMUM APPROACHES FOR RECOGNITION OF THE HIGH DEMAND ON CREW TIME

Space Station Reliability-Maintainability Discipline

- RELIABILITY-MAINTAINABILITY METHODS REQUIRE CLOSE EXAMINATIONS (E.G., FMEA MODIFIED TO INCLUDE MAINTAINABILITY CONSIDERATIONS)
- ALTERATIONS MAY BE REQUIRED OF ALL RELIABILITY DISCIPLINES FOR EARLY CONSIDERATIONS OF RELIABILITY-MAINTAINABILITY

Conclusions

- THE EIGHT STUDY CONTRACTS ADDED MATERIALLY TO MISSION DEFINITIONS AND ARCHITECTURAL OPTIONS AND PROVIDED IMPORTANT CONSIDERATIONS FOR RELIABILITY-MAINTAINABILITY
- THE CHALLENGE AHEAD IS TO DEVELOP THE NEEDED RELIABILITY-MAINTAINABILITY TECHNOLOGY TO FULFILL THE SPACE STATION NEEDS

THIRD MISSION ASSURANCE CONFERENCE — SPACE STATION WORKSHOP —

Los Angeles, California

June 7-9, 1983

Harry L. Wolbers, PhD
McDonnell Douglas Astronautics Company
Huntington Beach, California

MCDONNELL DOUGLAS

MISSION ASSURANCE DESIGN FOR MAINTAINABILITY

In designing advanced space systems three factors--(1) performance, (2) cost and (3) risk--should be considered when formulating a design philosophy to deal with the issues of the optimal type, form and extent of on-orbit maintenance.

The designer must base his approach to maintainability on his definition of the performance requirements and operational steps necessary to maintain the system. Are there force or sensory discrimination requirements, transportation requirements, or environmental constraints of temperature, pressure, radiation, etc., that either require or preclude direct human intervention? What implementation concepts on the continuum between direct human intervention at one extreme and completely independent "self healing" systems at the other are feasible? If more than one philosophic approach is applicable, what are the relative costs and risks of each approach?

MCDONNELL DOUGLAS

MISSION ASSURANCE — DESIGN FOR MAINTAINABILITY

Three Factors to Consider

- **Performance —**
  - **Where Along the Continuum From Direct Human Intervention, to Teleoperators, to Remotely Actuated and Controlled Systems, to Independent or Self-Healing Operations, Do the Maintenance Operations Fall?**
- **Cost —**
  - **If Alternative Maintenance Approaches Are Feasible, Which is the Most Cost-Effective?**
- **Risk —**
  - **What is the Success Probability, or Conversely, What is the Risk or Impact of System Failure?**

LOCATIONS WHERE MAJOR MAINTENANCE ACTIVITIES WERE PERFORMED ON SKYLAB

We have learned from the U.S. and Soviet space programs to date that systems can have indefinite operational lifetimes in space if they are designed to permit the contingency of in-orbit repair and maintenance.

Skylab repairs included the release of the Orbital Workshop's solar array that failed to deploy in the launch accident, the assembly and deployment of the large parasol sun shield, installation of the twin pole sun shield, the installation and checkout of a new gyro rate package, the repair of a two-axis gimballed antenna mounted external to the Skylab vehicle on the airlock module truss, and topping into and recharging a cooling system.

PRESENCE OF CREW WAS ESSENTIAL TO SKYLAB MISSION SUCCESS

The repairs, servicing and general maintenance on Skylab involved activities both inside the spacecraft and outside. For these activities, good quality, off-the-shelf hand tools were found to be quite adequate.

With the advent of manned platforms in space there are alternatives to the expensive use of redundant systems to achieve high levels of system reliability. Assurance of space mission success can be achieved by designing systems to be maintained by properly trained and provisioned space crews.

MCDONNELL DOUGLAS

PRESENCE OF CREW WAS ESSENTIAL TO SKYLAB MISSION SUCCESS

- **Assembled and Set Up Equipment**
- **Conducted Pre-Operations Tests (Checkout) of Experiment Equipment**
- **Performed Interactive Operations — Real-Time Display and Data Analysis to Determine Next Operation**
- **Management — Changed Ops Plans Due to "Surprises"**
- **Conducted Malfunction Tests**
- **Maintained and Repaired Subsystems**
- **Modified Instruments**
- **Analyzed and Interpreted Results**
- **Conducted Ground/Space Cooperative Tests**
- **Made Visual Observations — Discrimination**
- **Developed "Work-Arounds" — Heat Shield, Solar Array Deployment**
- **Recovered Payloads**
- **Assembled Large Experiments/Equipment From Parts**
- **Recovered Film**

SPACE PLATFORM

Another example of the impact that direct human intervention could have on the success of future space missions may be drawn from the recently completed Space Platform Study performed by MDAC for NASA/MSFC (Contract NAS8-33955). This study was one of two parallel efforts (the other was performed by the TRW Space Systems Group) to examine alternative system design concepts for an orbital facility that would provide support to the form of electrical power (11.5 to 25 kW), heat rejection, communications, data management and attitude control to a broad range of potential payloads.

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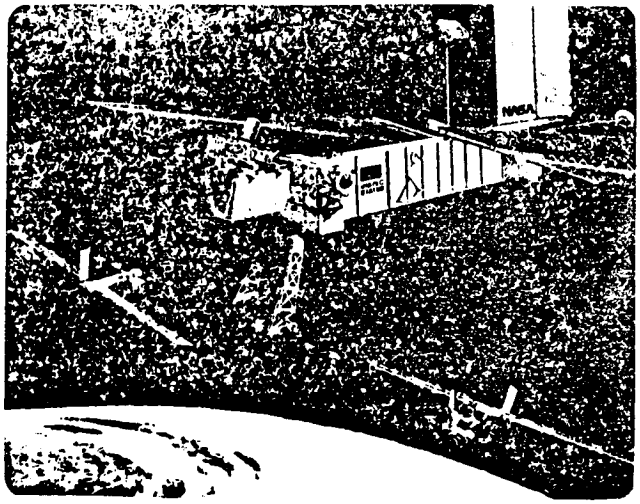
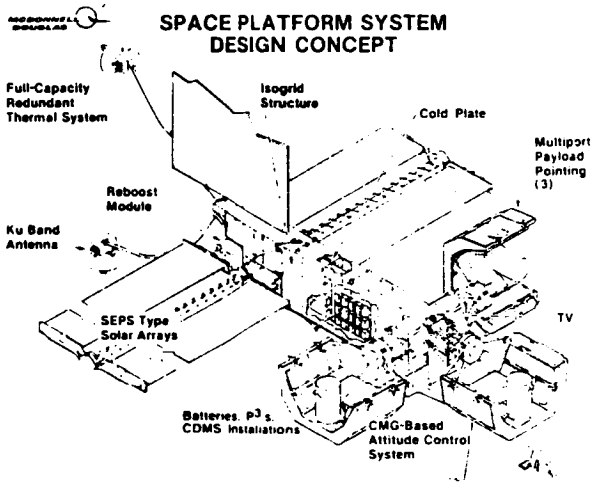


SPACE PLATFORM SYSTEM DESIGN CONCEPT

The Space Platform System was composed of solar arrays and batteries, programmable power processing units (P^3s), command and data management system (CDMS), radiators, payload berthing ports, control moment gyros (CMGs), a separable and replaceable reboost module and Ku-band antennas and equipment.

Payloads delivered by the STS system could be berthed to one of the three active berthing ports. These berthing ports provide the full range of the resources and services required by the pallet-mounted payloads



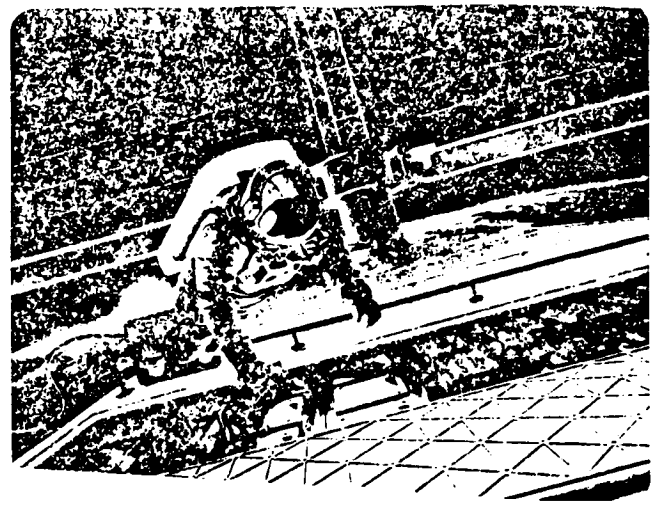
EVA MAINTENANCE AND SERVICING

The Space Platform was designed to be maintained and serviced in orbit by means of EVA. Cover plates on the main body were designed to be opened to provide access to all internally mounted components and handholds and other restraint devices were provided for the EVA crewman.

A series of tests to evaluate the maintenance and servicing concepts for the Space Platform were conducted in the simulated 0-g environment of the Neutral Buoyancy Simulator at NASA/MSFC. The number of tasks selected for evaluation required performing two separate testing sessions in order to determine the feasibility of EVA operations for the individual tasks. The first series of neutral buoyancy tests was performed in August 1982 and included the following tasks:

- Aft payload port deployment/retraction
- Control moment gyro (CMG) exchange
- Manual hand crank appendage deployment

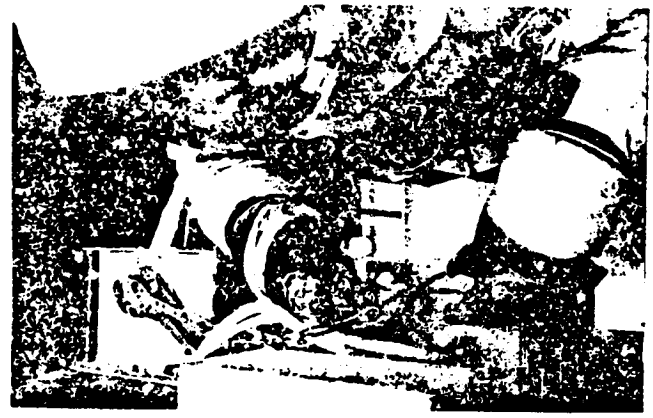
These tasks demonstrated contingency operations involving automatic mechanism overrides as well as an orbital replacement unit (ORU) exchange.



FINE MOTOR ACTIVITIES
NEUTRAL BUOYANCY EVA SIMULATION

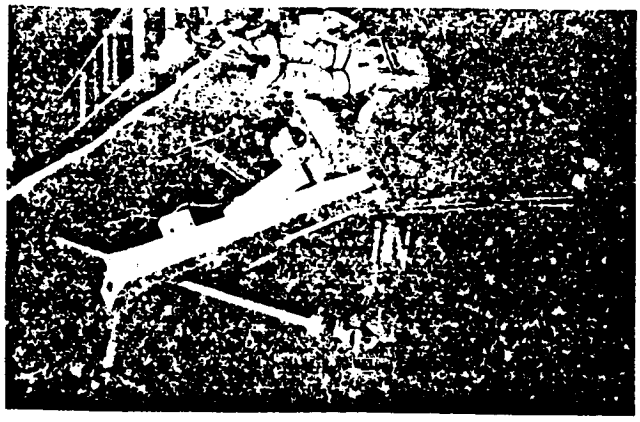
The second series of neutral buoyancy tests performed in November 1982 incorporated tasks designed to test the astronaut's manual dexterity skills in addition to evaluating solar array maintenance operations.

Fine motor activities were examined by exchanging various electrical connectors and black-boxes in a simulated coldplate compartment on the mockup. The coldplate activities involved EVA activation of electrical connectors which previously had not been considered to be EVA compatible. The first of these was the removal/replacement of two rectangular D-series connectors commonly found on communications equipment. In operation the subject easily manipulated the connectors successfully many times with his pressurized-gloved hand. The next task again tested the subjects fine motor skills by requiring the removal/replacement of several circular electrical connectors, both coaxial and multipin bayonet-type connectors. Special tools were developed so that the crewman could manipulate the connectors in a one-hand operation as illustrated. The use of these simple tools showed that extensive capability potentially exists in EVA to perform on-orbit refurbishment activities if the proper accommodations are provided.

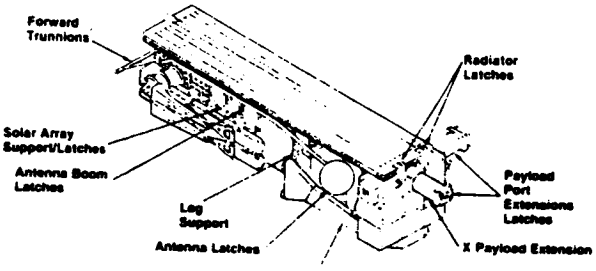


LARGE ITEM EXCHANGE

Large item exchange was accomplished by simulating the removal and replacement of an entire 15-kW solar array wing assembly. This assembly had a mass of approximately 900 lb and incorporated provisions for EVA. The solar array electrical connectors were of the NASA-approved type using EMU glove compatible wing tabs on the locking collars. The mechanical fastening was accomplished by high-strength overcenter latches with pip-pin double locks. Two subjects manipulated the electrical and mechanical fastenings, removed the solar array wing assembly, and fed the assembly to the RMS. This task was accomplished with foot restraints in approximately 10 minutes and without foot restraints in about 7.5 minutes. Results indicated that without foot restraints the task was performed more efficiently by allowing the two subjects increased mobility and thus reducing the task time by 25%.



CANDIDATES FOR EVA ACTIVATION



MECHANISMS FUNCTIONS OPTIMIZATION STUDY

In order to increase the reliability of the space platform elements in support of the design goals of 10 years or more of orbital life, it was believed desirable to:
(1) reduce the number of mechanisms required to activate the system elements and
(2) provide for the on-orbit replacement or servicing of all critical components.
Reducing the number of mechanisms requiring remotely controlled activation would not only increase total system reliability but could significantly reduce the costs involved in hardware procurement, space qualification and the use of redundant elements. Also the logistics costs of replacing elements due to failures could be reduced if interchangeable or common units could be provided. The results of a re-evaluation of the basic design concepts indicated that 27 mechanical or electro-mechanical functions could be accommodated by only 17 specific designs.

PAYLOAD BERTHING PORT (X-AXIS)

Using the criterion that mechanisms with infrequent or low activation cycles might be logical candidates for EVA implementation, provided that no free-flight activation is required and that the EVA activation is safe, some 15 candidate mechanisms were identified that would be eliminated by the use of an EVA crewman. Among these candidates were the three payload berthing ports. During the launch configuration these payload ports would be folded or stowed against the main body of the space platform (power system). If deployment was to be automatically activated by remote command, a deployment mechanism driven by an MDAC Payload Assist Module (PAM) motor derivative would be used to deploy or retract the berthing port. A remotely controlled restraint latch would also be required. If deployment was to be manually actuated through EVA a much simpler design would be possible.

MECHANISM FUNCTIONS OPTIMIZATION STUDY

Payload Support	
Item	Qty
Orbiter Umbilical	1
Payload Umbilical	0
Payload Rotation	3
Payload Latches	3
Total	7

Optimization Study

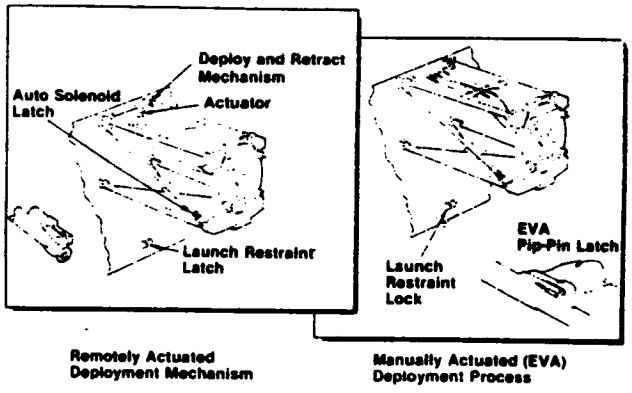
Operational Ease	
Item	Qty
Ku Antenna Gimbal	2
Solar Array Gimbal	1
Reboost Module Umbilical	0
Reboost Module Berthing Latch	1
Swing Link Pivot	2
Leg Pivot	1
Parking Port Latch	1
	8

Launch Packaging	
Item	Qty
Ku Antenna Mast	2
Fwd Support	1
Radiator Deploy	1
Radiator Latch	2
S/A Gimbal Restraint	0
S/A Launch Restraint	0
+X Payload Port	2
±Y Payload Port	1
Leg Storage	3
	12

→ 27 Functions

17 DESIGNS

PAYLOAD BERTHING PORT (X-AXIS)

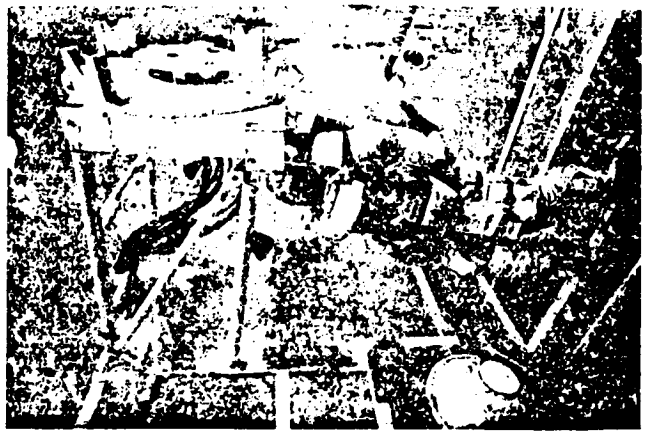


CANDIDATES FOR EVA ACTIVATION

The space platform in its stowed configuration would be carried to orbit in the cargo bay of the Orbiter. Once the Orbiter was on orbit, the cargo bay doors would open, the RMS would remove the stowed space platform from the cargo bay and the berthing legs would deploy and be mated to trunnion fittings in the Orbiter bay. The various appendages (solar arrays, radiator, antennas) would then be deployed; a payload, also carried in the Orbiter cargo bay during the initial launch, would be attached to the space platform and the space platform and its initial payload would be released. On subsequent Orbiter flights, additional payloads would be delivered to the space platform or exchanged with payloads whose operational missions were completed.

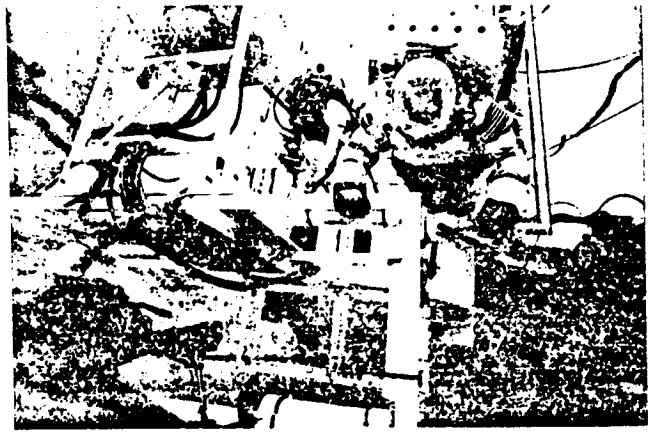
PAYLOAD BERTHING PORT DEPLOYMENT

The Space Platform aft payload port was deployed and restowed by suited test subjects successfully many times in the MSFC Neutral Buoyancy Simulation Facility. Handrails were located on the main structure so that the crewman could "walk" the port to the deployed or stowed position with one hand on the port structure and the other hand reacting forces through the handrails. Once the port was erected the crewman inserted pip-pins to lock the struts in the deployed position. The use of handrails eliminated the requirement for a foot restraint platform, affording the crewman the freedom of movement throughout the operation. These operations were performed in less than 5 minutes and after a few repetitions the test subject felt that this was a simple, straightforward task.



MANUAL APPENDAGE DEPLOYMENT

Manual deployment of appendages was investigated in the MSFC Neutral Buoyancy Facility by having the test subjects manipulate a crank assembly in both a restrained and unrestrained mode to explore man's limits and capabilities in space suits. During this task a fixed foot restraint platform was initially employed; however, the accompanying restriction of the crewman's vertical mobility resulted in unnecessary effort on the crewman's part. The task was easily performed by using a portable handhold that allowed the crewman additional freedom of movement.



EVA VS MECHANISMS

Costs for the design, development, production and qualification testing of each of the 15 mechanisms that were candidates for direct manual operation were estimated. The total cost for these 15 mechanisms was projected to be $2.406 million. Task analyses supplemented by zero-g simulations using hard mockups in the MSFC Neutral Buoyancy Simulator indicated that manned EVA activation of these mechanisms required, on the average, 10 minutes per operation. All 15 could be activated by one EVA crewman in 2.5 hours. Using the Shuttle EVA user charge per crewman, as defined in the Manned Maneuvering Unit (MMU) Users' Guide and assuming that for safety purposes two EVA crewmen would be required (although each task required only one person), the cost of manned activation during one 2.5-hour EVA period would be between $120,000 and $200,000. Using an estimated space station charge of $40,000 per hour, as defined in the recently completed Space Station Needs, Attributes and Architectural Options Study, and assuming two crewmen would be required for three hours each, an equivalent cost for manned activation from a manned space station might be $240,000.

EVA VS MECHANISMS

- **Reduction of Automatic Mechanisms**
  - Forward Launch Support — $133K
  - Solar Array Launch Latches — 1051K
  - Radiator Launch Restraints — 401K
  - +Y and -Y Berthing Port Mechanisms — 266K
  - Aft Berthing Port Mechanisms — 344K
  - Antenna Launch Latch — 211K

TOTAL COSTS FOR 15 MECHANISMS = $2406K

- **Manual Activation to Perform the Functions of the Above-Stated Mechanisms Involves 2 EVA Crewman Approximately 2.5 Hours Which is Well Within the Capability of EVA Operations**

EVA Costs (Per EVA Crewman) = $60K-100K, Depending on EVA Support Equipment*

$60K X 2 Crewman = $120K **$100K X 2 CREWMAN = $200K**

*Per MMU Users Guide, Martin Marietta Report MCR-78-517 (Contract NAS9-14593)

CONTINUOUS FLOW ELECTROPHORESIS

The foregoing comments have touched on the issues of performance and cost associated with direct manned involvement in orbital operations. The third of the three factors that must be considered in formulating a design philosophy to deal with the subject of on-orbit maintenance is the "risk" associated with system failure.

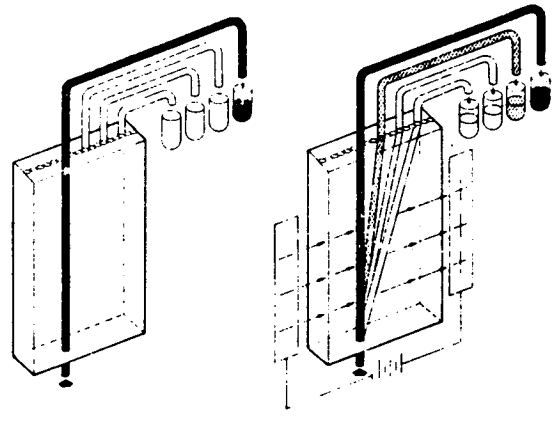
Commercial space missions in particular will be sensitive to risk of failure and such mission risks will have a significant impact on the willingness of private venture capitalists to invest in space systems. This will be especially true in manufacturing processes, where profits and value will be determined by the quality of the products produced.

Of the manufacturing processes examined to date, the electrophoresis operations in space (EOS) system, currently under development by the McDonnell Douglas Astronautics Company, provides one of the best illustrations of how direct human involvement can minimize the risk to sponsors.

Under the Joint Endeavor Agreement with NASA, MDAC is currently developing the technology to accomplish Electrophoresis Operations in Space. The development plan involves process proof of principle, pharmaceutical product evaluation, and demonstration of a production prototype system. Johnson and Johnson has teamed with MDAC, with the responsibility to conduct the clinical trials, FDA certification and market the product.

The electrophoretic separation process involves passing a buffer solution containing the materials to be separated through an electric field potential in the range of 140 to 400 volts. The length of the flow path and the potential applied, define the degree of resolution or purity of the materials collected at the output side of the system.

CONTINUOUS FLOW ELECTROPHORESIS



12 TYPICAL PHARMACEUTICAL PRODUCT CANDIDATES

The initial market analysis conducted by MDAC prior to embarking on the electrophoresis development program considered many potential products that could utilize the electrophoretic technique (hormones, enzymes, cells and proteins). The market analysis defined the benefits and needs of each and sought to identify those products with a uniqueness that could make electrophoretic processing in space a favorable method of production. These analyses led to the identification of the 12 products listed on the facing page, each of which offers significant social and economic benefits to the rest of the world.

The EOS products investigated were found to exhibit varying degrees of demand depending on the market price. For example, while beta cells may offer a one-time cure for diabetes, many patients may continue to use insulin as a preventative if the cost of beta cells is prohibitive.

The EOS annual potential patient population indicated on the facing page is probably a conservative (low) estimate. As an example, there are 800,000 emphysema sufferers in the United States. Only 100,000 are considered severe. Our internal economic market analysis for Alpha Antitrypsin considered usage by only 75,000 patients or 75 percent of the severe sufferers. As this market level is achieved, the production price can be expected to drop and it is possible that many less severe sufferers will consider usage.

The anticipated population benefitting from just the 12 products listed exceed 12 million persons in the United States alone, the worldwide usage could exceed 250 million individuals per year. This represents a multi-billion dollar annual market potential.

CANDIDATE PHARMACEUTICAL PRODUCTS
12 TYPICAL

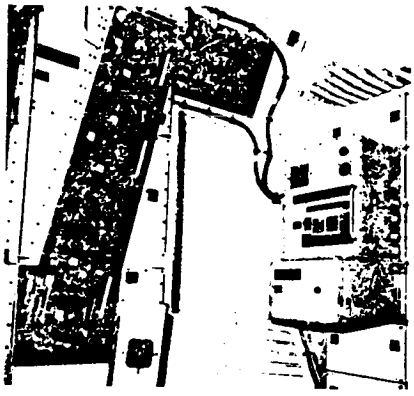
Typical Products	Beneficial Medical Application	Function/Status	Annual Patients (USA)
Alpha Antitrypsin	Emphysema	Research Quantities Only Now	100,000
Antihemophilic Factors VIII and IX	Hemophilia	100% Terminal by Age 40	20,000
Beta Cells	Diabetes	Possible Single-Dose Cure	600,000
Epidermal Growth Factors	Burns	Replacement Skin Grafting	150,000
Erythropoietin	Anemia	Replacement Transplants/ Transfusions	1,600,000
Immune Serum	Viral Infections	EOS Provides Higher Purity	185,000
Interferon	Viral Infections	Potential May Be Unlimited	10,000,000
Granulocyte Stimulating Factor	Wounds	Research Quantities Only Now	2,000,000
Lymphocytes	Antibody Production	Replace Antibiotics/Chemotherapy	600,000
Pituitary Cells	Dwarfism	Currently Not Curable	850,000
Transfer Factor	Leprosy/Multiple Sclerosis	Potential for Other Applications	550,000
Urokinase	Blood Clots	Low Development Costs	1,000,000

EOS MIDDECK SYSTEM

The first orbital flight of the MDAC prototype EOS facility occurred on STS-4 and the second on STS-6. The equipment was located in the middeck of the Orbiter and was accessible to the space crew for scheduled and unscheduled tasks. Scheduled crew activities included cycling the power on and off, starting and stopping the system operation, initialization (zero check), processing the sample product and collecting the product. In addition, photographs of the columnar flow required for later analysis on the ground were taken 14 times per day. The operator was also required to change the sample input and to change the collection trays.

In the separation process, nurturing of the product stream requires considerable skill on the part of the operator to recognize and interpret the flow pattern. While the use of a dye simplifies this task somewhat, such additives may not be desirable in processing certain types of products. The bandwidth required to transmit sufficiently detailed real-time images of this process to a remote control station would place a heavy burden on the data transmission system.

EOS MIDDECK SYSTEM



Joint Endeavor Agreement

STS	Flight Dates
4	July 1982 (Completed)
6	April 1983
7	June 1983
8	August 1983
12	March 1984
16	July 1984

Results From STS 4

1. Yield Increased 500 Times
2. Repeatable Quantitative Separation Demonstrated
3. EOS Design Concept Validated
4. Value Manned Participation Confirmed

EOS OPERATIONS

The electrophoresis facility being developed by McDonnell Douglas involves the use of a complex plumbing system with an inherent leakage problem. Leaks in the system are extremely difficult to detect with automated equipment. The system requires constant refrigeration to prevent product deterioration. The process is also characterized by dynamic instability, which requires continuous periodic adjustment of the system operating parameters.

Minimal requirements for human assistance in EOS operations include: (1) initiating system operation, (2) monitoring system operation, (3) intervening via the system auto motion interface when software and/or suspected hardware errors occur, (4) performing product supply, resupply and change operations, and (5) shutting the system down. Human tasks that would increase process efficiency and minimize the impact of system failures include: (1) fault diagnosis, (2) leak detection and repair, (3) quality control and (4) materials handling and product storage.

All these tasks can and are being accomplished to some degree via automation but these approaches are expensive and of unknown reliability at this time. The presence of a human operator would ensure reliable operation and boost processing efficiency. In addition, some future research and development and product production involving live cells cannot be accomplished without a qualified mission specialist on board.

EOS OPERATIONS

MAN REQUIRED FOR:

- Deployment/Replacement
- Supply/Resupply
- Maintenance/Servicing
- Product Change
- Sequential Multiproducts
- Live Cell Handling
- Faster Product Development
- New Product R & D
- Fast Response to Emergencies (R & D)
- Innovative Solutions

MAN DESIRED FOR:

- Access Buffering
- Lower System Cost
- Reduced Product Loss
- Reduced System Complexity
- Simplified Logistics
- Simplified Product Storage
- Increased Profit Margin
- Easier Sterilization
- Easier Quality Control
- Easier Maintainability/Leak Detection
- Easier System Diagnostics
- Minimal Down Time
- Batch Processing
- Product Assays

- Man is the Only Real-Time System Capable of Accepting and Operating on Asynchronous and Nonsequential Input Data

- The Overall Cost and Effectiveness of EOS Operations Will be Directly Influenced by the Level of Human Involvement and Productivity

EOS HUMAN OPERATORS ACTIVITY

During the STS-4 flight, five unanticipated malfunctions occurred requiring human intervention. Four were process-out-of-range errors and one was a mandatory Stop/Reset/Restart software problem. The presence of an onboard operator provided rapid resolution of these problems, and were a graphic illustration of the value of direct human intervention in maintaining the efficiency of EOS operations. Market projections suggest that the market for EOS products may easily be in the billion dollar range. If even only a fraction of this potential market is captured, the payoff potential is still so high that the premium for mission success mandates the direct involvement of a human operator to protect the initial investment, increase operational efficiency and thereby maximize the dollar return to the sponsors of the mission.

EOS HUMAN OPERATORS ACTIVITY
SHUTTLE MIDDECK TASKS
SCHEDULED OPERATOR CALLS

Perform as Power Loadmaster
- Cycle Power On/Off as Required

Change System Operation
- Start Stop
- Zero Check
- Process Sample
- Collect Sample

Take Photographs of Column
- Required 14X Each Day

Process Maintenance Service
- Change Sample Input
- Change Collection Trays

Product Stream Detection
- Observation is Possible but a Highly Skilled Mission Specialist is Required to Recognize and Interpret Pattern if Dye is Not Included With the Sample. Current Astronaut Training is Insufficient for Effective use of Information Obtained From Column Observation
- Shuttle Link to Ground Based Mission Specialist Lacks Adequate Bandwidth for Useful Interaction Between Astronautics and Ground

Five Malfunctions Occurred During the STS-4 Flight. Four Process Out-of-Range Errors and a Mandatory Stop/Reset/Restart Software Problem. These Incidents Coupled With the Limited Ground Link Indicate That an Onboard Mission Specialist Would Significantly Increase the Efficiency of EOS Operations on Future Flights

STS-4 EOS OPERATIONS SUMMARY

The STS-4 EOS mission is a classic example of the importance of direct manned involvement in a research and development operation. During the two days of operation, a total of 55 operator calls (events) occurred of which 14 (eight on 28 June and six on 30 June) were unscheduled. Resolution of these unscheduled events required 62 keyboard inputs to the central processing unit.

A similar activity pattern was observed on STS-6. Prototype production facilities to be installed in the Orbiter cargo bay are currently in the conceptual design phase and are being designed to operate continuously for five days. Longer operating periods of 30 days or more can be anticipated when free-flying platforms or manned space stations become operational. With these longer missions, the probability of unscheduled operator calls becomes progressively higher.

STS-4 EOS OPERATIONS SUMMARY

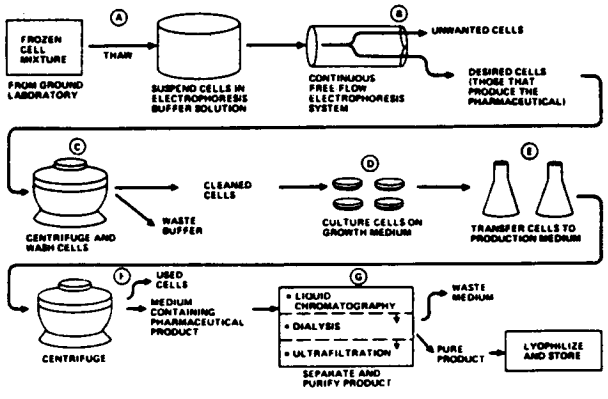
	28 June 1982	30 June 1982
Raw Parameters		
Total Operating Time	6.5 Hours	8 Hours
Total Number of CPU Operator Calls	27	28
Scheduled Calls	19	22
Unscheduled Calls	8	6
Total Number of Key-Board Inputs Required	99	83
Scheduled Calls	48	72
Unscheduled Calls	51	11
Averaged parameters		
Operator Calls/Hour	4	3
Scheduled Calls	3	3
Unscheduled Calls	1	1
Keyboard Inputs/Hour	15	10
Scheduled Calls	3	3
Unscheduled Calls	6	2
Operator Call Response Time	27 Sec	43.7 Sec

Manned Presence Essential to Reduce Risk of Failure

TYPICAL SPACE PHARMACEUTICAL PILOT PLANT

The production steps illustrated in the preceding figure can be simplified to highlight those specific operations in which direct manned involvement would be most desirable.

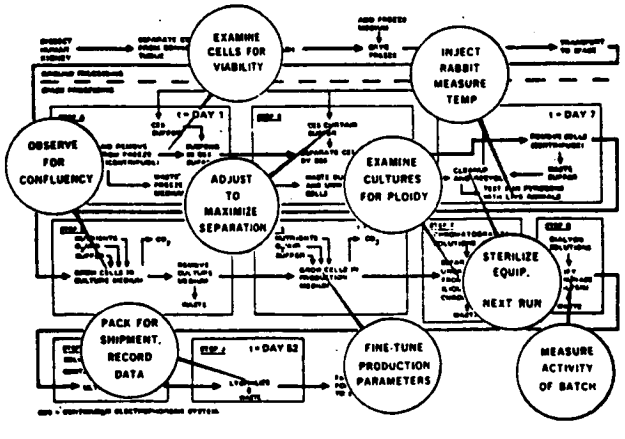
TYPICAL SPACE PHARMACEUTICAL PILOT PLANT
(Manned Involvement: Circled Letters)



ROLE OF MAN IN UROKINASE PROCESS DEVELOPMENT AND OPTIMIZATION

The electrophoresis separation process is just one step in the production of specific pharmaceutical products. In the case of urokinase, for example, the various production steps typically require up to 52 days from the initial separation process to the final output.

ROLE OF MAN IN UROKINASE PROCESS DEVELOPMENT AND OPTIMIZATION

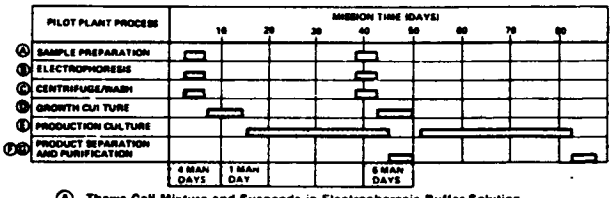


TYPICAL TIMELINE FOR PHARMACEUTICAL PILOT PLANT AND CREW OPERATIONS

The typical time requirements for the manned activities summarized on the preceding figure are illustrated in the accompanying figure.

In summary, the complexity of the separation and storage processes and equipment for longer-duration EOS systems, such as those utilized in actual production plants, is such that automatic control and robotic operation may be an unreasonable goal. The risk of malfunction and product loss compared to the potential return on investment will be a key criterion in the decision to use manned or robotic systems for these future EOS activities.

TYPICAL TIMELINE PHARMACEUTICAL PILOT PLANT AND CREW OPERATIONS



- (A) Thaws Cell Mixture and Suspends in Electrophoresis Buffer Solution
- (B) Introduces Cell Suspension Into Electrophoresis Unit and Collects Separated Products
- (C) Discards Unwanted Products. Centrifuges Wanted Cells a Number of Times — Resuspending Cells in Fresh Wash Water Between Centrifugations
- (D) Prepares Cell Cultures on Growth Medium in Culture Plates
- (E) Transfers Cell Colonies to Production Medium and, After Approximately 30 Days, Removes Cells by Centrifugation
- (F) Separates Pharmaceutical From Production Medium Via Successive Processes (e.g., Liquid Chromatography, Dialysis, and Ultrafiltration)
- (G) Lyophilizes Pure Pharmaceutical and Stores

ATTRIBUTES OF MANNED SPACE STATION

Three factors that must be considered in formulating a design philosophy to deal with the issues of the optimal type, form and extent of on-orbit maintenance in future space systems are. (1) performance, (2) cost, and (3) risk

Due to the functional complexity and dynamic qualities of future space systems, the presence of a human operator can have significant impact in achieving the optimal balance among these factors. An onboard mission specialist can contribute in the following areas:

- As the operator and monitor that even fully automated systems would still require to some degree.
- As a schedule compressor in research and development activities, contributing to reducing costs and risks while helping to achieve milestones.
- As a specialized programmable sensor with unique perceptual abilities, contributing to improved process control, fault diagnosis, leak detection and servicing and repair functions.
- As a buffering shield in commercial operations, minimizing the impact of unknowns and the unexpected, while protecting access to proprietary information.

On the basis of the knowledge available and the manned spaceflight experiences to date, we can conclude that almost any task that can be performed on the ground can also be performed in space, providing proper and adequate positioning restraints are used. This is not idle speculation but hard fact based upon nearly 90,000 manhours of experience in the weightlessness of space.

ATTRIBUTES OF A MANNED SPACE STATION

- Schedule Compression — Reduced Cost and Risk
- Combines Best Features of Unmanned Free-Flyer and Sortie Mission, e.g.,
  - Onboard Step-by-Step Development Sequence
  - Less Automation
  - Reduced Cost — No Free-Flyer Support Subsystems, Fewer Shuttle Launches
  - Common Support Equipment
  - Unlimited Data Gathering — Test Conduct Time — Flexibility
  - Infrequent Event — Seasonal Coverage
- Flight Crew Capabilities — Modifications Repair Replacement Assembly
  - Visual Observations
  - Real-Time Sensor Adjustments
  - Analyzing Data
  - Pointing Control
  - Targets of Opportunity
  - Failure Diagnosis/Repair
  - EVA for Structural Assembly — Equipment Adjustments
  - Iterative Operations
  - Learning Curve Benefits
- Contribution of Man in Space is Historical Fact

Man Responds Creatively as Unanticipated Events or Problems Arise

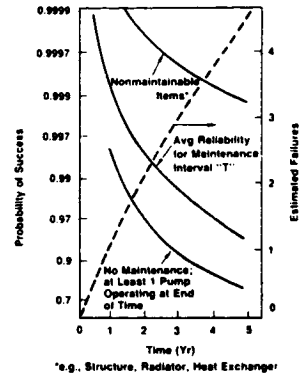
SPACE STATION — MISSION ASSURANCE

- Goal is to Provide Safe, Reliable, Long-Life Systems at the Lowest Possible Cost
- Dependable Transportation and Operations Essential for Commercial Development in Space
- Issues to be Resolved Include:
  - Design Philosophy
    - — Optimal Role of Man
    - — Modular Growth Versus Custom Design
    - — Safety Criteria — Dual Egress, Lifeboats, et. al.
    - — Design Approach to High Reliability
  - Operational Philosophy
    - — Value and Role of Ground Simulation
    - — Locus of Mission Control — Ground Versus Space

THERMAL CONTROL SYSTEM RELIABILITY

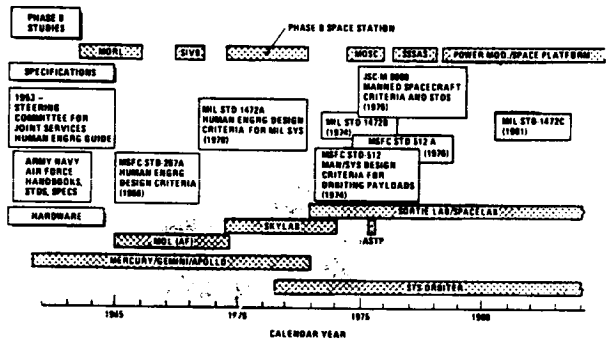
Design Factors

- Critical Subsystem to Mission Success
- Utilization of Working Fluids
- Moving Parts — Valves, Pumps
- System Vulnerable to Leaks
- Sealing Disconnects Required for Replaceable Elements

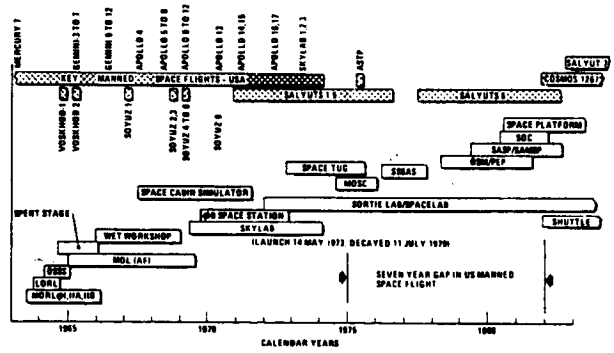


*e.g., Structure, Radiator, Heat Exchanger

DESIGN AND DEVELOPMENT HERITAGE



SPACE STATION HERITAGE



ON-ORBIT MAINTENANCE/SERVICING

PRESENTATION TO

MISSION ASSURANCE CONFERENCE

SPACE STATION WORKSHOP

[illegible] JUNE 1983

H. T. FISHER
SUPERVISOR CMPS SYSTEMS
SPACE SYSTEMS DIVISION
LOCKHEED MISSILES & SPACE COMPANY
SUNNYVALE, CALIFORNIA

AGENDA

1. INTRODUCTION
2. PRESENTATION OBJECTIVES
3. ESTABLISHING THE NEED FOR SERVICING/MAINTENANCE
4. CONSIDERATIONS IN ORBITER BASED SERVICING AND APPLICABILITY TO THE STATION
5. DIFFERENCES (?) IN THE NATURE OF RELIABILITY/MAINTAINABILITY FOR THE STATION
6. CONCLUSIONS

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MEETING OBJECTIVES

1. DISCUSS PRESENT SPACECRAFT DESIGN FOR MAINTENANCE FACTORS AND CONCEPTS
2. PRESENT SOME PRELIMINARY THOUGHTS ON R&M/MAINT FOR THE SPACE STATION

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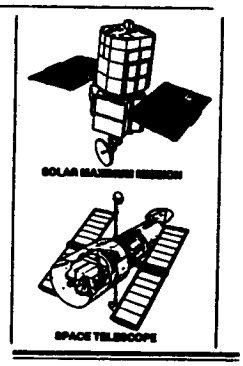
ESTABLISHING THE NEED FOR ON-ORBIT SERVICING

1. RELIABILITY AND MTBF FACTORS
2. ITEMS HIGHLY SUSPECT TO MALFUNCTION BUT WITH LIMITED FLIGHT RELIABILITY DATA
3. PREVENTATIVE MAINTENANCE CONSIDERATIONS
4. WEAR-OUT LIFETIMES
5. DEGRADATION LIFETIMES
6. ITEMS WHICH MAY RECEIVE INADVERTENT COLLATERAL DAMAGE
7. ITEMS SUBJECT TO EMI OR OTHER "SIGNAL" SPECTRA DAMAGE
8. INDUCED DAMAGE, e.g., LOSS OF THERMAL CONTROL AND SUBSEQUENT CHANGE OF TEMPERATURE PAST SURVIVABILITY LEVEL
9. MICRO-METEORITE PENETRATION/DAMAGE
10. CASCADING FAILURES OR POWER SURGES
11. EQUIPMENT/EXPERIMENT ITEM UPDATE/REPLACEMENT
12. NEW PAYLOAD REPLACEMENT
13. COMPLETE SUBSYSTEM REPLACEMENT
14. ETC.



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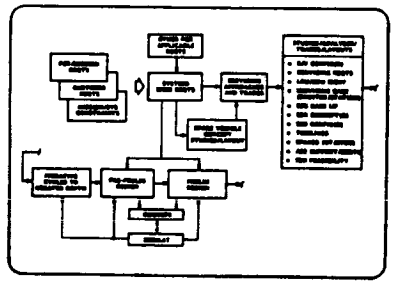
DESIGN APPROACH



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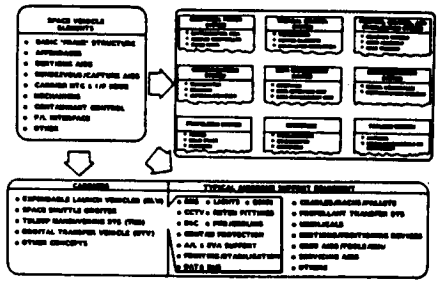
SPACE VEHICLE ELEMENTS & INTERFACES



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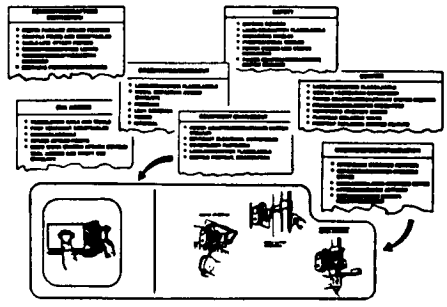
DESIGN FEATURES



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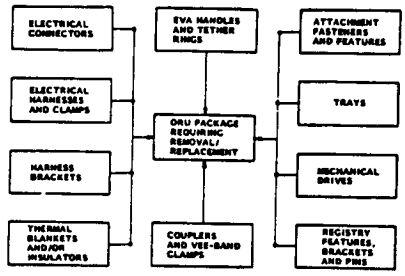
ON ORBIT REPLACEMENT HDWR DESIGN FOR CHANGEOUT



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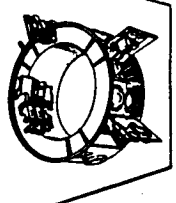
TYPICAL EQUIPMT MFG/INTEG CONSIDERATIONS

1. LARGE ITEM ORU LOCATION FOR CHANGEOUT
   - MTG ORIENTATION & ALIGNMENT
   - VOLUME - SIZE
   - REMOVAL/INSTAL SWEPT VOL
   - CABLE ROUTING
   - LOADS
   - ISOLATION
   - ENVIRON PROTECTION
   - HOLD-DOWN TECH.
2. BASIC ORU INSTALLATION AND CREW INTERACTION
3. LOADS TO OR ON BASIC STRUCTURE OR DOORS
4. GROUNDING AS IT MAY AFFECT CHANGEOUT TECHNIQUES
5. THERMAL I/Fs RELATIVE TO MTG FOR ON-ORBIT CHANGEOUT
6. PROXIMITY TO ASSOCIATED EQUIPMENT(S)
7. SHOCK OR VIBRATION & ASSOCIATED ATTENUATION
8. ALIGNMT FEATURES (COARSE AND FINE) FOR CHANGEOUT ITEMS
9. CENTER OF GRAVITY AND MASS ARRANGEMTS
10. INSTALL & REMOVAL FEATURES FOR BOTH GRND AND ON-ORBIT
11. 'PLUMBING' ROUTING & I/Fs - PARTICULARLY FOR ON-ORBIT ORUs
12. MTG FOOTPRINT VS REMOVAL DEVICES & ACCESS POTENTIAL
13. COLLATERAL DAMAGE POTENTIAL DURING CHANGEOUT ON-ORBIT
14. POSITIVE REGISTRY/GUIDES FOR PLACMG/POSITIONING/CHANGEOUT
15. 'QUICK' REMOVAL FEATURES FOR ITEMS TO BE JETTISONED
16. SHARP EDGES/CORNERS/PROTRUSIONS ELIMINATION



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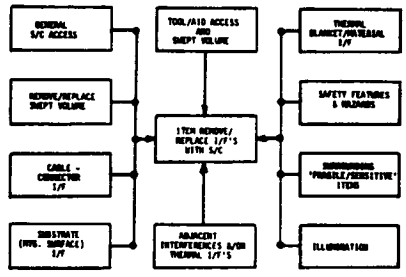
CHANGEOUT ITEM I/F WITH S/C TYPICAL



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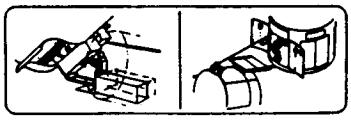
DESIGN FOR ORU CHANGEOUT

1. REMOVAL SWEPT VOLUME DIMENSIONS
2. GUIDES AND/OR CABLE & I/F
3. TOOL ACCESS TO FASTENING DEVICES
4. HANDHOLDS/HARDPOINTS
5. TETHER ATTACH POINTS
6. PROTECTION OF SENSITIVE 'AREAS'
7. GUIDING AND ATTACHMENT OR DISLODGEMENT FEATURES
8. ELIMINATION OF SHARP EDGES/CORNERS/PROTRUSIONS
9. UNOBSTRUCTED CHANGEOUT TRANSFER PATH/VOLUME
10. METHODS OF HANDLING DURING THE TRANSFER PROCESS
11. ILLUMINATION TO FACILITATE CREW VISION
12. C-G OF THE ITEM AND ITS BASIC MASS DISTRIBUTION
13. BASIC SIZE OF THE ITEM TO BE CHANGED OUT:
    - GRIPS HANDLING
    - GRIPS TRANSFER
    - HANDLING AIDS
    - 'KIDS-ASSEMBLY'
    - SHAPE VS MASS/CG DISTRIBUTION
    - HANDLING AND LOCATIONS
14. CONNECTOR AND GROUNDING STRAP DATA SUMMARY - CHANGEOUT



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DESIGNING FOR SAFETY

1. CREW INDUCED LOADS AND POTENTIAL COLLATERAL DAMAGE
2. EQUIPMENT DESIGN SAFETY FACTORS
3. STRUCTURAL DESIGN SAFETY FACTORS
4. AIRBORN SUPPORT EQUIPMENT SAFETY FACTORS
5. ELECTRICAL DESIGN CONSIDERATIONS
6. EXPLOSIVE, NUCLEAR, PYROTECHNIC, JETTISON CONSIDERATIONS
7. SHROUDS, COVERINGS, INSULATION, THERMAL BLANKET CONSIDERATIONS
8. PROTRUSIONS, EDGES, CONTOURS, CORNERS, SURFACES CONSIDERATIONS
9. EQUIPMENT TRANSFER/TRANSPORT/HANDLING CONSIDERATIONS
10. LIFE SUPPORT CONSIDERATIONS
11. PROCEDURAL AND INTERFACE SAFETY FACTORS
12. FLUIDS/GASSES TRANSFER SAFETY
13. CREW TETHERING
14. MASS HANDLING AND CONSTRAINT

REPRESENTATIVE SAFETY PROVISIONS AND PROCESSES

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible]
7. [illegible]
8. [illegible]
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12. [illegible]

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DESIGN FEATURE APPLICATION AND TYP DOCUMENTATION

CORE DESIGN FEATURE DOCUMENTATION (REPRESENTATIVE)
- COMPANY DESIGN STANDARDS
- COMPANY DRAFTING MANUAL
- COMPANY PREFERRED PARTS HANDBOOK
- COMPANY STANDARD MATERIALS HANDBOOK
- COMPANY PROCESS SPECIFICATIONS MANUAL
- COMPANY SAFETY, QUALITY, AND RELIABILITY STANDARDS
- COMPANY MODEL SPECIFICATION
- CUSTOMER SPECIFICATIONS
- CUSTOMER STANDARDS
- CUSTOMER DESIGN/REFERENCE DOCUMENTATION
- CUSTOMER SRLs AND SRDs
- CUSTOMER/COMPANY DEVELOPED KDPs AND KDPs
- NASA NSMS AND SHUA (FMA DOC)
- MIL SPECS (E.G., MIL-STD, ETC.)

CORE DESIGN FEATURE APPLICATION
- MANUFACTURING ASSEMBLY
- GROUND TEST, SIMULATION, AND CHECKOUT
- GROUND HANDLING AND ORBITER INSTALLATION
- REMOVE/REPLACE — FACTORY/PAD
- ORBITER/EVA AND ORBITER SIMULATION
- ON-ORBIT CREW IVA AND EVA OPERATIONS

CORE DESIGN FEATURE ALLOCATION
- STRUCTURE
- SUBSYSTEMS
- COMPONENTS/MODULES
- CREW SUPPORT ELEMENTS
- AIRBORNE (SPACE) SUPPORT EQUIPMENT
- INTERFACE HARDWARE — ARRIVE, ORBITER, SATELLITE

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SPACE SERVICING AND THE SPACE STATION

A. SPACE STATION SUPPORT FOR SCHEDULED SPACECRAFT SERVICING IS HIGHLY VIABLE

B. SPACE STATION SUPPORT FOR SCHEDULED SPACECRAFT SERVICING IS STRONGLY INFLUENCED BY:
1. S/C ALTITUDE & INCLINATION
2. ORBITAL MECHANICS & NODAL POINTS VS TIME
3. AVAILABILITY OF ORBITAL TRANSFER VEHICLES
4. GROUND TO STATION LOGISTICS
5. SERVICING LOCATION
6. S/C DESIGN FOR SERVICING
7. SPARES (ORU's) AVAIL
8. SERVICING SCHEDULES
9. STAGING SUPPORT
10. LEVELS OF CHECKOUT

C. NASA & DoD WILL HAVE TO TAKE A MORE AGGRESSIVE ROLE IN DEVELOPING SERVICEABLE S/C FOR THE STATION TO BENEFIT FROM THE SERVICING FUNCTION

D. LMSC HAS DEFINED SERVICING FROM 3 APPROACHES
1. TASK 1 SCENARIOS
2. LMSC PROGRAMS (HARDWARE)
3. GENERIC CONCEPTS

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FACTORS INFLUENCING SPACECRAFT ORBITAL LONGEVITY

RESOURCE DEGRADATION (LIFE LIMIT CAUSES)	SPACE SYSTEM ELEMENTS EXHIBITING TYPICAL DEGRADATION
A. BASIC SYSTEM FAILURES	
• CATASTROPHIC FAILURE	• POTENTIALLY ANY SUB-SYSTEM
• PORTION OF MISSION CAPABILITY LOSS	• ELECTRO-MECHANICAL
• NO MISSION BREAKDOWN (REDUNDANCY) HOWEVER A LOSS OF RELIABILITY	• ELECTRONICS
• INTER-SYSTEM "FLEXIBILITY" LOSS	• POWER
B. CONSUMABLE RESOURCE DEPLETION	
• PRE-DETERMINABLE	• PROPELLANTS AND PRESSURANTS
• STATISTICAL	• FUEL CELLS
	• LUBRICANTS
	• COOLING AGENTS
	• CATALYZERS
C. SYSTEM PERFORMANCE DEGRADATION	
• PRE-DETERMINABLE	• OPTICS (REFLECTIVITY OR TRANSPARENCY)
• STATISTICAL	• SOLAR ARRAYS
	• BATTERIES
	• THERMAL RADIATORS
	• MECHANICAL ASSEMBLIES (e.g., BEARINGS)
D. MISSION OBSOLESCENCE	• MOST FREQUENTLY IS PAYLOAD
E. HUMAN ERROR	
• INCORRECT OPERATION	• ANY SUBSYSTEM
• UNSAFE DESIGN OR FUNCTION	

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SPACE SERVICING AND THE SPACE STATION (CONTINUED)

E. SPACE STATION SUPPORT FOR UNSCHEDULED SPACECRAFT SERVICING IS STRONGLY INFLUENCED BY:
1. ACCESSIBILITY TO S/C
2. AVAILABILITY OF OTV
3. LOGISTICS IMPLICATIONS
4. SPARES (ORU) AVAILABILITY
5. TIMELINE FACTORS
6. CRITICALITY OF S/C ORBITAL AVAIL
7. FEASIBILITY OF ORBITAL SERVICE
8. STATION OF CONFIGURATION

F. NUMBER OF S/C WHICH STATION CAN SERVICE WITHOUT AN OTV OR OTHER SYSTEM ARE FEW

G. SERVICING OF SPACECRAFT BY OR AT STATION SUBSTANTIALLY INFLUENCES STA ARCHITECTURE
1. OTV PARKING/SERVICING
2. CONSUMABLES STORAGE/HANDLING
3. SPARES (ORU) STORAGE
4. CHECKOUT EQUIPMENT/LOCATIONS/ACCESS
5. SERVICING HANGER
6. OTV OR S/C APPROACH/DEPART ENVELOPES
7. DOCKING/BERTHING FACILITIES
8. RMS ACCESSIBILITY
9. SPARES (ORU) HANDLING/XFER ENVELOPES
10. SPARE S/C STORAGE/CONDITIONING
11. UTILITIES-RUNS & INTERFACES
12. S/C APPENDAGE ENVELOPES

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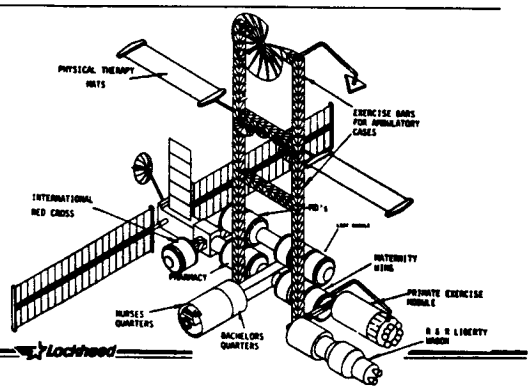
THE ULTIMATE LIFE SCIENCES RESEARCH FACILITY



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SPACE STATION MAINTENANCE - INTERNAL ELEMENTS

BASIC STATION INTERNAL ELEMENTS WHICH SHALL BE CONSIDERED SUB-SYSTEM CANDIDATES FOR MAINTENANCE INCLUDE THE FOLLOWING TYPICAL AREAS:

A. POINTING, CONTROL & STABILITY
B. ELECTRICAL POWER
C. DATA MANAGEMENT
D. INSTRUMENTATION AND C/O
E. COMMUNICATION
F. ENVIRON CONTROL & LIFE SUPPORT
G. UTILITY SERVICES
H. CREW ACCOMMODATIONS
I. EMERGENCY & CAUTION/WARNING
J. DISPLAY & CONTROL

AND

K. INTERNAL STATION SUPPORT ELEMENTS FOR INT/EXT OPS
- SERVICING
- LOGISTICS
- EVA
- SCIENCE
- COMMERCIAL
- STAGING/BASING
- REMOTE FUNCTIONS
- ASSY/CONSTRUCTION
- APPLICATIONS
- RSD FUNCTIONS

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STATION MAINTENANCE ISSUES (SELECTED)

A. DEGREE OF STATION AUTONOMY

B. BASIC INDIGENOUS STATION SUB-SYSTEM RELIABILITY

C. LEVEL OF FAULT ISOLATION AND DETECTION

D. LEVEL OF ON-BOARD MAINTENANCE

E. AVAILABLE CREW TIME FOR BASIC STATION MAINTENANCE

F. SPARES PHILOSOPHY AND APPROACH

G. COSTING IMPLICATIONS

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SPACE STATION MAINTENANCE - PROJECT EARLY START

A. CONSIDER MAINT DURING THE CONCEPTUAL STATION SYSTEM SUBSYSTEM DEFINITION & DESIGN PHASES:

1. NASA-HDQ SPACE STATION STUDIES
2. SPECIAL EMPHASIS STUDIES
3. IN-HOUSE (NASA) STUDIES & PHASE B RFQ

B. PLAN FOR MAINT STUDY/DESIGN IMPLEMENTATION:

1. RE-ASSESS HISTORICAL STDS, REQS, SPECS, ETC. FOR:
   - SCOPE AND SYS-OPS COVERAGE
   - CURRENCY
   - END-TO-END COVERAGE
2. CONSIDER NEED FOR 'UPDATED &/OR NEW' GUIDELINE DOCUMENTATION
3. PREPARE DOCUMENTATION 'UPDATES' WITH:
   - SUFFICIENT 'CLOUT'
   - CONTRACTOR 'WORKABLE' GUIDELINES
   - 'MEANINGFUL' GUIDELINES
4. EMPLOY GUIDELINES EARLY ENOUGH TO POSITIVELY INFLUENCE:
   - CONCEPTUAL APPROACHES
   - SYSTEMS ENGR TASKS
   - FULL DESIGN CYCLE
   - TEST AND VER PLANNING
   - ON-BD C/O PHILOSOPHY & APPROACH
   - COSTING GROUNDRULES & TECHNIQUES
   - SCHEDULING FACTORS & MILESTONES
   - REVIEW PLANNING & IMPLEMENTATION

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SPACE STATION MAINTENANCE DESIGN PHILOSOPHY

A. PLAN FOR DESIGNING-IN MAINT CAPABILITY FROM CONCEPT INITIALIZATION

B. DESIGN FOR NEAR-TOTAL ON-ORBIT MAINT

NOTE CONSOLES/RACKS/FRAMES/CABINETS, MAIN DISTRIBUTION PLUMBING/CABLING/UTILITY LINES & WIRE BUNDLES MAY REQUIRE EQUIPMT/SUPPLIES AND SPECIALIZED TECHS FROM EARTH FOR REPAIR/REFURBISHMT

C. CONDUCT STUDIES/TRADES EARLY-ON IN THE PROGRAM TO IDENTIFY APPROPRIATE STATION LRU (OR ORU) NEEDS & LEVELS

1. REQUIRES MORE THAN MTBF & FMEA DATA, INCLUDING SUCH TYPICAL DATA AS:
   - OPS DEGRADATION RANGE STATE (SLOWLY DEGRADING TO FULL FAILURE)
   - REL DISCRETES, STRING &/OR INTERACTIVE LEVELS
   - PLANNED REDUNDANCY VS FAIL OPS/FAIL SAFE
   - LEVEL OF MAINT
   - MALFUNCTION ISOLATION LEVELS & DIAGNOSTICS (ON-BOARD)
   - CREW MAINT PARTICIPATION, SKILLS, MOS, & TRNG
   - ON BOARD SPARES & COMMONALITY OF SPARES
   - LOGISTIC RE-SUPPLY FLIGHT INTERVALS & SPARES AVAILABILITY
   - ON-BOARD MAINT (CHANGE-OUT) WHILE MAINTAINING STATION OPS
   - REPLACEMENT/CHANGE-OUT FEASIBILITY/DIFFICULTY & ACCESSIBILITY
   - SPARES WEIGHT & VOLUME
   - SENSITIVITY OF SPARES TO 'LOGISTICS' CYCLE
   - INTERACTION BETWEEN RELIABILITY AND MAINT

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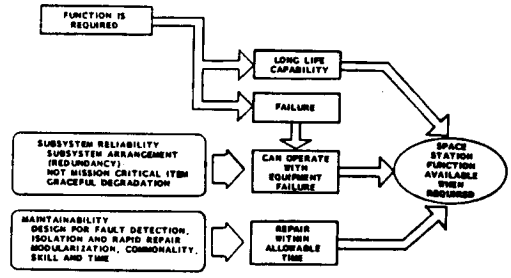
RELIABILITY AND MAINTAINABILITY CONTRIBUTION TO SPACE STATION AVAILABILITY



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SPACE STATION MAINTENANCE DESIGN PHILOSOPHY (CONTINUED)

2. NECESSITATES IDENTIFICATION & DEFINITION OF STANDARDIZATION
3. REQUIRES A COMMITTMENT TO AVAILABILITY OF SPARES (LRUs) UPON INITIAL STATION LAUNCH
4. OBVIATES THE NEED TO RIGOROUSLY FOLLOW-THRU (CONCEPT TO ORBIT) WITH MAINT APPROACH & ATTENDANT ASSOCIATED RESOURCES

D. IMPLEMENT A NASA* CENTER WIDE (STATION PARTICIPANTS) & CONTRACTOR MAINT FAM PROGRAM INCLUDING:

1. GENERAL RELIABILITY & MAINT APPROACH FAM PROGRAM:
   - NASA TBD RESPONSIBILITY
   - NASA TBD CONDUCTS FAM PROGRAM
     - IN CONCERT WITH & AT OTHER CENTERS
     - FOR INVITED CONTRACTORS AT NASA-TBD OR AT CONTRACTORS
2. NASA ASSUMES RESPONSIBILITY* TO PREPARE STATION REL/MAINT DOCUMENTATION
   - GENERAL PHILOSOPHY
   - STANDARDS
   - BASIC GUIDELINES
   - REQUIREMENTS

* CONTRACTOR SUPPORT MAY BE NECESSARY

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LOGISTIC IMPACTS

A. LOGISTICS LOOMS AS A KEY STATION ELEMENT AND DRIVER

GROUND

1. LIFE CYCLE COSTS
2. STS LAUNCH SCHEDULE
3. STS LAUNCH VOL RQT
4. SPARES PHILOSOPHY & DEV
5. GROUND LOG/SP FAC
6. DATA MGMT SYSTEM
7. HANDLING/TRANSPORT
8. CONDITIONING
9. PROVISIONING
10. VENDOR 'STATUS'
11. PREDICTIVE MGMT
12. ETC

B. STATION IMPACT

1. DOCKING/BERTHING PORT(s)
2. PORT HATCH PASS-THRU DIA
3. AIRLOCK SIZING
4. SPARES/LOGISTICS STA STAGING
5. INTERNAL STOWAGE
6. CONDITIONING
7. DATA MGMT & PROVNG
8. CONSUMABLES MGMT
9. CONTAMINT HANDLING
10. ITEM/CONTAINER RETURN
11. SUPPORT OPS
12. ETC

C. EMERGENCY/CONTINGENCY

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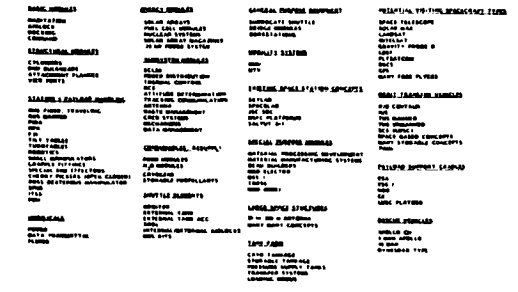
SPACE STATION HARDWARE ELEMENTS



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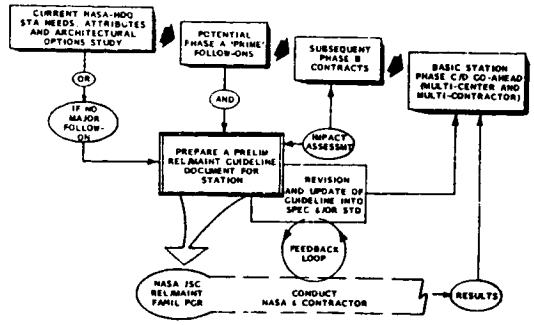
STATION REL/MAINT DOCUMENTATION/FAMILIARIZATION SCHEME



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WILL THERE BE A REL/MAINT REQT DIFFERENCE? (ELEMENT LEVEL)

SHORT TIME ON-ORBIT NON-LIFE CRITICAL	LONG TIME ON-ORBIT NON-LIFE CRITICAL	SHORT TIME ON-ORBIT LIFE CRITICAL	LONG TIME ON-ORBIT LIFE CRITICAL
• PIGGY-BACK EXPER • PALLETS • RACKS • EXPER CARRIERS • ETC.	• TANK FARM • TETHERED SYSTEMS • UNMAN FREE FLYERS (FORMATION FLYING) • MANUFACT FACILITIES UNMANNED • ANTENNA(s) PLATFORM • LARGE SPACE STRUCT • ETC.	• LOGISTICS ELEMENTS • INNER RESCUE HOVR • PROP TRANSFER SYS • ETC.	• CREW HABITAT MODULES • MANNED LAB MODULES • AIRLOCKS • DOCKING MODULES • TUNNELS • ORB STATIONED RESCUE VEHICLE • ENERGY MODULE • ETC.

SIMILARLY - SUB-SYSTEMS WHICH [illegible] ON-ORBIT

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CONCLUSIONS

- REL & MAINT STANDARD APPROACHES DON'T EXIST FOR SHUTTLE CARRIED P/Ls
- EXISTING 'R&M' APPROACHES NOT ADEQUATE FOR 'BLANKET' APPLICATION TO STATION
- STATION AUTONOMY ISSUE IS PIVOTAL TO DEVELOPMENT OF 'R&M' APPROACH
- R&M WILL BE A KEY COST FACTOR & STA DRIVER
- NO SPACE ILS APPROACH EXISTS FOR SHUTTLE SUPPORTED SYSTEMS
- SPARES (ORBITAL REPLACEMENT UNITS) APPROACH/PHILOSOPHY & AVAILABILITY CONTINUES AS A MAJOR PROBLEM
- CONTRACTORS NEED 'SOME' R&M GUIDANCE PRIOR TO NASA PHASE B STATION STUDIES

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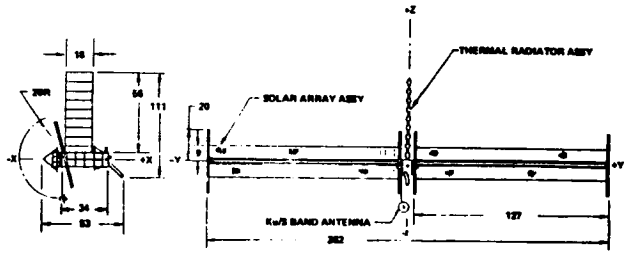
SESSION #3 RELIABILITY/MAINTAINABILITY

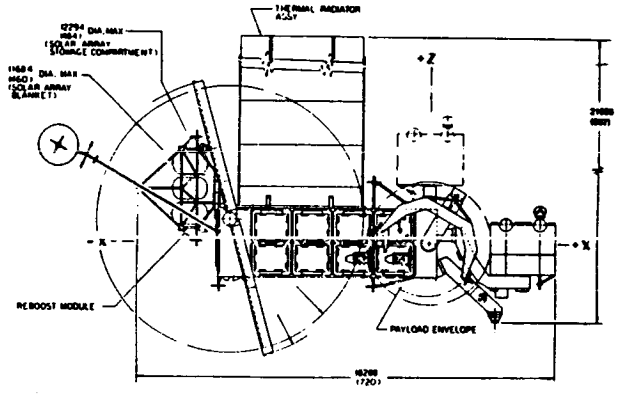
SPACE PLATFORMS

R.E. SHARPLES
8 JUNE 1983



NOTE: DIMENSIONS IN FEET

BASIC STUDY	SOURCE	RELATED STUDIES/COMMENTS
SPACE PLATFORM (SP) (AKA: POWER MODULE 25 kW POWER SYSTEM POWER SYSTEM PLATFORM)	NASA/MSFC	SCIENCE AND APPLICATIONS SPACE PLATFORM (SASP)
		SCIENCE AND APPLICATIONS MANNED SPACE PLATFORM (SAMSP)
		MANNED SPACE STATION (MSS)
POWER EXTENSION PACKAGE (PEP)	NASA/JSC	ENERGY KIT FOR SHUTTLE ORBITER INTENDED TO PERMIT ORBITER TO EXTEND ORBITAL STAY TIME FROM 7 TO 21 DAYS
SPACE OPERATIONS CENTER (SOC)	NASA/JSC	SPACE STATION INTENDED AS LEO OPERATIONS CENTER
MANNED SPACE STATION	NASA/HQ	MISSION DEFINITION STUDIES COMPLETED IN APRIL 1983



- CAPABLE OF ON-ORBIT PAYLOAD CHANGE-OUT AND MAINTENANCE
- CAPABILITY TO BERTH WITH ORBITER FOR PAYLOAD/SP MAINTENANCE
- CAPABLE OF OPERATION IN ANY LOW-EARTH ORBIT
- PROVIDE CONTAMINATION-FREE ENVIRONMENT FOR PAYLOADS
- COMPLY WITH STS SAFETY REQUIREMENTS
- INCORPORATE SIMPLE, COST EFFECTIVE GROWTH CAPABILITY
- DESIGN REQUIREMENTS COMPATIBLE WITH GROWTH TO A MANNED SYSTEM
- INDEFINITE LIFE WITH ON-ORBIT MAINTENANCE

- FAULTS ISOLATED BY SUBSYSTEM SELF-CHECKING AND BY SYSTEM-LEVEL REDUNDANCY MANAGEMENT
- ON-BOARD THRESHOLD DETECTION RESULTS IN AUTONOMOUS RECONFIGURATION AND RECOVERY
- RECOVERY DECISION DATA IMMEDIATELY FORWARDED TO GROUND
- ALL PERFORMANCE DATA TELEMETERED PERIODICALLY (OR WHEN DESIRED SELECTIVELY) IN ORDER TO VERIFY ON-BOARD DECISIONS AND TO MONITOR PERFORMANCE TRENDS
- ANALYSIS OF TELEMETRY DATA WILL BE USED FOR ORU REPLACEMENT DECISIONS

ON-ORBIT MAINTAINABILITY

- LARGE, STANDARD, MODULAR ORU'S USED TO MINIMIZE NUMBER OF UNIQUE REPLACEABLE UNITS
- ON-ORBIT REBONDING OF THERMAL CONDUCTIVITY INTERFACES AVOIDED
- STS-STANDARDIZED CREW SUPPORT EQUIPMENT AND OPERATIONS UTILIZED
- ACHIEVED COMMONALITY OF INTERFACES FOR GROWTH, SERVICE, REPLACEMENT OR JETTISON
- EXTERNAL ACCESS PROVIDED TO AVOID DEDICATED INTERNAL VOLUME, DOORS OR PANELS

ON-ORBIT MAINTAINABILITY (CONTINUED)

- APPLIED LEARNING FROM SPACE TELESCOPE AND OTHER PROGRAMS TO AVOID UNIQUE DESIGNS TO MINIMIZE SPECIAL TRAINING
- ACCESS PROVISIONS, STANDARDIZED EQUIPMENT, GENERIC AND SPECIFIC TRAINING, AND STANDARD ORBITER TOOL KIT PROVIDE EFFECTIVE SERENDIPITY REPAIR CAPABILITY
- NO MAINTENANCE PLANNED DURING THE FIRST FIVE YEARS EXCEPT FOR RBM EXCHANGE
- CONTINGENCY REPLACEMENT CAPABILITY PROVIDED FOR EQUIPMENT FAILURE, ON-ORBIT DAMAGE OR PERFORMANCE UPGRADE

ON-ORBIT REFURBISHMENT

- NEED FOR SP RETURN TO EARTH AND SUBSEQUENT ON-GROUND REFURBISHMENT AFTER FIVE YEARS OF OPERATION IS UNLIKELY
- POST-FIVE-YEAR REFURBISHMENT ON-ORBIT CAN BE DONE IN CONJUNCTION WITH PAYLOAD EXCHANGES
- BATTERY (POWER MODULE) CHANGEOUT IS MOST LIKELY BETWEEN SIXTH AND NINTH YEARS
- ON-ORBIT REFURBISHMENT SAVES DOLLARS AND TIME
  - UNINTERRUPTED PAYLOAD SERVICE
  - ELIMINATES ORBITER RETRIEVAL AND RELAUNCH FLIGHTS
  - AVOIDS EXTENSIVE ON-GROUND SP HANDLING

SOME COMPARISONS - UNIT AND MODULAR ORU'S

UNIT LEVEL ORU	MODULAR ORU
(+)	(+)
• NO CARGO BAY CARRIER FOR SOME ITEMS	• STANDARD ELECTRICAL/MECHANICAL INTERFACE
• FEWER RMS OPERATIONS	• STANDARD REPLACEMENT OPERATION AND TOOLS
	• HIGH PACKAGING DENSITY
	• ON-ORBIT GROWTH SIMPLIFIED
	• TRAINING COSTS MINIMIZED
(-)	(-)
• ELECTRICAL/MECHANICAL REDESIGN FOR EVA	
• THERMAL BONDING UNCERTAINTY	• PAYLOAD BAY CARRIERS AND OPERATIONS REQUIRED
• ACCESS REQUIRED FOR EACH UNIT (DOORS, LOW DENSITY, ETC.)	• SOME OPERATIONAL UNITS REPLACED

MODULAR ORU SIZING

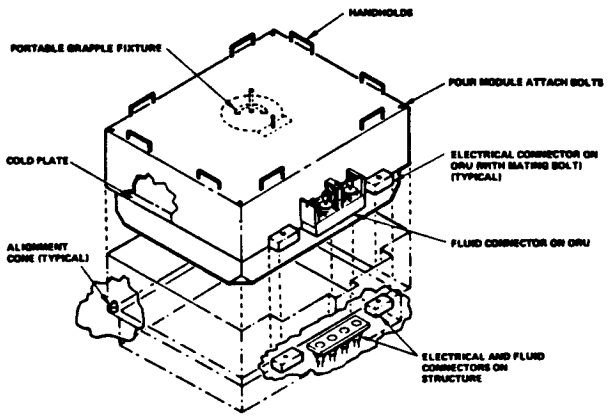
MAJOR DRIVERS:

- MINIMIZE NUMBER OF UNIQUE INTERFACES - COST AND COMPLEXITY
- KEEP SUBSYSTEM ELEMENTS TOGETHER
- BATTERY, CHARGER, CONVERTER SIZE
- CMG SIZE
- MAINTAIN SYSTEM OPERATION DURING ORU REPLACEMENT
- COMPATIBILITY WITH EVA AND RMS CREW HANDLING CAPABILITIES

APPROACH:

- 30 x 46 x 58 INCH STANDARD MODULE FOR MOST EQUIPMENT
- SOLAR ARRAY, ANTENNA, RADIATOR, STAR TRACKERS AND TV CAMERAS/LIGHTS ARE UNIQUE UNITS BECAUSE OF CONFIGURATION AND LOCATION REQUIREMENTS

MODULAR ORU CONFIGURATION



MAINTENANCE CONCENTRATED IN MODULAR ORU' S

- POTENTIAL FAILURES ARE CONCENTRATED IN THE MODULAR-TYPE, STANDARD ORU'S

	ORU TYPES	MODULAR ORU	LARGE ORU	COMPONENT ORU
81% OF EQUIP FAILURE RATE	1. POWER	✓		
	2. CMG	✓		
	3. ATTITUDE CONTROL/DATA HANDLING	✓		
	4. COMMUNICATION/DATA HANDLING	✓		
	5. ACTIVE THERMAL CONTROL	✓		
18% OF EQUIP FAILURE RATE	6. ANTENNA ASSEMBLY		✓	
	7. SOLAR ARRAY		✓	
	8. RADIATOR		✓	
	9. STAR TRACKER			✓
	10. BERTHING ARM		✓	
	11. PAYLOAD ROTATION ARM		✓	
	12. BERTHING LIGHTS			✓
	13. BERTHING CAMERA			✓
1%	ALL NON-REPLACEABLES			

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ORU ON-ORBIT CHANGEOUT SUMMARY

TYPE	ORU BASIC	SIZE (APPROXIMATELY)	MECHANICAL ATTACHMENT	ELECTRICAL CONNECTION	FLUID CONNECTION	REPLACEMENT APPROACH	NUMBER OF EVA CONTROLS	EVA TIME (MIN)
1	ELECTRICAL POWER	STD MODULE*	4 BOLTS	A	A	EVA & [illegible]	2	1
2	CONTROL MOMENT GYRO	STD MODULE*	4 BOLTS	A	N/A	EVA & [illegible]	2	2
3	ATTITUDE CONTROL/ DATA HANDLING	STD MODULE*	4 BOLTS	A	A	EVA & [illegible]	2	2
4	COMMUNICATION/ DATA HANDLING	STD MODULE*	4 BOLTS	A	A	EVA & [illegible]	2	2
5	ACTIVE THERMAL CONTROL	1/2 STD MODULE	4 BOLTS	A	A	EVA & [illegible]	2	2
6	ANTENNA ASSEMBLY	70 x 70 x 40 IN. 200 LB. [illegible]	BOLTS	C	N/A	EVA & [illegible]	2	2
7	SOLAR ARRAY	35 x 72 x 240 IN.	MANUAL [illegible]	B	N/A	EVA & [illegible]	2	2
8	SOLAR ARRAY DRIVE ASSEMBLIES	20 x 24 x 40 IN.	BOLTS	C	N/A	EVA & [illegible]	2	2
9	RADIATOR	470 x 110 x 20 IN.	8 BOLTS	A	A	EVA & [illegible]	2	2
10	STAR TRACKER/ RATE GYRO	12 x 14 x 16 IN.	BOLTS	C	N/A	EVA	1	1.5
11	BERTHING ARM	140 x 30 x 30 IN.	BERTHING MECH.	B	N/A	EVA	700	700
12	PAYLOAD ROTATION ARM	700 x 100 x 30 IN.	BERTHING MECH.	B	B	[illegible]	[illegible]	-
13	BERTHING LIGHTS	6 x 6 x 6 IN.	BOLTS	C	N/A	EVA	1	1
14	BERTHING CAMERAS	5 x 5 x 10 IN.	BOLTS	C	N/A	EVA	1	1

"STD" = 50" x 20"

A – TOOL-OPERATED CONNECTOR [illegible]
B – AUTOMATIC

C – HAND-OPERATED CONNECTORS [illegible]
N/A – NOT APPLICABLE

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SP AVAILABILITY DERIVATION

- AVAILABILITY IS THE MEASURE OF THE SYSTEM CAPABILITY TO PROVIDE THE INTENDED SERVICE
- AVERAGE AVAILABILITY = $\frac{\text{SERVICE TIME}}{\text{MISSION TIME}}$
- CONCEPTUAL ILLUSTRATION OF RELIABILITY RESTORATION USING ON-ORBIT ORU REPLACEMENT:

- DETERMINE BY MONTE CARLO AVAILABILITY SIMULATION PROGRAM
- PROGRAM SIMULATES EQUIPMENT FAILURES AND SCHEDULES ORU REPLACEMENT UPON PREDEFINED REPLACEMENT STRATEGY AND ORBITER REVISIT FREQUENCY
- PROGRAM KEEPS A RECORD OF "WHAT HAPPENED" FOR EACH MISSION
- PROGRAM REPEATS INDIVIDUAL MISSIONS MANY TIMES
- SUMMARIZES THE STATISTICS FROM RECORDS ACCUMULATED OVER MANY MISSIONS

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MAINTAINABILITY TRADE/STUDY SUMMARY

- MEAN TIME TO CONTINGENCY ORU REPLACEMENT
  - FREQUENCY OF REPLACEMENT DETERMINED FOR TWO ON-ORBIT REPLACEMENT STRATEGIES: CONSERVATIVE AND OPTIMISTIC
  - RESULTS INDICATE ON-ORBIT REPLACEMENT ACTIVITY, EVEN WITH A CONSERVATIVE STRATEGY, WILL NOT BE EXTENSIVE OR BURDENSOME
- SP AVAILABILITY
  - AVAILABILITY DETERMINED FOR TWO REPLACEMENT STRATEGIES AND ALTERNATE ORBITER REVISIT SCHEDULES
  - RESULTS CLEARLY DEMONSTRATE SP CAPABILITY AS A UTILITY IN SPACE

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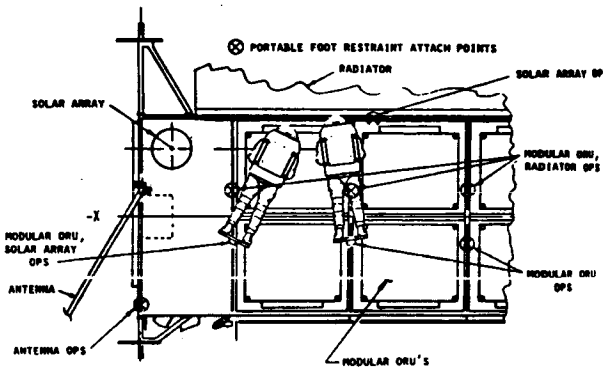
FOOT RESTRAINTS ATTACH POINTS PORT SIDE



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RESULTS OF SIMULATIONS

- ORU CONTINGENCY MEAN TIME TO REPLACEMENT

ORU	MEAN TIME TO REPLACEMENT (YEARS)	
[illegible]	[illegible]	[illegible]
1 POWER	0.3	> 10
2 CMG	> 10	> 10
3 ATTITUDE CONTROL/DATA HANDLING	7.0	> 10
4 COMMUNICATION/DATA HANDLING	3.2	> 10
5 ACTIVE THERMAL CONTROL	> 10	> 10
6 ANTENNA ASSEMBLY	> 10	> 10
7 SOLAR ARRAY	> 10	> 10
8 RADIATOR	> 10	> 10
9 STAR TRACKER	> 10	> 10
10 BERTHING ARM	> 10	> 10
11 PAYLOAD ROTATION ARM	> 10	> 10
12 BERTHING LIGHTS	> 10	> 10
13 BERTHING CAMERA	> 10	> 10

- SP AVAILABILITY

REPLACE UPON	REVISIT CYCLE	
	6 MO	12 MO
LOSS OF REDUNDANCY	0.99+	0.99
LOSS OF PERFORMANCE	0.97	0.95

- AVERAGE REPLACEMENT OF ORU'S ARE NOT EXCESSIVE
- HIGH AVAILABILITY OF SERVICE TO PAYLOADS

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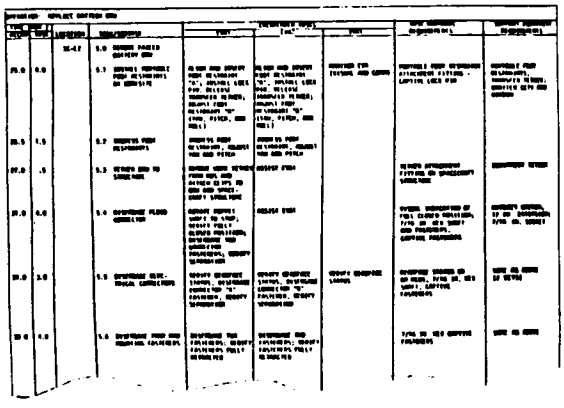
EVA TASK ANALYSIS



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MINIMIZING COST OF ORBITAL MAINTENANCE OPERATIONS

- MODULARIZE TO REDUCE UNIQUE EVA OPERATIONS
- UTILIZE CREW SUPPORT EQUIPMENT AND OPERATIONS DEVELOPED FOR SHUTTLE AND SPACE TELESCOPE PROGRAMS
- REDUCE TRAINING BY MINIMIZING UNIQUE EVA OPERATIONS
- UTILIZE COMMON INTERFACES FOR JETTISON, GROWTH AND REPLACEMENT OF NON-MODULAR ORU'S (SOLAR ARRAY, RADIATOR, ANTENNA)
- EXTERNAL MOUNTING MINIMIZES:
  - ACCESS DOORS AND PANELS
  - DEDICATED ACCESS VOLUME

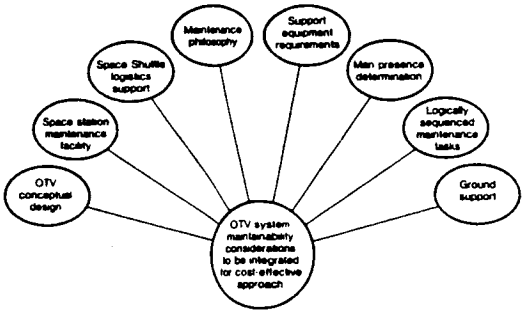
SPACE-BASED ORBITAL TRANSFER VEHICLE (OTV) MAINTAINABILITY TECHNOLOGY DEVELOPMENT

8 June 1983

Presented at
Mission Assurance Conference
Space Station Workshop

GENERAL DYNAMICS
Convair Division

SPACE-BASED OTV MAINTAINABILITY FACTORS



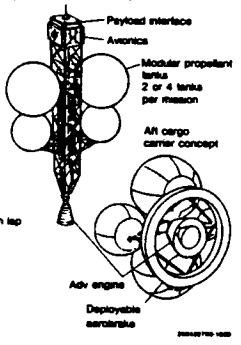
SPACE-BASED OTV

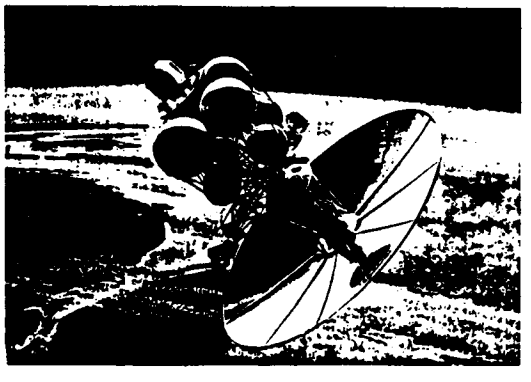
Advantages
- Free from Shuttle constraints (size, loads)
- Reusable (lower cost)
- Modularity (mix & match capability)

Key issues
- Long-term space exposure
- Orbital integration, servicing
- Efficiency (low weight, high isp)
- Low-cost operations (propellant delivery to LEO)
- Deployment & retrieval
- Future payloads & mission characteristics

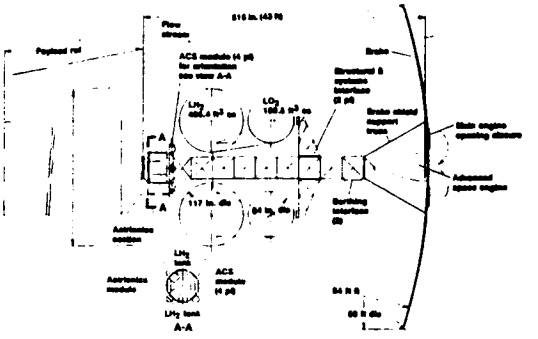
Technology needs
- Lightweight (thin gage) tanks
- Lightweight (composite) structure
- Lightweight/high temperature aerobrake materials
- Long life/space maintainability engine (low weight, high isp
- Cryogenic propellant management – thermal control (MLI insulation, mixing, venting), propellant acquisition gaging
- Meteoroid & space debris protection
- Redundant, fault-tolerant, hardened avionics
- Auto rendezvous/docking

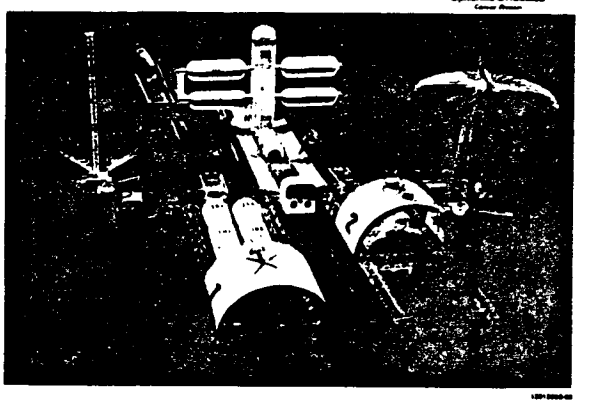
Space assembled concept





REPRESENTATIVE SPACE-BASED OTV CONCEPT





MAINTENANCE FACILITY EVALUATION

	IVA	SEMI/IVA	EVA	EVA
Space Station support	Full Pressurized Hangar	Pressurized Shelter/Hangar	Shelter	No Shelter
Facilities	• Complex stationary hangar • Hangar pressure system	• Hybrid OTV assembly module • Module pressure system • Simple mobile shelter	• Simple mobile shelter • No pressure system	• No shelter • No pressure system
Life support system	• Large volume system • 3.5 lbs O_2 with complex airlock & repressurization	• 1-10 hangar volume • 1-4.7 lbs O_2 with airlock & repressurization	• Extravehicular mobility units	• Extravehicular mobility units
Support equipment	• Standard handling • Standard space tools	• Special & standard handling • Special & standard space tools	• Special handling • Special tools	• Complex handling • Special tools
OTV Maintenance	• Shirtsleeve repair • Propellant servicing outside hangar	• Shirtsleeve & EVA repair • Propellant servicing in place	• Robotic & EVA repair • Propellant servicing in place	• Robotic & EVA repair • Propellant servicing in place
Facilities Maintenance	• EVA repair • O_2 purge & mobility system • Temperature regulation system • Airlock seals & valves	• O_2 purge & mobility system • Temperature regulation system • Shelter mobility system	• Shelter mobility system	• No maintenance
Spares Storage	• Spares storage space available	• Spares storage space available	• Spares storage space available on inner walls	• Requires spares storage structure
Safety	• Residual propellant hazard • Meteoroids & radiation protection	• Residual propellant hazard • Meteoroids & radiation protection	• Residual propellant safe • Meteoroids & radiation protection	• Residual propellant safe • No environmental protection
Growth potential	• Difficult add-on	• Simple add-on	• Simple add-on	• Easy add-on
Cost	• High cost	• Medium cost	• Lower cost	• Lowest cost

SHELTER SELECTION RATIONALE

The selected nonpressurized mobile shelter configuration provides the basic needs for OTV maintenance in space

Shelter attributes
- Provides protection against meteoroids, debris & radiation
- Configuration is residual propellant safe
- Reduced complexity minimizes facility maintenance
- Provides for balanced mix of semiautomatic (or robotic) & EVA OTV maintenance operations
- Provides for spare parts & equipment storage on inner walls
- Configuration has growth potential
- Feasible to transport on Shuttle & assemble at space station
- No apparent showstoppers

OTV MAINTENANCE PHILOSOPHY

Three-level maintenance — based on level-of-repair analyses
- I OTV local maintenance
- II Space station maintenance of replaceable units
- III Return-to-earth maintenance

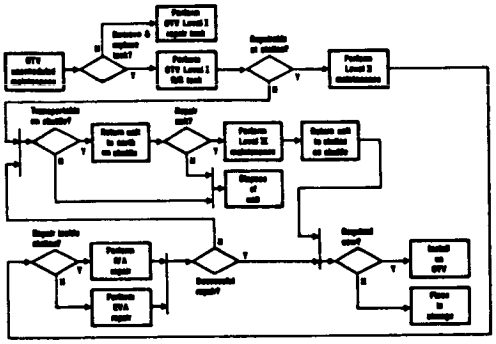
Stock spare parts based on reliability, criticality & cost
- Station storage vs shuttle delivery

Stress modular construction for replacement capability

Provide operational flight instrumentation & built-in test
- Fault isolate to replaceable unit

Optimize EVA vehicle maintenance operations
- Consider safety in hazardous situations
- Tradeoff EVA vs support equipment
  - — TV inspection
  - — Robotic remove & replace

OTV CORRECTIVE MAINTENANCE OPERATIONS



OTV MAINTENANCE DEVELOPMENT TESTS

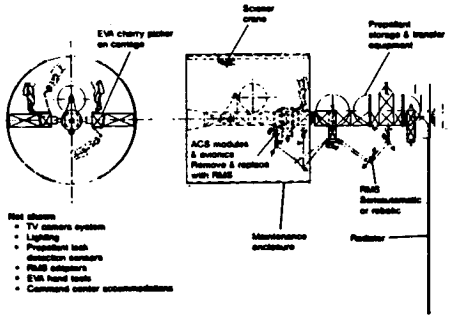
Maintenance Task	Development Requirements			Rationale for Space Station Tests
	Ground	Shuttle	Station	
Visual inspection	✓		✓	Preliminary rehearsal & [illegible] maintenance concept proofing
Fault detection	✓	✓		
Fault isolation	✓			
Remove & replace	✓	✓	✓	Verify EVA accessibility & replacement concept — verify sample procedures & timelines
Unscheduled repair	✓			
System operational verification	✓			
Servicing	✓	✓	✓	Verify & monitor performance of propellant supply system in zero-g environment
Handling	✓	✓	✓	Verify OTV handling concepts & equipment compatibility — verify mating procedures & equipment/EVA integration

OTV PROPELLANT SERVICING IN SPACE

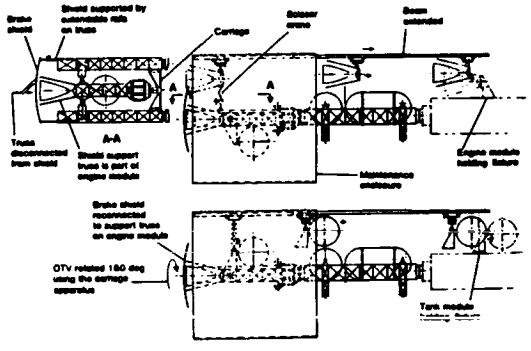
Main propulsion system
- Provide propellant storage & transfer capability at space station vs separate free-flyer propellant depot
- Perform propellant servicing in place at maintenance dock
- Provide automated controls for propellant servicing process
- Conduct OTV servicing through quick disconnect interface system

Attitude control system
- Provide self-contained ACS modules with simplified OTV interface
- Replace ACS modules after each operational mission
- Conduct changeout operations with semiautomatic or robotic equipment
- Resupply ACS modules via Shuttle & store modules on station

BASIC OTV MAINTENANCE FACILITY & SUPPORT EQUIPMENT



MAINTENANCE TDM — ENGINE & TANK CHANGEOUT



TDM MAINTENANCE SUMMARY — PROPULSION

Functional Requirements	Equivalent Ground Task	TDM Task	IVA	EVA	Support Equipment Requirements
Maintenance: Main Engine	Procedure: HPS 1-00347				
*Remove & replace preparations					
• Crew orientation	• Review procedures	• Review maintenance plan	✓		• Computer system
• EVA crew	• Obtain planning paper	• Don EVA gear	✓		• EVA gear & tools
	• Record removal procedure on check sheets	• Perform EVA airlock transition	✓	✓	• TV system & comm link
		• Monitor EVA progress (command center)	✓		
• Maintenance facilities	• Pick up handling tool with overhead crane	• Activate TDM maintenance facility	✓		• Shelter lighting installation
		— Shelter lighting			• CCTV system
		— TV system			• Scissor crane & extender beam
		— Crane control			
		— Cherry picker control			• Cherry picker on carriage
	• Position crane over engine	• Position crane over engine	✓		

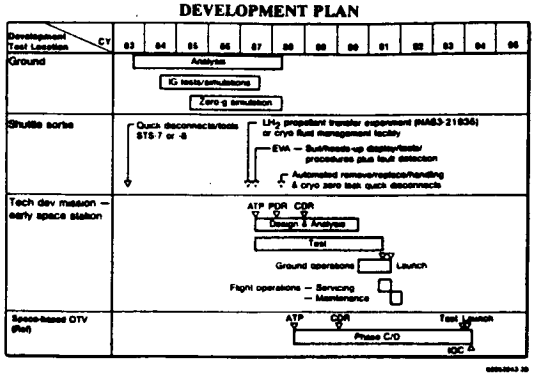
GENERAL DYNAMICS
Convair Division

TDM MAINTENANCE SUMMARY — PROPULSION
(continued)

Functional Requirements	Equivalent Ground Task	TDM Task	IVA	EVA	Support Equipment Requirements
*Remove engine	• Remove plumbing & electrical wiring • Drain lines & reduce pressure to zero • Disconnect 12 plugs & tie back	• Transfer EVA crew to cherry picker • Check local cherry picker controls & communication • Translate crew to engine work area		✓ ✓ ✓	
• Detach aerobrake & stow		• Attach aerobrake to rail truss		✓	• Truss extender on truss structure
		• Detach aerobrake from OTV shield support truss • E-stand aerobrake away from engine	✓	✓	
• Attach crane to engine	• Install handling tool on engine • Support engine weight with crane	• Attach crane to engine		✓	
• Remove engine	• Remove 2 actuators • Remove 4 engine mounting bolts • Verify engine free for handling	• Loosen engine mounting hardware		✓	• EVA tools or latches on OTV
		• Detach engine from OTV		✓	• Special tool or OTV mechanical provisions
• Translate crew to safe area		• Translate EVA crew to safe area		✓	• Cherry picker
• Separate engine from OTV	• Raise engine & place on trailer • Secure engine to trailer	• Withdraw engine with crane	✓		• Scissor crane
• Translate engine & mount to holding fixture	• Install mounts to LO_2 & fuel lines • Cover gimbal block & tie	• Translate engine to holding fixture			• Engine holding fixture

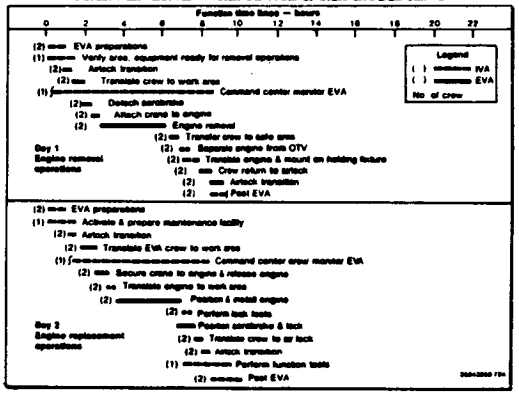
GENERAL DYNAMICS
Convair Division

MAINTENANCE TECHNOLOGY DEVELOPMENT PLAN



GENERAL DYNAMICS
Convair Division

MAIN ENGINE — REMOVAL & REPLACEMENT



GENERAL DYNAMICS
Convair Division

KEY ISSUES & RECOMMENDATIONS

Key issues

- OTV maintenance level
  - Local maintenance at space station dock
  - Space station maintenance of replaceable units
  - Return to earth maintenance
- OTV operational flight instrumentation & built-in test
- OTV modular construction for replacement capability
- Man's role in local maintenance vs robotics
- Space station spare parts vs Shuttle delivery
- Ground support

Recommendations

- Perform systems analysis & trade-offs to establish guidelines & policies
- Perform analysis & ground tests for key technology development items
- Perform precursor experiments in Shuttle sorbe missions
- Perform appropriate technology development missions on early space station

SPACE STATION

EVA SYSTEMS

MAINTAINABILITY

June 1983

UNITED TECHNOLOGIES HAMILTON STANDARD

SPACE STATION

EVA SYSTEMS

MAINTAINABILITY

June 1983

UNITED TECHNOLOGIES HAMILTON STANDARD

SPACE SHUTTLE EMU

The existing EMU provides 7 hours nominal EVA capability and is designed to accommodate 95th percentile population. The EMU consists of 18 contract end items (CEI's).

SHUTTLE EMU

1. Primary Life Support System (PLSS) - The backpack, mounted on the rear of the hard upper torso, contains the life support subsystem expendables and machinery.

2. Displays and Control Module (DCM) - The chest mounted displays and control module contains all external fluid and electrical interfaces, controls, and displays required for one-man operation of the EMU. The DCM houses the fan switch, water pump switch, communications selector switch and audio volume control, oxygen quantity indicator, suit pressure gauge, cooling control valve, purge valve, and status indicators. The location and size of the DCM is such that the crewmember can read displays and reach manual controls without undue compromise of work visibility and mobility. The individual DCM controls have been engineered to prevent inadvertent actuation by either the crewmember or external equipment contact.

3. EMU Electrical Harness (EEH) - This internal harness provides bio-instrumentation and communications connections to the DCM.

4. Secondary Oxygen Pack (SOP) - This pack is mounted to and removable from the base of the PLSS. It contains a 30-minute emergency O_2 supply and a valve and regulator assembly.

5. Service and Cooling Umbilical (SCU) - This umbilical connects the airlock support system (ALSS) to the EMU for recharge and for intravehicular activity (IVA). The SCU contains power, recharge and communication lines, water and O_2 recharge lines, and a water drain line. It has a multiple connector at one end and a permanent fitting at the other.

6. Battery - The battery provides electrical power used by the EMU during EVA. The battery is stored dry and is filled, sealed, and charged prior to flight. The battery is rechargeable.

SHUTTLE EMU (Continued)

7. Contaminant Control Cartridge (CCC) - This assembly integrates LiOH, charcoal, and a filter into one assembly. It is replaced in flight without use of tools.

8. Hard Upper Torso (HUT) - This assembly is the structural mounting interface for most of the EMU-- helmet, arms, lower torso, PLSS, DCM, and electrical harnesses. It also includes the top half of the donning entry body seal closure.

9. Lower Torso - This assembly consists of the pants and boots, and contains the bottom half of the body seal closure, as well as the hip, knee, and ankle joints.

10. Arms (Left and Right) - This assembly contains the shoulder joint and upper arm bearings that permit shoulder mobility, as well as the elbow joint and wrist bearing.

11. Helmet - The helmet consists of a clear, polycarbonate bubble; neck disconnect; and ventilation pad.

12. Gloves (Left and Right) - Gloves contain the wrist disconnect, wrist joint, the fingers, and thermal protection.

13. Liquid Cooling and Ventilation Garment (LCVG) - This garment, worn under the pressure garment, contains the liquid cooling tubes and gas ventilation manifolding.

14. Urine Collection Device (UCD) - This item consists of the adapter tubing, storage bag, and disconnect hardware for emptying liquid.

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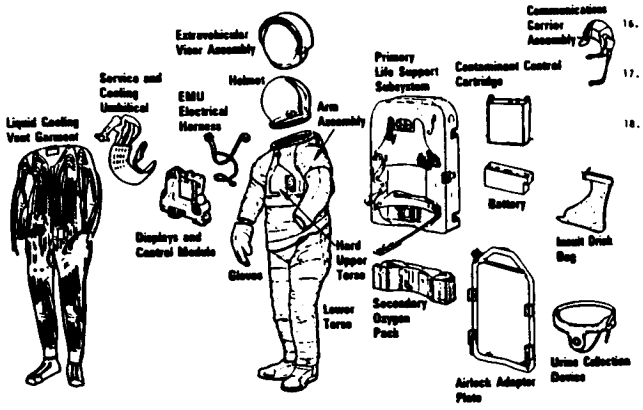
SHUTTLE EMU



Shuttle EMU (Continued)

15. Extravehicular Visor Assembly (EVVA) - This assembly attaches externally to the helmet and contains visors which are manually adjusted by the crewman to shield his eyes.

16. In-Suit Drink Bag (IDB) - This assembly stores liquid in the HUT and has a tube projecting up into the helmet to permit the crewman to drink while suited.

17. Communication Carrier Assembly (CCA) - This assembly consists of a faric head cover which mounts the headphones and microphone to the crewman.

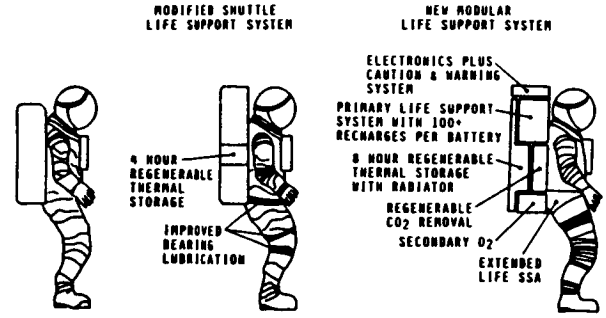
18. Airlock Adapter Plate - This item is the mounting fixture for the EMU during stowage and is used as an aid in donning and doffing the EMU.

EMU EVOLUTION

This slide presents the three EMU configurations considered representative of options available for space station. These configurations represent the natural progression in Space Suit Assembly (SSA) and Primary Life Support System (PLSS) evolution from the existing Shuttle EMU to a total regenerable PLSS and extended life, maintainable SSA. The intermediate configuration adds a regenerable ice pack to the existing PLSS to provide four hours of non-venting operation while working close to sensitive payloads. The existing EMU requires refurbishment after each 5-10 EVA's. The intermediate configuration will achieve greater than 15 EVA's primarily due to improved bearing lubrication. The extended life SSA will support up to 65 EVA's before scheduled maintenance is required.

UNITED TECHNOLOGIES HAMILTON STANDARD

EMU EVOLUTION



CONFIGURATION 1 SHUTTLE EMU | CONFIGURATION 2 NON-VENTING EMU | CONFIGURATION 3 SPACE STATION EMU

REGENERATIVE EMU SYSTEM

The Space Station EMU will not only operate at 8 psi but also be completely regenerative within the thermal and CO_2 control. The current EMU utilizes a water sublimation thermal control subsystem (12 lbs. H_2O/seven-hour EVA). The Space Station EMU will incorporate a hybrid radiator-thermal storage system; the radiator unit will be capable of providing baseline thermal control; and the thermal storage unit will be available for handling peak loads--giving the Space Station EMU an 8-hour thermal control capability.

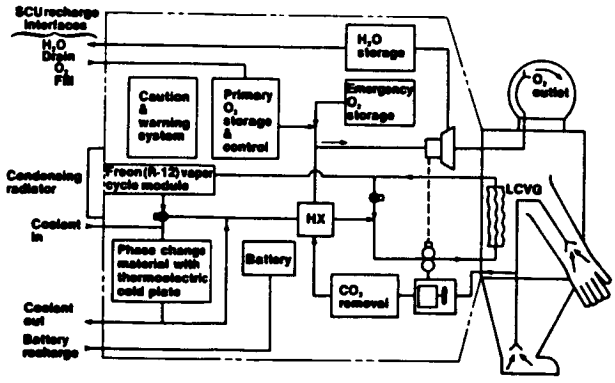
The current EMU contains a replaceable cartridge for CO_2 control called the Contaminant Control Cartridge (CCC). The contaminated LiOH must be repaced after each EVA (regardless of the EVA time) and cannot be reused on-orbit. Regenerative CO_2 systems have been researched and developed with three or four showing promise, namely, solid amines, membrane systems, electrochemical depolarizer (ECD) systems, and metallic oxides. The Space Station EMU will most likely use solid amine or metallic oxides.

An EVA crewmember will use approximately 1.2 lbs. of O_2 per 7-hour EVA. In addition, the current EMU uses a silver-zinc battery which provides 23.5 amp-hour of power and may be recharged up to eight times. The Space Station EMU may utilize a lithium battery, capable of up to 100 recharges.

Overall, the Space Station EMU will be much less dependent upon Space Station resupply and much more conducive to increased EVA activity.

UNITED TECHNOLOGIES HAMILTON STANDARD

EMU WITH REGENERATIVE THERMAL AND CO_2 CONTROL



EMU MAINTAINABILITY ISSUES

EMU maintainability will not only assure crewmember safety, but increase EVA frequency and extend on-orbit stay times. A maintenance policy is necessary to allow continuous EVA capability while using the same EMU and providing economic on-orbit operations. The cost of EMU resupply is prohibitive for a high EVA frequency scenario, unless a maintainable EMU is available. The level of maintenance complexity is a direct function of crewmember capability on orbit. Suit pressure integrity, interface connections, quality assurance, and reliability are paramount prior to EVA--consequently, crewmember level of repair must adhere to EVA quality assurance criteria.

EMU support equipment trade-offs are required and discussed on the following page. In all situations, an inventory of EMU spares is required--spares which on one hand increase total number of EVA's potential between space station resupply, yet on the other hand occupy volume. The location of the EMU maintenance/work station is important and may be combined to serve many functions, e.g., work station, donning/doffing station, recharge station, and spares storage section. In addition, human anthropometric design implementation into the work station and task sequencing must be conducted for efficient zero-g operations.

UNITED TECHNOLOGIES HAMILTON STANDARD

EMU MAINTAINABILITY ISSUES

- CONTINUOUS ON-ORBIT OPERATIONS REQUIREMENT/EVA FREQUENCY
- REPAIR/MAINTAIN LEVEL OF COMPLEXITY
- EMU CHECKOUT INTEGRITY
- SUPPORT EQUIPMENT
  - VOLUME
  - POWER
  - REGEN
- EMU SPARES
- WORK STATION ARCHITECTURE
- CREW ORIENTATION TO STATION

UNITED TECHNOLOGIES HAMILTON STANDARD

MAINTAINABLE EMU SUBSYSTEMS / SUBASSEMBLIES

- HARD UPPER TORSO
- PRIMARY LIFE SUPPORT SYSTEM
  - HIGH PRESSURE O_2
  - LOW PRESSURE O_2
  - CAUTION AND WARNING SYSTEM
  - COMMUNICATIONS
  - SENSOR ADJUST
- SECONDARY OXYGEN PACK
- DISPLAYS AND CONTROL MODULE
- SPACE SUIT ASSEMBLY
  - GLOVES
  - JOINTS, INTERJOINT SECTIONS
  - LEAKAGE CHECK

EMU MAINTENANCE EVOLUTION

The major maintenance evolution from the current Shuttle EMU to the Space Station EMU lies in the modularity of the Space Station EMU systems. The PLSS will be subdivided into low and high pressure subsystems to facilitate maintenance on high technology items. Subsystems include:

- Hard Upper Torso
- Primary Life Support Systems
  - High Pressure
  - Low Pressure
  - Caution and Warning System
  - Communications
  - Sensor Adjustment
- Secondary Oxygen Pack
- Displays and Control Module
- Space Suit Assembly
  - Gloves
  - Joints, Interjoint Sections
  - Leakage Check

These subsystems will be designed such that maintenance (repair, clean, refurbish) can occur as described on the facing page.

UNITED TECHNOLOGIES HAMILTON STANDARD

EMU MAINTENANCE EVOLUTION

SPACE SHUTTLE EMU	SPACE STATION EMU
REPLACE EXPENDABLES	• RECHARGE VIA REGEN SUBSYSTEMS
– O_2	• REPAIR MODULAR EMU
– LiOH	• REPLACE BATTERY
– H_2O	• CLEAN LCVG (EVERY 6-10 EVA'S)
– BATTERY	• DRY-WIPE SSA
• CHECKOUT PLSS WITH CWS	• LEAKAGE CHECK
• ADJUST SENSORS	• CHECKOUT PLSS WITH CWS
• LEAKAGE CHECK	• CHECKOUT CWS WITH STATION SYSTEM
• DRY-WIPE SSA	• CLEAN UCD

EMU MAINTENANCE SUPPORT EQUIPMENT

The EMU recharger/don-doff station will constitute the majority of EMU maintenance equipment. The current EMU recharger interfaces are the Display and Control Module (DCM) and the Service Cooling Umbilical (SCU). The current EMU would require a stowage area for replacement CO_2 cartridges (LiOH cartridges) as well as Space Suit Assembly (SSA) spares and cleaning supplies. The Space Station EMU recharge station functionally is identical to the current EMU recharge station, except for the regenerative subsystems. The recharge station will provide thermal control, O_2, water, and CO_2 control recharge. In addition, the work station will provide cleaning materials, EMU repair and maintenance tools (screwdrivers, pliers, etc.), EMU leakage integrity controller, biomedical monitor, and an EMU Caution and Warning System checkout point.

UNITED TECHNOLOGIES HAMILTON STANDARD

EMU MAINTENANCE SUPPORT EQUIPMENT

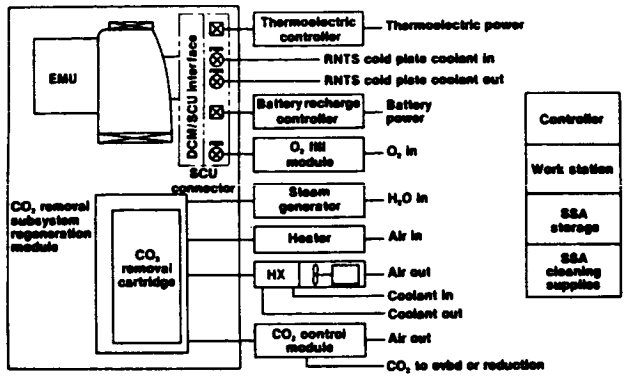
- CO_2 SYSTEM RECHARGER
- TCS RECHARGER
- O_2, H_2O RECHARGER
- POWER RECHARGE
- EMU SPARES/STOWAGE
- WORK STATION WITH CLEANING MATERIALS
- TOOLS
- LEAK DETECTION SYSTEM
- SERVICE AND COOLING UMBILICAL
- BIOMEDICAL MONITOR CHECKOUT

EMU RECHARGE STATION

The EMU recharge station will provide O_2, CO_2, H_2O, power, and thermal control recharge. All recharge interfaces, except the CO_2 control recharge, will be made via the Service and Cooling Umbilical (SCU). The regenerative thermal control subsystem (RNTS - Regenerative Non-Venting Thermal Sink) will require a thermoelectric controller/power system. The CO_2 removal system is also regenerative and requires a designated recharge facility. The stowage area and requirements differ from those of the current EMU stowage in that LiOH cartridges are no longer necessary; and the level of maintenance upon the Space Suit Assembly and the Primary Life Support System is more complex, requiring the larger variety of spares. The RNTS/Battery/O_2/CO_2 recharge equipment is required for each EMU. This is due to a 12-hour recharge period.

UNITED TECHNOLOGIES HAMILTON STANDARD

RECHARGE STATION



RECHARGE STATION AISLE ACCESS REQUIREMENTS

Design of an EMU maintenance facility will be contingent upon (a) maintenance/function complexity, (b) work station location within module, (c) frequency of EVA, and (d) number of EVA crewmen.

UNITED TECHNOLOGIES HAMILTON STANDARD

RECHARGE STATION AISLE ACCESS REQUIREMENTS

SYSTEM	REQUIRED FRONT ACCESS AREA FT^2	ACCESS/AISLE VOLUME FT^3
DONNING STATION	29	87
STORAGE 2 EMU'S	21	63
REGENERATIVE CO_2 EQUIPMENT	9.4	28.2
RECHARGE CONTROLLER	3.1	9.3
REPAIR STATION	14.3	42.9
SCU	6.3	18.9
TOTAL	83.1 FT^2	249.3 FT^3

EMU SPARES

This list provides the type and volume of EMU spares required to support a 90-day, high frequency (5-EVA/week/EMU) mission. Quantities of each spare are dependent upon total crew and mission.

UNITED TECHNOLOGIES HAMILTON STANDARD

EMU SPARES

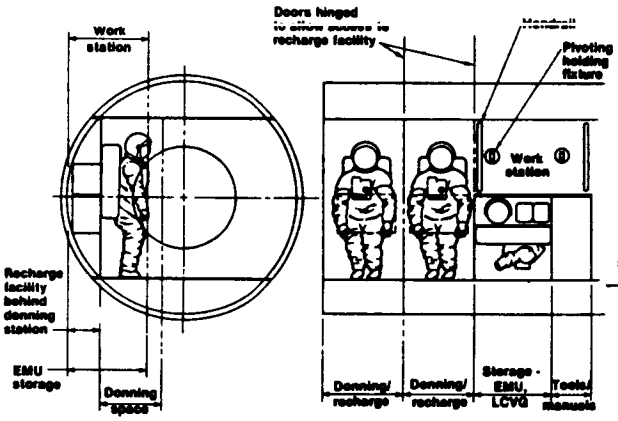
ITEM	VOLUME (FT^3)
EMU STOWED IN AAP	22.1
PLSS	5.1
HELMET	3.0
LCVG	0.8
GLOVES	0.2/PR
ARMS	1.9/PR
LEGS WITH BOOTS	3.2/PR
BODY STOCKING	10 IN^3
MCD	150 IN^3

EVA MAINTENANCE/PREPARATION STATION LAYOUT

The EVA work station configuration is created to optimize module volume while providing smooth transgression of operations and task execution. The donning station will also be used as a recharge station for each EMU.

UNITED TECHNOLOGIES HAMILTON STANDARD

EVA MAINTENANCE / PREPARATION STATION LAYOUT



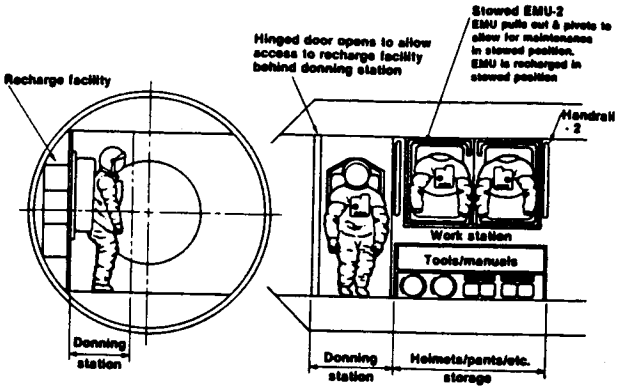
ALTERNATE

EVA MAINTENANCE AND PREPARATION

STATION CONCEPTS

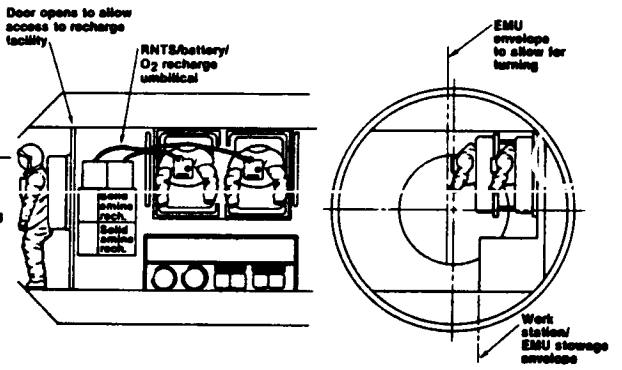
UNITED TECHNOLOGIES HAMILTON STANDARD

ALTERNATE EVA MAINTENANCE AND PREPARATION STATION CONCEPTS



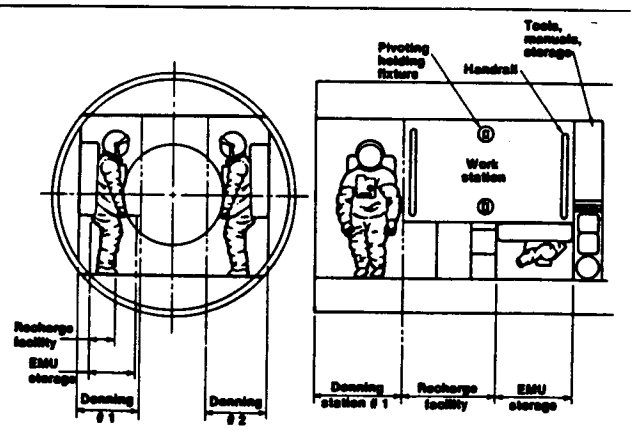
UNITED TECHNOLOGIES HAMILTON STANDARD

ALTERNATE EVA MAINTENANCE AND PREPARATION STATION CONCEPTS (CONTINUED)



UNITED TECHNOLOGIES HAMILTON STANDARD

ALTERNATE EVA MAINTENANCE AND PREPARATION STATION CONCEPTS (CONTINUED)



SPACE STATION MISSION ASSURANCE ISSUE:

NATIONAL SECURITY (DOD) MISSION SURVIVABILITY ...

- COMPATIBLE MISSIONS FOR JOINT CIVIL/MILITARY SPACE STATION
  - RESEARCH & DEVELOPMENT
  - LOGISTICS (TRANSPORTATION, SERVICING, STORAGE, ASSEMBLY)
    - IN PEACETIME, MISSIONS ARE ASSURED
    - MISSIONS NOT CRITICAL IN WARTIME
    - LOW PROVOCATION DETERS ATTACK
- SURVIVABILITY PHILOSOPHY FOR MISSION ASSURANCE
  - DECOUPLE MISSIONS FROM WARTIME OPERATIONS
  - NO HEROIC DEFENSE FOR CONFLICTS
  - PROTECT AGAINST HARASSMENT (e.g., ELECTRONIC JAMMING)

Rockwell International

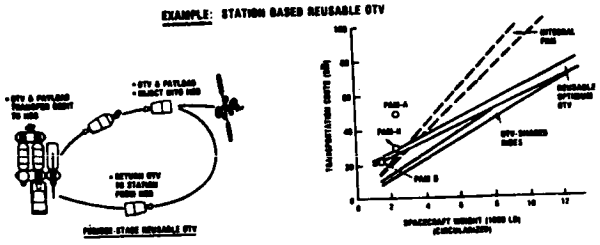
SPACE STATION MISSION ASSURANCE:

LESSONS FROM THE PAST ...

KEEP USERS INVOLVED DURING DEVELOPMENT

- MISSION SUCCESS IS A SATISFIED USER
- USER INTERACTION NECESSARY TO ASSURE STATION SERVICES (CAPABILITIES, AVAILABILITY, COSTS) MEET USER NEEDS

EXAMPLE: STATION BASED REUSABLE OTV



ISSUE: PAYLOAD WEIGHT DISTRIBUTION vs TIME

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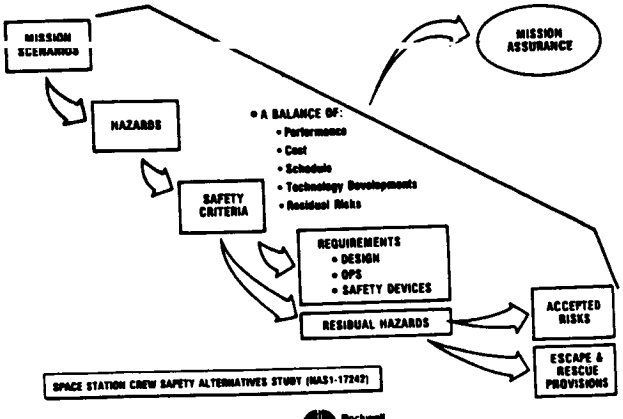
SPACE STATION MISSION ASSURANCE ISSUE:

CREW SAFETY ...



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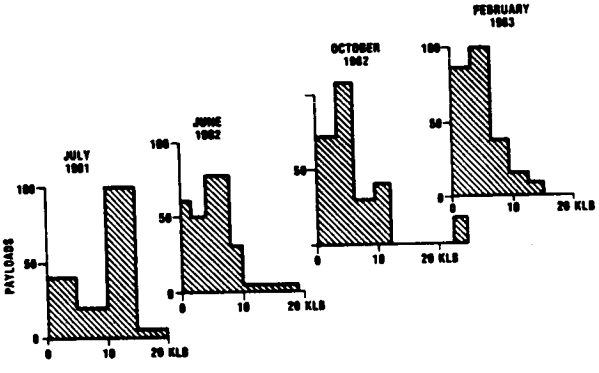
SIZE DISTRIBUTION OF HIGH ENERGY PAYLOADS ...

SPACE STATION MISSION MODELS, 1990-2000



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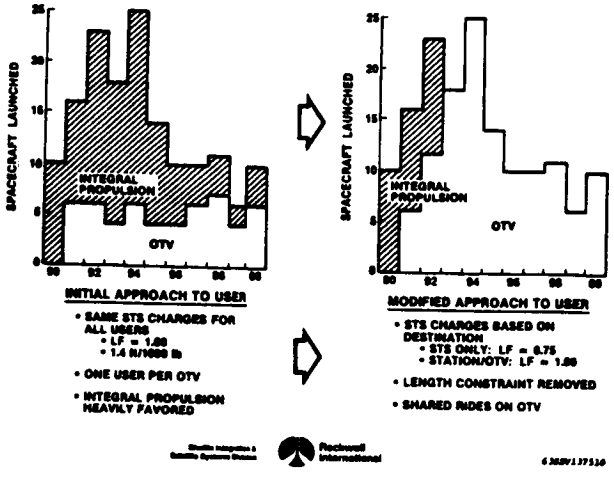
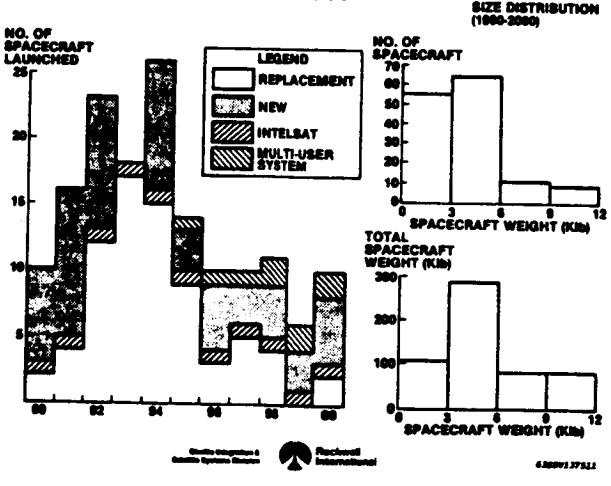
SPACE STATION/OTV CAPTURE . . .



ANALYSIS OF SCENARIO 5 . . .



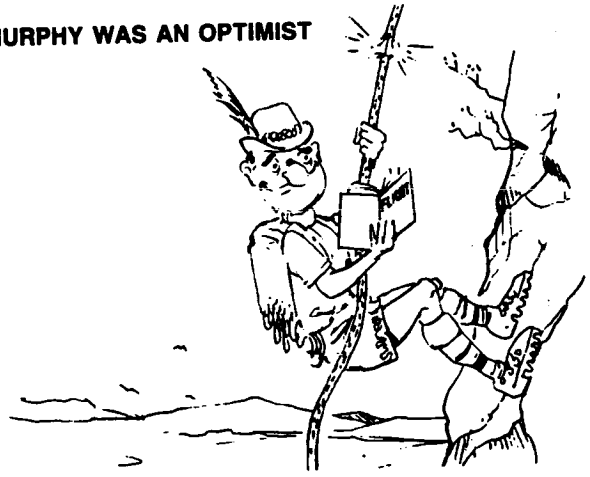
MISSION ASSURANCE CONFERENCE
SPACE STATION WORKSHOP
SESSION 4
LESSONS FROM THE PAST

DICK KLINE
GRUMMAN AEROSPACE CORP
JUNE 9, 1983

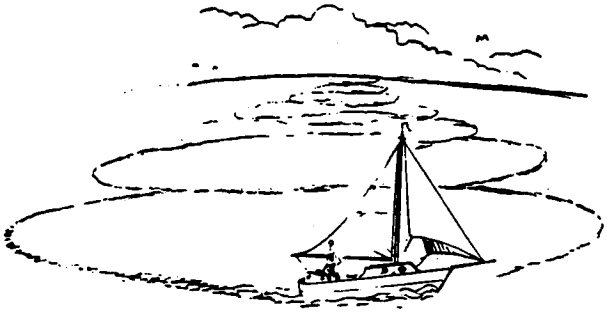
LESSONS LEARNED

DEPEND ON THE RABBIT'S FOOT IF YOU WILL, BUT REMEMBER IT DIDN'T WORK FOR THE RABBIT...

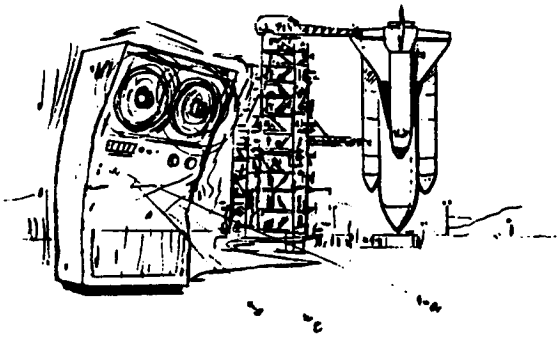
MURPHY WAS AN OPTIMIST



WORKING WITHOUT A PLAN IS LIKE SAILING WITHOUT A COMPASS...



TO ERR IS HUMAN...TO REALLY FOUL THINGS UP REQUIRES A COMPUTER!



IF PRESENT TECHNOLOGY CONTINUES, MAN WILL ATROPHY ALL HIS LIMBS BUT HIS PUSH-BUTTON FINGER...

PEOPLE WHO WILL NEVER CHANGE THEIR MIND HAVE NO MIND TO CHANGE...

BETTER IS THE ENEMY OF GOOD ENOUGH...

EVERYTHING COMETH TO HIM WHO WAITETH, SO LONG AS HE WHO WAITETH WORKETH LIKE HELL WHILE HE WAITETH...

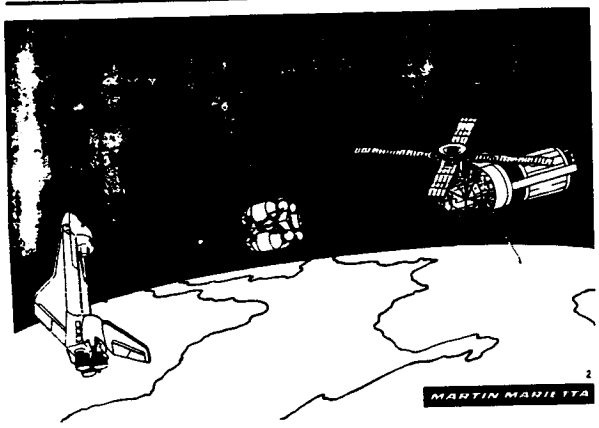
THE MORE TIME YOU SPEND IN REPORTING ON WHAT YOU HAVE DONE THE LESS TIME YOU HAVE TO DO ANYTHING. ULTIMATELY YOU SPEND ALL YOUR LIFE DOING NOTHING AND REPORTING ON THE NOTHING YOU ARE DOING...

Mission Assurance Conference
Lessons Learned

S. Schrock
June 7, 8 & 9, 1983

MARTIN MARIETTA

Teleoperator Retrieval/Skylab Boost System



2

MARTIN MARIETTA

Lessons Learned

PROGRAM
- SKYLAB AND SKYLAB REBOOST PLANNING

PROBLEM
- SKYLAB ORBIT WAS DECAYING
- RESULT--UNCONTROLLED RE-ENTRY

SOLUTION
- REBOOST THE SKYLAB MODULE USING A TELEOPERATOR RETRIEVAL SYSTEM (TRS)
  - UNMANNED RENDEZVOUS
  - REMOTELY CONTROLLED FROM THE SHUTTLE
  - SHUTTLE LOCATED 1000 FEET FROM SKYLAB

SKYLAB DATA BASE
- NO CENTRALIZED OR CONTROLLED DATA BASE EXISTED
- INADEQUATE DATA AVAILABLE TO FULLY CHARACTERIZE THE PROBLEM
  - DOCKING INTERFACES
  - MASS PROPERTIES
  - LOADING DATA
  - EQUIPMENT STATUS/CONFIGURATION
  - COMMAND/CONTROL INFORMATION

SPACE STATION
- ANALOGOUS PROBLEM ANTICIPATED ON SPACE STATION
- SPACE STATION IS A LONG DURATION PROGRAM AS COMPARED TO SKYLAB AND WILL REQUIRE:
  - SYSTEM EVOLUTION
  - SYSTEM CHECKOUT AND REPAIR
  - SYSTEM UPGRADING
  - PERIODIC MAINTENANCE
  - DAMAGE REPAIR
  - ETC
- [illegible]
  - CONTRACTS ARE NOT EXTENDED FOREVER
  - CONTRACTORS HAVE A TENDENCY TO RID THEIR FILES OF DATA
- FRANTIC EFFORT TO COLLECT REQUIRED DATA
  - SEARCH OF NASA/CONTRACTOR FILES
  - INTERVIEWS WITH KNOWLEDGEABLE SKYLAB PERSONNEL

RECOMMENDATIONS FOR SPACE STATION
- DEVELOP A CENTRALIZED DATA BASE THAT:
  - CONTAINS ALL SS PERTINENT DATA
  - IS CONTINUOUSLY MAINTAINED/UPDATED
  - SHOULD BE ACCESSIBLE FROM SS AND GROUND

MARTIN MARIETTA

LESSONS LEARNED FROM "PROJECT COMMON HARDWARE"

- EXPERIENCE FROM THE ESA SPACELAB PROGRAMME -

SPACE STATION WORKSHOP
LOS ANGELES, 7 - 9 JUNE 1983

Lars Tedeman
European Space Agency

(2)

"COMMON HARDWARE" BACKGROUND

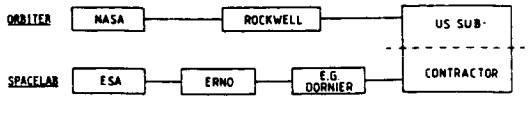
- o DURING THE STUDY PHASE IT WAS DECIDED TO TAKE ADVANTAGE OF THE ORBITER DEVELOPMENT PROGRAMME BY PROCURING "SPACELAB / ORBITER COMMON HARDWARE" (SOCH ITEMS).
- o THIS DECISION WAS DRIVEN BY THE POLICY (MEMORANDUM OF UNDERSTANDING, ARTICLE III, PARAGRAPH 2):

  "IN THE INTEREST OF MINIMISING DEVELOPMENTAL AND OPERATIONAL COSTS, AND MAXIMISING RELIABILITY, AN EFFORT WILL BE MADE TO OPTIMISE COMMONALITY BETWEEN SPACELAB AND SHUTTLE COMPONENTS."

(3)

"COMMON HARDWARE" IMPLEMENTATION

- o THE ITEMS SELECTED AS SOCH ITEMS INCLUDED:
  - O_2 / N_2 CONTROL SYSTEM
  - SMOKE DETECTION / FIRE SUPPRESSION
  - FREON PUMP PACKAGE AND HEAT EXCHANGERS FOR THE THERMAL SYSTEM
  - MASS MEMORY UNIT
  - ETC.
- o THE IMPLEMENTATION WAS TO SEPARATELY DIRECT THE RESPECTIVE CONTRACTOR FOR PROCUREMENT. THIS INCLUDED THE RESPONSIBILITY FOR THE CONTRACTORS TO COMPLY WITH THEIR PROJECT REQUIREMENTS.



(4)

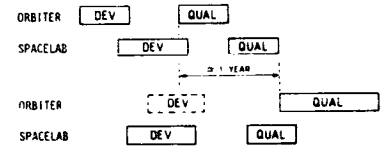
"COMMON HARDWARE" EXPERIENCE

- o PROBLEMS ENCOUNTERED:
  - CHANGES HAVE TAKEN PLACE WITHOUT CONSIDERATION OF IMPACTS ON THE OTHER PROJECT.
  - DELAYS, INCLUDING STOP OF WORK FOR ONE YEAR, IN ONE PROJECT RESULTED IN INCOMPATIBLE SCHEDULES.
  - ORBITER PROGRAMME PHILOSOPHY CHANGED FROM SEPARATE DEVELOPMENT AND QUALIFICATION TESTS TO COMBINED DEVELOPMENT / QUALIFICATION TEST.
  - EXTRA TESTING REQUIRED DUE TO NON-AVAILABLE TEST RESULTS FROM THE OTHER PROJECTS.
  - COST IMPACTS RESULTING FROM THE ABOVE.

(5)

"COMMON HARDWARE" EXPERIENCE - CONT'D

- o SCHEDULE OVERVIEW



(6)

"COMMON HARDWARE" - CORRECTIVE ACTION

- o IN ORDER TO OVERCOME THESE PROBLEMS, A SOCH COMMITTEE WAS ESTABLISHED WITH THE PRIMARY RESPONSIBILITY TO:
  - ESTABLISH EFFECTIVE COMMUNICATION AND VISIBILITY TO THE PARTIES CONCERNED AND TO ACHIEVE COST-EFFECTIVE PROCUREMENT OF SOCH ITEMS.
- o AS A RESULT OF THIS COMMITTEE, BASIC AGREEMENTS WERE REACHED, EG.:
  - DESIGN AUTHORITY ASSIGNED TO ONE CONTRACTOR.
  - RESPONSIBILITY FOR PROBLEM SOLVING AND NECESSARY HARDWARE MODIFICATIONS FOR SOCH ITEMS.
  - ROUTINE EXCHANGE OF INFORMATION BETWEEN SPACELAB AND ORBITER CONTRACTORS.
  - SPACELAB AND ORBITER PARTIES TO PARTICIPATE AS OBSERVERS IN EACH OTHERS REVIEWS AND TESTS.
  - REGULAR TELECONS FOR STATUS REPORTING.

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(7)

"COMMON HARDWARE" - CONCLUSION

- IN CASES OF PARALLEL DEVELOPMENT, A PROBLEM WITHIN ONE PROJECT CAN EASILY RESULT IN SERIOUS TECHNICAL, SCHEDULE AND COST IMPACTS ON THE OTHER PROJECT.
- IN SUCH CASES, MAKE SURE THAT PROPER CONTROL IS ESTABLISHED FOR THE RELATED ACTIVITIES, I.E. CONTRACTUAL AUTHORITY TO CONTROL THE PROJECT INTERFACES.
- IF CONTRACTUAL CONTROL CANNOT BE EXERCISED, THE EARLY ESTABLISHMENT OF A COORDINATION FUNCTION IS A NECESSITY.
- THE ABOVE EXPERIENCE CAN BE APPLICABLE TO:
  - INTERFACE CONTROL WITHIN A PROJECT.
  - INTERFACE CONTROL BETWEEN DIFFERENT CUSTOMERS WITHIN A PROGRAMME.
  - INTERFACE CONTROL BETWEEN MAIN SPACE VEHICLE AND ITS PAYLOADS.

LESSONS LEARNED

SAFETY - RELIABILITY TERMINOLOGY

- EXPERIENCE FROM THE ESA SPACELAB PROGRAMME -

SPACE STATION WORKSHOP
LOS ANGELES, 7 - 9 JUNE 1983

Lars Tedeman
European Space Agency

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(2)

TERMINOLGOY - BACKGROUND

DURING THE ESTABLISHMENT OF THE SPACELAB PRODUCT ASSURANCE PROGRAMME, POLICY DECISIONS INCLUDED:-

- o INTEGRATE THE SAFETY AND RELIABILITY ACTIVITIES IN A COST EFFECTIVE MANNER;
- o ALLOCATE EMPHASIS OF REQUIREMENTS AND EFFORT, ACCORDING TO THE CRITICALITY OF THE FUNCTION.

---

(3)

TERMINOLOGY - IMPLEMENTATION

- o THE IMPLEMENTATION OF THIS POLICY WAS PRIMARILY DEPENDENT ON THE INTERACTION BETWEEN SAFETY AND RELIABILITY WHERE THE FMECA RESULTS SERVED AS A DIRECT INPUT TO THE SAFETY ANALYSIS. ACCORDINGLY, CRITICALITY IN THE FMECA WAS:-

CRITICALITY	DEFINITION OF FAILURE
1	LOSS OF LIFE OR VEHICLE
2	LOSS OF MISSION
3	ALL OTHERS

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(4)

TERMINOLOGY - IMPLEMENTATION (CONT'D)

- o IN THIS INTERACTION, THE RELIABILITY CRITICALITY 1 OUTPUT AFFECTED THE FOLLOWING RELEVANT ASPECTS:-
  - INPUT TO THE HAZARD ANALYSIS
  - SAFETY CRITICAL ITEMS ASSIGNMENT AND CONTROL
  - QUALIFICATION TEST PROGRAMME
  - ASSIGNMENT OF HIGHEST QUALITY LEVEL OF EEE PARTS (TWO LEVELS WERE USED ON SPACELAB)
  - LEVEL OF CONTROL OF THE CONTRACTORS
- o EVEN THOUGH THE APPROACH WAS IN GENERAL EFFECTIVE, SOME CONTRACTORS EXPERIENCED PROBLEMS IN TERMS OF INTERPRETATION.

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(5)

TERMINOLOGY - PROBLEM

- o THE DIFFERENTIATION BETWEEN FUNCTION, FAILURE, FAULT, EFFECT AND EVENT BECAME BLURRED.
- o AS AN EXAMPLE, THE INITIAL FMECA ASSIGNED A TYPICAL CASE TO
  - CRITICALITY CATEGORY 1
- o REDUNDANCY WAS INTRODUCED AND THE RE-RUN OF THE FMECA NOW RESULTED IN AN ASSIGNMENT OF
  - CRITICALITY CATEGORY 2/3
- o THIS ASSIGNMENT WAS PERFORMED FROM A PURE RELIABILITY POINT OF VIEW BY ASSESSING
  - THE EFFECT OF A FAILURE (SINGLE FAILURE TOLERANT)

  RATHER THAN PROPERLY ASSESS THE CONSEQUENCE OF
  - THE FAILURE OF THE FUNCTION.

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(6)

TERMINOLOGY - CONCLUSION

- o IN RETROSPECT, THE DIFFERENTIATION OF TERMINOLOGY SHOULD HAVE BEEN RE-EXAMINED.
- o THUS, A CLEAR AND CONCISE DEFINITION OF THE TERMINOLOGY IS PARAMOUNT IN A COMPLEX ANALYSIS PROGRAMME.
- o THIS IS EVEN MORE PRONOUNCED IN AN INTERNATIONAL ENVIRONMENT WHERE DIFFERENT LANGUAGES AND STANDARDS MUST BE RECOGNISED.

SUMMARY OF ISSUES AND RECOMMENDATIONS

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Revision of Quality Assurance Requirements

Issue

Current satellite systems are designed for multiyear life in an environment where even minor subelement failure can cause significant degradation or even loss of the mission; the opportunity to repair the system has not existed. Quality Assurance requirements developed in this era had to be stringent and rigid. The Space Station environment, on the other hand, offers a unique opportunity to revise Quality Assurance requirements for many subsystems because onboard changeout or repair is possible.

Recommendations

a) Some current systems are based on 100% inspection or on inspection just prior to closeout. Little attempt has been made to develop an inspection system or technique based on the criticality of the inspection, assembly, or test activity. It is recommended that a set of requirements that drives inspection/test planning to a system based on criticality of the inspection, assembly, or test activity be developed. Heavier use should be made of the quality designee system. The critical inspections selected should be part of overall the producibility concept developed jointly by QA, manufacturing, and engineering personnel.

b) Some aerospace hardware and procedural specifications are unnecessarily tight, thereby needlessly driving up costs. Appropriate steps should be taken to relax overly restrictive specification requirements where it can be established that significant cost savings will result, and that mission assurance/safety will not be compromised.

c) Design criteria should be reviewed for application to a long life (multidecade) program such as Space Station. Develop new design criteria documents for Space Station to guide design. Documents should be developed early.

Suggested OPR

NASA Space Station Task Force

2. High Fidelity Engineering Mockup

Issue

There is need for a high fidelity engineering mockup for Space Station Operations.

Recommendations

Evaluate high fidelity hardware modeling systems utilizing flight-type hardware (such as SAIL lab at JSC and CITE at KSC) versus increased use of computer definition (e.g., CADAM) for physical interface definition.

a) There is agreement that this capability is required; the implementation method, however, is the subject of considerable debate. Alternative approaches need to be carefully evaluated. Options range from a high fidelity physical mockup utilizing flight-type hardware to complete computer simulation of both physical and functional interfaces. Implementation approaches need to be studied from the perspective of both cost (initial and long term) and feasibility.

b) With long duration missions the assurance that spare modules to be taken to orbit are physically and functionally interchangeable becomes critical. A method for checking this interchangeability prior to shipment is essential. Also, there is a need for a means to provide ground assistance in troubleshooting hardware and software inflight problems. A high fidelity mockup should be provided in the program to be utilized for fit checks and troubleshooting of inflight problems. The system for maintaining configuration control of the mockup over the multidecade lifespan of the Space Station needs to be defined. Further study is needed to define the fidelity and functions of the mockup.

Suggested OPR

NASA Space Station Task Force

3. Use of Astronauts in Station Operations

Issue

There is an opportunity to minimize system cost by increasing utilization of astronauts in station operations (e.g., manual deployment of infrequently used mechanical devices).

Recommendations

a) Consider designing mechanisms with infrequent operations to be accomplished by a manually activated mechanical device (potentially using EVA) as opposed to sophisticated complex automated design. To reduce design, development, and test/qualification costs and to increase system reliability by reducing the number of mechanisms required, all automated mechanisms with infrequent or low activation cycles should be reevaluated for possible redesign for manual (IVA/EVA) activation or operation, provided IVA/EVA meets crew safety and capability requirements. It is essential to avoid involving astronauts in frequently used repetitive operations or

in hazardous situations, however.

b) It is essential that NASA/DoD establish a "cost per astronaut hour" for input into design and operations trade studies. The key is to decide on a Space Station cost allocation and/or pricing policy for services (e.g., pressurized volume, port connection time, power, crew hours). These services will be priced based on a selected Government cost recovery policy; astronaut crew hour cost will fall out. The specific recommendation is that the Government establish the crew hour cost factors for particular architectural concepts, and these factors be used in all trade studies to ensure that these trade results are meaningful.

Suggested OPR

NASA Space Station Task Force

4. Design Reviews

Issue

The approach to design reviews needs to be revised and improved in the area of mission assurance.

Recommendations

Procedural changes should be made to enforce the rigor needed in the design review process. Design reviews include the preliminary design review (PDR) and the critical design review (CDR); the intent is to accomplish the baselining of the specification at the PDR, and the baselining of the design at the CDR. The concern is that these design reviews are not rigorous in that documentation is often not available or is incomplete; also the design team makeup is often incomplete or not sufficiently experienced for the purpose of preventing downstream problems. A study using case histories and presently used procedures to determine how well these were followed and how effective they were should be prepared. Alterations to enforce the rigor are needed in the design review process.

Suggested OPR

NASA Space Station Task Force

5. Measuring Large Structures in Space

Issue

There is need to develop a design approach to measure large structures erected or deployed in space.

Recommendations

A measurement handbook is needed to provide measuring techniques and accuracies attainable for measuring length/diameters of large structures. Large structures were defined as any size larger than 8 to 10 feet. A capabilities handbook should be developed by the National Bureau of Standards (NBS), or by industry with the cooperation of the NBS, to describe existing accuracies/uncertainties associated with measurements related to large scale structures. Techniques for achieving cost-effective measurements should be described. This information should be disseminated to design functions, to provide state-of-the-art capability data, and Quality/Product Assurance functions, to provide methods/techniques for measurement of large scale structures to various accuracies.

Suggested OPR

NASA Space Station Task Force in conjunction with the National Conference of Standards Laboratories (NCSL) and/or the AIA Quality Assurance Committee

WORKSHOP D

ADVANCED ASSURANCE TECHNOLOGY

Chairmen:

A. D. Martin
Director of Quality Assurance
Boeing Aerospace Company

Dr. Richard Sapp
Director, Reliability and Quality Assurance, NASA

Coordinator:

Charlie H. Donald
Boeing Aerospace Company

SESSION 1 — MICROELECTRONICS

Improvements in Line Verification Methods	W. Geller, LMSC
Testing VLSI Devices	E. R. Hnatek, Viking Labs
High-Speed CMOS	P. R. Mason, Jr., NASA/Goddard SFC
Experience with Leadless Carriers	W. S. Shipley, JPL
New Military Standard and Specification for Large Scale Integrated Circuits for Space Programs Management — Procurements	A. J. Carlan, Aerospace
Cosmic Ray Effects in Large Scale Integrated Circuits	A. J. Carlan, Aerospace

SESSION 2 — SOFTWARE ASSURANCE

Software Fault Tolerance Benefit to Software Quality Assurance	G. E. Migneault, NASA/Langley
An Integrated Software Quality Assurance and Metric Program	C. L. Carpenter, Jr., General Dynamics; G. E. Murine, Metrigs, Inc.
AIA Views on MIL-STD-SQAN	G. E. Dufoe, McDonnell Douglas
Software Design Inspection for Preliminary Design	J. McKissick, Jr., M. J. Somers, W. Rosenberger, GE
The Latest on Stars	S. T. Redwine, Jr., MITRE
The Startup Mechanics in Assuring a Realistic and Integrated SQA Program	D. V. LaRosa, AVCO
Anatomy of a Software Quality Assurance Program	W. R. Burr, Boeing
Proposed MIL-STD-SQAM: What is it?	E. R. Baker, Logicon

WORKSHOP D

ADVANCED ASSURANCE TECHNOLOGY

SESSION 3 — CAD/CAM/CAV

Integrated System of Computer-Aided Quality Assurance	G. W. Bancroft, and T. J. Phillipp, General Dynamics
Anomaly Analysis and Processing Pilot Program Utilizing a Networked CAD System	M. Simons, Martin Marietta
Paperless Quality Assurance Operations	T. H. Poyer, T. J. Nolan, R. V. Caine, GE
Automated Inspection in an Unmanned Flexible Machining Cell Environment	N. Rogers, Vought Corp.
The Role of Computer-Aided Design, Verification and Manufacturing in the Development of Integrated Circuits	Q. C. Cassen and J. N. Culliney, Aerospace
CAD/CAM/CAV Systems for M & P Laboratory	E. H. L., MSFC

SESSION 4 — RECORDS

Paperless Quality Assurance Operations	T. H. Poyer, T. J. Nolan, R. V. Caine, GE
Techniques Used to Process, Store and Retrieve Product Records	D. J. Clemens, General Dynamics
Products Record Panel	J. H. Tilton, Lockheed
External Tank Records Retention Program	L. Herkes, Martin Marietta
Electronic Filing in the 1980's	J. McAfee, OMEX
B-1B EMUX Program Information Center Concept	L. A. Baugher, Harris Corp.
Product Records in the Aerospace Field	A. A. Macias, Aerospace

SESSION 5 — COMPOSITES

NDE for Fiber Reinforced Composites Standards/Criteria/Approaches	A. Vary, NASA Lewis Research Center

SESSION 6 — VERIFICATION OF LARGE STRUCTURES

Best Fit Program for Dimensional Reference Adjustment	C. F. Nix, Jr., Lockheed-Georgia Co.

MISSION ASSURANCE CONFERENCE
ADVANCED ASSURANCE TECHNOLOGY WORKSHOP
MICROELECTRONICS PANEL

IMPROVEMENTS IN LINE VERIFICATION METHODS

WARREN GELLER
TECHNICAL DIRECTOR
MONITORED LINE SERVICE PROGRAM

LOCKHEED MISSILES & SPACE CO., INC.

INTRODUCTION

The traditional contracting technique for parts has been as follows—

a) Prepare a specification
b) Send a Purchase Order with the Specification to the Supplier
c) Possibly perform some in-process inspection using an itinerant inspector
d) Require the supplier to perform some lot sample testing
e) Accept or reject the lot based upon the results of the lot test

This example may be an oversimplification of the process but it serves to indicate that primary reliance was placed upon the supplier to understand the specification, to properly control his manufacturing, inspection and testing, and to deliver an acceptable product. It was assumed there was little need for direct, continuing interface with the supplier during the manufacturing and testing of the product.

This technique was satisfactory for parts having the complexity of washers or resistors but loses efficiency rapidly as we attempt to purchase complex devices.

Today we are discussing procurement of semiconductor parts whose complexity is that of what formerly was included in a wall covered with equipment. We must now review management techniques formerly associated with equipment and extend them to complex parts procurement.

What this translates to is - greater use of *people* to verify the product on the line. The AF/LMSC Monitored Line was created using this rationale. We would like to share our experience in managing this program with you.

IMPROVEMENTS IN LINE VERIFICATION METHODS

OBJECTIVE

OBTAIN RELIABLE SEMICONDUCTOR PARTS, ON SCHEDULE, AT REASONABLE COST, TO SUPPORT PROGRAM NEEDS.

PROBLEM

ALTHOUGH THE COMPLEXITY OF SEMICONDUCTOR PARTS HAS REACHED A LEVEL FORMERLY ASSOCIATED WITH EQUIPMENT, WE CONTINUE TO USE PROCUREMENT MANAGEMENT TECHNIQUES DEVELOPED FOR SIMPLE PARTS.

SOLUTION

APPLY SYSTEM MANAGEMENT TECHNIQUES, SUCH AS DEVELOPED FOR EQUIPMENT PROCUREMENT, TO THE PARTS PROCUREMENT CYCLE. THIS MEANS SIGNIFICANT INCREASE IN THE RELIANCE ON PEOPLE TO MANAGE SEMICONDUCTOR PARTS, RESULTING IN IMPROVED LINE VERIFICATION METHODS.

IMPROVEMENTS IN LINE VERIFICATION METHODS

NEED FOR DEVELOPING MONITORED LINE SERVICE PROGRAM (1972)

- EXCESSIVE HARDWARE FAILURES
  - MANY FAILURES IN SUBCONTRACTOR EQUIPMENT
  - SIGNIFICANT PORTION OF FAILURES FROM SEMICONDUCTORS
- HARDWARE DESIGN MODIFICATION TO ADVANCED TECHNOLOGY (BLOCK CHANGE)
  - MAJOR SYSTEM UPGRADE TO COMPLEX INTEGRATED CIRCUITS FROM TRANSISTORS
- NO SOURCE OF SPACE PARTS AVAILABLE FOR SMALL SUBCONTRACTOR USE
  - POTENTIAL REPEAT OF PREVIOUS PROBLEMS

REQUIRED – NEW APPROACH TO PARTS MANAGEMENT

NEED FOR DEVELOPING THE MONITORED LINE SERVICE PROGRAM (1972)

The Monitored Line Program was conceived and developed, not as an abstract exercise but as a solution to a using Program's problem.

Having experienced many costly and time-consuming failures in semiconductor parts with 1960's (transistor dominated) designs, when a major systems upgrade (complex integrated circuit dominated) was planned, it was realized that the effort should incude upgrading the parts procurement system. This planning included providing sources of space quality parts for use of the smaller subcontractors.

IMPROVEMENTS IN LINE VERIFICATION METHODS

OVERVIEW OF MONITORED LINE SERVICE PROGRAM

- CENTRAL (AF/LMSC) PROGRAM MANAGEMENT
- SUPPLIER MANAGEMENT
- RIGOROUS MANAGED TEST PROGRAM
- REJECTION OF RELIABILITY HAZARD DEVICES (BEYOND SPEC REQUIREMENTS)
- EXTENSIVE DATA PACKAGE SHIPPED WITH PARTS
- RECORD/DATA RETENTION TO SUPPORT DOWNSTREAM PROBLEMS
- COORDINATED PROCUREMENT
- ABILITY TO ADD NEW PARTS IN RESPONSE TO PROGRAM NEEDS

OVERVIEW OF MONITORED LINE SERVICE PROGRAM

The initial program planning called for a comprehensive specification system to document our requirements, supported in the field by a team consisting of a resident Reliability Engineer and a Quality Engineer. The specifications included 100% screening (visual and electrical) wherever possible; 240 hours, 125°C, dynamic burn-in with tight post burn-in drift requirements and 2% PDA on burn-in failures. It was planned that this rigorous routine, consisting of in-process verification and a comprehensive test program managed by our resident personnel, would solve the reliability problem without the necessity for additional lot acceptance testing.

Early in the program, it was recognized that *building* the part right was the key to obtaining the desired reliability. For this reason, inspectors were hired to supplement the engineering team. They perform 100% internal visual inspection and other monitoring functions necessary to make process control a main element in the Monitored Line Program.

IMPROVEMENTS IN LINE VERIFICATION METHODS

MONITORED LINE, A MANAGED SYSTEM

CENTRAL PROGRAM MANAGEMENT

- AF PROJECT MANAGER
- LMSC PROGRAM OFFICE
  - TECHNICAL DIRECTOR
  - PRODUCT ASSURANCE PROGRAM MANAGEMENT REPRESENTATIVE
  - PROBLEM MANAGEMENT CENTER
  - COMMUNICATION CONTROL
    - COMPUTER COMMUNICATION WITH USERS & FIELD
- AF/LMSC APPROVED PROGRAM PLAN
- MONITORED LINE DIRECTIVES & OPERATING INSTRUCTIONS
- NEARLY 300 DRAWINGS & SPECIFICATIONS

CENTRAL PROGRAM MANAGEMENT

The organization structure is characterized by central AF/LMSC management. It was decided early in the program to retain Quality Engineering personnel in the LMSC/SSD Product Assurance Organization although available, full time, to the technical director. This was done in order to remove any question of the authenticity of the product verification.

The Technical Director is supported by a Problem Management Center to handle technical coordination between the field and user personnel and by a Communication Control function.

Program documentation includes nearly 300 drawings and specifications, an AF/LMSC approved Program Plan and Directives and Operating Instructions as needed. Copies of the Program Plan, drawings and specifications are available upon request through Communication Control.

IMPROVEMENTS IN LINE VERIFICATION METHODS

MONITORED LINE, A MANAGED SYSTEM

SUPPLIER MANAGEMENT

- RESIDENT TEAM ASSIGNED TO EACH FACILITY
  - RELIABILITY ENGINEER, QUALITY ENGINEER, INSPECTORS
  - SUPPLIER BASELINE MANAGEMENT
  - MATERIAL REVIEW CAPABILITY TO SUPPORT PROGRAM NEEDS
- "BUILD THE PARTS RIGHT"
  - IDENTIFIED MONITORING POINTS FOR PROCESS CONTROL ON BASELINE
- "TEST TO VERIFY PERFORMANCE"
  - 100% SCREENING UNLESS DESTRUCTIVE
  - TIGHT PARAMETER DRIFT REQUIREMENTS
  - REVIEW OF LOTS WITH SIGNIFICANT FAILURE RATES (2% PDA)
- REJECTION OF RELIABILITY HAZARD DEVICES (BEYOND SPEC REQUIREMENTS)

SUPPLIER MANAGEMENT

It is in the area of supplier management (or line verification) that we have concentrated our effort. Sixty to seventy percent of our dollars are spent in this effort, in order to concentrate our money where the problem really is.

A significant advantage of having field personnel occurs in two areas - management of non-conforming hardware and detection of reliability hazards - defects not specifically identified in the specification. We assist the users in *their* disposition of non-conforming hardware in order to protect their schedule. Since this effort is also of value to the supplier, he compensates by rejecting hardware mutually agreed, to present a reliability hazard.

The program approach is based upon the concept —"Build it Right— then Test to Verify Performance". It is the responsibility of the field teams, not only to verify that the parts are built right but also to confirm that they are tested right.

IMPROVEMENTS IN LINE VERIFICATION METHODS

BASELINE—THE KEY TO SUPPLIER MANAGEMENT

BASELINE IS A DESCRIPTION OF THE MANUFACTURING & TEST FLOW, INCLUDING SPECIFICATIONS FOR MATERIALS, OPERATIONS, PROCESSES, INSPECTIONS & TEST.

BASELINE — THE KEY TO SUPPLIER MANAGEMENT

The primary instrument for controlling line verification is the Supplier Baseline. Use of this document, a recognition of how the supplier manages his factory, is the key that has led to the success of our verification program.

IMPROVEMENTS IN LINE VERIFICATION METHODS

SUPPLIER BASELINE MANAGEMENT - THE BASIS FOR LINE VERIFICATION

- RECOGNITION THAT THE SUPPLIER MANUFACTURES & TESTS TO HIS SPECIFICATIONS PROCEDURES & TEST PROGRAMS
- INITIAL REVIEW & APPROVAL OF BASELINE FOR CONFORMANCE WITH MONITORED LINE REQUIREMENTS
  - UNDESIREABLE MATERIALS, PROCESSES OR TESTS SCREENED OUT OF BASELINE
  - ESTABLISHMENT OF MONITORING CHECK POINTS
- VERIFICATION OF SUPPLIER COMPLIANCE WITH HIS BASELINE REQUIREMENTS
  - INITIAL FACILITY VERIFICATION
  - FIRST ARTICLE AUDIT
  - CONTINUOUS RESIDENT MONITORING
  - SCHEDULED AUDIT OF ALL BASELINE OPERATIONS
- BASELINE MAINTENANCE
  - UPDATE TO NEW SPECIFICATION REQUIREMENTS
  - REVIEW & APPROVAL OF SUPPLIER REQUESTS FOR BASELINE CHANGES

SUPPLIER BASELINE MANAGEMENT

Establishing a supplier management system that treats the user specification as though it is the supplier's primary document, is similar to theorizing an astronomic system that assumes the sun revolves around the earth. The ***Baseline*** is the supplier's *primary* management document. The user specification cannot contain everything necessary to control a supplier.

It is in the Baseline where we control what materials will be used, how the part will be built, what test procedures will be used, which test tapes and burn-in boards . . . etc. will be used for our parts. Monitoring gates or check points are listed in the baseline.

After approval of the baseline, we must verify that the supplier does build and test parts to those requirements. We start with a facility verification, then audit the initial production through each operation, verifying procedures, materials and equipment. Routine production monitoring is concentrated at critical points in the flow. Since our field personnel have unescorted access, they audit the entire flow.

This activity is further supplemented by a scheduled review of each baseline item, the more critical areas receiving more frequent reviews.

IMPROVEMENTS IN LINE VERIFICATION METHODS

RESIDENT ACTIVITIES

- ASSEMBLY MONITORING
  - SEM - Audit & Approve Photographs - Lot Jeoperdy (LJ)
  - Wire Bond Strength Sampling (LJ)
  - Die Shear Sample
  - 100% Pre-Cap Visual Inspection
  - Configuration Control
- TEST MONITORING (AUDIT)
  - Witness Station Proofing
  - Verify Equipment Calibration
  - Verify Burn-In Boards
  - Verify Test Tapes
- PRE-SHIP ACTIVITIES
  - Destructive Physical Analysis (LJ)
  - External Visual Sample
  - Radiographic Film Review
  - Traceability Verification
  - Part Packaging Verification
  - Data Package Verification
  - Verification Report

IMPROVEMENTS IN LINE VERIFICATION METHODS

RESIDENT ACTIVITIES

- ADDITIONAL SPECIFICATION REQUIREMENTS
  - Direct Failure Analysis of Selected Screening Rejects
  - Review PDA Lot Failures and Direct Corrective Action
  - Manage Configuration Change Request Testing
- EVALUATE CONFIGURATION CHANGE REQUESTS
- REPORT SIGNIFICANT IN-PROCESS YIELD LOSSES WITH SCHEDULE IMPACT
- ANALYZE DISCREPANT HARDWARE CONDITION, WHEN REQUESTED, FOR USER TO ASSESS
- MONITOR AND REPORT ASSEMBLY AND TEST PROGRESS ON SELECTED "HOT" LOTS
- SUPPORT PROBLEM MANAGEMENT ACTIVITIES

OTHER RESIDENT ACTIVITES (NON-INTERFERENCE)

- MONITOR PROCESS VERIFICATION TESTING
- DIRECT SPECIAL LOT TESTING
- PROVIDE TRACEABILITY INFORMATION

RESIDENT ACTIVITIES

The resident teams are responsible to perform four types of duties—

1) Verifications required by the drawings
2) Monitoring of the entire assembly, inspection and test activity
3) Final verification at ship
4) Supporting user problems

The charts provide some detail regarding these activities. As these activities are reviewed, it becomes apparent that they have a similarity to the functions performed in managing the procurement of equipment. It also becomes apparent that these functions can be of great usefulness in supporting the kinds of problems that do occur in processing complex semiconductor parts.

Improved line verification methods have become the heart of the supplier management function within the Monitored Line Service Program.

IMPROVEMENTS IN LINE VERIFICATION METHODS

MONITORED LINE, A MANAGED SYSTEM

DOCUMENTATION APPROACH

- COST/EFFECTIVE PART DOCUMENTATION BASED UPON CLASS "S"
- ABILITY TO ADD NEW PARTS
  REALISTIC QUALIFICATION REQUIREMENTS
- FLEXIBILITY TO RESPOND TO PROGRAM REQUIREMENTS
  RADIATION REQUIREMENTS
- ELIMINATION OF COSTLY/TIME CONSUMING LOT TESTING
  SUBSTITUTE—

  RESIDENT MONITORING TEAMS
  100% INSPECTING & TESTING
  PARAMETER DRIFT SCREENING

DOCUMENTATION APPROACH

Monitored Line documentation has been designed and tailored to work in the Monitored Line System. We mean by this that full recognition has been given to the fact that there are resident people in the field to manage the hardware.

Some of the documentation benefits that occur from this are worth noting.

Qualification of new products, a verification that the product can be manufactured and will conform to its specification, can be performed in the field concurrent with a production purchase (although with some risk).

Special test techniques (e.g. radiation characterization) can be developed with the supplier more quickly while working directly with our field personnel.

Because experience and low failure history has demonstrated that our extensive line verification performs very effectively, we can confidently state that this function, is an acceptable substitute for lot quality conformance testing.

IMPROVEMENTS IN LINE VERIFICATION METHODS

MONITORED LINE, A MANAGED SYSTEM
RECORDS/DATA RETAINED TO SUPPORT DOWNSTREAM PROBLEMS

- MASTER COPIES OF DATA PACKAGES
- X-RAY FILMS
- DPA SAMPLES
- MANUFACTURING DATA FOLDERS (FOR EACH LOT)
  - ASSEMBLY & TEST TRAVELERS
  - MANUFACTURING TRACEABILITY RECORDS
  - REJECT PARTS FOR EMERGENCY TESTING
- RECORD OF SHIPMENT FOR ALL PARTS
- DOCUMENTATION CHANGE HISTORY FILE

RECORDS/DATA RETAINED TO SUPPORT DOWNSTREAM PROBLEMS

Our data retention capability also makes use of the line verification function.

In addition to retaining copies of the normal deliverable data, our field activities also include retention of the wafer traceability and SEM data, the assembly and test travelers, and records of the results of our inspections. As an added feature, the "closed folders" retaining this data also include electrical, x-ray, and visual rejects. This not only ensures that these devices will be removed from the lot, but also makes them available to perform special inspection or testing to support downstream part failure investigations. These records will be retained for 15 years.

Our line verification does not end when the parts are shipped.

IMPROVEMENTS IN LINE VERIFICATION METHODS

STRENGTHS OF MONITORED LINE VERIFICATION

- USE OF RESIDENT VERIFICATION TEAMS RATHER THAN ITINERANT INSPECTORS
- STAFFING THE TEAM WITH ENGINEERING PERSONNEL TO MAKE REAL-TIME DECISIONS IN THE FIELD
- USE OF THE SUPPLIER BASELINE AS THE VERIFICATION DOCUMENT ENABLES MORE COMPLETE CONTROL OF MATERIALS & PROCESSES
- ABILITY TO SUPPORT USER NEEDS WITH ACCURATE TIMELY DATA

WEAKNESSES OF MONITORED LINE VERIFICATION

- FIXED COST FOR RETAINING RESIDENT TEAMS
- COST OF ESTABLISHING A NEW SUPPLIER
- NOT APPLICABLE FOR LOW-VOLUME SPECIALITY PARTS

STRENGTH AND WEAKNESSES OF MONITORED LINE VERIFICATION

The real strength of the Monitored Line System is the line verification portion of the Program. We use a trained resident team, consisting of a Quality Engineer and inspector to verify conformance to requirements and a Reliability Engineer to perform real-time technical investigations to support Quality findings. This is the major contributing factor to the success of the program. The strategy of performing line verification, making use of the supplier baseline, has proven to be a successful approach.

The weaknesses of the Monitored Line relates to the high fixed cost of establishing new monitored facilities and maintaining resident teams. The cost problem has the capability to be relieved with greater volume.

IMPROVEMENTS IN LINE VERIFICATION METHODS

ALTERNATIVES TO MONITORED LINE APPROACH
- MILITARY/JAN PARTS

MIL-M-38510 CLASS B MIL-M-38510 CLASS S	INTEGRATED CIRCUITS
MIL-S-19500 JANTXV MIL-S-19500 CLASS S	TRANSISTORS & DIODES

- CAPTIVE LINES
  - AF – MINUTEMAN, MX
  - NAVY – POLARIS, POSEIDON, TRIDENT
  - HIGH OPERATIONS COST JUSTIFIED BY LARGE VOLUME PROCUREMENT
- USER DRAWINGS
  - TWO APPROACHES
    - PARTS MANUFACTURED TO ORDER
      - ITINERANT SOURCE VERIFICATION/INSPECTION
    - PARTS PURCHASED FROM INVENTORY
      - EXTENSIVE TESTING/SCREENING
      - NO TRACEABILITY OR PROCESS CONTROL

ALTERNATIVES TO THE MONITORED LINE APPROACH

Captive lines typically have the resources to not only perform line verification with resident teams, but also to purchase, if necessary the special facilities needed to optimize reliability. These operations are justified by large volume production usually associated with missile systems.

MIL/JAN lines do not require full-time resident verification but could do so. The JAN line verification approach relies heavily on supplier capability and integrity, although the Class S is continuing to become more effective by defining in-process check points and utilizing more trained personnel.

Monitored Line is a subset of user drawings except that typical line verification performed by other users utilized itinerant rather than resident personnel. In the case of large procurements, a residency may be established to support that activity with no intent to maintain that function for other program use.

IMPROVEMENTS IN LINE VERIFICATION METHODS

- LMSC SUBCONTRACTOR USERS OF MONITORED LINE SERVICE

ADCOLE	MOTOROLA
BARNES	NORTHRUP
BELL HOWELL	NOVATRONICS
BENDIX	ODETICS
CELESCO	PRECISION
CERMIC	QUARTIC
CONSOLIDATED CONTROLS	ROCKWELL
CUBIC	SCI, INC.
ECHO SCIENCE	SPERRY
GULTON	SUNDSTRAND
HONEYWELL	THERMAL SYSTEMS

- NON-LMSC USERS OF MONITORED LINE SERVICE

ADCOLE	HONEYWELL
BALL AEROSPACE	HTL II-WEST
BEI	HUGHES
BENDIX	ITEK
BOEING	MARTIN-MARIETTA
CONTROL DATA	MOTOROLA
CUBIC	PERKIN-ELMER
DELCO	RCA
FAIRCHILD SPACE & ELECTRONICS	ROCKWELL
GENERAL DYNAMICS	SINGER-KEARFOTT
GENERAL ELECTRIC:	SPERRY
SYRACUSE	TECHNITROL
UTICA	TRANSCO
VALLEY FORGE	TRW
HAMILTON STANDARD	UNITED TECHNOLOGIES
HARRIS INDUSTRIES	WESTINGHOUSE

PARTS SUPPLIED TO AFSD, SAFSP, NAVY, AND NASA PROGRAMS

USERS OF THE MONITORED LINE SERVICE

An essential part of this discussion relates to the performance of the parts and usefulness of the line verification techniques to the users. As we pointed out earlier, this program was designed to assist programs in solving real hardware problems.

In the 10 years that we have been providing this service, we have delivered parts to neary 50 major aerospace users. These deliveries have not been devoid of problems but the failures have been few and the support provided to the users has proven to be useful.

The fact that this number of companies have used the service and then reordered, would indicate that the program has achieved its performance and usefulness goals.

IMPROVEMENTS IN LINE VERIFICATION METHODS

ACTIVE MONITORED LINE PARTS/SUPPLIERS

INTEGRATED CIRCUITS

PART TYPE	*VLSI SUPPLIER	NUMBER OF TYPES	
		[illegible]	[illegible]
DIGITAL	NATIONAL		
	TEXAS INSTRUMENTS	[illegible]	[illegible]
OPERATIONAL AMPLIFIERS	SILICONIX	[illegible]	[illegible]
LARGE SCALE	TEXAS INSTRUMENTS	[illegible]	[illegible]
LINEAR	NATIONAL		
	TEXAS INSTRUMENTS	[illegible]	[illegible]
TOTAL INTEGRATED CIRCUITS		[illegible]	[illegible]
TRANSISTORS			
BIPOLAR	TEXAS INSTRUMENTS	17	17
FIELD EFFECT	SILICONIX	14	21
POWER	TEXAS INSTRUMENTS	17	[illegible]
TOTAL TRANSISTORS		[illegible]	[illegible]
TOTAL INTEGRATED CIRCUITS AND TRANSISTORS		[illegible]	[illegible]

*ALL [illegible] ARE BUY [illegible] SOURCE

[illegible]

ACTIVE MONITORED LINE PARTS/SUPPLIERS

The Monitored Line currently maintains active lines at four facilities—

Texas Instruments — Dallas, TX
Texas Instruments — Midland, TX
National Semiconductor — Tucson, AZ
Siliconix — Santa Clara, CA

Since the inception of the program, we have suffered three major facility moves. However, these moves did provide opportunities to review and improve our verification techniques.

IMPROVEMENTS IN LINE VERIFICATION METHODS

MLP PART FAILURES IN EQUIPMENT
ALL TEST LEVELS
ALL PROGRAMS

PART TYPE	QUANTITY RECEIVED	OXIDE FAULTS	OPEN METAL	CONDUCTIVE PARTICLES	OPEN BONDS	OTHER	TOTAL
Digital ICs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Linear ICs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Hybrid ICs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Large Scale ICs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Power Transistors	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Field Effect Transistors	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Bipolar Transistors	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

JUNE 1973 – MARCH 1983

MLP PART FAILURES IN EQUIPMENT JUNE 1973-MARCH 1983

One of the objectives of the Monitored Line Program has been to accumulate failure data with the interest of identifying assignable causes in order to eliminate them. Our success in accomplishing this objective can be observed with regard to two entries in the chart — 36 Hybrid IC Conductive Particle failures and 67 Digital Oxide Fault failures, accounting for nearly half of the failures.

The first problem was eliminate in 1976 by modifying the wire bonding and lid sealing processes, and maintaining those fixes. The second problem was more subtle since it involved flaws in the oxide under the metal where they could not be detected by visual inspection. After much analysis, we were able to develop an electrical test which provided failure precursor information. This test was incorporated into our specification in 1978.

It should be observed that through process control, we have not yet experienced a wire bond failure in any IC and have seen only 16 conductive particle failures other than the 36 discussed above.

The low failure rate shown here has been constantly decreasing as we eliminate problems and monitor to see that they remain eliminated.

IMPROVEMENTS IN LINE VERIFICATION METHODS

MLP PART FAILURES IN EQUIPMENT
ALL TEST LEVELS
ALL PROGRAMS

PART TYPE	QUANTITY RECEIVED	OXIDE FAULTS	BOND PLACEMENT SHORT	CONDUCTIVE PARTICLES	OPEN BONDS	OTHER	TOTAL
Digital ICs	[illegible]	2	0	0	0	4	6
Linear ICs	[illegible]	1	0	1	0	3	5
Hybrid ICs	[illegible]	0	0	0	0	3	3
Large Scale ICs	[illegible]	0	0	0	0	0	0
Power Transistors	[illegible]	0	0	0	0	1	1
Field Effect Transistors	[illegible]	0	0	0	0	0	0
Bipolar Transistors	[illegible]	0	2	1	2	1	6
TOTAL	[illegible]	3	2	2	2	12	21

JUNE 1980 THRU MARCH 1983

MLP PART FAILURES IN EQUIPMENT — JUNE 1980-MARCH 1983

This matrix clearly shows that through Program maturity, and a constant striving to identify and eliminate failure mechanisms, a continuing lower failure rate can be achieved.

Even more significant, there are no concentrations of failures that can be readily associated with assignable causes.

IMPROVEMENTS IN LINE VERIFICATION METHODS

PERFORMANCE IN EQUIPMENT (10 YEARS OF DELIVERIES)

- APPROXIMATELY 5000 LOTS DELIVERED
- ONE KNOWN RETROFIT FOR LOT RELATED PROBLEM
  LOT PASSED SEM SAMPLE (METHOD 2018) BUT HAD BAD METAL COVERAGE
- MOST FAILURES OCCUR EARLY IN TEST PHASE
  INITIAL EXPOSURE TO NEW ENVIRONMENT
- SIGNIFICANT PROGRAM COST REDUCTION BECAUSE OF FEW TEST FAILURES AND THOSE, OCCURRING EARLY IN THE TEST CYCLE
- TWO REPORTED SYSTEM TEST LEVEL FAILURES
  CONCLUDED TO BE NON-LOT RELATED
- NO REPORTED OPERATIONAL FAILURES
  OPERATIONAL LIFE AS LONG AS 6 YEARS

PERFORMANCE IN EQUIPMENT (10 YEARS OF DELIVERIES)

Several conclusions can be drawn from this data justifying the Monitored Line approach.

1) It is possible, through a managed program, to essentially eliminate part failures, even on complex semiconductor devices.

2) Rigorous process control and maximum use of 100% screening can produce parts sufficiently failure-free and homogenious to preclude the need for costly and time consuming lot testing.

3) Utilizing the supplier baseline as the basis for supplier management is a viable approach.

IMPROVEMENTS TO LINE VERIFICATION METHODS

SUMMARY

CONTINUING INCREASE IN COMPLEXITY OF SEMICONDUCTOR PARTS HAS LED TO A REDESIGN OF THE PART PROCUREMENT SYSTEM TO EMPHASIZE LINE VERIFICATION

THE MONITORED LINE SYSTEM WAS DEVELOPED HAVING THE FOLLOWING ATTRIBUTES

1. CENTRAL PROGRAM MANAGEMENT
2. PRIMARY FOCUS ON SUPPLIER MANAGEMENT
   RESIDENT TEAMS MANAGING LINE VERIFICATION
   USE OF BASELINE MANAGEMENT IN THE VERIFICATION PROCESS
3. PLANNED SUPPORT TO USERS

THE MONITORED LINE SYSTEM HAS DEMONSTRATED THE EFFECTIVENESS OF ITS LINE VERIFICATION METHODS THROUGH THE 10 YEAR PERFORMANCE OF DELIVERED PARTS

SUMMARY

The Monitored Line Service Program was constructed around the framework of strong line verification.

The organization and expenditure planning placed primary emphasis on the field activities.

In the course of operating the program, it was found that the supplier Baseline document was the key to supplier management. The line verifications process was greatly enhanced by the use of this document.

Outstanding performance of the parts and continued use by many Programs and companies confirms the success of our approach.

IMPROVEMENTS TO LINE VERIFICATION METHODS

OBSERVATION

MANY OF THE PART DEFICIENCIES THAT WE CONTINUE TO OBSERVE ARE MORE RELATED TO SUPPLIER MANAGEMENT THAN TO SPECIFICATION OR TEST DEFICIENCIES.

CURRENT PART PROCUREMENT PRACTICE CONTINUES TO RELY ON THICKER SPECIFICATIONS AND POST-SEAL TEST PROGRAMS FOR ACHIEVING RELIABILITY.

CONCLUSION

IT IS CONCLUDED THAT GREATER RELIANCE SHOULD BE PLACED UPON SUPPLIER MANAGEMENT USING LINE VERIFICATION TECHNIQUES SUCH AS HAVE BEEN SUCCESSFULLY DEMONSTRATED ON THE MONITORED LINE, TO ACHIEVE THE DESIRED RELIABILITY OF COMPLEX SEMICONDUCTOR PARTS FOR USE IN SPACE PROGRAMS.

TESTING VLSI DEVICES

EUGENE R. HWATEK

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SUNNYVALE, CA.

HISTORICAL OVERVIEW -

LSI - DEVICES

TEST PATTERN GENERATION BY FUNCTIONAL MODEL

OR

THE HEURISTIC APPROACH

DOMINANT TEST DEVELOPMENT METHOD FOR LSI USED BY SEMICONDUCTOR USERS

FAULT COVERAGE WAS UNKNOWN

REPRESENTS MOST COSTLY TEST DEVELOPMENT METHOD

PROBLEMS:

- INSUFFICIENT LOGIC DETAILS
- MANUFACTURER'S TEST PROGRAMS NOT AVAILABLE
- PROLIFERATION OF TEST EQUIPMENT

USER HAD NO ALTERNATIVE

REASON FOR USING A HEURISTIC APPROACH

LSI DEVICE COMPLEXITY WAS COMPREHENSIBLE

IT WAS FEASIBLE TO CONSTRUCT MEANINGFUL TESTS FROM FUNCTIONAL DESCRIPTION OF THE DEVICE.

FAULT COVERAGE WAS ACHIEVED THROUGH A REGRESSION PROCESS

- TEST PARTS
- BURN-IN
- TEST, ANALYZE FAILURES AND CORRECT TRUTH TABLE
- FIELD FAILURE DATA IS ANALYZED AND TRUTH TABLE IS ADJUSTED

PROBLEM:

FAULT COVERAGE NOT KNOWN:

A NEW QUALITY TERM: "WARM FUZZY FEELING"

MOST COSTLY TEST METHOD FOR LSI

TEST DEVELOPMENT TIME OFTEN ORDERS OF MAGNITUDE GREATER THAN ESTIMATE DUE TO UNFORSEEN PROBLEMS:

- DATA SHEETS WERE OFTEN NOT WRITTEN WITH TESTING IN MIND
  - WHICH PARAMETERS ARE 100% TESTED?
  - WHICH PARAMETERS ARE GUARANTEED?
  - WHICH PARAMETERS ARE GUARANTEED OVER TEMPERATURE?
  - ARE THE FORCING FUNCTIONS THE SAME OVER TEMPERATURE?
  - ERRORS IN TIMING AND TRUTH TABLES
- INCOMPATIBILITY BETWEEN USER'S AND MANUFACTURER'S TEST SYSTEM CAUSED TEST CORRELATION PROBLEMS
- REQUIRED "GOLD" OR "KNOW GOOD" UNIT

PROJECT BECOMES AN INTENSIVE TEST DEVELOPMENT EFFORT DUE TO NUMBER OF UNKNOWN PARAMETERS AND WE HAVEN'T EVEN GOT TO THE FUNCTIONAL TESTS.

MOST COMMERICAL TEST PROGRAMS AVAILABLE ARE BASED ON FUNCTIONAL RATHER THAN LOGIC SIMULATION

REASON:

- INSUFFICIENT LOGIC DETAILS TO SYNTHESIZE DATA BASE
- MANUFACTURER'S TEST PROGRAMS NOT AVAILABLE TO USERS
- PROLIFERATION OF TEST EQUIPMENT CREATED TRANSFER PROBLEMS WHER TEST PATTERNS WERE AVAILABLE FROM MANUFACTURERS

WITHOUT LOGIC DETAILS AND FAULT SIMULATION, THE USER IS UNABLE TO GENERATE FUNCTIONAL TESTS WITH MEASURABLE FAULT COVERAGE AT THE LSI LEVEL.

HOW THEN DO WE CONSTRUCT TESTS FOR VLSI?

EVOLUTION OF MODELING TECHNIQUES FOR "STUCK AT" FAULTS WERE DRIVEN BY THE LACK OF DOCUMENTATION.

THATTE AND ABRAHAM MODEL FOR MICROPROCESSOR TESTING IS AN EXAMPLE OF PATTERN GENERATION -

SEGMENTED PROCESSOR INTO 5 BLOCKS

- DATA TRANSFER
- DATA STORAGE
- DATA MANIPULATION
- REGISTER DECODING
- INSTRUCTION DECODING AND CONTROL

THIS MODEL GUIDES THE DEVELOPMENT OF THE DIAGNOSTIC PROGRAM

VLSI CIRCUITS

VLSI CIRCUITS BECAUSE OF TRANSISTOR COUNT AND CIRCUIT FUNCTION REQUIRE AN EXPONENTIAL INCREASE IN BOTH DESIGN TIME AND TEST PROGRAM DEVELOPMENT TIME

MAN YEARS VS MAN MONTHS FOR LSI CIRCUITS

TEST PROGRAM DEVELOPMENT TIME
(MANUAL GENERATION)

FUNCTION	NO. OF ON-CHIP TRANSISTORS	TEST PROGRAM DEVELOPMENT TIME (HRS.)
SSI/MSI	~200	120
PERIPHERAL CHIPS	2000	320
MICROPROCESSORS	20,000	1000
VLSI MICROPROCESSORS	200,000	3300

TO SOLVE THESE PROBLEMS OF ESCALATING CHIP COMPLEXITY A NUMBER OF SOPHISTICATED AND AUTOMATED WORK STATIONS WILL BE REQUIRED.

VLSI TESTING IS
ESSENTIALLY A SOFTWARE PROBLEM

TEST PROGRAM GENERATION MUST BE AUTOMATED AND TIED TO THE CHIP DESIGN PROCESS VIA THE CAD SYSTEM AND A MAINFRAME COMPUTER SUCH AS AN IBM OR VAX VARIETY.

FURTHERMORE VLSI CIRCUITS WILL REQUIRE THE DEVELOPMENT OF SEMICONDUCTOR MANUFACTURING AND TESTING FACILITIES THAT CAN EFFECTIVELY HANDLE A WIDE VARIETY OF LOW VOLUME PARTS - THIS MEANS THAT MANY DEFFERENT CIRCUIT DESIGNS AND MANY DEFFERENT TEST PROGRAMS MUST BE GENERATED IN SHORT PERIODS OF TIME.

HISTORICALLY, DESIGN ENGINEERS HAVE USED LOGIC AND DESIGN VERIFICATION SIMULATORS, WHILE TEST ENGINEERS HAVE USED FAULT SIMULATORS AND AUTOMATIC TEST GENERATORS

- THE ENGINEERS WERE IN SEPARATE GROUPS
- THE SIMULATOR PACKAGES WERE SEPARATE
- THE DESIGN AND TESTING TASKS WERE CONSIDERED SEPARATE AND COMMUNICATIONS BETWEEN THE GROUPS WAS MINIMAL

THIS HISTORICAL SEPARATION OF LOGIC DESIGN FROM TESTING CAN NO LONGER ECONOMICALLY EXIST.

- IN VLSI DESIGNS WHICH ARE CONCEIVED INDEPENDENTLY WITHOUT REGARD TO TESTABILITY REQUIREMENTS, THE INTERNAL CIRCUIT NODE POINTS ARE NOT AVAILABLE FOR TESTING.

- IN VLSI DESIGNS WHERE SHEER MAXIMUM LOGIC SPEED AND NOT TESTABILITY IS THE MAJOR THOUGHT, UNRETESTABLE TIMING AND/OR RACE CONDITIONS CAN AND WILL EXIST

- FUNCTIONAL TESTING FROM EXTERNAL PIN RESULTS IN PROHIBITIVELY COMPLEX AND VERY SLOW TEST ROUTINES, IF IN FACT THEY ARE ADEQUATE AT ALL.
  - MASSIVE LOGIC NETWORKS CONTAINING STORAGE AND RECURSIVE MICRO INSTRUCTION LOOPS ARE EXTREMELY COMPLEX TO CHARACTERIZE AND TEST.

- IN CIRCUIT TESTING INTERNALLY OR SUBFUNCTIONAL COMBINATORIAL BLOCKS OR NETS IN A VLSI DEE IS IMPRACTICAL IF NOT IMPOSSIBLE.

THE MOST SUCCESSFUL VLSI DESIGNERS AND USERS WILL GIVE TESTABILITY AN EQUAL PRIORITY WITH LOGICAL FUNCTIONALITY DURING INTERNAL SPECIFICATION AND DESIGN. A CLOSER WORKING RELATIONSHIP BETWEEN DESIGN AND TEST ENGINEERS (A TEAM EFFORT) WILL BE REQUIRED.

IT IS NO LONGER POSSIBLE TO REVIEW A DEVICE SPECIFICATION OR DATA SHEET, DEFINE ALL POSSIBLE TEST CONDITIONS AND IMPLEMENT THAT TEST.

THE PROBLEM OF TESTING VLSI DEVICES MUST FIRST BE APPROACHED WITH THE PHILOSOPHY THAT THE DEVICE IS BASICALLY UNTESTABLE.

THE PROCESS OF TEST DEFINITION PLACES HEAVIER EMPHASIS ON A TEST ENGINEER OR ENGINEERING MANAGERS ABILITY TO DIGEST THE FUNCTION OF THAT DEVICE IN A GENERAL OR SPECIFIC APPLICATION.

THE IMPLEMENTATION OF THIS PHILOSOPHY WILL REQUIRE SOLID ENGINEERING DECISIONS TO BE MADE AS TO WHAT TO TEST, WHAT NOT TO TEST, WHAT DEPTH TO TEST WITHIN THE CONSTRAINTS OF MATERIAL, CAPITAL AND PERSONNEL RESOURCES.

COMPUTER AIDED DESIGN TOOLS, LOGIC SIMULATION, FAULT SIMULATION AND FAULT VERIFICATION WILL GREATLY AID THIS TASK.

NOW THE TEST ENGINEER WILL HAVE TO FORM AN ALLIANCE WITH THE LOGIC DESIGNER AND WORK TO ENSURE TESTABILITY IN THE INITIAL DESIGN. THE CAD/CAT SYSTEM THEN AUTOMATICALLY GENERATES THE TEST ROUTINES, VECTORS, AND TEST TAPES FOR THE APPROPRIATE ATE.

MANY KEY ISSUES RELATIVE TO VLSI TEST SOFTWARE DEVELOPMENT MUST BE ASSESSED IN AN OPEN FORTHRIGHT MANNER. ALL OF THESE IMPACT TESTING BY THE VENDOR, THE USER OR AN ITL.

- O ENGINEERING LEARNING FACTOR OF GENERIC DEVICES - CONTROLLERS, ETC.
- O EFFECTS OF MIXED TECHNOLOGIES ON-CHIP(CMOS, NMOS, BIPOLAR (LSTTL, ECL, I²L)
- O EFFECTS OF MIXED FUNCTIONS (ANALOG AND DIGITAL)
- O EFFECT OF ON CHIP REDUNDANCY
- O TEST STRATEGY/TEST PROGRAM DEVELOPMENT
- O DESIGN FOR TESTABILITY
- O LOGIC SIMULATION AND VERIFICATION (CORRECTNESS OF LOGIC DESIGN AND TIMING VERIFICATION)
- O FAULT SIMULATION, FAULT COVERAGE AND FAULT VERIFICATION
- O TEST PATTERN GENERATION AND VERIFICATION
- O WAVEFORM SIMULATION
- O TEST SYSTEM/CAD SYSTEM COMPATIBILITY
- O TEST SYSTEM COMPATIBILITY BETWEEN USER AND VENDOR, BETWEEN ITL AND VENDOR.
- O AVAILABILITY OF SOURCE CODES, TEST VECTORS, OR DATA BASE TAPES FROM VENDOR
- O EFFECT OF SECOND SOURCES.
- O SOFTWARE DOCUMENTATION
- O SOFTWARE PORTABILITY BETWEEN SYSTEMS
- O TESTER TYPE AND ENVIRONMENT: HARDWARE CAPABILITIES AND TARGETING (TIMING ON THE FLY, BULK MEMORY, PIPELINE ARCHITECTURE, WAVE FORMATTING), SOFTWARE LANGUAGE, UTILITIES, OFF-LINE PROGRAM DEVELOPMENT, TEST PATTERN TOOLS, USER FRIENDLY INTERFACE, ETC.
- O TYPES OF AVAILABLE DEVICE SAMPLES.

HOW DOES ONE RESOLVE THE HISTORICAL PROBLEM OF PATTERN SENSITIVITY OF LSI DEVICES? IT WILL BE IMPOSSIBLE TO PERFORM THESE TESTS FOR VLSI DEVICES - DUE TO THE SHEER TIME MAGNITUDE INVOLVED.

FOR A GIVEN GENERIC DEVICE TYPE, ONE NEEDS TO AUTOMATE THE TEST DEVELOPMENT PROCESS BY

- O USING AUTOMATIC TEST PROGRAM GENERATION TOOLS
- O USING STANDARDIZED TEST VECTOR GENERATION TOOLS AND FORMAT
- O STANDARDIZED TEST PROGRAM FORMAT
- O TESTABILITY CONDITIONS
- O PATTERN/TEST PROGRAM COMPRESSION BASED ON FAULT COVERAGE EFFECTIVITY

PROBLEM WITH COMPUTER AIDED TESTING (CAT)

- O TEST PROGRAM SHOWS AN ABSENCE OF PATTERN, STRUCTURE OR INTUITIVE MEANING. THIS IS DUE TO THE FACT THAT THE ALGORITHMS GENERATED AUTOMATICALLY HAVE NO KNOWLEDGE OF THE CIRCUIT'S OVERALL STRUCTURE AND FUNCTION.
- O SIMULATION TECHNIQUE MUST BE DEVELOPED TO LET THE EFFECT OF COMPLEX PATTERNS BE EVALUATED WITHOUT NEED TO SIMULATE ALL OF THE SIGNAL CHANGES.
- O TO HANDLE TEST PROBLEMS WITH COMPLEXITY OF CURRENT VLSI CHIPS, CAT ARCHITECTURE MUST DEVELOP TO A POINT AT WHICH SIMILAR TECHNIQUES CAN BE APPLIED THAT ARE SIMILAR TO THOSE USED BY HUMAN EXPERTS.

STEPS IN TEST PROGRAM DEVELOPMENT BY HUMAN EXPERTS

- O LEARNS DEVICE ORGANIZATION AND ELECTRICAL SPECIFICATION (FROM VENDORS AND OTHER SOURCES IN VARIOUS FORMS)
  - FUNCTIONAL DESCRIPTION
  - LOGIC FUNCTION
  - CONTROLLING SIGNALS TO EACH PIN OF THE DEVICE
  - BLOCK DIAGRAM OF INTERNAL STRUCTURE
  - PIN OUT
  - TIMING DIAGRAM FOR EACH CRITICAL SEQUENCE
- O DEVELOP TEST STRATEGY
- O GENERATE TEST CODE PER DOCUMENTATION
  - OBSERVE SIGNALS AND COMPARE WITH FUNCTIONAL TRUTHTABLE AND LOGIC DIAGRAM
  - START WITH SIMPLE AND BASIC TESTS TO CONFIRM THAT DEVICES BEHAVE PROPERLY SUCH AS DC AND FUNCTIONAL TESTS.
  - THEN BEGIN ADDING TESTS TO EXERCISE REMAINING DEVICE PINS.
  - NEXT WORK TOWARD MORE COMPLEX PATTERN AND TIMING TESTS.
  - DEBUG AND REFINE SOFTWARE.
- O ALL OF THESE INVOLVE UTILIZING THE TEST ENGINEERS PRIOR KNOWLEDGE AND EXPERIENCE - i.e. HIS REFERENCE LIBRARY IF YOU WILL. THIS RESULTS IN TESTS THAT ARE COMPACT IN FORM.
- O PERFORM CHARACTERIZATION TESTING - THIS DETERMINES WHICH PATTERNS ARE EFFECTIVE IN WEEDING OUT FAULTS AND WHICH SHOULD BE USED IN 100% TESTING AND STILL NOT REDUCE FAULT COVERAGE.
- O GENERATES 100% INSPECTION TEST PROGRAMS.
- O RELEASE TEST PROGRAM.

A NEW RELATIONSHIP BETWEEN VENDORS AND USERS BASED ON MUTUAL TRUST AND RESPECT WILL BE REQUIRED TO ADDRESS THE TOPIC OF TESTING VLSI DEVICES.

IN SUMMATION FOR VLSI DEVICES

- O BURDEN OF TEST SHIFTS TO DESIGN
- O USER IS UNABLE TO ECONOMICALLY GENERATE TEST PROGRAM
- O USER WILL HAVE TO DEPEND ON VENDOR FOR TEST PATTERNS
- O WILL THE VENDOR RELEASE THE SOFTWARE?
- O HOW DOES THE USER ENSURE THAT HE HAS THE COMPLETE TEST VECTOR SET?

VHSIC

VHSIC - JOINT PROGRAM TO DEVELOP VERY LARGE SCALE INTEGRATED CIRCUITS FOR HIGH THROUGHPUT DATA PROCESSORS DESIGNED TO SUPPORT UNIQUE MILITARY SYSTEM REQUIREMENTS AND TO PERFORM THOROUGHLY SPECIFIED MILITARY FUNCTIONS WITHIN STRINGENT MILITARY ENVIRONMENT.

CHARACTERISTICS OF VHSIC

- NARROW USER BASE
- SMALL VOLUME OF COMPLEX CIRCUIT FUNCTIONS
- UNIQUE CHIP PACKAGING REQUIREMENTS - HIGH PIN COUNT
- HIGH SPEED DEVICES
- UNIQUE CIRCUIT FUNCTIONS TO MILITARY COMMUNITY

THE AUTHOR BELIEVES THAT VHSIC WILL SEE EVEN MORE LIMITED USE THAN VLSI DEVICES AND FOR THE SAME REASON AS FOR VLSI DEVICES - DEVICES BEING SO SPECIALIZED WILL NOT BE PRODUCED BY COMMERCIAL SEMICONDUCTOR VENDORS BUT PRIMARILY BY COMPANIES THAT ARE PRIME OR SUBTIER MILITARY CONTRACTORS AND THAT HAVE SEMI-CONDUCTOR MANUFACTURING CAPABILITIES BY VIRTUE OF THE EXTREMELY SMALL VOLUMES REQUIRED: DETAILED DOCUMENTATION, PROCESS CONTROL AND TESTING PROCEDURES; AND COMPLEX DEVICE DESIGNS. THESE INCLUDE BUT ARE NOT LIMITED TO:

- TRW
- HUGHES AIRCRAFT
- BOEING AEROSPACE
- LOCKHEED MISSILES AND SPACE CO.
- ROCKWELL INTERNATIONAL
- MCDONNELL DOUGLAS
- WESTINGHOUSE
- RAYTHEON
- HONEYWELL
- IBM
- GENERAL ELECTRIC

THE ROLE OF THE INDEPENDENT TEST LAB WITH VLSI AND VHSIC DEVICES

BECAUSE OF THE FOREGOING IT IS CONCLUDED THAT IN GENERAL THE INDEPENDENT TEST LABORATORY (ITL) WILL NOT BE ABLE TO AFFORD TO PERFORM ELECTRICAL TESTING FOR THE FOLLOWING:

- THE MAJORITY OF VLSI DEVICES - SEMI CUSTOM AND FULL CUSTOM
- VHSIC DEVICES

THE ITL CAN RESCREEN EITHER VLSI OR VHSIC CHIPS IF THE VENDOR PROVIDES A SOURCE CODE, SET OF TEST VECTORS, OR TEST PROGRAM (TAPE) FROM THE SAME ATE SYSTEM AS THE ITL HAS. THIS SYSTEM COMPATIBILITY IS MANDATORY.

THUS THE ITL WOULD SIMPLY VERIFY THE VENDORS TESTING USING THE SAME SOFTWARE BASE.

THE ITL'S ROLE IN SERVING THE NEEDS OF THE MILITARY/AEROSPACE COMMUNITY WILL BE AS FOLLOWS:

- PERFORM INCOMING INSPECTION, DEVICE RESCREENING, OR DEVICE UPGRADE (MIL-STD-975) FOR
  - PASSIVE COMPONENTS - RESISTORS AND CAPACITORS
  - DISCRETE SEMICONDUCTOR DEVICES
  - 54XX, 54LSXX, 54SXX, 54HXX, 54ALSXX, 54ASSXX SERIES OF LOGIC DEVICES
  - 54HCT SERIES OF LOGIC DEVICES
  - CD4000 SERIES OF LOGIC DEVICES
  - LINEAR ICs
  - STANDARD MEMORIES AND MICROPROCESSORS
- PERFORM DETAILED DEVICE CHARACTERIZATION AND EVALUATION TESTING IN ACCORDANCE WITH CONTRACTORS REQUIREMENTS
- PERFORM QUALIFICATION AND QCI TESTING
- PERFORM TESTING ON SELECTED "NICHE" VLSI STANDARD AND SEMICONDUCTOR DEVICES WHICH HAVE A LARGE CUSTOMER (USER) BASE AND THUS WHERE COSTS FOR SOFTWARE DEVELOPMENT CAN BE SPREAD AMONG MANY CUSTOMERS.

GALLIUM ARSENIDE IC

TECHNOLOGY

Ga As TECHNOLOGY

- AT SAME STAGE AS SILICON TECHNOLOGY WAS IN THE 1960'S - AT THE BEGINNING OF THE LEARNING CURVE: MUST DEVELOP MATERIAL HANDLING, DESIGN RULES, PACKAGING, AND TESTING CONCEPTS, NEW KINDS OF PRODUCTION EQUIPMENT.
- WILL NOT REPLACE SILICON IN MANY APPLICATIONS
- ADVANTAGES INCLUDE
  - HIGHER SPEED - 5-10 TIMES SILICON
  - LESS SUSCEPTIBLE TO EMI CAUSED BY NUCLEAR RADIATION
  - ABILITY TO FUNCTION OVER WIDER TEMPERATURE RANGE THAN SILICON
  - INHERENT SEMI-INSULATING PROPERTIES
- DISADVANTAGES
  - HIGH COST OF Ga As WAFERS
  - NO KNOWN STABLE OXIDE AS WITH SILICON
  - CANNOT PERFORM DIFFUSION ECONOMICALLY
  - LACK OF ESTABLISHED WELL DEFINED PROCESS CONTROLS

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Ga As IC DEVELOPMENTS

- FRENZIED R&D PACE
- NO MAJOR COMMERCIAL U.S. SEMICONDUCTOR MANUFACTURERS (WITH EXCEPTION OF TI) ARE PURSUING Ga As IC DEVELOPMENT - ONLY DISCRETE Ga As DEVICES. BELIEVE THAT SILICON WILL CONTINUE TO BE DOMINANT.
- TWO U.S. STARTUPS CREATED FOR SOLE PURPOSE OF FABRICATING Ga As DIGITAL ICs.
- MOST OTHER U.S. COMPANIES THAT ARE INTERESTED IN Ga As ICs ARE LARGE AEROSPACE COMPANIES.
- MAJOR JAPANESE GOVERNMENT (MITI) SPONSORED JOINT "SUPER COMPUTER" RESEARCH PROJECT INVOLVING MOST MAJOR JAPANESE SEMICONDUCTOR MANUFACTURERS.
  - HITACHI
  - FUJITSU
  - NEC
  - MITSUBISHI/SONY
  - OKI
  - TOSHIBA

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PRIMARY APPLICATION IN US: MILITARY/AEROSPACE.

PRIMARY APPLICATION IN JAPAN: FIFTH GENERATION OF SUPER COMPUTERS.

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PER A REPORT PREPARED BY STRATEGIC, INC., SAN JOSE, CA.

"THE U.S. Ga As IC INDUSTRY'S SINGLE MINDED FOCUS UPON SERVING ONLY INHOUSE REQUIREMENTS HAS RESULTED IN AN ENTRENCHED, SLOW - MOVING INDUSTRY SUBJECT TO DOMINATION BY FOREIGN SUPPLIERS."

"IF FUJITSU IS NOT TAKEN SERIOUSLY --- FUJITSU IS LIKELY TO BECOME THE WORLD LEADER IN THE LARGE MAINFRAME - COMPUTER MARKETPLACE BASED UPON THE USE OF Ga As IC TECHNOLOGY."

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HIGH SPEED TECHNOLOGY - 2 NATIONS RUNNING IN 2 DEFFERENT DIRECTIONS

U.S. - PUSHING SILICON - STATE-OF-THE-ART AND VIRTUALLY IGNORING Ga As.

JAPAN - FUTURE OF COMPUTER PROCESSING LIES IN Ga As; MAJOR FUNDED GOVERNMENT R&D STUDY.

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DOD ESTABLISHED APPROXIMATELY $100 MILLION PROGRAM TO DEVELOP Ga As MEMORIES AND GATE ARRAYS BECAUSE MAJOR SOURCES OF SUPPLY ARE JAPANESE AND DUE TO PENTAGON'S CONCERN THAT U.S. EFFORTS WERE TOO SMALL. (ELECTRONIC NEWS, MAY 16, 1983)

- FASTER COMPUTERS
- LOW NOISE,HIGH SPEED, LOW POWER MICROWAVE APPLICATIONS

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Pentagon to fund GaAs pilot lines

Eager to pull gallium arsenide chips out of the laboratory, the Department of Defense is set to fund one or more GaAs pilot production lines this fall. The goal for the three-year program, to be administered by the Defense Advanced Research Projects Agency, is a capability of a hundred 3-in. wafers per week for each pilot line by early 1986. Target device types are gate arrays of at least 6,000 gates and static random-access memories of at least 16-K density. At least two bidding teams are known: Texas Instruments Inc., of Dallas, with McDonnell Douglas Corp. of St. Louis, and Honeywell Inc., Minneapolis, with Rockwell International Corp., headquartered in Pittsburgh. The cost for each pilot line funded is expected to be $20 million to $40 million.

Electronics/May 31, 1983

Ga As IC STARTUP COMPANIES

GIGABIT LOGIC: CULVER CITY, CA.

- COMPUTATIONAL APPLICATIONS

HARRIS MICROWAVE: MILPITAS, CA.

- BOTH SIGNAL PROCESSING AND COMPUTATIONAL APPLICATIONS
- RECENTLY ENTERED INTO JOINT DEVELOPMENT WITH CRAY RESEARCH OF MINNEAPOLIS TO DEVELOP HIGH SPEED Ga As DIGITAL ICs

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CAPTIVE U.S. Ga As IC SUPPLIERS/USERS

COMPANIES PERFORMING INTERNALLY AND GOVERNMENT FUNDED Ga As R&D EFFORTS

- HUGHES AIRCRAFT CO.; CULVER CITY, CA.
- LOCKHEED MISSILES & SPACE CO.; SUNNYVALE
- MC DONNELL DOUGLAS CORP.; ST. LOUIS, MO.
- ROCKWELL INTERNATIONAL CORP., ELECTRONIC RESEARCH CENTER; THOUSAND OAKS, CA.
- JPL MICROELECTRONICS CENTER
- RAYTHEON RESEARCH DIVISION; LEXINGTON, MASS.
- HONEYWELL
- IBM
- TI CENTRAL RESEARCH LABORATORY; DALLAS, TX.
- HEWLETT PACKARD, CENTRAL RESEARCH LAB: PALO ALTO, CA.
- TEKTRONIX; BEAVERTON, OREGON
- AVANTEK, SANTA CLARA, CA.

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Ga As PRODUCT DEVELOPMENT

- ROCKWELL INTERNATIONAL CORP., ELECTRONICS RESEARCH CENTER
  - 5X5 PARALLEL MULTIPLIER WITH 260 GATES AND DELAYS OF 150 pS
  - 8X8 MULTIPLIER WITH 600 SDFL DEVICES
    - PERFORMS MULTIPLICATION IN 6 nS
    - 300 MW POWER CONSUMPTION
    - DIE SIZE 10,000 MIL^2
  - 4K STATIC RAMS WITH Taa = 1-2nS (IN DEVELOPMENT)
- LOCKHEED MISSILES AND SPACE CO.
  - 4K STATIC RAM
    - 200x140 MIL DIE SIZE
    - Taa = 5-10nS (2U GEOMETRIES)
    - Taa = 2-4nS (1U GEOMETRIES)
  - TEST LOGIC IC
    - GATE DELAY OF 50 pS
    - CLOCK FREQUENCY 2GHZ
  - DIVIDE-BY-2 PRESCALER
  - 2 BIT ADDER
  - GATE ARRAY (320 GATES USING SDFL)
    - 192 FOUR INPUT NOR GATES
    - 128 TWO INPUT OR-NAND GATES
    - 40 PROGRAMMABLE I/O BUFFERS

    } 19 STATE RING OSCILLATOR tpd = 184 pS
- THOMPSON-CSF CENTRAL RESEARCH LABORATORY---MESFETs
  - 11 STAGE RING OSCILLATOR WITH A GATE DELAY OF 22 PS @ 25°C (DCFL)
  - GATE LENGTH = 0.7 UM, tpd = 32.5,pS P_{DISS} = 62 MW
  - 4x2 BIT RAM
    - Taa = 0.6 nS
    - P_{DISS} = 80 MW
    - USES LPFL CIRCUITS
  - 256 RAM
    - Taa = 1.5 nS
  - 1K RAM
    - Taa < 2 nS
  - PLA USING BUFFERED FET LOGIC
- HEWLETT PACKARD
  - 56 BPS WORD GENERATOR
    - INCORPORATE 400 MESFETs AND 230 SCHOTTKY DIODES
    - CONTAINS ECL-TO-Ga As INTERFACE AMPLIFIERS, A TREE OF 2:1 MULTIPLEXERS FORMING AN 8:1 PARALLEL-TO-SERIAL DATA CONVERTER, A TIMING CONTROL GENERATOR AND A BLANKING CONTROL CIRCUIT.
    - OUTPUTS CLEAR WAVEFORMS WITH 100 PSEC TRANSITION TIMES AT BIT RATES FROM 1K TO 56 BPS.
- MC DONNELL-DOUGLAS
  - 1K RAM
    - ORGANIZATION = 256x4
    - Taa = 900 pS
    - P_{DISS} = 600 MW
    - USING DEPLETION MODE LOADS

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- 4K RAM (4Kx1)
  - T_{AA} = 6 nS
  - P_{DISS} = 100 mW
  - USING Ga As LOAD RESISTORS

- NTT'S MUSASHINO ELECTRICAL COMMUNICATION LABORATORY
  - 15 STAGE RING OSCILLATOR WITH GATE DELAY OF 30 pS NEXT TO 3 GHZ DIVIDE-BY-2 AND DIVIDE-BY-8 PRESCALERS
  - 1K RAM CONTAINING 7000 GaAs FETS USING DCFL
    - T_{AA} = 2.6 nS
    - P_{DISS} = 240 mW
    - 0.8U GATE LENGTHS

- TEXAS INSTRUMENTS CENTRAL RESEARCH LABORATORIES
  - 16 BIT STATIC RAM USING MESFETS WITH STANDBY POWER of 0.1 mW
  - 64 BIT STATIC RAM $T_{AA} < 1$ nS
  - GATE ARRAY (114 GATES) COMBINING I^2L WITH Ga Al As/Ga As HETEROJUNCTION BIPOLAR TRANSISTORS
    - tpd = 0.77 nS
    - P_{DISS} = 0.3mW/GATE
    - 3U DESIGN RULES
  - 8 STATE PRESCALERS & SHIFT REGISTERS
    - tpd = 48 AND 61 nS
    - P_{DISS} = 0.56 mW/GATE

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- TOSHIBA
  - 500 GATE GATE ARRAY USING DCFL
  - 15 STAGE RING OSCILLATOR
    - 2V POWER SUPPLY
    - tpd = 160 pS, f_0 = 1
    - tpd = 640 pS, f_0 = 3
    - P_{DISS} = 0.8 mW/STAGE
- NEC
  - 32 BIT ADDER (400 GATES)
    - 3nS CARRY tpd
    - 300mW TOTAL P_{DISS}
- JAPAN'S MITI ELECTRO TECHNICAL LABORATORY
  - TRIAL COMPUTER CONTAINING 11 ELEMENTS AND 3U LINE WIDTHS
    - 120 pS DELAY/ELEMENT
    - 10-12 mW POWER CONSUMPTION/ELEMENT
  - WITH 1U LINE WIDTHS MITI BELIEVES THAT THESE PARAMETERS COULD BECOME
    - 50 pS DELAY/ELEMENT
    - 3-6 mW POWER CONSUMPTION/ELEMENT
- FUJITSU
  - 4 BIT ALU
    - 99 GATES
    - POWER SUPPLIES: 3.5V, -2.9V
    - INTERNAL LOGIC SWINGS = 1V
    - POWER CONSUMPTION = 1W
    - DATA PATH DELAYS = 2nS

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- CRYOGENIC LOGIC
  - NEW WITH 17 pS SWITCHING TIME
  - .96 mW P_{DISS}
  - COOLED TO -100°C
- 1024 BIT RAM (32x32) - 3U GEOMETRICS
  - T_{AA} = 4nS
  - P_{DISS} = 70mW

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HIGH-SPEED CMOS

(COMPLEMENTARY METAL OXIDE SEMICONDUCTOR)

PERFORMANCE IMPACT

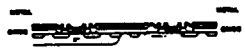
ASSURANCE IMPACT

NASA/GODDARD SPACE FLIGHT CENTER
PERRY R. MASON, JR.

JUNE 7, 1983

TYPICAL CMOS STRUCTURES

METAL GATE CMOS



SILICON GATE CMOS

HIGH-SPEED CMOS ADVANTAGES

- LOW POWER
- HIGH SPEED
- HIGH NOISE IMMUNITY
- WIDE VOLTAGE RANGE
- OUTPUT DRIVE
- IMPROVED INPUT PROTECTION
- MULTIPLE SOURCES

COMPARISON OF PRINCIPAL PARAMETERS

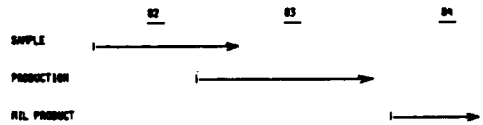
GATE - 25°C - V_{CC} = 5.0V

SYMBOL	PARAMETER	H-S CMOS		CMOS		LS[2]		UNITS
		MIN	MAX	MIN	MAX	MIN	MAX	
V_{IH}	INPUT HIGH VOLTAGE	3.5		3.5		2.0		V
V_{IL}	INPUT LOW VOLTAGE		1.0		1.5		0.7	V
V_{OH}	OUTPUT HIGH VOLTAGE	4.95		4.95		2.5		V
V_{OL}	OUTPUT LOW VOLTAGE		0.05		0.05		0.4	V
I_{OH}	OUTPUT CURRENT-HIGH	-4.0		-0.44		-0.4		mA
I_{OL}	OUTPUT CURRENT-LOW	4.0		0.44		4.0		mA
V_{CC}	SUPPLY VOLTAGE	2.0	6.0	3.0	18	4.5	5.5	V
I_{CC}	QUIESCENT SUPPLY CURRENT		2		7.5		4.4 (mA)	mA
T_{PHL}/T_{PLH}	PROPAGATION DELAY (C_L = 50 PF)		15		250		15	nS
V_{NML}	NOISE MARGIN LOW	0.9		0.9		0.4		V
V_{NMH}	NOISE MARGIN HIGH	1.4		1.4		0.7		V

DISADVANTAGES

- RADIATION SENSITIVITY
- AVAILABILITY

HIGH-SPEED CMOS AVAILABILITY



HIGH-SPEED CMOS MARKET PLACE

MANFACTURERS	DESIGNATIONS	TYPES
RCA	CD54HC	230
MOTOROLA	MC54HC	135
NATIONAL	MM54HC	196
SIGNETICS	PC54HC	
TOSHIBA	TC4HCH	
OTHERS		

HIGH-SPEED CMOS MARKET POTENTIAL

	80	81	82	85
LSTTL	60%	59%	54%	53%
CMOS	40%	41%	42%	34%
HS-CMOS	--	--	2%	13%

PROCUREMENT OF QUALITY ASSURED MICROCIRCUITS

- INDIVIDUAL SPECIFICATIONS
- COMMERCIAL "BASE" AND SCREEN
- MILITARY STANDARD PARTS (MIL-M-38510)

PAGE 16 INTENTIONALLY BLANK

MIL PRODUCTS

FAMILY	FRACTION COVERED BY SPECIFICATIONS
54	76%
54LS	73%
CD4000	40%

ALERTS ON MIL-M-38510 PRODUCT

DATE	ALERT	PROBLEM	PARTS AFFECTED
3/20/81	X1-A-81-01	ELECTRICAL TESTS NOT IN CONFORMANCE WITH MIL-M-38510	80 DEVICE TYPES, 4 YEAR PERIOD
6/25/81	VV-A-81-01	BURN-IN UNDERSTRESS	9 DEVICE TYPES, 37 LOTS
4/24/82	VV-A-82-01	IMPROPER BURN-IN & ELECTRICAL TESTS	63 DEVICE TYPES, 3 YEAR PERIOD
10/12/82	VV-A-82-01	INCORRECT QUALITY CONFORMANCE INSPECTION	ALL DIGITAL DEVICES, 1 YEAR PERIOD
1/31/83	VV-A-83-02	FULL QUALITY CONFERENCE INSPECTION NOT PERFORMED	1 PART, 10 LOTS
4/4/83	VV-A-83-03	BURN-IN IRREGULARITIES	6 PARTS, 11 LOTS

IMPACT OF MIL-M-38510 ALERTS

- QUESTIONABLE PRODUCT IN EQUIPMENT
- COST OF RESOLVING PROBLEMS
- LOSS OF CONFIDENCE

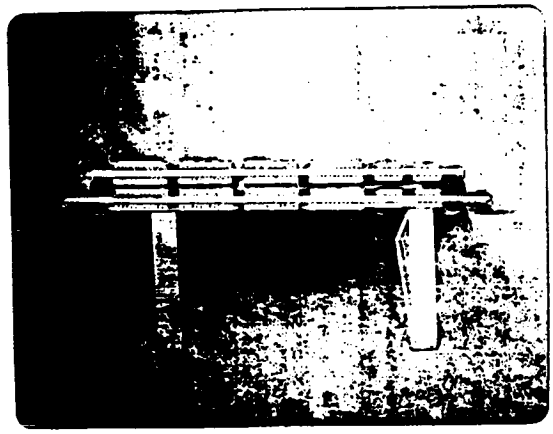
CHALLENGE

HOW CAN THE AEROSPACE COMMUNITY OBTAIN QUALITY ASSURED MICROCIRCUITS?

EXPERIENCE WITH LEADLESS CARRIERS

W. S. SHIPLEY

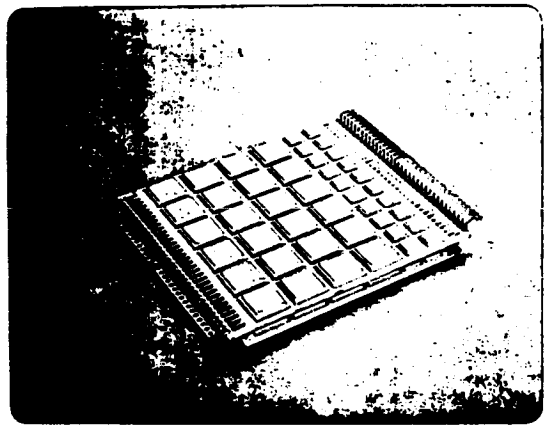
JUNE 7, 1983

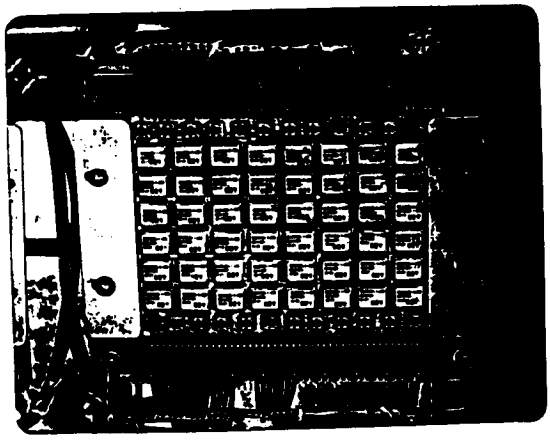


GALILEO MEMORY

- 190K WORDS - TC 244 - 1024 BIT RAMS
- 2 DOUBLE-SIDED CERAMIC BOARDS PER MODULE
- 48 TC 244 RAMS, 12 4028's, 4 4053's, 8 4049's -- ALL LEADLESS CARRIERS

WSS-1
6/7/83





EXPERIENCE

- FRACTURE OF BOARDS - TWIST, CRACK
  - CERAMIC - CERMALLOY
  - CO-EFFICIENT OF EXPANSION
  - USED DUPONT DIELECTRIC TO RESOLVE
- SOLDER BALL - IMPACT OF CLEANING
  - PROCESS PRIOR TO VAPOR PHASE SOLDERING
  - STOPPED CLEANING
- ELECTROSTATIC DAMAGE OF PARTS

WSS-5
6/7/83

NEW

MILITARY STANDARD AND SPECIFICATION

FOR

LARGE SCALE INTEGRATED CIRCUITS

FOR

SPACE PROGRAMS

MANAGEMENT - PROCUREMENT

A. J. CARLAN
8 JUNE 1983
MISSION ASSURANCE CONFERENCE
PANEL ON TEST (J)

- o PRESENT STATUS
  - MIL-STD-XXXX (USAF) DRAFT JUNE 1983
    MANAGEMENT OF CUSTOM LARGE SCALE INTEGRATED CIRCUITS FOR USE IN SPACE PROGRAMS
  - MIL-L-XXXX (USAF) DRAFT JUNE 1983
    GENERAL SPECIFICATION FOR LARGE SCALE INTEGRATED CIRCUITS FOR SPACE VEHICLES
- o FUTURE PLANS
  - RELEASE BY SD FOR GUIDANCE PURPOSES
- o HISTORY
  - SPACE PARTS WORKING GROUP (SPWG) LSI COMMITTEE FORMED IN 1980
    - o CHAIRMAN: A. J. CARLAN, AEROSPACE
    - o SUBCOMMITTEES:
      - LSI PROGRAM MANAGEMENT
        PAUL DICK, GENERAL ELECTRIC, CHAIRMAN
      - PRODUCT ASSURANCE
        W. RICHARD (DICK) SCOTT, JPL, CHAIRMAN
      - HARDNESS ASSURANCE
        E. A. (AL) WOLICKI, NRL, CHAIRMAN
      - TESTING AND TESTABILITY
        CHARLES (CHUCK) GWYN, SANDIA, CHAIRMAN
      - DESIGN AND CONSTRUCTION
        JACK HILTBRAND, RCA, CHAIRMAN

MEMBERS SPWG/LSI COMMITTEE

- LSI PROGRAM MANAGEMENT
  - I. FEIGENBAUM, COMSAT
  - V. YOUNG, MARTIN MARIETTA
  - D. COLE, GENERAL ELECTRIC
  - M. WILLIAMSON, BOEING
  - J. WIESNER, AEROSPACE
- PRODUCT ASSURANCE
  - D. PARKER, HUGHES
  - B. DROTMAN, JPL
  - F. LEIKAM, MARTIN MARIETTA
  - S. FLOYD, NASA GSFC
  - C. ANDERSON, HARRIS
  - R. MCGOWAN, HUGHES
  - L. NESS, JPL
  - L. LINHOLM, RBS
  - R. ENZ, AEROSPACE
- DESIGN AND CONSTRUCTION
  - C. GIBBON, SANDIA
  - D. NIXEN, AEROSPACE
  - D. FRESH, AEROSPACE
- HARDNESS ASSURANCE
  - R. PEASE, NRC
  - J. RAYMOND, NRC
  - M. GAUTHIER, JPL
  - J. SPRATT, SAI
  - M. COOPER, LITTON
  - P. BUCHMAN, AEROSPACE
- TESTING AND TESTABILITY
  - M. BREUER, USC
  - C. ACKER, SANDIA
  - W. KINER, NSWC(DAHLGREN)
  - W. DEBANY, RADC
  - J. ACKER, SANDIA
  - N. STAHLBERG, AEROSPACE

KEY PROVISIONS

- o MIL-STD ON MANAGEMENT OF CUSTOM LARGE SCALE INTEGRATED CIRCUITS (CLSIC)
  - APPLIES TO CONTRACTORS (PRIME AND SUBTIER)
  - COMPATIBLE WITH MIL-STD-1546
    (PMP CONTROL AND MANAGEMENT PROGRAM FOR SPACE VEHICLES)
  - GENERAL REQUIREMENTS
    - o JUSTIFICATION FOR USE OF CLSIC
    - o APPLICATION TO SYSTEM REQUIREMENTS
      - RADIATION REQUIREMENTS CATEGORIZATION
      - PERFORMANCE REQUIREMENTS
      - ANALYSIS
- o CUSTOM LARGE SCALE INTEGRATED CIRCUITS (CLSIC) (CONT.)
  - o CLSIC PROGRAM PLAN - WITH DESIGNER AND MANUFACTURER
    - TESTABILITY ASSURANCE PROGRAM
      - o REQUIREMENTS
      - o ANALYSIS
      - o SYNTHESIS
        FAILURE MODES
        FAULT POPULATION
        TEST STRATEGY
        INTERMITTENT DETECTION
      - o EVALUATE EFFECTIVENESS

      PRODUCT ASSURANCE PROGRAM
      - o CONTRACTOR
        DPA
        CONFIGURATION CONTROL
        SOURCE SURVEILLANCE
- o CUSTOM LARGE SCALE INTEGRATED CIRCUITS (CLSIC) (CONT.)
  - o PMPCB ROLE
  - o PROGRAM AND DESIGN REVIEWS
  - o PREPARATION OF DETAILED SPECIFICATION
  - o CAPABILITY AUDIT
    - DESIGNER
    - MANUFACTURER
      - o MANUFACTURING BASELINE
      - o PRODUCT ASSURANCE PLAN
  - o HARDNESS ASSURANCE PROGRAM
    - CONTRACTOR
    - DESIGNER
    - MANUFACTURER
- o CUSTOM LARGE SCALE INTEGRATED CIRCUITS (CLSIC) (CONT.)
  - o CONCEPTUAL PHASE
    - FUNCTIONAL REQUIREMENTS
    - DESIGN DEFINITIONS
    - DESIGN ASSURANCE, DOCUMENTATION
    - TECHNICAL REVIEWS
  - o FUNCTIONAL DESIGN PHASE
    - DESIGN REQUIREMENTS
    - TESTABILITY REQUIREMENTS
    - DESIGN ASSURANCE
    - TEST CHIPS AND STRUCTURES
    - BUILT-IN-TEST DESIGN

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- CUSTOM LARGE SCALE INTEGRATED CIRCUITS (CLSIC) (CONT.)
  - PHYSICAL DESIGN PHASE
    - DESIGN REQUIREMENTS
    - TESTABILITY DOCUMENTATION
    - HARDNESS ASSURANCE DOCUMENTATION
      - HARDNESS VERIFICATION
  - FABRICATION PHASE
    - PRODUCTION SURVEILLANCE
    - HARDNESS REQUIREMENTS
  - LOT ACCEPTANCE
    - DEVICE CHARACTERIZATION
    - RELIABILITY ASSESSMENT
    - TEST COVERAGE
    - LOT ACCEPTANCE CRITERIA
    - RADIATION HARDNESS
  - CONTRACTOR INSPECTIONS
    - DPA, FAILURE ANALYSIS

KEY PROVISIONS

- MILITARY SPECIFICATION - LARGE SCALE INTEGRATED CIRCUITS FOR SPACE VEHICLES
  - GENERAL LSIC SPECIFICATION
    - SPACE APPLICATIONS
  - COMPATIBLE WITH CLSIC MILITARY STANDARD
  - USED BY CONTRACTOR FOR PROCUREMENT
  - REQUIREMENTS
    - FLIGHT ACCREDITATION (QUALIFICATION)
      - AUDITED DESIGN AND MANUFACTURING BASELINES
      - PRODUCT EVALUATION TESTS
      - SCREENING TESTS
      - LOT CONFORMANCE TESTS
      - ACCEPTABLE FAILURE HISTORY
        - COMPATIBLE WITH RELIABILITY PREDICTION
    - PROCESSES AND CONTROLS
      - LOT PROCESS CONTROL
      - CERTIFIED OPERATORS
      - WORKMANSHIP
      - TEST FEATURES
        - BUILT-IN-TEST
        - FUNCTIONAL PERFORMANCE
    - DESIGN REQUIREMENTS
      - CURRENT DENSITY
      - METALLIZATION
      - PASSIVATION
      - ASSEMBLY
      - PACKAGE MATERIALS
      - ENVIRONMENTAL DESIGN

- DESIGN REQUIREMENTS (CONT.)
  - PERFORMANCE IN SPECIFIED ENVIRONMENTS
    - RADIATION
    - HUMIDITY
    - PRESSURE
    - SHOCK
    - TEMPERATURE
  - OPERABILITY
    - RELIABILITY
    - SERVICE LIFE
    - STORAGE

- QUALITY ASSURANCE PROVISIONS
  - INSPECTIONS AND TESTS
  - PMP CONTROLS
  - RECORDS
  - INSPECTORS
  - MANUFACTURING CONTROLS
    - ASSEMBLY TESTS
  - PRODUCT EVALUATION
    - DESIGN VERIFICATION
    - ELECTRICAL TESTS, CRITERIA CHARACTERIZATION
    - RELIABILITY ASSESSMENT
      - BURN-IN
      - LIFE TESTS
      - TEST CHIPS

- QUALITY ASSURANCE PROVISIONS (CONT.)
  - SCREENING
  - FAILURE ANALYSIS
  - LOT ACCEPTANCE CRITERIA
  - PRODUCT EVALUATION
    - LIFE TESTS
    - LOT CONFORMANCE TESTS
    - RADIATION TESTS
  - QUALIFICATION (FLIGHT ACCREDITATION)
- TAILORED APPLICATION
- ORDERING DATA
  - SCD
  - PURCHASE ORDER
- HARDNESS ASSURANCE APPENDIX
  - LOT CONFORMANCE TESTS

ACKNOWLEDGMENTS:
The graphical materials used in this briefing were taken from presentations at the NSA-DARPA Single Event Effects Symposium, 20 April 1983 and other publications.

I acknowledge, with thanks, the authors of the information used.

COSMIC RAY EFFECTS

IN

LARGE SCALE INTEGRATED

CIRCUITS

A. J. CARLAN
8 JUNE 1983
MISSION ASSURANCE CONFERENCE
WORKSHOP D
ASSURANCE TECHNOLOGY -
MICROELECTRONICS PANEL

OUTLINE - COSMIC RAY EFFECTS IN LSICS

- RADIATION IN SPACE
- BACKGROUND OF COSMIC RAY PROBLEMS
- HOW COSMIC RAYS AFFECT LSICS
- FUTURE TRENDS TOWARD VLSIC AND VHSIC
- HARDENING LSICS
- SYSTEM LEVEL WORKAROUNDS

RADIATION IN SPACE - NATURAL ENVIRONMENT

- RADIATION BELTS SURROUNDING THE EARTH
  - ENERGETIC ELECTRONS, PROTONS - TRAPPED BY EARTH'S MAGNETIC FIELD - ENERGY ≈ 1 MeV
  - VARIES WITH ALTITUDE, LATITUDE, LONGITUDE AND SOLAR CYCLES
  - TOTAL ACCUMULATED RADIATION OR "TOTAL DOSE"

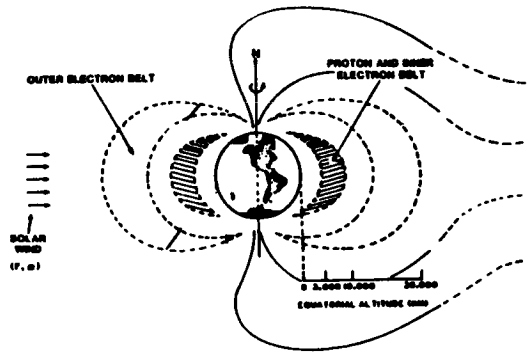
RADIATION IN SPACE (Cont'd)

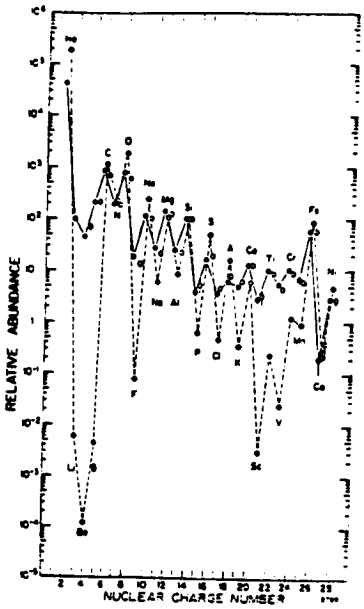
- COSMIC RAYS
  - SOURCE - OUTER SPACE - BEYOND SOLAR SYSTEM
    - SOLAR FLARES
  - CONSISTS OF
    - HEAVY IONS, SUCH AS
      - IRON
      - OXYGEN
      - CARBON
      - NICKEL
    - PROTONS, HELIUM

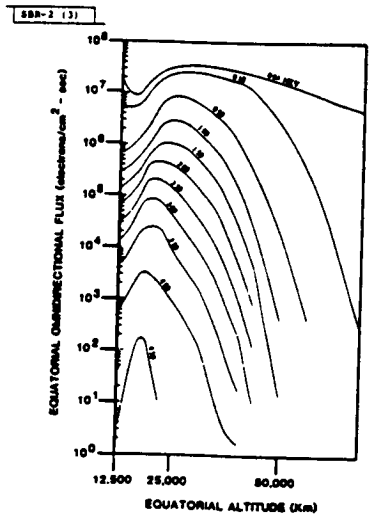
RADIATION IN SPACE (Cont'd)

- WITH ENERGIES
  - RANGING FROM ABOUT 10 MeV TO 10^4 MeV PER NUCLEON
- HIGHEST DENSITY OF COSMIC RAYS AT LOWER ENERGY PORTION OF SPECTRUM (He, C, N, O, Ne, ETC.)
- ELEMENT — RELATIVE ABUNDANCE

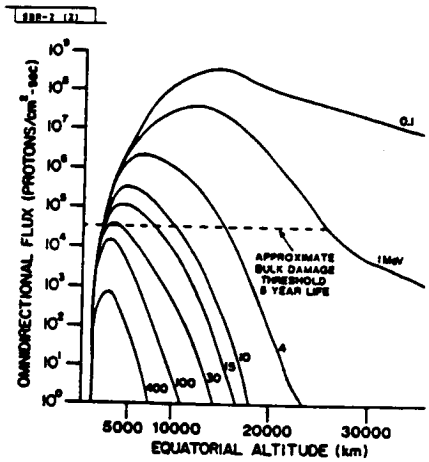
ELEMENT	RELATIVE ABUNDANCE
He	10^5
C, O	10^3
Fe, Mg, Si, S	10^2
Ca, Ti, Cr	10^1
Ni	10^0



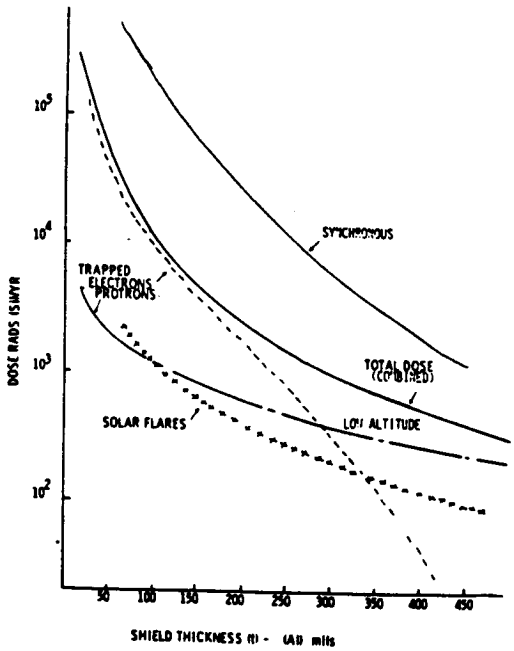




Outer belt electron flux (AE4 model).



Equatorial omnidirectional proton flux distribution (AP8 MIN model).



BACKGROUND OF SATELLITE COSMIC RAY PROBLEMS - TYPICALLY "SOFT ERRORS"

- o FIRST REPORTED BY BINDER AND SMITH (NAC) IN 1975
- o DYNAMIC RAM UPSETS REPORTED BY MAY AND WOODS (INTEL) 1978

  AND PICKEL AND BLANDFORD (RI) 1978
- o LATCHUP IN CMOS RAMS DUE TO HEAVY IONS REPORTED BY KOLASINSKI

  AND BLAKE (AEROSPACE) 1979

NON COSMIC RAYS AFFECT LSICS (Cont'd)

- o COSMIC RAY UPSET PREDICTIONS
  - • COSMIC RAY INDUCED ERROR RATE (CRIER)
  - • J. BLANDFORD, J. PIKEL, ROCKWELL INTERNATIONAL
  - • P. SHAPIRO, E. PETERSON, NRL
  - • E. BURKE, RADC
  - • OTHERS

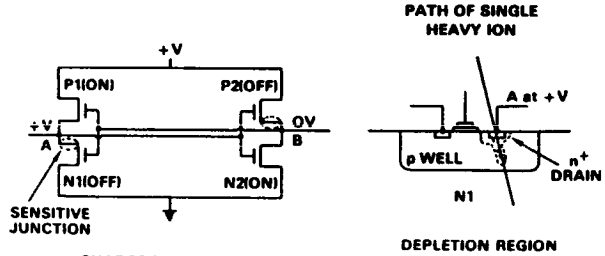
BACKGROUND OF SATELLITE COSMIC RAY PROBLEMS - TYPICALLY "SOFT ERRORS" (Cont'd)

- • TDRS
  - o ONE OR MORE UPSETS PER DAY REPORTED IN

    93L422 (256 X 4 BIPOLAR RAM)
  - o GPS
  - o SOLAR MAXIMUM MISSION
  - o GALILEO CONCERNS
    - • AMD 2901B AND 2901C
  - o OTHERS

NON COSMIC RAYS AFFECT LSICS

SINGLE EVENT UPSET MECHANISM CMOS STATIC RAM



CHARGE PULSE AT A WILL CAUSE FLIP AT P2

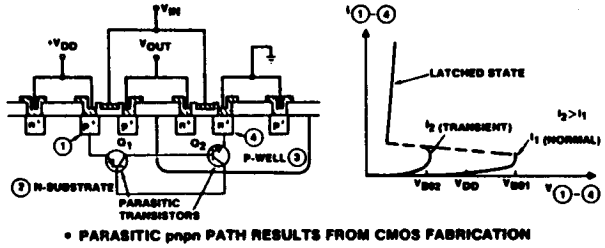
DEPLETION REGION AND FUNNEL COLLECT ELECTRONS

NON COSMIC RAYS AFFECT LSICS

- o CRICITAL CHARGE, Q_c
  - • SENSITIVITY TO UPSET, LATCHUP
  - • EXPOSURE TO COSMIC RAY SPECTRUM
- o CROSS SECTION
  - • UPSET, LATCHUP
    - o ACTIVE DEVICE AREA
      - • NUMBER OF STORAGE ELEMENTS
      - • AREA OF SENSITIVE REGIONS

NON COSMIC RAYS AFFECT LSICS

CMOS RAM LATCHUP MECHANISM



- • PARASITIC pnpn PATH RESULTS FROM CMOS FABRICATION
- • WHEN $\alpha(Q_1) + \alpha(Q_2) > 1$, STABLE LOW IMPEDANCE STATE OCCURS
- • α CAN BE INCREASED BY CURRENT INJECTED FROM SINGLE PARTICLE IONIZATION, YIELDING SMALLER V_{BO} (90MeV Fe => 0.28pC/μm => ~ 3ma/μm)
- • WHEN V_{BO} REDUCED TO LESS THAN V_{DD}, LATCHUP OCCURS

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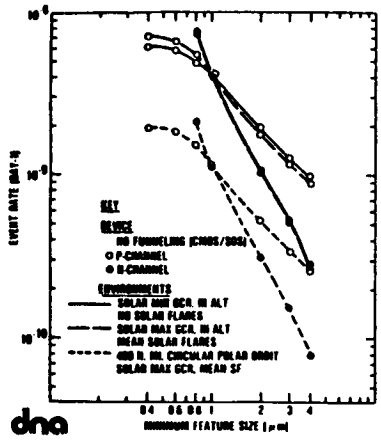
FUTURE TRENDS TOWARD VLSIC AND VHSIC

- SMALLER FEATURE SIZES
  - 0.7 to 1.25 MICROMETERS COMPARED TO 2 TO 10 MICROMETERS TODAY
  - REDUCES Q_c
  - INCREASES SUSCEPTIBILITY TO LOW ENERGY (HIGH FLUENCE) SPECTRUM



EFFECT OF MODEL ENVIRONMENTS ON SCALING FOR P-FET AND N-FET HITS TO CMOS/SOS

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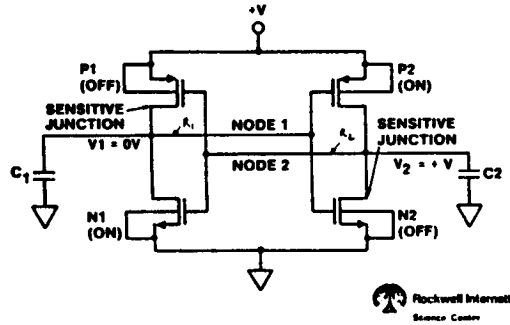
FUTURE TRENDS TOWARD VLSIC AND VHSIC (Cont'd)

- HIGHER DENSITY OF ACTIVE CIRCUIT ELEMENTS
  - UPWARDS OF 10^6 ACTIVE DEVICES PER CHIP
  - INCREASES UPSET CROSS SECTION
  - INCREASES GAIN FOR LATCHUP
  - POTENTIAL FOR MULTIPLE SIMULTANEOUS UPSETS
- LOWER INTERNAL VOLTAGE MARGINS
  - REDUCES Q_c

HARDENING LSICS (Cont'd)

- INCREASE Q_c
- USE RESISTORS IN MEMORY CELL FEEDBACK LOOPS



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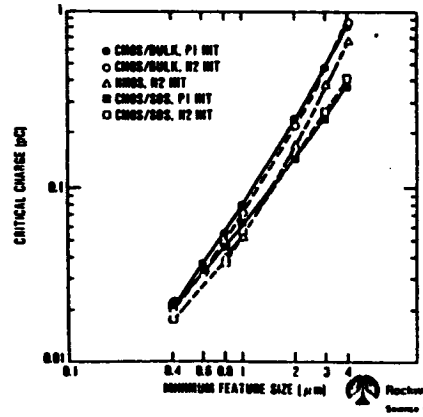
CRITICAL CHARGE VERSUS MINIMUM FEATURE SIZE



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HARDENING LSICS (Cont'd)

- HARDNESS ASSURANCE
  - TEST, VERIFY NO LATCHUP
    - EPITAXIAL SUBSTRATES
    - NEUTRON IRRADIATION
  - TEST FOR COSMIC RAY INDUCED UPSETS
    - ENERGETIC PARTICLE TESTS

HARDENING LSICS (Cont'd)

- CYCLOTRON
  - KRYPTON
  - ARGON
  - OXYGEN
  - CARBON
- VAN DE GRAAF
- DETERMINE CRITICAL CHARGE
- SENSITIVE VOLUME
- PREDICT UPSET RATE IN ORBIT

SYSTEM LEVEL WORK AROUNDS IF HARD DEVICES NOT AVAILABLE

- MEMORIES - USE ERROR CORRECTING CODES
  - USE LATCHUP FREE DEVICES
- COMPUTERS, CONTROL LOGIC - FAULT TOLERANCE
  - TRIPLE MODULAR REDUNDANCY (TMR) - VOTING
  - DUAL REDUNDANT HARDWARE - PARALLEL COMPUTATION
    COMPARE

SYSTEM LEVEL WORK AROUNDS - IF HARD DEVICES NOT AVAILABLE (Cont'd)

- DUAL - SEQUENTIAL COMPUTATION
  - IF ERROR,
  - REINITIALIZE TO PRIOR STATE
  - RECOMPUTE
  - REQUIRES HARD MEMORY
- OTHER
  - RESIDUE CODES
  - TBD

ACKNOWLEDGEMENTS:
The graphical materials used in this briefing were taken from presentations at the NSWC-DARPA Single Event Effects Symposium, 30 April 1983 and other publications.

I acknowledge, with thanks, the authors of the information used.

SOFTWARE FAULT TOLERANCE BENEFIT TO SOFTWARE QUALITY ASSURANCE

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Hampton, Virginia

In the recent past there has been an increasing amount of attention paid to fault-tolerant computer systems. The attention has been motivated by ever increasing requirements for reliability of the systems--in particular, for levels of reliability greater than those of the separate components which constitute the systems. In the case of hardware, various structures, often tailored to applications, have been and are being proposed for the purpose of introducing redundancy in a well structured manner--redundancy which is a necessary condition for fault tolerance. The mathematical analysis of such systems goes back at least to Shannon's 1951 paper on making more reliable switching systems out of less reliable switching relays. And the concept is certainly older. Witness the ubiquitous spare tire!

Only recently, however, has an analogous concept been seriously proposed for software. The belatedness is undoubtedly because of the non-physical nature of the software object. The concept of reliability, which conventionally pertains to the physical degradation of systems, has had to be perceived from a different viewpoint. Thus, software fault-tolerance schemes address themselves to system failure modes due to design flaws within the structured interconnection of the software system components as well as to design flaws within the components.

There is a potential for application of software fault-tolerance schemes to the objectives of software quality assurance programs. In particular, software fault-tolerance system designs can be proposed apart from any consideration of their effect on system reliability, with the objective in mind of furthering the assurance that the quality of software will not degrade with the passage of time after the system is operational. Note that even though software is not physical in nature, such degradation can come about as a consequence of maintenance actions which, while ostensibly meant to correct deficiencies, often introduce further "bugs" in the software. The fault-tolerance techniques can also contribute indirectly to the same goal by providing a means for controlling life cycle costs, thus freeing resources which can be applied directly to providing a higher quality product. In addition, the techniques suggest a mechanism for conveniently introducing performance improvements into a software system after it is operational. Presently, there is no such convenient mechanism; modifications to an operational software system which are proposed in order to provide desirable performance improvements but which are not mandated in order to correct an intolerable deficiency within the system present an obvious dilemma to the management of an operational project. Moreover, the management functions required to control and resolve such dilemmas are an additional overhead cost which one might hope to reduce. To illustrate the

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preceding assertions, consider two widely known schemes, the Recovery Block scheme and the N-Version Programming scheme.

The Recovery Block scheme, depicted in Figure 1, is a standby sparing concept. The difficult aspect of the scheme is its implementation details which are not discussed here. Conceptually the scheme is straightforward. A function is implemented in a number of "dissimilar," redundant modules which are referred to as the Prime module and Alternates 1, 2, etc. During operation, the outputs of the Prime are continually and dynamically examined for acceptability by another module, called the Acceptance Test module. As long as the outputs are deemed acceptable, the Alternates remain unused spares. When an output is not acceptable, the Alternates are called in turn until an acceptable output is found or until there is no Alternate left. Implementation details of the Recovery Block scheme provide for nesting of Blocks within Blocks so that when no acceptable output can be found, a Discrepancy Return to a higher level Block occurs. If the higher level Block also contains redundancy, the process continues on the higher level. Of course, there is eventually a point, an outermost level, at which there is no more redundancy, and at which the computer system must await external intervention. What percentage of the time this outcome results in system failure depends upon the application and external variables. Also, there is the possibility that erroneous outputs are not detected internally, and that the system fails without warning. Assuming independence among the modules, Figure 2 depicts the relation, in one cycle of operation of a Recovery Block, of system failure probability to the amount of redundancy (i.e., number N of alternates) and to the percentage of Discrepancy Returns which can be salvaged by external intervention (e.g., pilot action). The efficacy of the redundancy scheme is clear for the cases when the percentage which can be salvaged by external intervention is small. More detailed examination of the reliability implications of Recovery Blocks can be found in section 4 of NASA CR-172122, "Development of Software Fault-Tolerance Techniques."

The N-Version Programming scheme, depicted in Figure 3, is an active redundancy scheme analogous to NMR multiprocessor hardware structures such as the SIFT computer on test at NASA's Langley Research Center. It is even simpler in concept than the Recovery Block scheme. A function is implemented in N dissimilar modules (i.e., N versions). In operation, the outputs of all the modules are examined by Consensus modules which form the input to a next stage (i.e., rank) of function modules. Assuming independence among the modules, the relation between the error rate of a stage to the error rates of the component software modules, the number N of redundant modules and the number M of executions of the stage per second in an application is depicted in Figure 4. (A detailed development of the relation is contained in NASA TM 84546, "The Cost of Software Fault Tolerance.")

Clearly, software fault-tolerance schemes are intended to increase the reliability of systems containing software. What is not

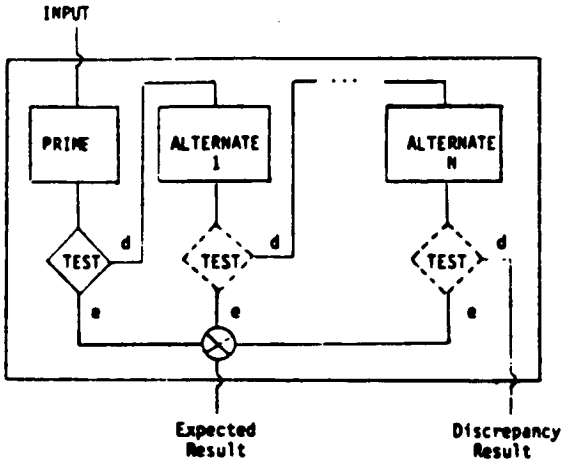
so obvious is that they also offer a promise of assistance in cost control when they are not required for reliability purposes. Figure 5 depicts the interesting fact that different "bugs" within a software module have different (increasingly less) probability of causing a module error (per execution) and hence are increasingly difficult and INCREASINGLY EXPENSIVE to detect and remove prior to operational delivery of the software. What this means is that there can come a point where the cost of one module of given reliability is more than the cost of several less reliable modules which achieve the same system reliability by virtue of a fault-tolerance scheme--the software equivalent of Shannon's reliable system of less reliable relays.

Finally, software systems have another characteristic of note. After a software module has generated an error, it is none the worse off than it was before. That is, the fault that caused the error was always present. If the software served its purpose before the error occurred, there is no reason to suppose it will not continue to serve its purposed after the unique condition which caused it to err has passed. As a consequence, after an error has occurred, and been tolerated by the fault-tolerance system, there is no overwhelming reason to perform any maintenance functions. If the system was designed to the required reliability level, it can even be considered unwise to perform maintenance actions which could alter the achieved reliability level.

Thus, from the point of view of Software Quality Assurance goals, the strategy of encouraging systems to be designed to achieve their reliability goals by means of fault-tolerance schemes practically eliminates the need for maintenance during the operational life of the system. This eliminates both a source of software degradation and an element of life cycle cost.

In addition, the nature of the Recovery Block scheme, which allows the Alternate modules to be of degraded performance capability, can be turned on its ear, so to speak, and utilized to allow the creation of a Prime module which is a null module. In this manner a blank space can be effectively reserved for insertion of the eventual "improved" algorithm. While the new module would have to be validated separately, it might be possible to avoid total revalidation of the rest of the system, an effort which would ordinarily be required to ensure that system reliability had not been degraded by the "improvement." Thus the management dilemma previously referred to would be alleviated if not eliminated.

Admittedly, the benefits to Software Quality Assurance programs which have been suggested above are presently only potential. Moreover, the suggested strategy encroaches upon the territory of the system designer. However, the system goals of the design staff and the quality assurance staff are not in conflict here, and the benefits, if they can be realized, appear significant.



RECOVERY BLOCK SCHEME

FIGURE 1

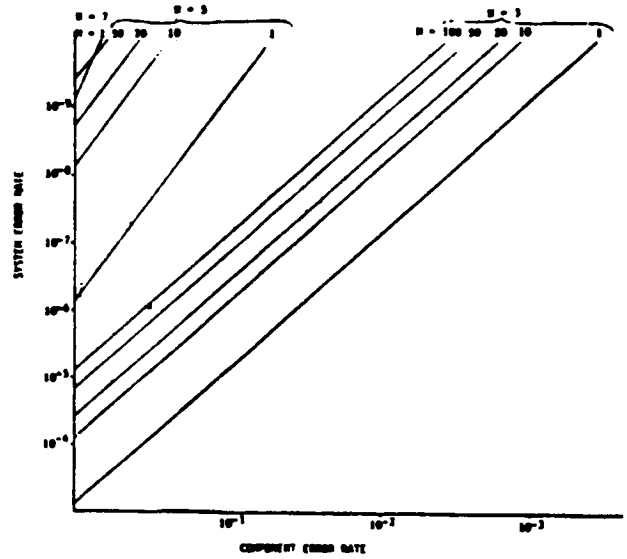


FIGURE 4

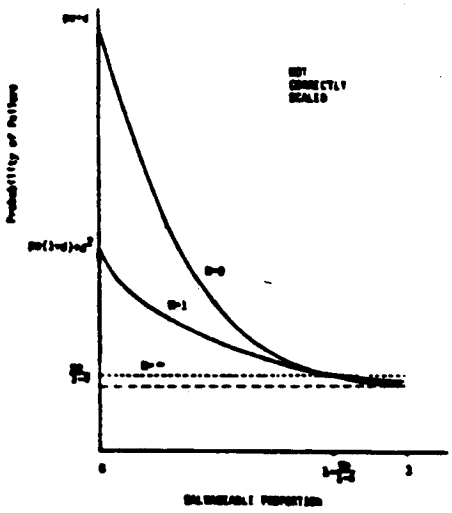
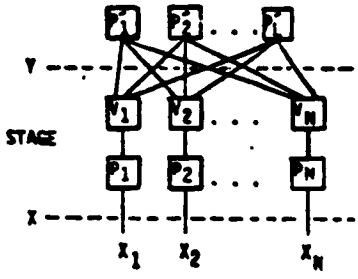


FIGURE 2



N-VERSION PROGRAMMING VARIANT

FIGURE 3

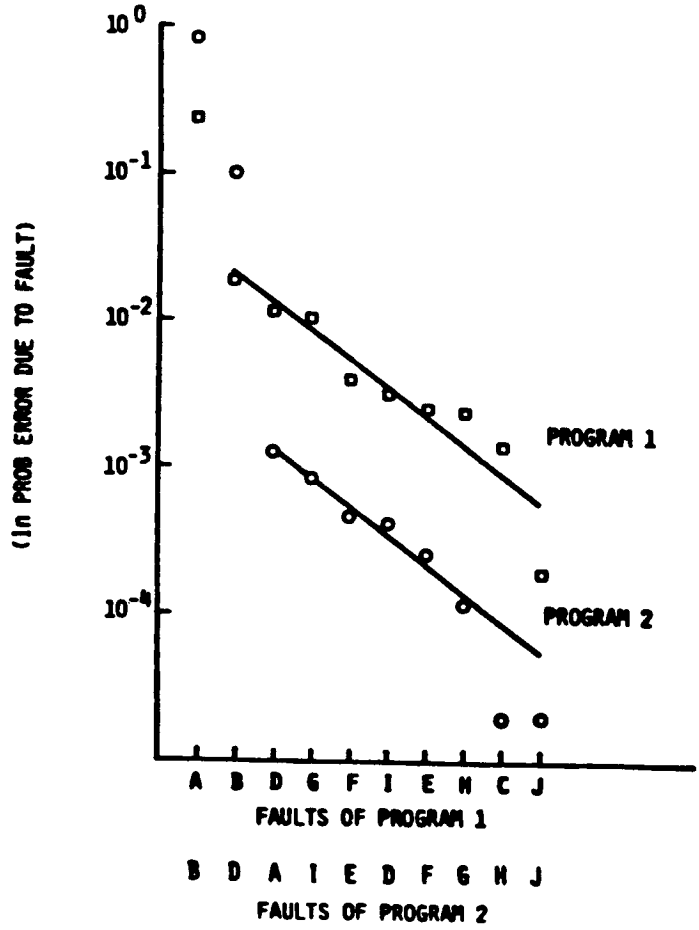


FIGURE 5

AN INTEGRATED SOFTWARE QUALITY ASSURANCE AND METRIC PROGRAM

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QA Project Administrator
General Dynamics/Convair

G.E. Murine
President
Metriqs, Inc.

INTRODUCTION: Software quality programs, as we understand them today through either the literature or their practical application, are primarily process oriented. They evaluate process-related functions and activities such as standards, reviews and audits, milestones, and schedules. These functions and activities are measurable to the extent that they exist, are adequate, and compliant.

The measure of the software product and its quality poses a significantly more difficult problem. In todays environment such measurements are binary and generally consist of technical requirements verification and validation testing. The software either satisfies or does not satisfy some requirement-in many cases ill-defined. This is not a measure of the actual software product quality, in that it does not quantifiably measure, in a continuous manner, specified quality attributes of the software.

The role of Software Quality Assurance (SQA) typically involves verifying that technical software requirements have been satisfied. In most cases, this means ensuring that the software end product includes all specified functions and that it meets performance requirements.

What it has not meant, until recently, is that the quality of the software product also be verified. And this is not without understanding. Little effort has been made by the software community to actually define what is meant by software quality or to provide for its evaluation. Neither have many customers or users ever included software product quality provisions in a purchase order, beyond that the software should work-whatever that means. Nor do current government or commercial software standards require product quality definition or verification. What is not realized by the software community at large is that current government standards and Data Item Description (DID) documents are repleat with measurable conditions or characteristics that actively contribute to some degree of software excellence. This should suggest that the SQA function, as we now understand it, is only capable of doing part of the job.

If this were the case, then the traditional SQA role must be complemented by a new software product evaluation methodology-Software Quality Metrics (SQM). Current SQA product associated activities are aimed primarily at verifying that software functional and performance requirements have been satisfied. SQM goes beyond this limited application. SQM provides for continuous evaluation of the software product throughout each incremental development phase to measure degree of accomplishment of pre-defined quality goals. Thus by combining the traditional SQA approach with the new SQM methodology, we are now able to not only verify technical requirements but also to define and evaluate actual software product quality.

SQM, similarly, supplements the traditional SQA requirements verification approach. By specifically identifying and selecting unique software attributes, the SQM methodology can be used independently to more precisely evaluate the software product. Rather than just verify functional or performance requirements, the software technical effort can be examined more rigorously and in greater detail to evaluate its accomplishment. This supplemental approach also faciliates establishing short term measurable quality objectives. Coupled with the usual SQA verification, SQM provides another dimension to evaluating software.

THE PROBLEM: As previously mentioned, the current software MIL-STDs and Data Item Description (DID) documents contain numberous references to various attributes of the software that provide or determine a desired characteristic. Yet these are rarely considered as either "design to" or "quality" requirements. When envoked all requirements of the MIL-STD or DID, must be satisfied unless specifically excluded. This would imply that a SQM program is needed to 1) properly identify specified attributes, 2) to select those attributes the software must include, and 3) to evaluate continuously the software product as to the extent those attributes are being achieved.

IMPLEMENTING THE SOLUTION: Background- The subject of SQM is not new. From its initial suggestion by Hartwick and Rubey (1) in 1968 to the development of a practical application methodology by Murine (2) in 1979, SQM has been the target of skeptics and supporters alike. It has left a trail of contributions to the software engineering community with classical analysis such as the works of Boehm (3) and Gilb (4).In large part, it has been the motivation behind the Joint Logistic Commanders proposed military standards for software - MIL-STD-SQAM and MIL-STD-SDS. In general, the subject of SQM has had a beginning of uncommon exposure to a community of critics.

The twelve currently accepted set of software quality factors is the set proposed by Murine in 1979 and patterned after those of McCall and Walters (5) in 1977. The definitions used by Murine, McCall and Walters are in general basically the same as those given by Boehm in 1973, and are widely accepted by the software engineering community. We would not suggest any major deviation from these definitions due to this somewhat universal acceptance and to their quantifiable nature.

All the factors are defined in a fashion suitable to maximum - minimum theory. They begin "The extent to which ..." or "The effort required ..." thereby enabling the analyst to determine a degree of compliance and in turn quantify factor condition. For the sake of completeness, we include the twelve factors and their definition in Table I.

Each factor is measurable by quantifying its constituants called "criteria". For example, a score for correctness is obtained by measuring the attributes of the software which constitute correctness; namely traceability, completeness, and consistency.

TABLE I: SOFTWARE QUALITY FACTORS

Correctness- Extent to which a program satisfies its specifications and fulfills the user's mission objectives.
Reliability- Extent to which a program can be expected to perform its intended functions with required precision.
Efficiency- The extent to which a computer program uses minimum resources to perform a function.
Integrity- Extent to which access to software or data by unauthorized persons can be controlled.
Reusability- Extent to which a program can be used in other applications-related to the packaging and scope of the functions that programs perform.
Usability- Effort required to learn, operate, prepare input, and interpret output of a program.
Maintainability- Effort required to locate and fix an error in an operational program.
Testability- Effort required to test a program to ensure it performs its intended functions.
Flexibility- Effort required to modify an operational program.
Portability- Effort required to transfer a program from one hardware configuration and/or software environment to another.
Interoperability- Effort required to couple one system with another.
Intraoperability- Effort required to totally communicate between software components.

Integrating SQA and SQM: There is a need to combine the SQM and existing SQA programs into a Software Quality Assurance and Metrics (SQAM) program without causing total disruption of existing programs. The need is clearly recognizable and certainly not new.

The most difficult problem in certifying software for flight or ground support use is assuring its quality. A cardinal principle of system failure analysis is that hardware failure maybe due to component deterioration or design errors, while software failures are almost always design in nature that can be detected only under certain operating conditions. Post-release validation provides no more assurance of the software's quality or effectiveness than does conscientious review and control during design and development. Responsible developers of computer systems long have understood that complete testing and verification of complex systems under other than actual conditions is impractical and prohibitively expensive. It is, rather, the common industry practice to verify major functions of software systems with relatively simple testing, and to rely on the sophisticated customer and his resources to ultimately discover and correct any latent errors. These facts suggest that the Government should further encourage the quality control of flight and ground support software early and throughout the development cycle.

Software quality, the degree to which a software product possesses a specified set of attributes necessary to fulfill a stated purpose, has two aspects: those attributes required, and the extent to which they are achieved. The assessment or measure of this achievement reflects the level of quality. Once a computer software product is developed, its quality is established. It doesn't change unless the computer program is altered. Testing, in of itself, does not improve the quality of the software. It must be built in from the beginning and continuously

measured throughout development. The level of quality achieved in a software product is determined primarily by the development process followed, the standards used, and the controls implemented. These three elements in consort constitute the software quality program. Such a program must embody those functions, activities, and processes necessary to provide a software end product that satisfies predefined, technical requirements and quality attributes. In addition, to be cost effective, the program must be economically planned, tailorable, and most importantly, be measurable from both process and product standpoints.

IMPLEMENTING A SQAM PROGRAM

In this section, we will outline the steps taken in implementing a SQAM program on a major tactical military project. As far as we know this was the first actual application of an integrated SQA and SQM program. At the time the SQAM Program was initiated, a Software Development Plan (SDP) had been approved and the program performance specification completed. The application software was being developed under MIL-STD-1679. Our SQAM approach to measuring the quality of the software product was first, to identify the software goals, and then, to select the appropriate metrics from various sources. The goals were extracted from the SDP, as inferred by the software development team. Since MIL-STD-1679 had been contractually imposed and identified as the vehicle for such software quality assessment, this document became the basis for the measurement guidelines. The metrics were selected to be responsive to the contractual quality requirements and the project's pre-defined scope. In addition, the reporting of SQM measurements was made adaptable to the existing SQA reporting system as part of the SQAM program.

A total of 217 requirements which related to the 12 quality factors were extracted from the software development plan. A frequency of occurrence of these requirements, as they related to the software quality factors (explicitly or implicitly), was established and plotted (Figure 1). The three factors occurring most frequently were selected as the trial set of objectives.

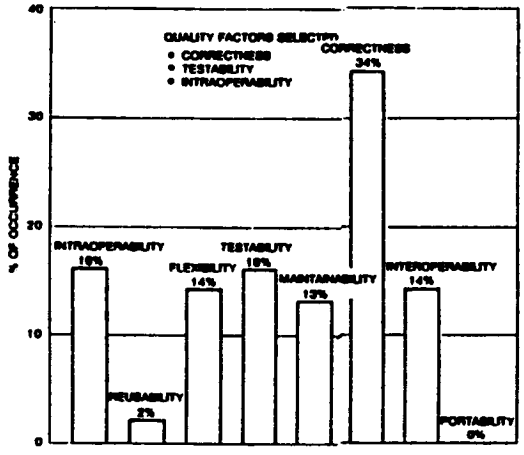


Figure 1. Factor Frequency Chart.

The SDP document analysis provided sufficient data for the software QA and development team to establish an unbiased ordering of the software quality factors by group. The first group, considered to be of the highest priority, contained the factors of correctness, testability, and intraoperability. From this group, a list of criteria was defined which, themselves, were measures of the three factors.

These criteria were traceability, completeness, consistency, simplicity, modularity, instrumentation, self-descriptiveness, communications commonality, and data commonality.

A final step in this systematic approach to identifying software goals and providing for their measurement was to establish a series of metrics for assessing their accomplishment. Since MIL-STD-1679 is not directly metric oriented, it was necessary to identify its individual requirements, seperate them into categories, and group the metric-related requirements by criteria. We believed this major undertaking would complete the deductive association of contractual requirements, to software quality metric, to software quality goals. A total of 416 requirements were extracted from the relevant sections of MIL-STD-1679 and divided into four categories. The distribution of the metric requirements by category is shown in Figure 2.

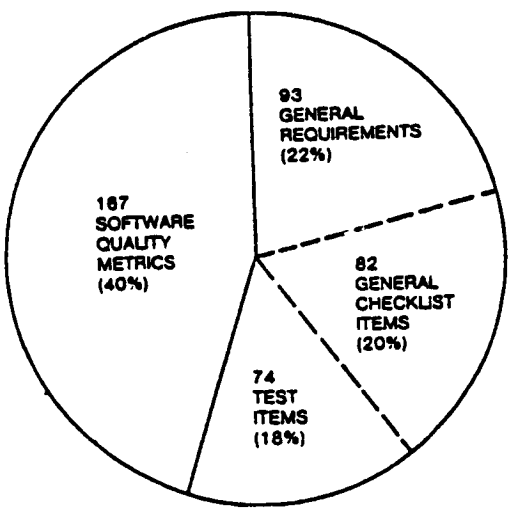


Figure 2. Distribution of requirements.

The nine criteria directly related to the three selected factors contained 97 of the MIL-STD metrics. Some criteria were found to be without direct reference in the MIL-STD. Additional metrics were needed. From the Murine Metric Set, 87 additional metrics were identified to support the defined criteria (Table II). These metrics had been used previously on similar projects and were selected in part on this account. A final set of metrics was generated from the various Data Item Description (DID) documents.

Table II. Selected criteria — metric set.

Criteria	MIL-STD-1679 Metrics	Murine Metrics	Metrics
Traceability	0	6	6
Completeness	29	13	42
Consistency	4	22	26
Simplicity	12	19	31
Modularity	10	5	15
Instrumentation	1	0	1
Self-descriptiveness	37	13	50
Communications commonality	0	5	5
Data commonality	4	4	8
	97	87	184

It was now necessary to identify those documents upon which the measurement of software quality attributes would be performed. The requirements definition phase was completed and software development had progressed well into the design phase. The program performance specification and program design specification documents are prepared and examined during the software design phase - the program description document during the code phase. These documents describe the

software product and its quality attributes. Accordingly, they were selected for measurement.

SOME RESULTS FROM THE SAMPLE SQAM PROGRAM

As an example, we now cite a few of the results from the actual application of the SQAM program. We will limit our discussion to a single CPCI over a single phase (design).

For the particular CPCI, over 1700 SQM inspections were made whereby 242 software discrepancies were detected (approximately 15% errors overall). Of the 242 discrepancies 121 (50%) were priority 1 (line-stoppers),Using GAO statistics,this represents a $484,000 potential savings for this single CPCI.

On the other hand, 73 SQA discrepancies were detected for this same CPCI during this phase, In this case, 41 (56%) were identified as major (category B) discrepancies.

The results of this SQAM analysis appeared in the SQAM evaluation folder. The outline of the content is shown in Figure 3.

Overall all SQAM evaluation data is kept in a SQAM evaluation notebook whose content is listed in Figure 4.

CONCLUSION:

We have discovered that incorporation of the Software Quality Metrics methodology into our SQA program has satisfied all our initial quality objectives as well as some not previously contemplated. It provides a real, positive quality impact on software product development and measurement and can be used as a major cost reduction tool as well. Some of the benefits derived were:

* Meaningful product quality measures.
* Frequent software quality measure which permits timely detection of errors.
* Project management visibility of software quality during each phase (not only at code completion).
* Much better documentation.
* A basis for objective evaluation against the users requirements.

A. INTRODUCTION
B. SUMMARY OF RESULTS
   2.1 CRITERIA SCORE SHEETS
   2.2 METRIC SUMMARY SCORE SHEETS
   2.3 DISCREPANCY REPORTING
C. METRIC EVALUATION FORMS
   3.1 TRACEABILITY
   3.2 COMPLETENESS
   3.3 CONSISTENCY
   3.4 SIMPLICITY
   3.5 MODULARITY
   3.6 INSTRUMENTATION
   3.7 SELF-DESCRIPTIVENESS
   3.8 COMMUNICATIONS COMMONALITY
   3.9 DATA COMMONALITY
D. SOFTWARE DISCREPANCY REPORTS
   4.1 SQM DISCREPANCIES
   4.2 SQA DISCREPANCIES
E. DID-DI-E-2138 CHECKLIST
   MIL-STD-1679 CHECKLIST
APPENDIX II: PPS REQUIREMENTS
PDS REQUIREMENTS
APPENDIX III: SQA DISCREPANCIES FOR:
-DATA BASE DOCUMENT (DBD)
-TEST SPECIFICATION (TS)
APPENDIX III: METRIC/CHECKLIST SELECTION CRITERIA.

Figure 3. Software Quality Assurance & Metric Evaluation Folder.

* Early establishment of quality goals which would not have been considered until solodification of code.
* Cooperative association with software developers.
* Complete traceability from evaluation to disposition.
* Measurable QA impact during software development.

We have concluded that it is indeed feasible and, in fact, desirable,to include Software Quality Metrics as a SQA tool to support management's commitment to improve software quality.Even though the methodology requires additional validation, we have found it a valuable technique for continuously monitoring the pulse of software quality development. Quantifying the measurement of unique quality requirements is possible and unambigously reportable. Visibility of the software quality process and product is facilitated by use of SQM.It is our recommendation that SQM become an integral part of any SQA program

I. DOCUMENT WORK CERTIFICATION DATA
II. PRE-CONTRACT AWARD DATA
III. CONTRACTUAL DOCUMENT DATA
IV. PROGRAM MANAGEMENT DATA
V. DATA MANAGEMENT DATA
VI. REQUIREMENTS ANALYSIS DATA
VII. DESIGN ANALYSIS DATA
VIII. DESIGN IMPLEMENTATION (CODE) ANALYSIS
IX. LIBRARY PROCEDURES AND DATA
X. TEST DOCUMENTATION DATA
XI. CDRL DATA
XII. REVIEW AND AUDIT DATA
XIII. SOFTWARE TEST DATA
XIV. SQA PLAN DATA
XV. SQM PLAN DATA
XVI. SOFTWARE PROBLEM TRACKING
XVII. NOTES

Figure 4. Software Quality Assurance & Metric Evaluation.

REFERENCES:

1. R. Hartwick and R. Rubey, Quantitative Measurement of Program Quality, Proceedings 23rd ACM National Conference, pp. 671-677, October 1968.
2. G.E. Murine, Applying Software Quality Metrics in the Requirements Analysis Phase of a Distributive System, Proceedings from Minnow Brook Conference, 1980.
3. B.W. Boehm, Quantitative Evaluation of Software Quality, Proceedings 2nd International Conference on Software Engineering, pp. 592-605, October 1976.
4. T. Gilb, Software Metrics, The Emerging Technology, Data Management (USA), pp. 34-37, July 1975.

AN INTEGRATED SOFTWARE QUALITY ASSURANCE AND METRIC PROGRAM

MISSION ASSURANCE CONFERENCE AND WORKSHOP
LOS ANGELES, CALIFORNIA
JUNE, 1983

C.L. CARPENTER, JR.
GENERAL DYNAMICS/CONVAIR
SAN DIEGO, CA

G.E. MURINE
METRIOS, INC.
CARLSBAD, CA

TODAYS SOFTWARE QUALITY PROGRAM ARE

- PROCESS - ORIENTED
- EVALUATE
  - STANDARDS
  - REVIEWS
  - AUDITS
- MEASURE
  - EXISTANCE
  - ADEQUACY
  - COMPLIANCE

PROCESS VALIDATION

A DOCUMENTED PROGRAM THAT PROVIDES A HIGH DEGREE OF ASSURANCE THAT A SPECIFIC PROCESS WILL CONSISTENTLY PRODUCE A PRODUCT MEETING ITS PRE-DETERMINED SPECIFICATIONS AND QUALITY ATTRIBUTES

TODAYS SOFTWARE PRODUCT MEASUREMENTS ARE

- BINARY
- REQUIREMENTS VERIFICATION
- VALIDATION TESTING

DO NOT MEASURE SOFTWARE PRODUCT "QUALITY"

SOFTWARE QUALITY

- ACCEPTED DEFINITION
- REQUIRED
- ATTRIBUTES IDENTIFIED & MEASURED

GOVERNMENT STANDARDS & BIDs

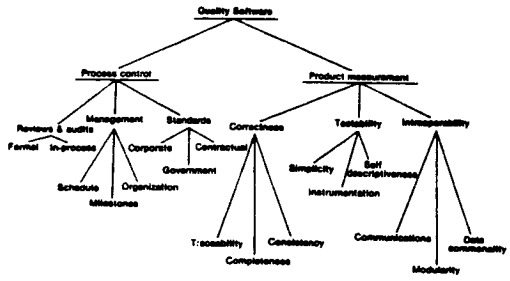
- MEASURABLE CONDITIONS OF SOFTWARE EXCELLENCE
- CONTRACTUALLY REQUIRED

SOFTWARE QUALITY

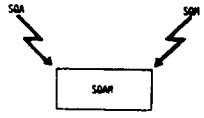
A DEFINITION:

THE DEGREE TO WHICH A SOFTWARE PRODUCT POSSESSES A SPECIFIED SET OF ATTRIBUTES NECESSARY TO FULFILL A SPECIFIED STATED PURPOSE.

QUALITY SOFTWARE TREE



SQA MUST BE COMPLEMENTED WITH SQM



THE PROBLEM:

DEVELOP A SQAM PROGRAM TO

- IDENTIFY ATTRIBUTES
- SELECT ATTRIBUTES
- EVALUATE SOFTWARE PRODUCT CONTINUOUSLY

A SOLUTION

- SOFTWARE QUALITY METRICS
- ACCEPTED SOFTWARE QUALITY TOOL
- RECENT APPLICATIONS IMPRESSIVE
- MINIMAL RISK
- MEASURES SOFTWARE QUALITY ATTRIBUTES
- PROVIDES VISIBILITY TO TOP MANAGEMENT

MAJOR SQM MILESTONES

- 1968 HARTWICK & RUBEY via ACM
- 1976 BOEHM ET AL via INTERNATIONAL CONFERENCE ON SOFTWARE ENGINEERING
- 1977 WALTERS & McCALL via RADC
- 1979 MURINE APPLICATION via RIMROCKBROOK CONFERENCE

SOFTWARE QUALITY FACTORS

Factors	Definition
Correctness	Extent to which a program satisfies its specifications & fulfills the user's mission objectives
Reliability	Extent to which a program can be expected to perform its intended functions with required precision
Efficiency	The extent to which a computer uses minimum resources to perform a function
Integrity	Extent to which access to software or data by unauthorized persons can be controlled
Reusability	Extent to which a program can be used in other applications related to the packaging & scope of the functions that programs perform
Usability	Effort required to learn, operate, prepare input & interpret output of a program
Maintainability	Effort required to locate & fix an error in an operational program
Testability	Effort required to test a program to ensure it performs its intended functions
Flexibility	Effort required to modify an operational program
Portability	Effort required to transfer a program from one hardware configuration and/or software environment to another
Interoperability	Effort required to couple one system to another
Interoperability	Effort required to totally communicate between software components

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MOST SOFTWARE ERRORS

- DESIGN IN NATURE
- DETECTED ONLY UNDER CERTAIN OPERATING CONDITIONS

POST-RELEASE VALIDATION PROVIDE NO MORE ASSURANCE OF SOFTWARE QUALITY THAN DOES CONSCIENTIOUS REVIEW AND CONTROL DURING DESIGN AND DEVELOPMENT.

ONCE A COMPUTER SOFTWARE PRODUCT IS DEVELOPED

- QUALITY IS ESTABLISHED
- QUALITY CHANGES ONLY IF THE PROGRAM CHANGES

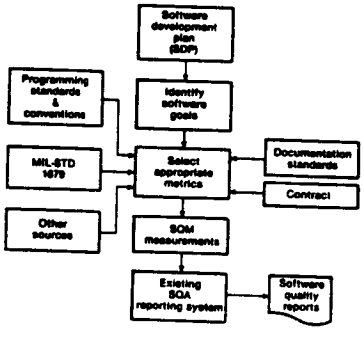
TESTING DOES NOT IMPROVE THE QUALITY OF SOFTWARE

SOFTWARE QUALITY PROGRAM

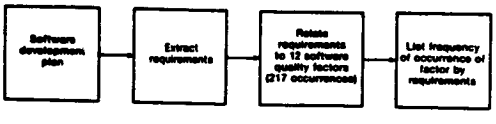
A MANAGEMENT SYSTEM THAT EMBODIES THOSE FUNCTION, ACTIVITIES & PROCESSES NECESSARY TO PROVIDE A QUALITY SOFTWARE END PRODUCT THAT SATISFIES THE USER'S REQUIREMENTS

- INCREMENTAL DEVELOPMENT APPROACH
- EXISTENCE & USE OF RELEVANT STANDARDS
- IMPLEMENTATION OF CONTROLS
- TAILORABLE
- COST-EFFECTIVE
- REASURABLE

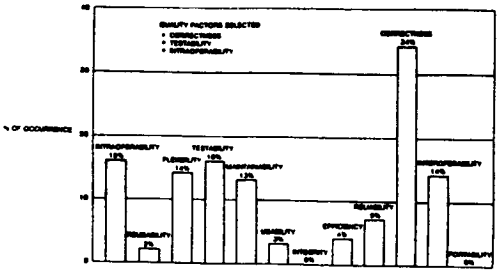
APPLYING SOFTWARE QUALITY METRICS



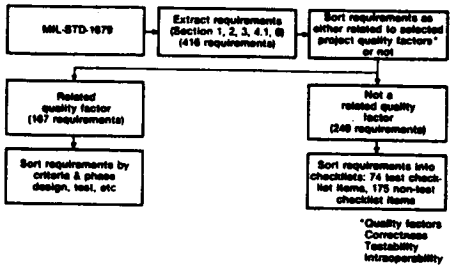
SOFTWARE QUALITY FACTORS SELECTION PROCESS



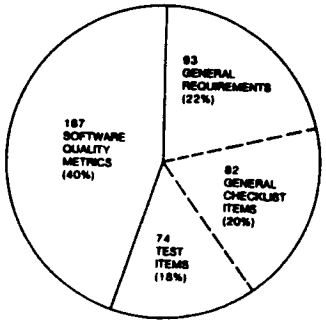
FACTOR FREQUENCY CHART



IDENTIFY SOFTWARE REASURABLE REQUIREMENTS FROM MIL-STD-1679 TO SUPPORT SELECTED QUALITY FACTORS



DISTRIBUTION OF 416 MIL-STD-1679 REQUIREMENTS



SUPPLEMENT THE MIL-STD-1679 METRICS TO PROVIDE A SUITABLE BASE FOR SELECTION OF PROJECT METRICS

Criteria	MIL-STD-1679 Metric	Marine Metric	Total Metrics
Traceability	0	6	6
Completeness	29	13	42
Consistency	4	22	26
Simplicity	12	19	31
Modularity	10	5	15
Instrumentation	1	0	1
Self-descriptiveness	37	13	50
Communications commonality	0	5	5
Data commonality	4	4	8
	97	87	184

SQAM RESULTS
ONE CPCI - ONE PHASE

SQM	1700*	INSPECTIONS
	242	SOFTWARE DISCREPANCIES
	15%	ERRORS DETECTED
	50%	MAJOR (LINE-STOPPERS) DISCREPANCY
	$484,000	PROJECTED SAVINGS
SQA	73	DISCREPANCIES
	41	MAJOR (CATEGORY 0) DISCREPANCY
	56%	ERRORS DETECTED WERE MAJOR

SOFTWARE QUALITY ASSURANCE & METRIC EVALUATION

I. DOCUMENT WORK CERTIFICATION DATA
II. PRE-CONTRACT AWARD DATA
III. CONTRACTUAL DOCUMENT DATA
IV. PROGRAM MANAGEMENT DATA
V. DATA MANAGEMENT DATA
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XVII. NOTES

SOFTWARE QUALITY ASSURANCE & METRIC EVALUATION FOLDER

SECTION VII DESIGN ANALYSIS DATA

A. INTRODUCTION
B. SUMMARY OF RESULTS
  2.1 CRITERIA SCORE SHEETS
  2.2 METRIC SUMMARY SCORE SHEETS
  2.3 DISCREPANCY REPORTING
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  3.5 MODULARITY
  3.6 INSTRUMENTATION
  3.7 SELF-DESCRIPTIVENESS
  3.8 COMMUNICATIONS COMMONALITY
  3.9 DATA COMMONALITY
D. SOFTWARE DISCREPANCY REPORTS
  4.1 SQM DISCREPANCIES
  4.2 SQA DISCREPANCIES
E. DID-DI-E-2139 CHECKLIST
  MIL-STD-1679 CHECKLIST

APPENDIX I: PPS REQUIREMENTS
PBS REQUIREMENTS

APPENDIX II: SQA DISCREPANCIES FOR:
- DATA BASE DOCUMENT (DBD)
- TEST SPECIFICATION (TS)

APPENDIX III: METRIC/CHECKLIST SELECTION CRITERIA

CONCLUSIONS

THE APPLICATION OF SQAM PROVIDES

- MEANINGFUL PRODUCT QUALITY MEASURES
- FREQUENT SOFTWARE QUALITY MEASURE THAT PERMITS TIMELY DETECTION OF ERRORS
- PROJECT MANAGEMENT VISIBILITY OF SOFTWARE QUALITY DURING EACH PHASE
- MUCH BETTER DOCUMENTATION
- A BASIS FOR OBJECTIVE EVALUATION AGAINST THE USERS REQUIREMENTS
- EARLY ESTABLISHMENT OF QUALITY GOALS
- COOPERATIVE ASSOCIATION WITH SOFTWARE DEVELOPERS
- COMPLETE TRACEABILITY FROM EVALUATION TO DISPOSITIONS
- MEASURABLE QA IMPACT DURING SOFTWARE DEVELOPMENT

AIA VIEWS

ON

MIL-STD-SQAM
(SOFTWARE QUALITY ASSESSMENT AND MEASUREMENT)

G. C. Dufoe
June 8, 1983

1) SOFTWARE QUALITY PROGRAM REQUIREMENTS SHOULD BE DEFINED IN ONE DOCUMENT.

PROPOSED MIL-STD-SQAM DEFINES REQUIREMENTS FOR SOFTWARE QUALITY ASSESSMENT. OTHER QUALITY PROGRAM REQUIREMENTS ARE NOT TOTALLY DEFINED IN THE PROPOSED MIL-STD-SQAM. SOFTWARE QUALITY PROGRAM REQUIREMENTS ARE CURRENTLY DEFINED IN MIL-S-52779A, MIL-STD-1679, AND OTHER DOCUMENTS. THE RELATIONSHIP OF THE PROPOSED SQAM TO THESE DOCUMENTS IS UNCLEAR. THE INCLUSION IN ONE DOCUMENT OF ALL SOFTWARE QUALITY PROGRAM REQUIREMENTS, INCLUDING SQAM REQUIREMENTS, IS RECOMMENDED

2) SQAM DEFINITIONS ARE INCONSISTENT WITH PRIOR DEFINITIONS.

DEFINITION OF TERMS IS FUNDAMENTAL TO ESTABLISHING ANY REQUIREMENT. VARIOUS GROUPS HAVE LABORED LONG AND HARD TO ESTABLISH ACCEPTABLE DEFINITIONS. SQAM DEPARTS IN MANY CASES BY ESTABLISHING TOTALLY NEW DEFINITIONS FOR SOFTWARE TERMS; SOME DEFINITIONS ARE EVEN IN CONFLICT WITH MIL-STD-SDS. SOFTWARE DEFINITIONS MUST BE CONSISTENT THROUGHOUT NEW JLC-SPONSORED SOFTWARE REQUIREMENT DOCUMENTS. AIA RECOMMENDS USAGE OF PREVIOUSLY DEFINED TERMS, E.G., IEEE/RADC, WHEREVER POSSIBLE.

3) MIL-STD-SQAM SHOULD BE REWRITTEN AND CONDENSED

THE PROPOSED SQAM IS REPETITIOUS, INCONSISTENT, VAGUE AND VERBOSE - IT IS MORE LIKE A STATEMENT OF WORK THAN A STANDARD.

4) SOFTWARE QUALITY MEASUREMENT TECHNIQUES ARE NOT MATURE.

NEITHER MEASUREMENT REQUIREMENTS NOR TECHNIQUES ARE ADDRESSED IN MIL-STD-SQAM. THE AIA AGREES WITH THIS OMISSION BECAUSE QUANTITATIVE MEASUREMENTS ARE INSUFFICIENTLY MATURE AT THIS TIME. VALUABLE WORK IS BEING DONE IN THIS AREA WITHIN THE ACADEMIC/R&D COMMUNITY, BUT PRACTICAL CONTRACTUAL IMPLEMENTATION APPEARS TO BE YEARS AWAY. THEREFORE, IT IS RECOMMENDED THAT "MEASUREMENT" BE DELETED FROM THE TITLE OF THE PROPOSED STANDARD.

5) REQUIRED SOFTWARE FACTORS SHOULD BE SPECIFIED.

THE PROPOSED SQAM IDENTIFIES SOFTWARE FACTORS (SUCH AS CORRECTNESS, EFFICIENCY, MAINTAINABILITY, PORTABILITY, ETC.) AS QUALITY REQUIREMENTS. (REFERENCE RADC DACS GLOSSARY). WHEN THE GOVERNMENT DESIRES THESE SOFTWARE FACTORS AS REQUIREMENTS, THEY SHOULD BE INCLUDED IN THE SPECIFICATION PREPARED BY THE GOVERNMENT. SOFTWARE QUALITY SHOULD BE REQUIRED TO EVALUATE COMPLIANCE WITH THE SPECIFICATION.

6) CRITERIA FOR TAILORING IS NEEDED.

MISSION CRITICAL SOFTWARE IS NOT DEFINED IN THE PROPOSED SQAM. DEFENSE SYSTEM SOFTWARE SHOULD BE ADDRESSED BY APPROPRIATELY TAILORED STANDARDS, RATHER THAN USING THE PHRASE "MISSION CRITICAL".

7) CONCURRENT EVALUATION OF JLC PACKAGE IS NECESSARY.

SQAM, SDS, AND OTHER DOCUMENTS IN THE JLC PACKAGE MUST BE CONSISTENT; THEY CURRENTLY ARE NOT. SINCE THEY ARE ALL ON SEPARATE PREPARATION/REVIEW SCHEDULES, THERE IS RISK OF FURTHER INCOMPATIBILITY. THE FINAL DRAFT OF THE TOTAL JLC PACKAGE SHOULD BE REVIEWED AT ONE TIME.

8) FIRMWARE QUALITY SHOULD BE ADDRESSED.

AIA REQUESTS THAT SQAM DEFINE THE REQUIREMENTS FOR SOFTWARE QUALITY RELATIVE TO THE SEVERAL CATEGORIES OF FIRMWARE.

IT IS RECOMMENDED THAT FIRMWARE WHICH IS SOFTWARE-INTENSIVE AND SUBJECT TO SQAM BE CLASSIFIED AS COMPUTER PROGRAM CONFIGURATION ITEMS. THESE GOVERNMENT SELECTED CPCI'S WOULD BE SPECIFICALLY IDENTIFIED IN THE CONTRACT. ALL OTHER FIRMWARE WOULD BE MANAGED IN ACCORDANCE WITH THE OVERALL HARDWARE REQUIREMENTS OF THE CONTRACT.

9) SOFTWARE QUALITY PROGRAM PLANNING SHOULD BE ONE DOCUMENT

AS PROPOSED, SDS REQUIRES A SOFTWARE QUALITY PROGRAM PLAN; SQAM REQUIRES ITS OWN SEPARATE PLAN. AIA RECOMMENDS THAT ONE DOCUMENT EXPRESS THE TOTALITY OF SOFTWARE QUALITY PLANNING.

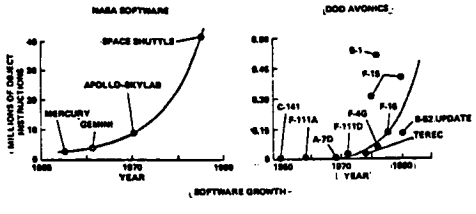
HR TEXTRON

THE CHALLENGE OF DFCS SOFTWARE

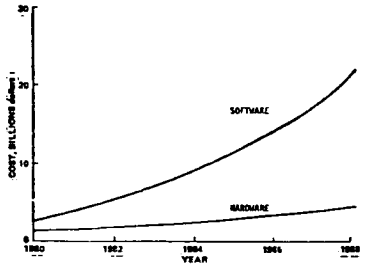
- SOFTWARE TRENDS
- DFCS SOFTWARE
- DEVELOPMENT AND VERIFICATION PROCESS
- CONCLUDING REMARKS

PIO DE FEO

TRENDS IN SOFTWARE



EMBEDDED COMPUTERS COST



"ELECTRONIC INDUSTRIES ASSOCIATION" PROJECTION FOR DOD

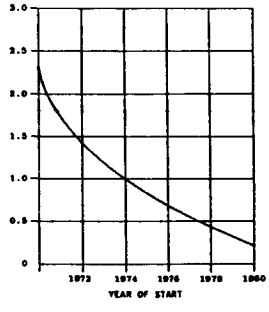
EMBEDDED COMPUTERS RELIABILITY

	DOWNTIME	
	HARDWARE	SOFTWARE
BELL SWITCHING SYSTEM	25%	35%
FEDERAL RESERVE TRANSFER FUNDS #1	38%	35%
FEDERAL RESERVE TRANSFER FUNDS #2	39%	51%
AIRLINE RESERVATION SYSTEM	41%	35%
AIR FORCE SIGNAL PROCESSING SYSTEM	28%	10%
STANFORD LINEAR ACCELERATOR	56%	35%
AVERAGE	37%	33%

DFCS SOFTWARE
MEMORY REQUIREMENTS BY FUNCTION

FUNCTION	MEMORY REQUIREMENT
CONTROL & NAVIGATION	25%
LOGIC	20%
TESTING & VOTING	20%
I/O & EXECUTIVES	20%
MISCELLANEOUS	15%
TOTAL	100%

SOFTWARE FAULT DENSITY
(%)

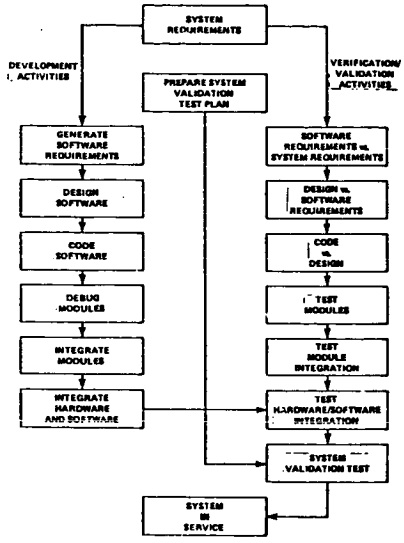


RECENT		ASSEMBLY	
ASSEMBLY	HOL	PRE 1977	RECENT
1.03	.15	2.2	1.03

SOFTWARE "FAULTS CLASSIFICATION"

	DFCS	HIPS	TBM 1	TBM 2	TBM 3	TOTAL
COMP	17.3	4.2	17.2	11.5	2.4	7.4
LOGIC	35.6	66.3	27.2	30.5	47.5	47.1
I/O	16.0	10.3	16.6	23.4	12.2	15.8
INTERFACE	14.5	15.6	20.1	20.2	25.8	16.2
DATA BASE	16.5	3.3	18.8	14.4	12.2	13.5

THE SOFTWARE DEVELOPMENT AND VERIFICATION PROCESS



VERIFICATION AND VALIDATION ACTIVITIES
GROUPED BY CRITICALITY

	CRITICALITY		
VERIFICATION OR VALIDATION ACTIVITY	CRITICAL	ESSENTIAL	NON-ESSENTIAL
VERIFY SOFTWARE REQUIREMENTS vs. SYSTEM REQUIREMENTS	REQUIRED	FUNCTION OF EFFECTS OF DESIGN ERRORS	RECOMMENDED
VERIFY DESIGN vs. SOFTWARE REQUIREMENTS	REQUIRED	FUNCTION OF EFFECTS OF DESIGN ERRORS	RECOMMENDED
VERIFY CODE vs. DESIGN	REQUIRED	FUNCTION OF EFFECTS OF DESIGN ERRORS	RECOMMENDED
TEST SOFTWARE MODULES	REQUIRED	FUNCTION OF EFFECTS OF DESIGN ERRORS	RECOMMENDED
TEST MODULE INTEGRATION	REQUIRED	FUNCTION OF EFFECTS OF DESIGN ERRORS	RECOMMENDED
TEST HARDWARE/SOFTWARE INTEGRATION	REQUIRED	REQUIRED	RECOMMENDED
SYSTEM VALIDATION TESTING	REQUIRED	REQUIRED	REQUIRED

3 HISTORY CASES

	CASE 1	CASE 2	CASE 3
CRITICALITY CATEGORY	ESSENTIAL/CRITICAL	CRITICAL	CRITICAL
CONFIGURATION	FAIL SAFE	FAIL-OP/FAIL SAFE	FAIL-OP/FAIL SAFE
SOFTWARE LANGUAGE	ASSEMBLY	HIGH ORDER	HIGH ORDER
SOFTWARE TOOLS, TECHNIQUES	ASSEMBLER X-REF SIMULATION	COMPILER X-REF WALK THRU SIMULATION	COMPILER X-REF, SET/USE WALK THRU SIMULATION
LAB EQUIPMENT	PALLET(S)	PALLET(S) IRON BIRD	PALLET(S) IRON BIRD
SOFTWARE DEVELOPMENT	100% AVIONICS	100% AVIONICS	85% AIRFRAME 15% AVIONICS
SOFTWARE VERIFICATION	90% AIRFRAME 90% AVIONICS	30% AIRFRAME 70% AVIONICS	70% AIRFRAME 30% AVIONICS

CONCLUDING REMARKS

- SOFTWARE IS THE MAJOR CONTRIBUTOR TO THE SYSTEM LIFE CYCLE COST
- THE CONTRIBUTION OF SOFTWARE TO SYSTEM DOWN TIME IS SIGNIFICANT
- GUIDELINES HAVE BEEN DEFINED FOR SOFTWARE DEVELOPMENT AND VERIFICATION WHICH ARE SUPPORTED BY GOVERNMENT AND INDUSTRY; NO ATTEMPT HAS BEEN MADE, HOWEVER, TO SPECIFY TOOLS AND TECHNIQUES
- THE USE OF HIGH ORDER LANGUAGE CAN SIGNIFICANTLY IMPROVE THE RELIABILITY OF FLIGHT SOFTWARE
- DISCIPLINED SOFTWARE DEVELOPMENT (STRUCTURED PROGRAMMING, SMALL MODULE SIZE, ETC.) CAN ALSO IMPROVE SOFTWARE RELIABILITY
- AN INCREASING USE OF ADVANCED DEVELOPMENT AND VERIFICATION TOOLS AND TECHNIQUES SHOULD REDUCE COST AND IMPROVE THE QUALITY OF THE SOFTWARE

Software Design Inspection for Preliminary Design

John McKissick, Jr. Mark J. Somers Wilhelmina Rosenberger

Abstract

The continuing need for improved computer software demands improved software development techniques. A technique for the inspection of preliminary software designs is described in this paper. Experience and results from the application of this technique are presented.

Introduction

Significant benefits have resulted from the use of software design inspections at the completion of the Preliminary Design Phase. Deficiencies are identified and corrected earlier in the Software Development Process. Communication and education about the project is improved. Productivity of new employees is increased. Early information on the quality of the software design is available. The net result is more efficient software development and an improved software product.

The Preliminary Design Phase is described in the next section. This is followed by a description of how software design inspections are implemented. Experience and results are presented in conclusion.

The Preliminary Design Phase

The software development process we use to develop computer software for military electronic systems is illustrated in Figure 1. This process has been documented by John McKissick Jr., and Robert A. Price. (Ref. 1)

The software requirements and the interfaces between software and equipment are defined before the Preliminary Design Phase begins. This information is documented in a Computer Program Performance Specification (CPPS) and a Hardware/Software Interface Control Specification (ICS).

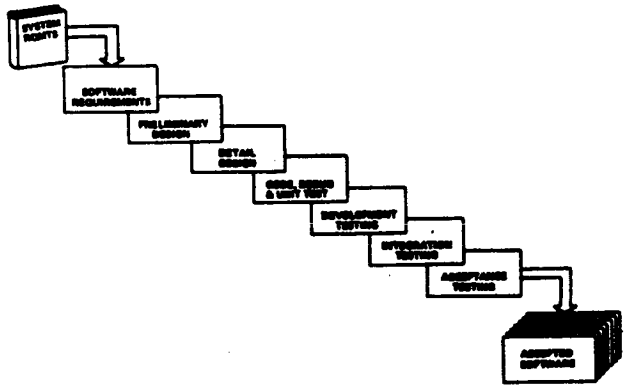


Figure 1. The Software Development Process

During the Preliminary Design Phase, the computer software design is partitioned into subprograms, and the software requirements are allocated to these subprograms. A preliminary design is developed for each subprogram using a program design language. This high level design describes each function to to be implemented by the subprogram. The results of this activity are documented in a Software Development Notebook for each subprogram. (Ref. 2 describes Software Development Notebooks.)

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Software Design Inspections

Software design inspections are conducted by a team consisting of a system engineer, a software architect, the lead software design engineer, a software test engineer and a software quality assurance engineer. Each team member is assigned responsibility for reviewing the design for certain attributes.

The system engineer is responsible for reviewing the design for correct interpretation of the requirements and correct implementation. The software architect and the lead software design engineer are responsible for reviewing the design for accuracy, modularity, completeness and consistency. The software test engineer is responsible for reviewing the design for testability. The software quality assurance engineer is responsible for reviewing the design and design documentation for compliance with standards. The software quality assurance engineer also acts as the moderator and recorder at the design inspection meeting.

It is necessary for all team members to be briefed on their responsibilities prior to the first design inspection. It is also important that they know how the design inspections will be conducted.

When a subprogram preliminary design is complete, the software design engineer submits the design to the lead software design engineer. If the lead software design engineer concurs that the design is complete, a software design inspection meeting is scheduled and the design disclosure package (Software Development Notebook) is distributed to the reviewers.

Each team member reviews the design from his perspective prior to the software design inspection meeting. If any team member has not been able to review the design prior to the meeting, the meeting is rescheduled.

During the meeting the design disclosure package is inspected page by page. All participants present findings and questions resulting from their review. The moderator/recorder chairs the meeting and records deficiencies.

At the end of the meeting, the software quality assurance engineer and the software architect vote on whether or not the design is ready for detailed design. Both must concur for the design to pass. No major redesign is the pass criterion.

If the design passes, identified deficiencies are recorded in the meeting minutes, and corrective action is tracked to closure by the software quality assurance engineer. The software quality assurance engineer prepares a response form for each deficiency identifed. The response form is given to the software design engineer who indicates the corrective action that will be taken and the planned date of completion. The response form is returned to the software quality assurance engineer who later examines the Software Development Notebook to assure the deficiency has been corrected.

Results

The results to date have been impressive. Four hundred ninety-two (492) deficiencies were identified and corrected as a result of thirty (30) design inspections. These deficiencies are categorized in Figure 2.

Two hundred sixty (260) of these deficiencies were design errors which were corrected prior to detailed design and coding. The efficiency of the software development process and the quality of the software design have been improved.

This early identification of deficiencies results in a cost savings and improved quality.

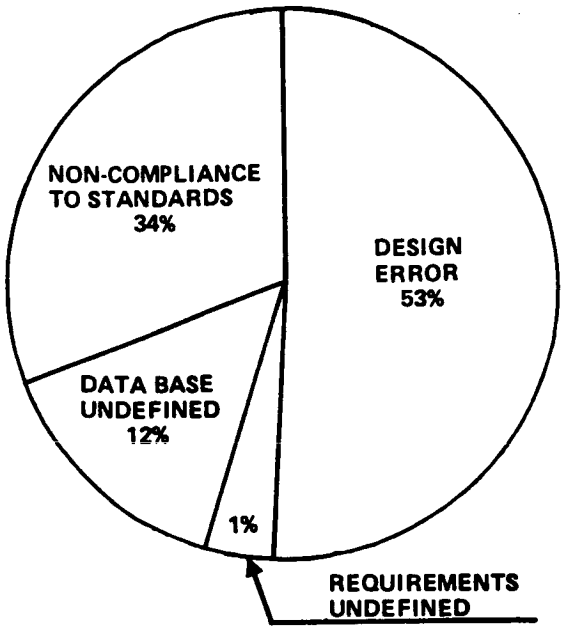

Figure 2. Deficiencies Categorized

References

1. J. McKissick and R.A. Price, "Quality Control of Computer Software", 1977 ASQC Technical Conference Transactions, May 1977.

2. J. McKissick and R.A. Price, "The Software Development Notebook - A Proven Technique", Proceedings 1979 Annual Reliability and Maintainability Symposium, January 1979.

Biographical Material

John McKissick, Jr. received the B.S. degree in Electrical Engineering from Carnegie-Mellon University in 1954 and the M.S. degree in Engineering Administration from Syracuse University in 1967. Subsequent postgraduate courses were selected in the areas of reliability and computer software. The General Electric Modern Engineering Course was completed in 1972.

He joined General Electric in 1954 as a design engineer. After serving in the U.S. Army in Europe as an Electronics Warfare Analyst Officer, he returned to the Electronic Systems Division of GE in Syracuse, N.Y. He has contributed to the development of large missile guidance, radar and sonar systems such as ATLAS, MISTRAM, PAR, STR, OTH, AN/SQS-26, AN/SQS-53, and AN/SQR-19. He has served as a project engineer, reliability group leader, assistant program manager and technical manager. He is currently the Manager of Computer Software Reliability and Quality Assurance and Manager of OTH Program Product Assurance.

Mr. McKissick is a member of IEEE, ASQC, Eta Kappa Nu and Sigma XI. He is currently active in NSIA Sofware QRAC, ASA Software Assurance, and IEEE Software Standards committees.

Mark J. Somers received the B.S. degree in Management Science and the M.S. degree in Computer Science from the State Univesity of New York where he did work in software quality assurance as a Research Assistant.

Mr. Somers joined General Electric in 1982 as a Computer Software Reliability and Quality Assurance Engineer. He is currently contributing to the development of the NSS, ASWCS, and OTH systems.

He is a member of ACM.

Wilhelmina Rosenberger received the B.A. degree in Mathematics from the State University of New York, College at Potsdam. She is currently working towards the M.S. degree in Computer Science at Syracuse University.

Ms. Rosenberger joined General Electric in 1980 as a Computer Programmer/Analyst, concentrating in Graphics Display programming. She is currently a Computer Software Reliability and Quality Assurance Engineer. She has contributed to the development of the ERM, NSS, OTH, and AN/SQS-53'C' systems.

She is a member of ASQC.

SOFTWARE DESIGN INSPECTION

FOR PRELIMINARY DESIGN

JOHN McKISSICK, Jr

MARK J. SOMERS

WILHELMINA ROSENBERGER

ELECTRONIC SYSTEMS DIVISION
GENERAL ELECTRIC COMPANY

SOFTWARE DESIGN INSPECTION
WHY DESIGN INSPECTIONS

ELECTRONIC SYSTEMS DIVISION

CONTRIBUTION OF DEFECT SOURCES TO TOTAL DEFECTS

DESIGN DEFECTS	45%
CODING DEFECTS	25%
"SECOND LEVEL" PROBLEMS	20%
PUBLICATION ERRORS	7%
OTHERS	3%
	100%

DESIGN PROBLEMS ARE THE LARGEST SOURCE OF DEFECTS

4
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SOFTWARE DESIGN INSPECTION

ELECTRONIC SYSTEMS DIVISION

- WHY DESIGN INSPECTIONS
- REQUIREMENTS FOR DESIGN INSPECTIONS
- DESIGN INSPECTION METHODOLOGY
- SUBPROGRAM DESIGN INSPECTION RESULTS

2
2/7/83

SOFTWARE DESIGN INSPECTION
WHY DESIGN INSPECTIONS

ELECTRONIC SYSTEMS DIVISION

PEER REVIEWS AND WALKTHROUGHS (INFORMAL)

- SEEKS AND RECORDS ERRORS
- INITIATES REWORK

DESIGN INSPECTIONS (FORMAL)

- INDEPENDENT REVIEWERS
- SEEKS AND RECORDS ERRORS
- USE STANDARDIZED CHECKLISTS AND TECHNIQUES
- INITIATES AND INSPECTS REWORK
- PASSES WORK
- PROVIDES EARLY ERROR DATA COLLECTION

DESIGN INSPECTIONS PROVIDE VISIBILITY AND EARLY MANAGEMENT CONTROL

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SOFTWARE DESIGN INSPECTION
WHY DESIGN INSPECTIONS

ELECTRONIC SYSTEMS DIVISION

CRITICAL PROBLEMS IN THE SOFTWARE DEVELOPMENT INDUSTRY

1. DEVELOPING SOFTWARE EFFICIENTLY AND ON SCHEDULE
2. THE QUALITY OF THE SOFTWARE DEVELOPED

3
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SOFTWARE DESIGN INSPECTION
WHY DESIGN INSPECTIONS

ELECTRONIC SYSTEMS DIVISION

ADVANTAGES OF DESIGN INSPECTIONS

- EARLY MILESTONE THAT MUST BE PASSED
- EARLY DETECTION OF ERRORS
- STATISTICS ON ERRORS
- COMMUNICATION AND EDUCATION ABOUT THE PROJECT
- EARLY INFORMATION ON THE QUALITY OF THE DESIGN

DESIGN INSPECTIONS EDUCATE NEW EMPLOYEES AND IMPROVE THEIR PRODUCTIVITY

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SOFTWARE DESIGN INSPECTION
REQUIREMENTS FOR DESIGN INSPECTIONS

ELECTRONIC SYSTEMS DIVISION

ESD-SYRACUSE REQUIREMENTS

- "ASSURANCE REVIEWS WILL BE ACCOMPLISHED BY BRINGING TOGETHER RESPONSIBLE ENGINEERS WITH QUALIFIED INDEPENDENT REVIEW CONSULTANTS TO EVALUATE THE ADEQUACY OF THE DESIGN."
- "SOFTWARE QA WILL INSPECT DESIGNS FOR TECHNICAL ADEQUACY AND COMPLIANCE WITH THE SOFTWARE STANDARDS AND PROCEDURES MANUAL."

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SOFTWARE DESIGN INSPECTION
DESIGN INSPECTION METHODOLOGY

ELECTRONIC SYSTEMS DIVISION

DESIGN INSPECTION METHODOLOGY

- PLANNING
- EDUCATION
- PREPARATION
- INSPECTION
- INSPECTION REPORT
- FOLLOW-UP

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SOFTWARE DESIGN INSPECTION
DESIGN INSPECTION METHODOLOGY

ELECTRONIC SYSTEMS DIVISION

PLANNING

- DESIGNATE PARTICIPANTS
  - SYSTEMS ENGINEER
  - SOFTWARE PROJECT ENGINEER
  - SOFTWARE ARCHITECT
  - LEAD SOFTWARE ENGINEER
  - SOFTWARE ENGINEER
  - SOFTWARE TEST ENGINEER
  - SOFTWARE QA ENGINEER

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SOFTWARE DESIGN INSPECTION
DESIGN INSPECTION METHODOLOGY

ELECTRONIC SYSTEMS DIVISION

EDUCATION

- BRIEF ALL OF THE PARTICIPANTS ON THEIR ROLE
- BRIEF THE PARTICIPANTS ON THE REQUIREMENTS
- BRIEF THE PARTICIPANTS ON THE CONDUCT OF THE INSPECTION
- BRIEF THE PARTICIPANTS ON THE FOLLOW-UP

ALL PARTICIPANTS MUST UNDERSTAND THEIR ROLE IN DESIGN INSPECTIONS PRIOR TO THE FIRST INSPECTION

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SOFTWARE DESIGN INSPECTION
DESIGN INSPECTION METHODOLOGY

ELECTRONIC SYSTEMS DIVISION

PREPARATION

- SOFTWARE QA PREPARES HANDBOOK ITEM AND CHECKLIST
- LEAD SOFTWARE ENGINEER SCHEDULES THE MEETING AND DISTRIBUTES DESIGN DISCLOSURE PACKAGE TO THE PARTICIPANTS
- ALL PARTICIPANTS REVIEW THE DESIGN FOR THEIR RESPECTIVE RESPONSIBILITY PRIOR TO THE MEETING

THE DESIGN IS REVIEWED BY ALL PARTICIPANTS BEFORE THE INSPECTION MEETING

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SOFTWARE DESIGN INSPECTION
DESIGN INSPECTION METHODOLOGY

ELECTRONIC SYSTEMS DIVISION

INSPECTION MEETING

- STEP THROUGH THE DESIGN DISCLOSURE PACKAGE PAGE BY PAGE
- ALL PARTICIPANTS PRESENT THEIR FINDINGS OR QUESTIONS
- THE DESIGN IS EXAMINED AGAINST ITS SPECIFICATION
- DEFICIENCIES ARE RECORDED
- THE DESIGN IS PASSED OR FAILED

THE PURPOSE IS TO FIND ERRORS, NOT SOLUTIONS

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SOFTWARE DESIGN INSPECTION
DESIGN INSPECTION METHODOLOGY

ELECTRONIC SYSTEMS DIVISION

- "DESIGN PASSES"
  - REPORT DOCUMENTS ALL DEFICIENCIES AND RECOMMENDATIONS
- "DESIGN FAILED"
  - REPORT DOCUMENTS THE NEED FOR REWORK AND REINSPECTION

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SOFTWARE DESIGN INSPECTION
DESIGN INSPECTION METHODOLOGY

ELECTRONIC SYSTEMS DIVISION

FOLLOW UP

- RESPONSE FORMS GENERATED
- CORRECTIONS ARE MADE
- LEAD SOFTWARE ENGINEER REVIEWS DESIGN
- DESIGN IS RELEASED
- SOFTWARE QA USES RESPONSE FORMS TO INSPECT THE DESIGN FOR CORRECTION OF ALL DEFICIENCIES

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SOFTWARE DESIGN INSPECTION
SUBPROGRAM DESIGN INSPECTION RESULTS

ELECTRONIC SYSTEMS DIVISION

	NUMBER OF DEFICIENCIES	%
SPECIFICATION DEFICIENCIES		
• REQUIREMENTS UNDEFINED	5	1
DESIGN DEFICIENCIES		
• DESIGN ERROR	260	53
• DATA BASE UNDEFINED	59	12
• NON-COMPLIANCE TO STANDARDS	168	34
TOTAL	492	100

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2/7/83

SOFTWARE DESIGN INSPECTION
SUBPROGRAM DESIGN INSPECTION RESULTS

ELECTRONIC SYSTEMS DIVISION

NUMBER OF SUBPROGRAMS	13
NUMBER OF MODULES	83
NUMBER OF DESIGN INSPECTIONS	30
NUMBER OF DEFICIENCIES IDENTIFIED	492

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SOFTWARE DESIGN INSPECTION
SUBPROGRAM DESIGN INSPECTION RESULTS

ELECTRONIC SYSTEMS DIVISION

	SUBPROGRAMS PASSED	SUBPROGRAMS FAILED
FIRST INSPECTION	1	12
SECOND INSPECTION	4	6
THIRD INSPECTION	4	1
FOURTH INSPECTION	1	0

AVERAGE NUMBER OF INSPECTIONS/SUBPROGRAM 2.3

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SOFTWARE DESIGN INSPECTION
SUBPROGRAM DESIGN INSPECTION RESULTS

ELECTRONIC SYSTEMS DIVISION

THE BOTTOM LINE

38 DEFICIENCIES IDENTIFIED PER SUBPROGRAM

17 DEFICIENCIES IDENTIFIED PER DESIGN INSPECTION

CONCLUSION

SOFTWARE DESIGN INSPECTIONS IDENTIFY PROBLEMS EARLY

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THE LATEST ON STARS

KEYNOTE

WORKSHOP PANEL ON ADVANCED ASSURANCE TECHNOLOGY FOR SOFTWARE

1983 CONFERENCE AND WORKSHOPS
ON
MISSION ASSURANCE
7 JUNE 1983

SAMUEL T. REDWINE, JR.
MITRE

SOFTWARE TECHNOLOGY FOR ADAPTABLE, RELIABLE SYSTEMS STARS

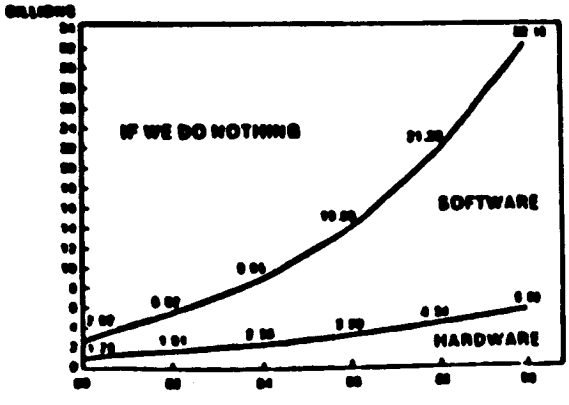
OVERVIEW

- WHAT IS STARS
- MISSION ASSURANCE AND STARS
- RECENT ACTIVITIES AND CURRENT STATUS OF STARS

MOTIVATION

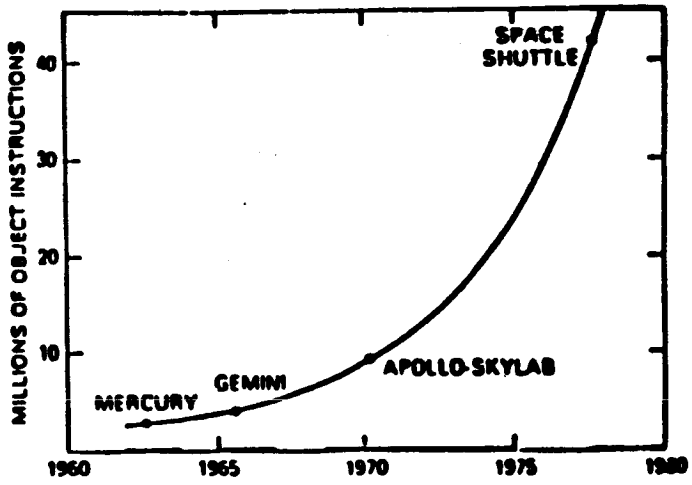
- COMPUTERS ARE ESSENTIAL TO THE MILITARY MISSION
- SOFTWARE OFFERS FLEXIBILITY
- DoD IS EXPERIENCING PROBLEMS IN EXPLOITING THE TECHNOLOGY

DoD EMBEDDED COMPUTER SOFTWARE/HARDWARE

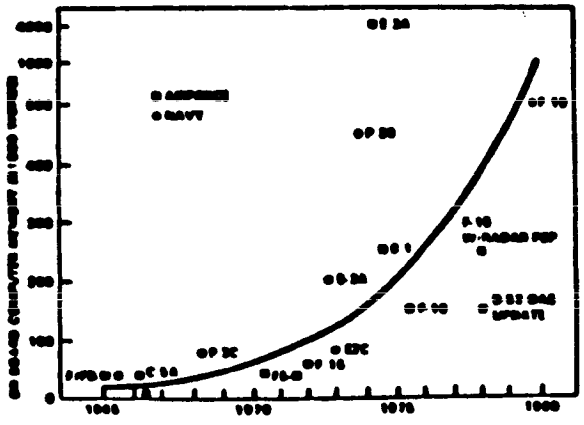


Source: Electronic Industries Association

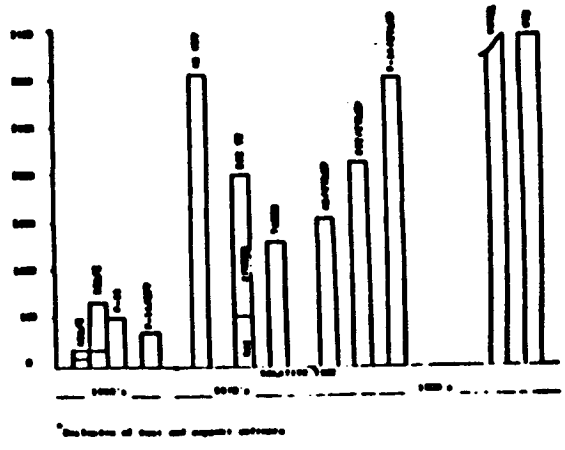
GROWTH IN NASA SOFTWARE DEMAND



GROWTH IN MILITARY AIRCRAFT SOFTWARE REQUIREMENTS



GROWTH IN NAVAL AVIATION SOFTWARE



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THERE IS NO SINGLE PROBLEM,

STARS GOAL

IMPROVE PRODUCTIVITY WHILE ACHIEVING GREATER SYSTEM RELIABILITY AND ADAPTABILITY

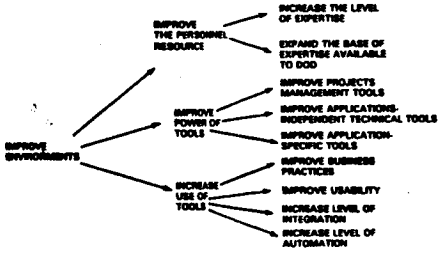
ACQUIRE SOFTWARE THAT IS MORE

- POWERFUL
- RELIABLE
- ADAPTABLE

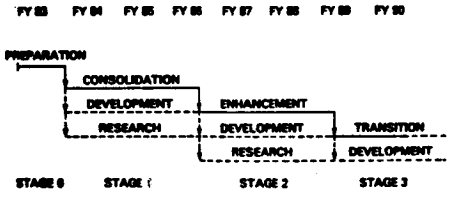
MAKE DEVELOPMENT AND SUPPORT MORE

- RESPONSIVE
- COST EFFECTIVE
- PREDICTABLE

OBJECTIVES



INITIATIVE STRATEGY

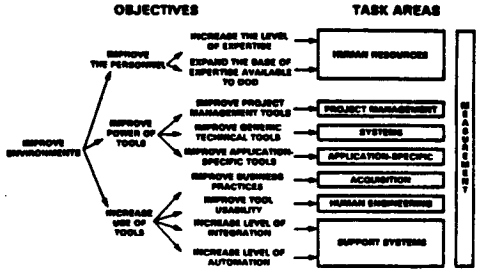


STRATEGY

- SPECIAL EMPHASIS-SEVEN YEARS
- BUILD ON EXISTING EFFORTS
- COORDINATE CURRENTLY PLANNED EFFORTS
- Ada® WILL SERVE AS FOCUS

®Ada IS A TRADEMARK OF THE DEPARTMENT OF DEFENSE

STARS FUNCTIONAL TASK AREAS



System Technology Requirements

- Embedded Computer Systems Require an Integrated Systems Approach to Their Design, Development and Support
  - Target Computers
  - Target Software
  - Run-Time Support Software
  - Host Development and Support Software
  - Specialized Support Software

Systems Properties

- Performance
- Adaptability
- Reliability
- Security
- Fault Tolerance
- Survivability
- Maintainability
- Affordability
- Timely Construction

DoD System Technology Needs

- Analyze Planned Systems Including Major Upgrades
- Derive Combinations of Property Values Needed Over Time
- Use Property Combinations to Drive R&D and Inform Marketplace
- Prototype, Assess, Demonstrate and Tool Results
- Make Results Available for Wide (Re)Use
- Use of Results Meet Real Needs

Systems Consolidation Phase

- Computer Architecture
- Systems Software
- Software–Hardware Synergy
- Reliability
- Environmental Concerns
- Focusing R&D on Future Mission Needs

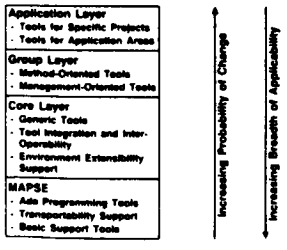
STARS Support Systems Objectives

- Evolve a Realistic, Modern Software Life Cycle Process
- Develop and Demonstrate and Improved Understanding of How to Integrate Tools, Methods and Management Practices to Support This Process
- Provide a Production-Quality Environment That:
  - Supports the Full Life Cycle
  - Is Easily Rehosted and Retargeted
  - Evolves from a Core Environment Which Is Available Early
- Promote Real-Life Experiments in the Use of Methods and Environments
- Sponsor Research (In Cooperation with Other Agencies) to Investigate Promising Revolutionary Improvements in Support Systems

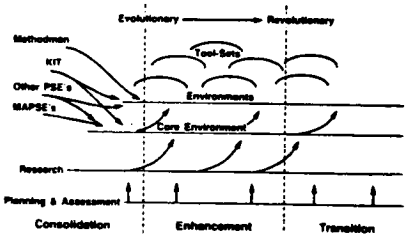
Support Systems Strategy

- Establish an Ada* Compatible Software Development Methodology Based on Current Methodmen Activities that Encompasses the Software Life Cycle
- Build a Common Automated Support Environment (Available Early) Based on Current Ada* Support Environments
- Build Prototype Extended Environments Supporting Multiple Tool Sets
- Demonstrate the Value of These Environments and Methods Through Brassboard Testing and Demonstration
- Conduct Research and Development in Alternative Support Systems Approaches

Support System Environment Organization



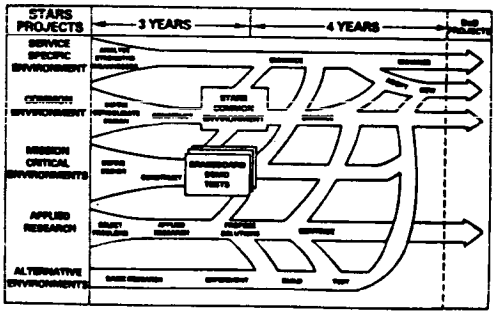
Support Systems Strategic Concept



SOFTWARE ENGINEERING INSTITUTE

- MAINTAIN A STATE-OF-THE-ART SOFTWARE SUPPORT SYSTEM
- ENGINEER THE TECHNOLOGY
- PERFORM SYSTEMS INTEGRATION
- PROVIDE BASE OF SUPPORT SYSTEMS EXPERTISE
- RESEARCH (LIMITED)
- EDUCATION AND TRAINING
- SYSTEMS INTERFACE STANDARDS

STARS PROJECT LINKAGES



MISSION ASSURANCE AND SOFTWARE

- A Systems Concern (not just software)
- Achieve goals at Time of Mission (i.e. future)
- Reliability and Adaptability
- Different Kinds of Software
  - Operational Software
    - Prime
    - Fault Compensating
  - Support Software
    - General
    - Mission Specific

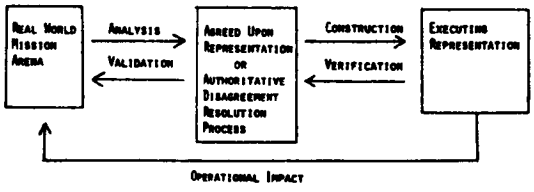
RELIABILITY

- Real World vs. Specifications
- Faults, Errors, and Failures
- Fault Prevention and Fault Tolerance

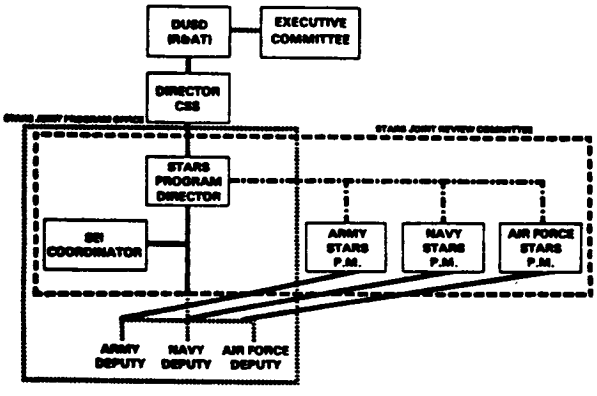
SYSTEMS AREA "RELIABILITY" SUBTASK

- Program Testing and Analysis
- Methods for Fault-tolerant Systems
- Prototyping as a Reliability Tool
- Early Lifecycle Software Quality Assurance
- Proofs and Program Transformation

REAL WORLD VS. SPECIFICATIONS



STARS MANAGEMENT STRUCTURE



DEFINITIONS

Fault: An Accidental Condition that Causes a Functional Unit to Fail to Perform its Required Function (ISO & IEEE) -- the Bug

Error: A Discrepancy between a Computed, Observed, or Measured Value or Condition and the True, Specified, or Theoretically Correct Value or Condition (ANSI & IEEE) -- Error State

Failure: The Inability of a System or Component to Perform a Required Function within Specified Limits (IEEE) -- Too Big an Uncorrected Error

IEEE Glossary of Software Engineering Terminology

FAULT PREVENTION

- Fault Avoidance
  - Quality Resources -- e.g., Personnel and Tools
  - Quality Process
  - Quality Products -- Intermediate and Final
- Fault Removal before Mission or after Modification
  - Fault Detection
    - Static Analysis and Dynamic Testing
    - Single Representation and Multiple Representations
  - Fault Treatment
    - Find or Adjudge Cause
    - Fix

FAULT TOLERANCE

- Error Detection
  - Input Exception
  - Result Exception
- Damage Assessment (Aided by Design for Damage Confinement)
- Error Recovery
  - Undo and Retry (e.g., Recovery Block Approach)
  - Selection (e.g., N-version Programming)
- Continued Service
  - Work-around
  - Fault Treatment
  - Version Switch/Reconfiguration

HISTORY

JUL 82	JOINT TASK FORCE -- SOFTWARE PROBLEMS
OCT 82	STRATEGY FOR DoD SOFTWARE INITIATIVE
NOV 82	JOINT SERVICE TASK FORCE -- REFINE PLAN
DEC 82	BRIEFING FOR JLC
JAN 83	BRIEFING FOR EXECUTIVE COMMITTEE
FEB 83	WORKSHOP -- RALEIGH, NC
FEB 83	REVIEW BY NATIONAL ACADEMY OF SCIENCE
FEB 83	REVIEW BY JLC/JDL PANELS

The Startup Mechanics in Assuring a Realistic and Integrated SQA Program

Domenic V. La Rosa
Manager, Quality Management Systems
Avco Systems Division

1. **Introduction** – Software Quality Assurance (SQA) is becoming a more common and understood discipline within the framework of DoD embedded software systems. More intense, clear direction has been initiated within the government, military, and the defense industry. There is a wide awareness of the need to have viable, cost effective software methodologies become a common practice in developing the sophisticated software that is controlling the diverse applications of C^3, ATE, data processing, graphics and other software driven functional applications.

2. **Presentation Highlights** – This presentation gives a capsule digest of the evolution of the Software Quality Assurance program within the division. This SQA implementation process has been unfolding for over three years and has matured very much. In terms of its actual growth cycle, it probably is a young adolescent with clear growth signals programmed to develop into a mature satisfying adult in the next two to three years.

3. **SQA Program Cornerstone** – The cornerstone to the Avco SQA program consists of three major building blocks:

   a. An integrated functional approach that combines all elements of the software development team (Eng. Configuration Management, QA, Test, Program Office and Customer) into a highly cohesive operation.

   b. Formally structured software standards for developing and controlling software for each major discipline.

   c. Total traceability throughout the development life cycle to assure objective evidence is available with proper V & V functions defined and performed.

The material captures the tangible accomplishments (e.g., policy, funding, traceability matrices, Software Development Notebooks, and the techniques and tools for performing realistic SQA.) Perhaps more importantly, it stresses the more subtle, intangible accomplishments, such as item 3a above, for implementing an effective SQA program. This includes extensive missionary work to develop the rapport and level of acceptance for SQA.

4. **SQA Program Road Map** – The features the reader can gain from these graphical and narrative viewgraphs are: A cookbook or road map on how to go about starting a similar SQA operation; the pros and cons of implementing each phase of the process; and the major lessons learned in this effort. The material concludes by defining the awesome challenge on how SQA can become a more scientific, measurable and contributing force to the delivery of reliable software products. This 3.5 year SQA journey at Avco has been laden with some important and challenging hurdles, each one necessary to resolve in the given order, to then be in the correct position to advance the total SQA program to its next milestone.

5. **SQA Similarities** – An interesting and somewhat surprising issue surfaced in implementing the divisions's SQA program. Namely the basic objectives, approaches and discipline that the industry's software engineering advocates are promoting are, in essence, the *same* ones that are an integral part of instituting a *total* SQA program. Examples of this ordered and common approach are: It is illogical to implement SQA audits of Software Development Notebooks (SDN) without having software engineering adopt use of the SDN as part of its structured methodology. Similarly it seems inappropriate to verify PROM masters without first having well-defined baselined, library controls as part of a functioning Software Configuration Management organization. Another one is, to perform validation testing is non-profitable without first having objective evidence of the system requirements defined up front. These last few examples clearly convey a very pointed message "First things first", or another interpretation would be, "You can't have one (SQA) without

the other (Eng., SCM, test, documentation)." It is quite apparent that as a company commits to implementing a SQA program, it is in reality saying that it will initiate integrated methodologies in order to reap the benefits and justify the investment for establishing its total SQA charter.

6. **Functional vs Organizational SQA** – The SQA program reflects itself not only as an organization performing its critical V & V mission, but it also serves a critical catalyst role, especially in a newly established SQA program. The SQA organization lays the foundation for instituting the tangible features of SQA as well as being an overseer to assure the total software development process is clearly defined.

7. **Total SQA Program** – The implementation of a *total* SQA program must address a critical requirement of "getting in early" and establishing a game plan for each software contract effort. This is highlighted herein by the employment of the Avco Software Requirements Task Force. This group consists of the key disciplines (preferably at RFP time), and defines the set of software management documentation such as the Software Management and Control Plan, and derivative plans of Software Engineering, Software Configuration Management and SQA. These events give a clearly delineated direction of what will transpire throughout the development process and provide all parties a visible means of controlling and measuring progress. There are other tasks that complement these and which are very pivotal in maximizing the software process-quality and its associated reliability. To the extent that the software process quality is properly implemented, then it will decidedly impact the resultant product quality and overall reliability of the delivered product.

8. **Future SQA Direction** – The presentation not only highlights the Avco approach and progress in implementing SQA mechanics, but also alludes to the voids that exist in having a totally mature SQA program. These voids are not only apparent in our SQA program, but when one steps back and views the entire industry-wide software development state of affairs, some startling similarities and trends appear. The key one is the lack of a sound integrated Software Development METHODOLOGY. Many groups involved in software development are echoing this theme. Until we establish a methodology with quantitative, automated, measurable, documented performance characteristics, we will not reach our common goal of developing proven reliable software products in a cost effective, on-time basis. We must engage in a concerted effort to have the process of software development and its related fields of SQA, SCM transition from a disjoint, art-based discipline to a formally structured, integrated scientific-based discipline.

9. **Software Standards/Tools** – Another dimension of a good software methodology is to have standards available on how to develop, measure, control and document a delivered software product. These standards cut across all software disciplines and are the fuel to an effective, total SQA program. Another area of concern is to acquire tailored, application-oriented automated tools. Avco reports its progress and gives recommendations on where we need to continue growing.

10. **Summary** – In summary, the three-year saga of SQA at Avco has been an important period. We have established a rapport with software development organizations, promoted the missions necessary to develop reliable software and established a common goal of growing into a fully mature, integrated software development team.

THE STARTUP MECHANICS IN ASSURING A REALISTIC AND INTEGRATED SQA PROGRAM

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PRESENTED AT

ADVANCED ASSURANCE TECHNOLOGY WORKSHOP #5 SOFTWARE PANEL

MISSION ASSURANCE CONFERENCE AND WORKSHOPS
LOS ANGELES AIRPORT HYATT HOTEL
LOS ANGELES, CA
7-9 JUNE 1983

A SYSTEM PERSPECTIVE TO SOFTWARE DEVELOPMENT ... WITH EMPHASIS ON SOFTWARE QUALITY ASSURANCE

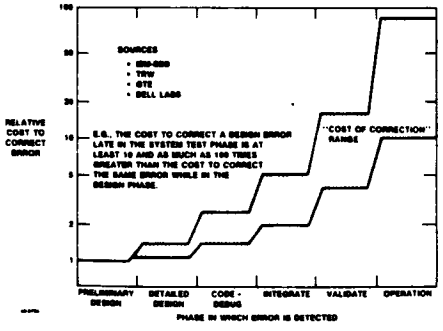
WHY DO WE NEED SQA?

- SOFTWARE DEVELOPMENT QUALITY IS BECOMING A PRIORITY TO CUSTOMER.
- SOFTWARE VISIBILITY AND CONTROL NEEDS TO BE INCREASED FOR BOTH CUSTOMER AND INTERNAL MANAGEMENT.
- MORE CONTRACTS ARE REQUIRING SOFTWARE DELIVERABLES (COMPUTER PROGRAMS, DOCUMENTATION).
- THERE IS NEED TO ESTABLISH FORMAL SOFTWARE METHODOLOGY AND ORGANIZATIONAL RESPONSIBILITIES.
- NEED TO ESTABLISH AND MAINTAIN A COMPETITIVE EDGE IN SOFTWARE DEVELOPMENT.

THE ABSENCE OF SQA HAS ADVERSE IMPACTS

- CONTRACT OVERRUNS
- SCHEDULE SLIPPAGES
- COMPUTER PROGRAM NOT COMPLETED
- POOR PERFORMANCE OF COMPUTER PROGRAM
- COMPUTER PROGRAM/MISSION FAILURES
- EXCESSIVE MAINTENANCE COSTS AFTER OPERATION
- POOR IMAGE TO CUSTOMER
- DEVELOPMENT QUALITY NEEDED

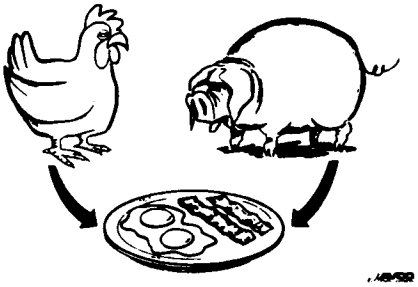
IT PAYS TO CATCH SOFTWARE ERRORS EARLY



IT'S A SMALL WORLD...

LYRICS	AS SEEN THRU THE EYES OF	
	ENGINEERING	SQA
IT'S A WORLD OF LAUGHTER	HUH!!! HUH!!! SQA??	NO!! NO!! SQA
IT'S A WORLD OF FEAR	GO AWAY! YOU'RE TOO EXPENSIVE AND TIME CONSUMING	IT'S SO HARD TO CHANGE THE STATUS QUO
IT'S A WORLD OF HOPE	I HOPE SQA CAN BRING SOME ORDER TO SOFTWARE DEVELOPMENT	IF GIVEN THE CHANCE SQA CAN BRING RELIEF
IT'S A WORLD OF CHEER	YEH!! SQA DOES HAVE SOMETHING WORTH HEEDING	YEH!! SQA IS WORKING
THERE'S SO MUCH THAT WE SHARE	WE ALL HAVE A COMMON GOAL TO DEVELOP QUALITY PRODUCTS	WE ALL HAVE A COMMON GOAL TO DEVELOP QUALITY PRODUCTS
THAT IT'S TIME WE'RE AWARE	HMMM!! SQA CAN MAKE OUR SOFTWARE BETTER AND MORE COST EFFECTIVE	SQA CAN BE A POSITIVE CATALYST TO SOFTWARE DEVELOPMENT
IT'S A SMALL WORLD AFTER ALL	IT'S A SMALL WORLD AFTER ALL WELCOME ABOARD SQA	IT'S A SMALL WORLD AFTER ALL GLAD TO BE ABOARD

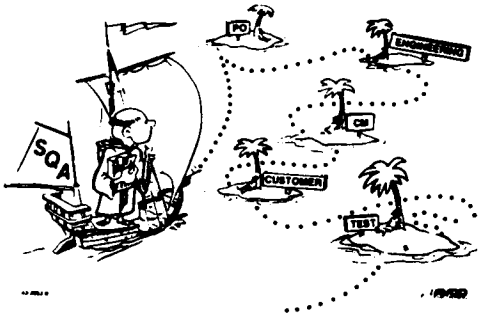
ARE WE INVOLVED... OR *COMMITTED* TO SQA?



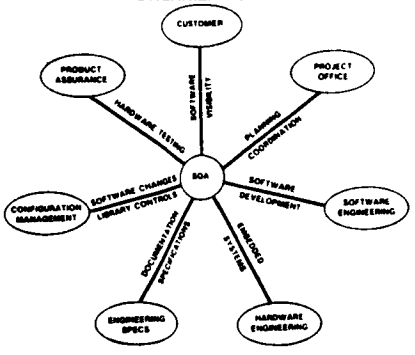
KEY INGREDIENTS TO ESTABLISHING A VIABLE SQA PROGRAM

INGREDIENT/ELEMENT	HOW ACHIEVED
COMPANY COMMITMENT	• SQA ORGANIZATION • FUNDING • VISIBILITY
POLICY	• AVCO POLICY 0115
PROCEDURES	• 4 VOLUME SOFTWARE REFERENCE MANUAL • DEVELOPMENT METHODOLOGIES
PRODUCTS	• COMPUTERS • SUPPORT EQUIPMENT • TOOLS
TRAINING	• MISSIONARY WORK WITH PROGRAM OFFICE AND LINE ORGANIZATIONS
OBJECTIVE EVIDENCE	• DOCUMENTATION ONE LIFE CYCLE • TRACEABILITY MATRIX • SOFTWARE DEVELOPMENT NOTEBOOK • AUDITS OF SE, SCM, SDN'S

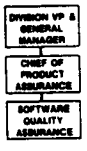
IN THE EARLY DAYS OF SQA... 'MISSIONARY WORK' WAS *THE WAY* TO GO.



SQA INTERFACES WITH SOFTWARE RELATED ORGANIZATIONS



SQA ORGANIZATION HAS HIGH VISIBILITY & AUTONOMY



SQA IS AN INTEGRAL PART OF THE COMPLETE SOFTWARE DEVELOPMENT PROCESS.

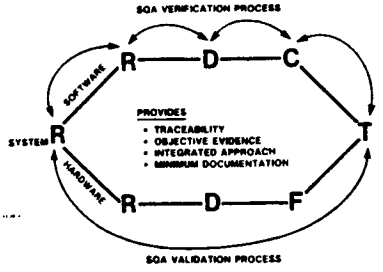
HERE ARE A FEW OF THE SQA PRIORITY TASKS TO IMPLEMENT

- COORDINATE IMPLEMENTATION PLAN STRATEGY WITHIN DIVISION
- ESTABLISH SQA CHARTER AND FUNCTIONS
- DEFINE MASTER SQA PROGRAM PLAN
- IDENTIFY SOFTWARE METHODOLOGY TASKS FOR ENG, SCM, AND SQA
- GENERATE SOFTWARE CONTROL PROCEDURES TO SUPPLEMENT POLICY
- ESTABLISH SOFTWARE TEST STRATEGY FOR QUALIFICATION /ACCEPTANCE
- CONDUCT SOFTWARE R&D ON STATE OF THE ART TECHNIQUES
- PROCURE AUTOMATED SOFTWARE DEVELOPMENT/TEST TOOLS
- MAINTAIN SOFTWARE REFERENCE LIBRARY
- GENERATE SOFTWARE PROPOSAL PREPARATION GUIDELINES
- DEFINE REALISTIC FUNDING ARRANGEMENTS

IMPLEMENTATION STRATEGY FOR SQA PROGRAM

- SERVE AS CATALYST TO ENHANCE SOFTWARE QUALITY AND VISIBILITY
- INTEGRATE SQA INTO ENGINEERING SOFTWARE DEVELOPMENT LIFE CYCLES — VS. "PATCH ON, AFTER THE FACT"
- EDUCATION IS THRUST OF SQA PROGRAM
- TEAM APPROACH — SOFTWARE TASK FORCES (ENG, CM, PO, SQA)
- PRIORITIZED TASKS DEFINED
- DYNAMIC AND NOT STATIC — PRACTICE SQA DAILY VS. ONLY COMPILING REFERENCE MATERIAL STORED IN MANUALS
- "ONE STEP AT A TIME" PHILOSOPHY
- EVOLVE FROM TRANSIENT TO STEADY STATE PROGRAM
- SQA INVOLVED FROM PREPROPOSAL TO CONTRACT COMPLETION
- MANAGEMENT VISIBILITY EMPHASIZED

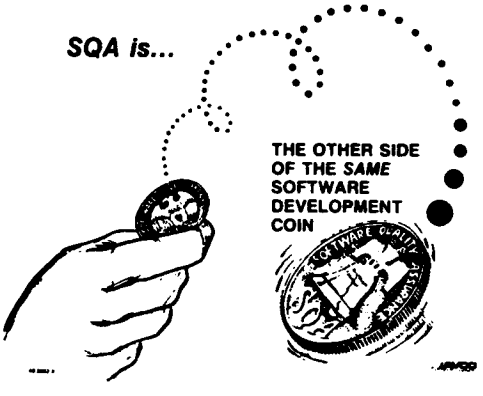
SQA PROVIDES V&V OVER ENTIRE DEVELOPMENT LIFE CYCLE



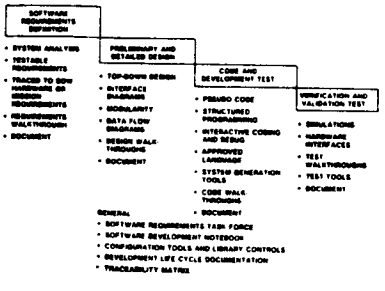
HIGH RETURN ON OUR SOFTWARE $ IF REQUIREMENTS ARE DEFINED

1. SOW AS CLEAN AS CAN BE
2. SYSTEM REQUIREMENTS (PERFORMANCE, RELIABILITY, SUPPORT)
3. FLOWDOWN OF SYSTEM REQUIREMENTS TO SOFTWARE/HARDWARE
4. KEEP VISIBILITY OF BOTH SOFTWARE/HARDWARE BUT DON'T ARTIFICIALLY SEPARATE — IF SEPARATED, REDUNDANCY AND AMBIGUITY RESULT.
5. TOTAL TRACEABILITY FROM SYSTEM TO SOFTWARE/HARDWARE
6. REQUIREMENTS CLEAR, TESTABLE, COMPLETE
7. CONTRACTOR FORMAT ALLOWED (USE INTENT OF MIL-STD-483)
8. TRI-SERVICE STANDARDS SHOULD BE FUTURE DIRECTION
9. ONCE IMPOSED, CUSTOMER SHOULD FOLLOW-UP ON DOCUMENTATION REVIEW
10. MORE TRAINED GOVERNMENT MONITORS IN COMPUTER SCIENCE NEEDED
11. SOFTWARE SHOULD BE DEFINED HIGHER IN WBS

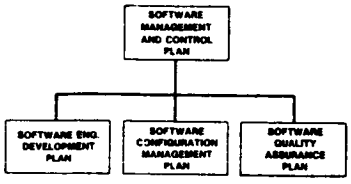
SQA is...

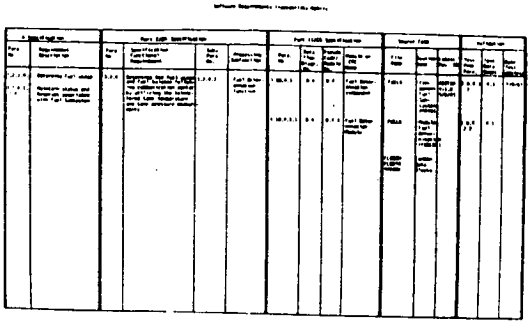


ENG/SQA METHODOLOGY ON A TYPICAL SOFTWARE PROJECT

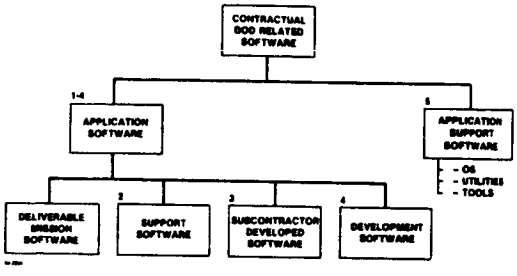


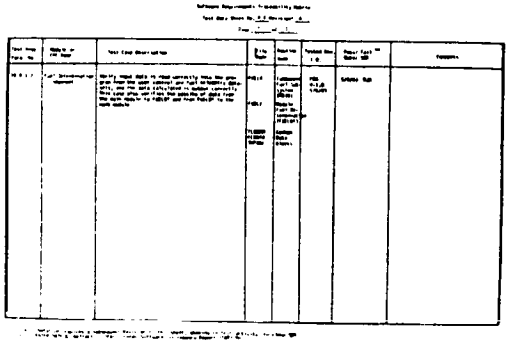
INTEGRATED SOFTWARE PLANNING IS CONDUCTED EARLY AND DOCUMENTED



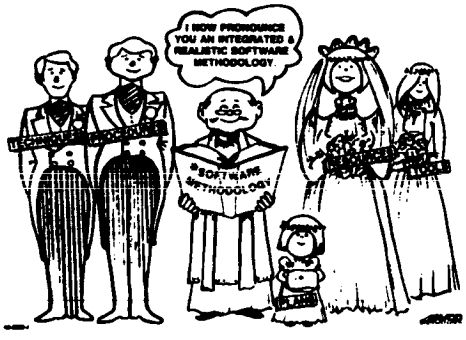


SOFTWARE CLASS TREE ENHANCES REALISTIC CONTROLS

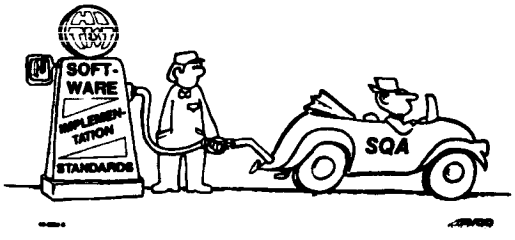


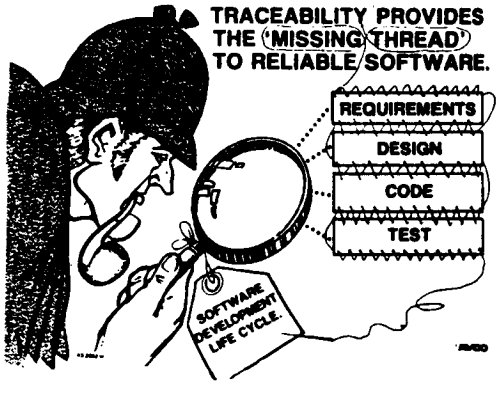


THE MISSING INGREDIENT *



SOFTWARE STANDARDS IS THE FUEL ... *TO YOUR SQA PROGRAM*





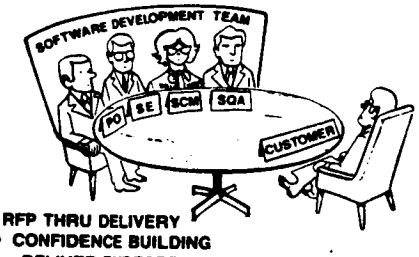
THE BACKBONE TO SOFTWARE PROGRAM IS THE SOFTWARE REFERENCE MANUAL

- 4 INTEGRATED VOLUMES (SE, SCM, SQA, DOC)
- JOINT PUBLICATION EFFORT
- AUDITABLE DOCUMENT
- LIVING DOCUMENT
- STANDARDS TAILORED TO EACH PROGRAM
- INITIATED JUN 82/COMPLETED 1 JAN 84
- COMPATIBLE WITH HDBK 334 AND AFCMD REQ 179-1

TOOLS ARE ESSENTIAL TO RELIABLE SOFTWARE PRODUCT DEVELOPMENT

TOOL / AREA	SE	SCM	SQA	TEST	MANAGEMENT
IDEF	X	X	X	X	X
AUTO FLOW	X	X	X	X	X
AUTO CHART/PDL	X		X	X	X
PROGRAM SUPPORT LIBRARY	X	X	X	X	
TESTPORT	X		X	X	
HOL COMPILERS	X		X		
PRODUCT DESIGN TREE	X	X	X	X	X
CHANGE DETECTOR		X	X		
REQUIREMENTS SIMULATOR	X		X	X	X
ADA ENVIRONMENT	X	X	X	X	X
PATH ANALYZER	X		X	X	
TRACEABILITY MATRIX	X		X	X	

THERE MUST BE A HIGHLY VISIBLE CUSTOMER/CONTRACTOR DIALOGUE.

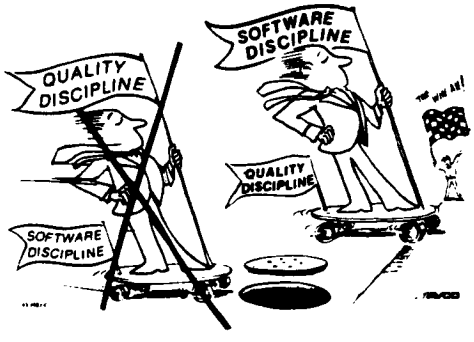


- RFP THRU DELIVERY
- CONFIDENCE BUILDING
- DELIVER EXPECTED PRODUCT

CUSTOMER SHARES IN DEFINING GOOD PRODUCT QUALITY

1. REALISTIC DEVELOPMENT LIFE CYCLE SCHEDULE
2. KEY MILESTONES DEFINED FOR SOFTWARE VISIBILITY (PDR, CDR, FCA/PCA, ACCEPTANCE)
3. COMPLIANCE DOCUMENTATION TAILORED
4. APPLICATION DOCUMENTATION — CAPTURE LIFE CYCLE PHASES (REQUIREMENTS, DESIGN, CODE, TEST)
5. MANAGEMENT DOCUMENTATION UP FRONT — CPDP, CONTROL PLANS, POLICY 6115, SOFTWARE REQUIREMENTS TASK FORCE, SQA/SCM PLANS.
6. ACTIVE PARTICIPATION AT TD MEETINGS BY SOFTWARE ENGINEERING/SCM/SQA.
7. WORK AS MUCH AS POSSIBLE IN RFP STAGES TO GET PROPER DEFINITION OF SOFTWARE REQUIREMENTS
8. FORMAL LIFE CYCLE UNDERLYING FACTOR TO TRACK REQUIREMENTS TO COMPLETION.

PICK THE RIGHT SET OF 'WHEELS'!



THE KEY INGREDIENTS THAT CHARACTERIZE AN SQA ENGINEER

- EXPERIENCE IN SOFTWARE DESIGN METHODOLOGIES
- UNDERSTANDING OF MILITARY DIRECTIVES ON SOFTWARE DEVELOPMENT AND DOCUMENTATION STANDARDS
- ORAL AND WRITTEN COMMUNICATIONS ABILITIES
- INTEREST AND FACILITY TO INTERFACE WITH MULTI ORGANIZATIONS AND DISCIPLINES
- PERSISTENCE AND ATTENTION TO DETAIL
- SCIENTIFIC, MATH, LOGIC, EXPERIENCE
- STRONG BACKBONE AND THICK SKINNED
- COMMON SENSE, TEMPERED, TACTFUL PRACTITIONER

LESSONS LEARNED IN IMPLEMENTING SOFTWARE QUALITY ASSURANCE

1. SQA SHOULD BE PURSUED AS AN INTEGRATED MULTI-DISCIPLINED EFFORT INVOLVING CUSTOMER, PROGRAM OFFICE, SYSTEMS, HARDWARE, SOFTWARE ENGINEERING, CONFIGURATION MANAGEMENT, TEST AND SOFTWARE QA.
2. SQA PROGRAM SHOULD BE DEFINED VIA A FORMAL COMPANY POLICY DIRECTIVE AND IMPLEMENTED THROUGH A SET OF INTEGRATED SOFTWARE STANDARDS.
3. CONTRACTS SHOULD HAVE DEFINITIVE OBJECTIVE EVIDENCE AS DELIVERABLES (EX. SOFTWARE MANAGEMENT CONTROL PLANS (SE, SCM, SQA); TECHNICAL DOCUMENTS (REQUIREMENTS DEFINITION, DESIGN, CODE PACKAGE, TEST PROCEDURES)
4. PROGRAM OFFICES SHOULD BE STAFFED WITH SOFTWARE DISCIPLINED TALENT TO BE PRIMARY, EARLY INTERFACE WITH CUSTOMER TO ASSURE SOFTWARE IS DEFINED AT THE HIGHEST WBS LEVEL AND THAT RFP REQUIREMENTS ARE TOTALLY ADDRESSED.
5. SOFTWARE ASSURANCE DOES NOT COST AS MUCH AS PEOPLE THINK IT DOES. THERE ARE "IMPLICIT" MEANS TO DEVELOP VIABLE PRODUCTS. SOFTWARE ENGINEERING CAN DO A LOT TO ASSURE THIS IMPLICIT QUALITY.

LESSONS LEARNED IN IMPLEMENTING SOFTWARE QUALITY ASSURANCE

6. SQA CANNOT EXIST UNLESS A COMPANY HAS A VIABLE SOFTWARE DEVELOPMENT METHODOLOGY IN PLACE & EXECUTED BY SOFTWARE DISCIPLINES.
7. WITHOUT GOOD SOFTWARE REQUIREMENTS ESTABLISHED EARLY, VERIFICATION & VALIDATION & FINAL SOFTWARE ACCEPTANCE BY CUSTOMERS IS MEANINGLESS. AT WORST WE NEED TO BACK OUT REQUIREMENTS FROM DESIGN INFORMATION.
8. CUSTOMER ACCEPTANCE OF SOFTWARE PRODUCTS IS BASED ON MANY FACTORS. IN PRIORITY, THEY INCLUDE A WORKING PRODUCT, GOOD SUPPORT DOCUMENTATION, MUTUAL CONFIDENCE, ETC. THE THREAD IS TO HAVE TOTAL TRACEABILITY, THROUGH OBJECTIVE EVIDENCE.
9. AN EXCELLENT DEVELOPMENT AID IS TO UTILIZE A SOFTWARE DEVELOPMENT NOTEBOOK THROUGHOUT DEVELOPMENT CYCLE. IT PROVIDES SQA WITH A GOOD OBJECTIVE SNAPSHOT, SAVES TIME TALKING TO DESIGNERS, AND AIDS CUSTOMER IN GAINING CONFIDENCE THAT PRODUCT IS EVOLVING.
10. TEST PROCEDURES ARE CRITICAL TO PROVE SOFTWARE WORKS PER REQUIREMENTS. THE FORMATS SHOULD BE TAILORED TO SOFTWARE PRODUCT (PURE SOFTWARE, EMBEDDED, ATE).

LESSONS LEARNED IN IMPLEMENTING SOFTWARE QUALITY ASSURANCE

11. SQA SHOULD PARTICIPATE IN SOFTWARE WALKTHROUGHS IN EACH PHASE; REQUIREMENTS, DESIGN, CODE AND TEST.
12. A SOFTWARE HIERARCHY SHOULD BE DEFINED TO IDENTIFY DIFFERENT TYPES OF SOFTWARE PRODUCTS AND THE ASSOCIATED LEVELS OF CONTROL FOR SCM, SQA, AND DOCUMENTATION. EACH CONTRACT CAN THEN SELECT FROM THIS TREE WHICH CLASS OF SOFTWARE WE NEED AND THE NOMINAL SET OF CONTROLS.
13. SQA ORGANIZATION SHOULD BE FUNDED BY BOTH DIRECT AND INDIRECT BUDGETS.
14. SQA SHOULD BE ON AUTOMATIC DISTRIBUTION TO RECEIVE ALL RFP'S TO EVALUATE EXTENT OF SOFTWARE IMPACT AND SUBSEQUENT NEED TO INITIATE INTEGRATED SOFTWARE RESPONSE.
15. SQA LABOR COSTS SHOULD BE COLLECTED BY THE PHASE OF DEVELOPMENT LIFE CYCLE; BY PROGRAM; FUNDING LEVEL AND TASK.
16. EFFECTIVE SQA METHODOLOGY NEEDS REGULAR MONITORING TO ASSURE COMPLIANCE TO EXISTING DEVELOPMENT STANDARDS AND CONTRACTUAL REQUIREMENTS. SQA PERSONNEL DISCIPLINED IN CS SHOULD BE ADDED TO PA AUDIT STAFF.

LESSONS LEARNED IN IMPLEMENTING SOFTWARE QUALITY ASSURANCE

17. AN SQA ORGANIZATION SHOULD START SMALL, CONDUCT MISSIONARY PR EFFORT, ESTABLISH RAPPORT WITH PROGRAM OFFICES AND LINE ORGANIZATIONS, DEFINE STANDARDS AND PROMOTE FUNCTIONAL SQA. SQA STAFF SHOULD BE PEERS TO SOFTWARE ENGINEERING STAFF
18. WHATEVER SQA TASK IS PERFORMED, IF IT MAKES SENSE IT WILL SURVIVE THE TEST OF ACCEPTABILITY AND FUNDING
19. IT IS IMPORTANT THAT THE SQA ORGANIZATION GETS IN EARLY AT THE RFP STAGE TO HAVE MAXIMUM CONTRIBUTION AND BENEFIT.
20. CUSTOMER CAN DECIDELY IMPACT SOFTWARE RELIABILITY BY DEFINING SUFFICIENT TAILORED CDRL'S AND THEN MONITORING THEM USING EXPERIENCED SOFTWARE CONTRACT MONITORING PERSONNEL
21. WHEN YOU STEP BACK AND LOOK AT THE SOFTWARE EFFORT, YOU SEE SOFTWARE ENGINEERING AND SQA METHODOLOGIES ARE TWO SIDES OF THE SAME COIN
22. AN SQA EFFORT MAKES MOST SENSE ON NEWLY DEVELOPED SOFTWARE TASKS AND DECREASES IN VALUE PROPORTIONATELY TO THE LEVEL OF THE DEVELOPMENT EFFORT. VENDOR SUPPLIED SOFTWARE LEAVES A BIG VOID TO EFFECT REALISTIC SQA, AFTER THE FACT.

CHRONOLOGY OF OUR 3 YEAR SQA SUCCESS STORY

TASK:

- ESTABLISHED SQA DEPT
- PERFORMED MISSIONARY WORK
- DEVELOPED SQA IMPLEMENTATION PLAN
- APPROVED SOFTWARE POLICY
- ESTABLISHED SOFTWARE REQUIREMENTS TASK FORCE
- REVIEWED ALL RFP'S
- RESOLVED SQA FUNDING
- ESTABLISHED DIALOGUES
- HIRED STAFF
- PERFORMED SQA ON CONTRACTS
- INITIATED SOFTWARE DEVELOPMENT NOTEBOOK
- PROMOTED SQA STANDARDS
- DEFINED SOFTWARE REFERENCE MANUAL
- GENERATED SRM STANDARDS

WE NEED TO PUT 'TEETH' TO SQA.

- INTEGRATED SOFTWARE METHODOLOGY
- USABLE SOFTWARE METRICS
- AUTOMATED TOOLS
- PROPER FUNDING LEVEL
- OBJECTIVE EVIDENCE

The Bottom Line:
RELIABLE SOFTWARE PRODUCTS

AVCO

FUTURE DIRECTION OF SQA EMPHASIZES ROUNDING OUT OUR METHODOLOGY

- DEFINE/PROCURE METRICS/TOOLS
- REFINE STANDARDS
- INITIATE SOFTWARE METHODOLOGY TRAINING
- COMPLETE AFPRO/AVCO SOFTWARE PROGRAM BASELINING
- INITIATE SOFTWARE COMPLIANCE PROGRAM

WE ARE BEGINNING TO SCRATCH THE SURFACE OF SQA

- SQA IMPLEMENTATION PLAN DEFINED & DISSEMINATED
- AVCO SOFTWARE DIALOGUE ESTABLISHED WITH PROGRAM OFFICES AND LINE ORGS
- SOFTWARE ENGINEERING AND CONFIGURATION MANAGEMENT ORGANIZATIONS/RESPONSIBILITIES ESTABLISHED
- SQA V&V FUNCTIONS NOW IN EFFECT ON 7 MAJOR AND 5 MINOR CONTRACTS
- 56 OF 133 SOFTWARE REFERENCE MANUAL PROCEDURES PUBLISHED
- MANAGEMENT TOOLS ACTIVELY USED
- CUSTOMER RAPPORT AND SQA VISIBILITY ENHANCED
- ATTENDANCE AT SEVERAL SOFTWARE COURSES BY KEY PERSONNEL
- OBJECTIVE EVIDENCE AVAILABLE
- AUTOMATED TOOLS PROCURED/BUDGETED

IT'S A SMALL WORLD AFTER ALL

ANATOMY OF A SOFTWARE QUALITY ASSURANCE PROGRAM

IUS SOFTWARE

William R. Burr
Software Quality Assurance Engineering
Boeing Aerospace Company

It is often heard that: "Software is different, therefore traditional Quality Assurance techniques used for hardware do not apply." There is some truth to the statement. Software is different e.g., there is no manufacturing by a separate organization, the software production process is not universally defined, software is invisible, it exists in the memory of a computer and we can only see and feel the media on which it is stored or manifestations of it in the form of a listing of the program. However, there are also a number of similarities. Software is a product, it has a requirement definition phase, a design phase, a production phase and a test phase. It can be identified as precisely as hardware in its requirements and design documentation. Manifestations of it can be reviewed and inspected. It can be part numbered and controlled to the lowest component level. Therefore, certain traditional quality assurance methods can be applied and used effectively. They do require certain disciplines and control and that's the rub. Granted, some unique practices are needed for computer software; but an entire new system need not be designed. Most companies have a proven quality assurance program for designing and producing hardware products. While new procedures for software quality assurance will probably be produced and fine tuned over a period of time, they will be based on existing quality assurance concepts. The Inertial Upper Stage (IUS) Quality Assurance organization decided to concentrate on similarities between hardware and software and use applicable quality assurance procedures, modify some and generate new procedures as deemed necessary.

This paper describes the software quality assurance program used by The Boeing Aerospace Company for the IUS spacecraft. The IUS is a spacecraft designed to boost payload satellites into a desired orbit from a Titan or Space Shuttle Vehicle. Functions such as navigation, guidance and control, communications, mission sequencing etc., are controlled by an on-board computer. The primary computer programs are the on-board flight software, simulator software for verification and validation of flight software and software for a test set to check out the entire IUS spacecraft. There are lesser deliverable software items and the usual array of support software, test software, test aids etc. The flight software and a compiler were subcontracted, the remainder of the software was developed by Boeing. The full scale development phase began in 1978 and was the first major software development under MIL-S-52779 by Boeing.

The software quality assurance program was designed to satisfy MIL-S-52779 using the frame work of existing controls and techniques used by Quality Assurance for hardware products. These controls and techniques are audit, review, inspection, engineering release, configuration management and the Boeing Integrated Records System. The latter a formal system of records and disciplines to provide progressive evidence of hardware and software completion and acceptance. Other

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features were also employed such as up front planning and participation in the software development activities, computer program libraries, configuration management and problem reporting and resolution during development phases. Traditional quality assurance and configuration management concepts and methods used for hardware deal largely with the manufacturing and inspection of the product. Software quality assurance is concerned with the development process; therefore considerable attention is given to standardizing and inspecting the design and code process. Disciplines such as configuration management and problem reporting and correction are applied during the development phase through Software Libraries and Software Problem Reports.

The normal Boeing method for controlling the manufacture of hardware may be summarized as follows: Prepare engineering design drawings, release the drawing through the Engineering Release Organization, at which time they would be placed under program configuration control, fabricate the product as specified by an Integrated Records System Work Order which authorizes fabrication of the part and specifies Quality Assurance inspection points, and test the product as specified by the test order. All software products and modules are part numbered such that they relate directly to the drawing that identifies them. This was the model used for the software program.

Since many of the traditional Quality Assurance disciplines were unfamiliar to the IUS software developers and in turn software development peculiarities were unfamiliar to most of the Quality Assurance organization, it was mandatory that Quality Assurance and Configuration Management policy and procedures for IUS software be defined, written and disseminated to the affected personnel as soon as possible.

The Boeing Aerospace Company had existing policy for software QA which needed to be tailored to IUS requirements, expanded to detailed procedures and disseminated to project personnel.

A Software Quality Engineer was assigned to the IUS project. Software Quality Assurance procedures were prepared, coordinated with the various IUS project organizations and authorized by the Program Manager in the form of IUS Program Directives. Software standards were compiled and coordinated with the BAC Software developers, the software subcontractor and the customer program office. Software development procedures were developed in concert with the software QA program. Thus, early involvement of the Quality Assurance organization was achieved. Another advantage of early involvement was customer recognition of the software QA program. This resulted in a software QA presentation at the regularly scheduled program status reviews which in turn gave visibility, status and authority to the software QA program.

Using standard Boeing methodology as a framework and adding a few innovations, as necessary, a software QA program was implemented. The software design was documented in a preliminary C5 specification which was maintained in the Engineering Development Software Library after Critical Design Review (CDR). (Current Boeing standards require that software design be documented as a drawing and subjected to program configuration control after CDR). Coding, unit testing and integration testing were performed by the software development organization and controlled in the Engineering Development Software Library.

Two software libraries were established, an Engineering Development Library and a Quality Assurance Master Library. The first library is used to control the software in the development phases.

Software is submitted to this library after unit testing is complete. All developing versions were maintained and controlled by the software configuration management organization which reports to the software manager. The second library is maintained by the quality assurance organization and contains masters and copies of released computer program code.

Prior to formal testing, software drawings were prepared that included a parts list specifying the part number and revision level of each module, a procedure for software system generation from source code, a procedure for making copies and verifying the copy process, labeling requirements and validation requirements. The purpose of a software drawing is to provide a formal means of identifying, labeling and controlling software design documents and code. The drawing was released with the computer program source code through the engineering release organization and a work order was prepared to authorize, record and authenticate the system generation (software production) process. The source code was released on magnetic tape and was considered a part of the drawing. Program listings were not released at this time. Copies were available in the library. The process included making and serializing a specified number of copies and applying appropriate labels. All authorized copies are stamped by Quality Assurance to indicate they are verified as exact copies although not yet validated. One of the copies is designated as an engineering master which is released to the engineering release vault, another is designated as a quality assurance master, the others are labeled as copies. The QA master and the copies are placed in quality assurance custody in a QA Master Library. From this point on all official copies are made from the QA master and accounted for by the work order. Only official copies are used in formal testing and for delivery.

Formal testing is planned and conducted by a separate test group reporting to the software manager. Formal tests are conducted under work order control. Test plans and procedures were reviewed by the software quality engineer and other qualified personnel. Prior to start of formal testing the computer program being tested and all supporting software is verified as being the correct version. Evidence of verification can be possession by Quality Assurance, an unbroken quality assurance seal, check sum, comparison against a master, computer printout or other methods approved by Quality Assurance. Supporting software and test aids were previously validated or otherwise certified by Quality Assurance and maintained in the Quality Assurance Master Library. Software media labels received a quality assurance stamp at the successful conclusion of formal testing indicating that the software has been validated and can be used or delivered as required.

Reviews and audits were a part of the software quality program. For the most part, design reviews and reviews of test plans were conducted both informally and at the Preliminary Design Reviews and Critical Design Reviews. Code reviews were conducted by the Software Quality Assurance group to ensure that the code and the design documentation were compatible. Code reviews compared current program listing against "official" design documentation.

Audits were conducted on a quarterly basis in accordance with an audit plan that was prepared for the IUS project. The audit plan described the activities to be audited for each development phase, a checklist for the activities and a description of the content and format of the audit reports. Audits are considered to be a very important part of the software quality assurance program because they represent an independent formal assessment of the software quality program which can be used by the software manager or the program manager as a part of his intelligence system.

Software problem reporting began after completion of unit testing when the computer program code was placed in the Software Development Library. Software problems are reported on a Software Problem Report (SPR) form, analyzed by the designer, the solution is reviewed by the Software Change Committee and a final disposition is approved by the software manager. The software manager chairs the change committee which is an advisory group consisting of members of his staff and the software quality assurance engineer. All changes are coordinated with systems and hardware designers to assure compatibility. During formal testing and beyond, software deficiencies are recorded on a rejection form (which is part of the Integrated Records System) as well as the SPR. The rejection form becomes an official IUS project record of the deficiency and its disposition. Non recurrance action is planned, accomplished and documented during the processing of this form.

Inspection can be applied to several software development activities. Included in these are the computer program code and some of the processes. For IUS, inspection was applied to the software production process and formal testing. Software production, as defined herein, includes the system generation process and duplication of software media. A typical quality assurance inspection would normally be performed by a semi-technical manufacturing quality assurance inspector. Operations such as witnessing formal testing and standard tape duplication can be and is often performed by functional test quality inspectors at Boeing. Computer program systems generation and some of the more sophisticated media duplication processes require the presence of quality engineers knowledgeable in computer software skills.

Witnessing of formal testing is a fairly standard process, but, inspection of the software generation process is not; therefore, a brief explanation is in order. Prior to formal testing of a computer program, it is important that the configuration of that program is accurately identified by released documentation and source code both of which are under formal configuration control. IUS source code was released and a quality assurance master copy was provided to the Quality Assurance Master Library. It is important to control the source code at this time because all changes to the computer program must be reflected in source code which is then converted to object code and tested or retested as required. Source code must not be allowed to get out of control.

Software system generation is a process which can be accurately described by a written procedure and must achieve identical results each time it is performed. Starting with the correct baselined source code and using the correct versions of support software is fundamental. Following a step-by-step procedure is necessary to prevent mistakes, as well as undocumented "tuning" of the software or the taking of "short cuts." Inspection of the process can insure that the procedure was followed and that the software was generated as documented. It is essential that a computer program load be produced from the correct versions of source code and support software. The software build work order appropriately stamped by Quality Assurance adds traceability and credibility to the pedigree of the computer program that is ultimately delivered to the customer.

One of the challenges of the IUS project was to develop an effective quality assurance relationship with a major software subcontractor. The subcontractor statement of work included a software quality assurance section specifying a strong and detailed quality assurance program. A common software standards manual was cooperatively produced which applied to both in-house and subcontractor software. Detailed software quality techniques were exchanged and the subcontractor was permitted to use its own techniques subject to Boeing approval. Audits were scheduled on a quarterly basis to evaluate the quality assurance program. The audits resulted in status reports and recommendations for corrective action. Prior to acceptance of the software from the subcontractor, a configuration audit was conducted which featured a detailed review of testing performed and configuration records of the delivered computer programs.

As can be seen from the above description the quality assurance program focused on configuration controls, audits, records and inspection of the IUS software, all of which are necessary, but have little effect on the early detection and correction of errors. Design reviews were conducted at PDR and CDR. The area of design review and code review was highlighted as requiring added emphasis within the software quality assurance program. New projects will incorporate design and code inspection methodology which has evolved with experience. Design and code inspections are formal inspections, as contrasted with informal peer reviews or walk-throughs. Early design and code inspection milestones will provide detection of errors, statistics on errors and early information on the quality of the design. Design inspections would be mandatory milestones that must be passed before PDR or CDR and before coding can be started on a computer program unit. Code inspection is a mandatory milestone to be completed before unit testing is started.

The IUS software is currently in a semi-production mode in which the baselined flight software is being updated to add enhancements, specific flight versions are also generated for unique mission requirements. All computer program production and duplication activities are witnessed by quality assurance and the official master copies maintained in the Quality Assurance Master Library. Delivery of the flight software versions are made from copies that are verified and certified as exact copies of the quality assurance masters.

Both production and testing of computer programs are authorized and recorded via work order and are certified by Quality Assurance. QA certification is evidenced by a QA stamp on the label of the software media (tape, disk, card, etc.).

In summary, the IUS software quality assurance program which is based on the traditional quality assurance structure at the Boeing Aerospace Company is sound and provides the required controls in the areas of configuration management, problem reporting, audits and witnessing to ensure delivery of adequately tested and certified software. There was no attempt to "re-invent the wheel" just because we were dealing with software. While software has some differences which must be dealt with, there are also many similarities to hardware which can be handled by the normal procedures. It would be unreasonably expensive to completely redefine an existing structure which has been proven over a period of time and which most people understand. By looking for similarities, advantage can be taken of existing facilities and procedures. Modifications and new procedures need only to be produced for the software unique features of a quality assurance program.

PROPOSED MIL-STD-SQAM: WHAT IS IT?

SUMMARY

This talk will present what MIL-STD-SQAM is and why there was a need for it. It will begin with a brief description of the evolution of SQA and how a large number of documents governing its implementation came into being. A partial listing of SQA requirements documents and interpretative guidebooks/handbooks/manuals will be shown. Several problems with implementing these documents will be described:

- Lack of definitive requirements
- Differences in interpretation
- Conflicts between implementing documents

A new approach was needed, and work was undertaken to come up with one. This approach, which resulted in MIL-STD-SQAM, will be briefly described.

Next, the role of the JLC in the production of MIL-STD-SQAM will be discussed. The outputs of this effort will be described. The concepts underlying MIL-STD-SQAM, its content, and the influence of this document on software quality assessment and measurement will be described. Finally, the current status of the effort will be shown.

SOFTWARE QUALITY STANDARDS: MIL–STD–SQAM –THE COMING REVOLUTION

DR. EMANUEL R. BAKER
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LOGICON INC

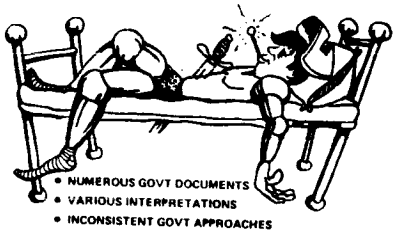
OVERVIEW

- PROBLEM AREAS, OBSERVATIONS, AND CAUSES
- CURRENT MILITARY SOFTWARE QA CONTRACT DOCUMENTS
- A NEW APPROACH

BACKGROUND

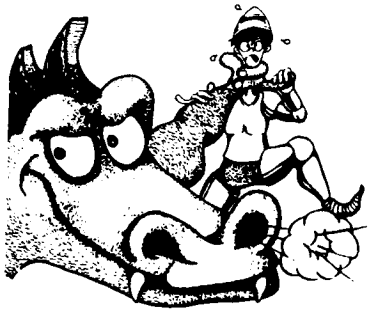
- WRONG STARTING POINT
  - EVOLVED FROM HARDWARE QA
- WHY STARTING POINT IS WRONG
  - INHERENT NATURES OF HARDWARE AND SOFTWARE
  - DEVELOPMENT METHODOLOGIES ARE DIFFERENT
  - QA METHODS ARE DIFFERENT

SQA PROBLEM SYMPTOMS



- NUMEROUS GOVT DOCUMENTS
- VARIOUS INTERPRETATIONS
- INCONSISTENT GOVT APPROACHES
- OVERLAP OF RESPONSIBILITIES
- LACK OF GOOD PEOPLE

STIGMA OF HARDWARE QA



"STIGMA" OF HARDWARE QA

- PERCEPTION OF SQA ROLE INTERNAL AND EXTERNAL TO QA COMMUNITY
  - QA FUNCTIONS AND RESPONSIBILITIES
  - QA TOOLS AND METHODOLOGIES
  - CALIBER OF QA PERSONNEL
  - TIMING OF QA ACTIONS
  - COST OF QA PROGRAMS
  - BENEFITS DERIVED
- PERCEPTION OF SQA PERSONNEL BASED ON EXPERIENCE WITH HARDWARE QA PERSONNEL
- PAST EMPHASIS ON INSPECTION AND TEST

PROBLEMS IN APPLYING SQA

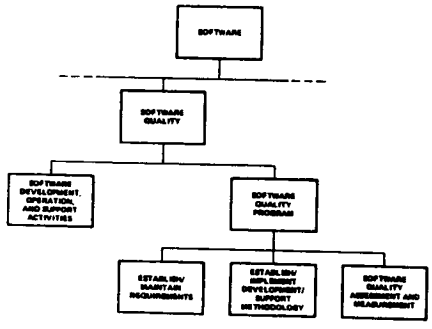
- PLETHORA OF SQA DOCUMENTS
- COPING WITH MIL-S-52779A – A CASE STUDY
- CONFLICTS BETWEEN DOCUMENTS

A SAMPLING OF RELEASED DOCUMENTS RELATED TO SOFTWARE QUALITY

MIL-S-52779A	SQA PROGRAM REQUIREMENTS
MIL-HDBK-334	EVALUATION OF CONTRACTOR'S SQA PROGRAM
AQAP-13	(NATO) SOFTWARE QUALITY CONTROL SYSTEM REQUIREMENTS
AQAP-14	(NATO) HANDBOOK
MIL-STD-1679A	WEAPON SYSTEM SOFTWARE DEVELOPMENT
FAA-STD-018	COMPUTER SOFTWARE QUALITY PROGRAM REQUIREMENTS
ANSI/IEEE STD 730	STANDARD FOR SOFTWARE QUALITY ASSURANCE PLANS
ESOM 74-1	SOFTWARE QUALITY ASSURANCE PROGRAM

A NEW APPROACH

SOFTWARE QUALITY FRAMEWORK



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NEED FOR JOINT SERVICE STANDARDIZATION

JLC QUALITY EFFORT

CSM SPONSORED

"MONTEREY I": POINTED TO NEED FOR STANDARDIZATION OF SOFTWARE ACQUISITION

"MONTEREY II": ADDRESSED SOFTWARE ACQUISITION ISSUES

"MONTEREY I" TASKS:

- JLC POLICY
- SOFTWARE DEVELOPMENT STD AND DIDS
- SOFTWARE QUALITY AREA

"MONTEREY I" OUTPUTS

- JLC POLICY/REG FOR COMPUTER RESOURCE MANAGEMENT
  - FRAMEWORK FOR S/W ACQUISITION
  - TERMINOLOGY/DOCUMENTATION
  - MANAGEMENT POLICIES
- ACQUISITION DOCUMENTS MIL-STD-SDS, 483, 480, 1521A, DIDS
- GUIDEBOOK/TRAINING COURSE

"MONTEREY I" OUTPUTS (Cont'd)

- JLC POLICY/REG FOR COMPUTER SOFTWARE QUALITY
  - FRAMEWORK FOR S/W QUALITY
  - TERMINOLOGY/DOCUMENTATION
  - MANAGEMENT POLICIES
- ACQUISITION DOCUMENTS
  - MIL-STD-SQAM, DIDS
- GUIDEBOOK/TRAINING COURSE

CONCEPTS

- SOFTWARE QUALITY PROGRAM IS NOT SYNONYMOUS WITH SQA PROGRAM OR SQC SYSTEM
- SOFTWARE QUALITY IS NOT SYNONYMOUS WITH SOFTWARE RELIABILITY
- PHYSICS OF SOFTWARE FAILURES IS NOT THE SAME AS THAT OF HARDWARE FAILURES
- QUALITY PEOPLE ARE NOT NECESSARILY QA PEOPLE
- SQAM ACTIVITIES OCCUR THROUGHOUT THE SOFTWARE DEVELOPMENT CYCLE
- VERIFICATION/VALIDATION IS A SUBSET OF SQAM

MIL-STD-SQAM SCOPE

GENERAL REQUIREMENTS

- ESTABLISH/IMPLEMENT SQAM PROGRAM
- SQAM PROGRAM PLANNING
- REVIEWS AND AUDITS
- REPORTING OF SQAM ACTIVITIES
- CORRECTIVE ACTION
- CERTIFICATION OF PRODUCTS
- STORAGE AND HANDLING
- SUBCONTRACTOR CONTROL
- DEVIATIONS AND WAIVERS

MIL-STD-SQAM SCOPE (Cont'd)

DETAILED REQUIREMENTS FOR EVALUATION

- PLANS, STANDARDS, PROCEDURES, TOOL, FACILITIES
- SOFTWARE REQUIREMENTS ANALYSIS
- SOFTWARE PRELIMINARY DESIGN
- SOFTWARE DETAILED DESIGN
- CODING AND UNIT TESTING
- SOFTWARE INTEGRATION, SOFTWARE INTEGRATION TESTING, AND SOFTWARE PERFORMANCE TESTING
- END ITEM DELIVERY
- CONFIGURATION MANAGEMENT

IMPACT OF MIL-STD-SQAM

- CAN BE USED AS COMPANION TO MIL-STD-SDS OR AS A STANDALONE
- CAN BE USED FOR IV&V AS WELL
- PLACES EMPHASIS ON PROJECT FRONT END
- PLACES EMPHASIS ON PROCESS AS WELL AS PRODUCT EVALUATION
- REQUIRES REQUIREMENT TRACEABILITY "SCORECARD"
- ADDRESSES TOTALITY OF ASSESSMENTS/MEASUREMENTS
- MEASUREMENTS NOT LIMITED TO METRICS
- INTEGRAL AND DEFINABLE COMPONENT OF TOTAL SOFTWARE QUALITY PROGRAM
- SQA PLAN DID REPLACED BY SQAM PLAN DID
- SOFTWARE QUALITY PROGRAM "PLAN" EMBEDDED WITHIN SDP

SOME IMPORTANT CONSIDERATIONS

- SQAM IS MORE THAN SQA
- SQAM IS A SUBSET OF THE SOFTWARE QUALITY PROGRAM (SQP)
  - MIL-STD-SQAM COVERS SQAM
  - MIL-STD-SDS COVERS REMAINDER OF SQP
  - NO DUPLICATE REQUIREMENTS PERMITTED
- STANDALONE NATURE OF MIL-STDs
  - CANNOT LEVY DOCUMENTATION REQUIREMENTS NOT IN SOW AND CDRL
  - CANNOT CHAIN REFERENCE MIL-SPECs/STDs
- "MEASUREMENT" INCLUDES
  - METRICS
  - TEST
  - DEMONSTRATION
  - INSPECTION

CURRENT MIL-STD-SQAM STATUS

- FIRST-DRAFT REVIEW COMPLETED
- COMMENTS SUBMITTED TO CSM
  - NAVMAT, DARCOM, AFSC, AFLC
  - EIA, NSIA, AIA
- SECOND DRAFT IN PREPARATION
- SECOND DRAFT INTO COORDINATION LATE 1983
- ESTIMATED AVAILABILITY FOR RELEASE EARLY TO MID-1984

INTEGRATED SYSTEM OF COMPUTER-AIDED QUALITY ASSURANCE

G.W. Bancroft
Quality Project Administrator-Special Projects
and
T.J. Phillipp
Manager, Quality Engineering
General Dynamics Convair Division

General Dynamics Convair Division, like most other aerospace companies, is developing a computer-aided verification (CAV) capability. Our goal is full integration with CAD/CAM systems to ultimately be an integral part of the factory of the future. We are well under way but much remains to be done. This paper describes where we are now, where we're planning to go, and some independent developments necessary to pave the way.

As indicated in Figure 1, communication occurs between our CAD and CAM activities via the IBM mainframe. In the product design area, more than 70 Computervision terminals are being used to develop product configuration data bases for selected portions of several current programs. These data bases are being used to some extent in the tool design and N/C programming areas. In the CAM world the IBM also hosts a bank of Westinghouse controllers that run our direct numerical control (DNC) machines.

The Quality computer-aided verification (CAV) activity (Figure 1) is currently a stand-alone system. More accurately, it is a collection of stand-alone computerized elements. Figure 2 shows our five-axis Bendix-Portage computer-controlled coordinate measuring machine (CCMM). It is uniquely capable of providing accurate measurements of the complex, internally machined Tomahawk cruise missile body sections.

Another CAV application, just now coming on line after extensive use in R&D programs, is our computer-aided ultrasonic inspection system (CAUSS). The CAUSS is shown schematically in Figure 3 and inspecting an experimental composite DC-10 floor beam in Figure 4. This system is being used to inspect composite structures for the Peacekeeper (MX) missile, kevlar panels for the Boeing 767 engine struts, and Tomahawk GSE elements.

Figure 5 depicts a highly successful CAV application, the solder bond evaluation system used to inspect superconductor for a Department of Energy large magnet coil. A completely automated production line machines a groove in a continuous copper bar, inserts a titanium/niobium superconductor, and solders it in place. Our in-line ultrasonic inspection station detects and sizes solder disbonds and the Interdata 610 computer integrates the cumulative area over various units of length. A signal is given when criteria are exceeded. Figure 6 is a photo of the station which has inspected more than 20,000 feet of conductor.

Another computer application is the "paperless work instructions" system currently being developed for our avionics production area (Figure 7). A network of Apple micro-computers display work to technicians via CRT. In this system the Quality Assurance Department "locks-in" verified work instructions and indicates acceptance via a secured code. The obvious advantage of reduced paper work inherent in this type of system is supplemented by the ease of change incorporation.

In addition to these CAV activities, we are operating several computer-assisted CMMs.

Our near-term objective is to integrate our stand-alone computerized equipment into a unified system. As shown in Figure 8, a PDP 11-44 currently on order from DEC will download operating programs to our CCMMs, including a DEA 2305 coming on line, and will collect data from all Quality sources. It will analyze the data, implement a preprogrammed sampling plan according to its findings, and output reports and analyses. Because of the complexities of the five-axis motion of the HA-5, that machine had been programmed totally in the self-teach mode. To avoid tying up the machine for reprogramming caused by changes, we have lined its 11-04 via a modem to a Harris 800. Editing and changes are now accomplished off line. This task will be transferred to the CAV host.

Our goal is to develop a system like that shown in Figure 9. The IBM will provide current product description, configuration control, and manufac-

turing planning data to our CAV host computer. Using the data, Quality Engineering will develop programs to instruct inspectors and/or run computerized inspection stations of various types.

Parts will enter the inspection station and the inspector will input part number, configuration level, and lot size via the remote terminal. The PDP 11-44 will determine that the inspection program it contains is of the proper configuration level for the part to be inspected and will download the program to the appropriate station. It will also tell the inspector, based on lot size and embedded part history, how many parts to inspect. Inspection results will be continuously fed to the CAV host computer which will dynamically update the sampling requirements on a feature-by-feature basis and forward them to the inspection station. When inspection has been completed, the 11-44 will output, through the local printer, any required defect reports. The data will be incorporated into the part history file, analyzed, and processed for Quality management reports and uploaded to the IBM for use in the company-wide management information system.

The next six figures depicit some of the inspection techniques alluded to earlier as currently under independent development.

Figure 10 shows a precision-parts inspection station. Several versions of this system are currently being marketed. They are designed around Hewlett-Packard micros such as the HP 85, 86, or 87 and most incorporate statistical sampling routes. We plan to link this station with the CAV host for program storage and, more importantly, for intra-lot dynamic feature sampling.

A current Convair research program is aimed at adapting developments in missile guidance technology to metrology. Figure 11 indicates our objective to develop a computerized station to accomplish non-contact three-dimensional inspection.

While it will not be a CAV station per-se, the on-line probe system shown in Figure 12 will be an integral segment of the machined-part CAV system. Data from this probe system will be fed through the DNC link to the IBM host and on to the CAV host. There it will influence the level of subsequent inspection and the severity of the sampling plan required.

In addition to the CAUSS system discussed earlier, other NDT applications are planned. Figure 13 shows an eddy current station. These are all to be linked interactively with the CAV host computer.

Other areas of development that we think are needed to pave the way for CAV integration are listed in Figure 15 and are discussed below.

The kind of total integration we have been discussing, using a common data base for CAD, CAM, and CAV is, of course, part of the "factory-of-the-future" ultimate goal. While most of us are heading in that direction, none of us have yet arrived. One of the primary reasons is the predicament we all confront in which ever-more-sophisticated, stand-alone, computerized elements speak different languages. The development of a common language, or at least a common interpreting interface, is critical to further integration of CAV. The development of such a language or interface is the subject of a recently undertaken CAM-I project.

In the assembly area, automated quantitative techniques are necessary to determine that an assembly has the right parts properly installed in the prescribed location. In many applications such as engines, aircraft fuel tanks, etc., to prevent foreign - object damage (FOD), it is also critical to ensure that no unspecified items are present.

The factory of the future will incorporate totally automated cells or flexible manufacturing systems. Many current concepts use an *in*-line inspection station; that is, a separate station in the flow path. Other concepts being addressed in industry allow on-machine verification to achieve even further efficiencies and economies.

Results are needed from current efforts toward in-line, real-time quantitative evaluation of other NDT system outputs. An example is x-ray film interpretation.

In other industries that use very-high-rate continuous process lines, expensive automated process control systems make both technical and economic sense. In the aerospace environment, where production is relatively low rate, such systems are still technically desirable but are usually difficult to justify economically. Simpler automated process control systems that can be integrated into the CAV system are needed.

Further development of non-contact inspection techniques for precision parts should continue, and should include automated three-dimensional image analysis.

Finally, to achieve a real, preventive quality control within CAD/CAM, systems are needed that can feed real-time quality information to the designers, production planners, and associated support groups. This means much more than time-

ly defect reports. An automatic "lock-out" of defect-causing practices based on current production experience should be built into the CAD system.

Many of these computer-age concepts are being acknowledged and pursued in our industry. But the limitless role of CAV can never receive too much attention.

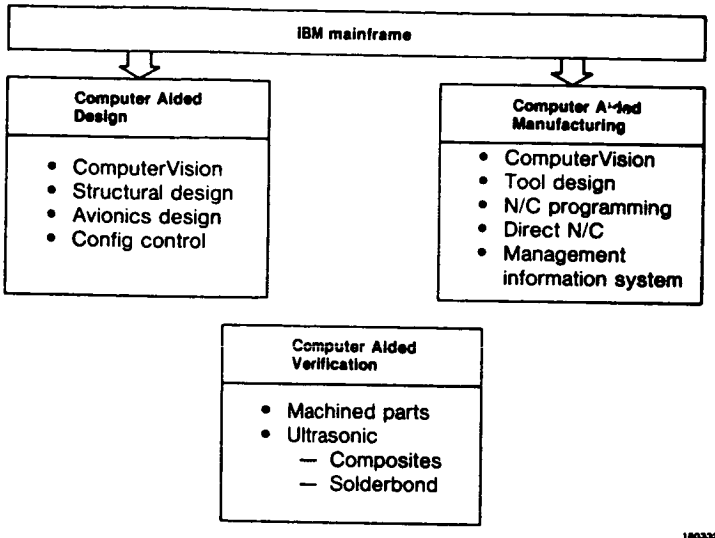

Figure 1. Current CAD/CAM/CAV at Convair.

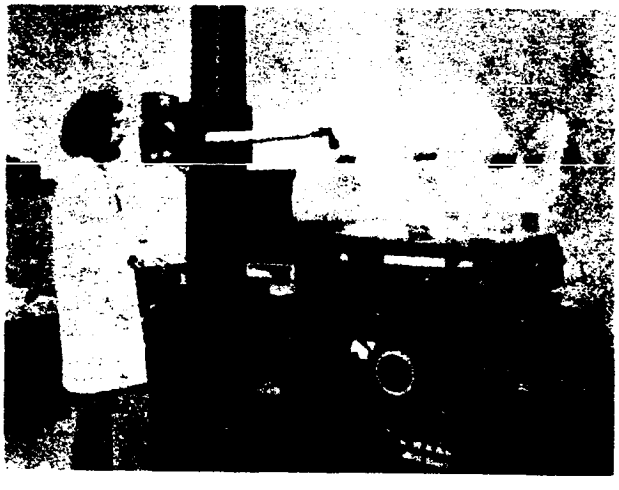

Figure 2. Convair's Bendix HA-5 5-axis CCMM.

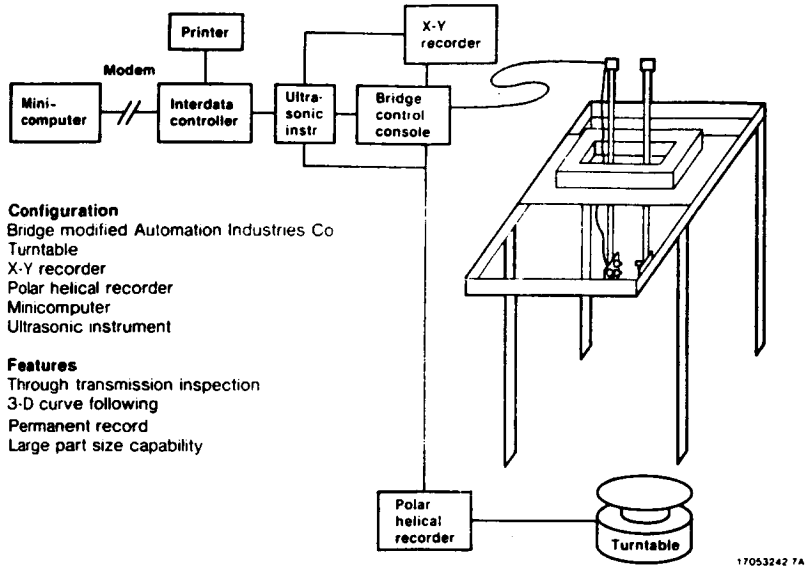

Figure 3. Computer-aided ultrasonic inspection system.

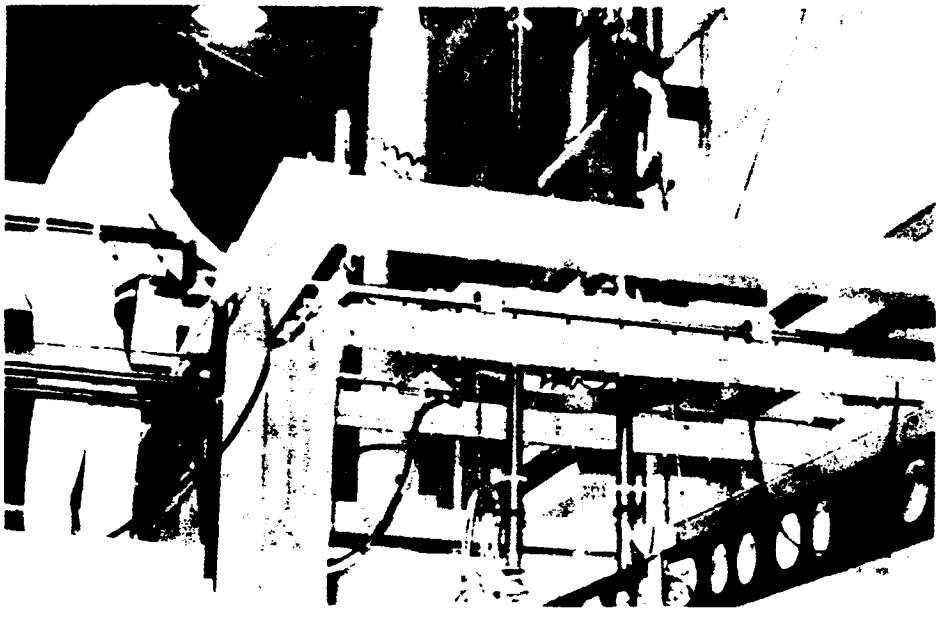

Figure 4. Computer-aided ultrasonic inspection station.

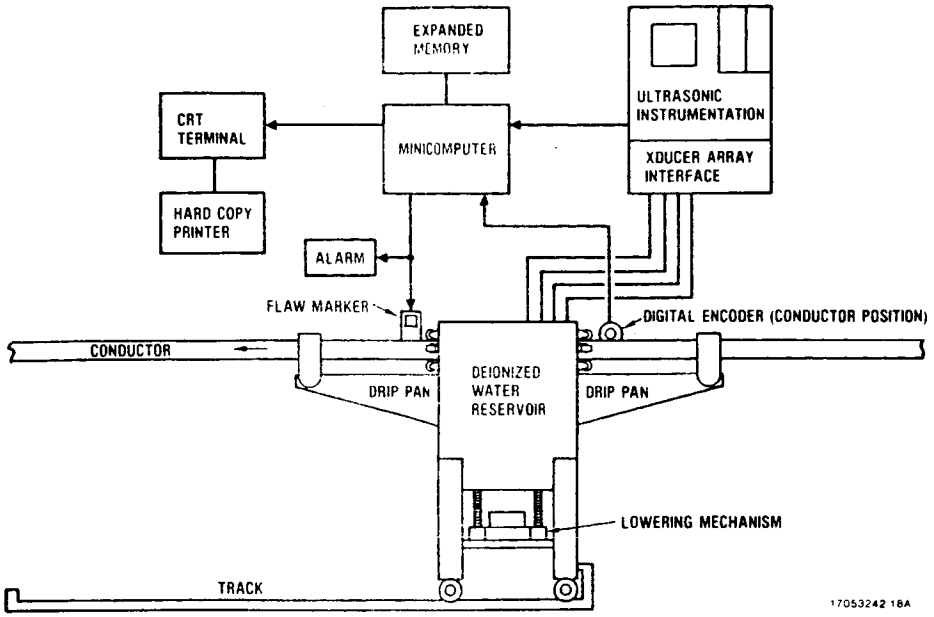

Figure 5. Automated ultrasonic solder-bond inspection system.

Figure 6. Automated ultrasonic solder-bond station.

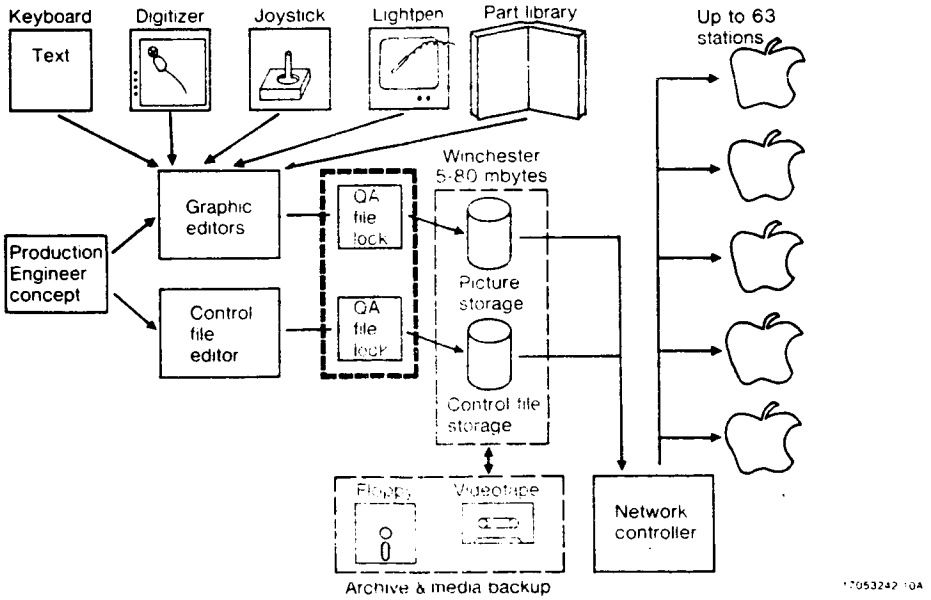

Figure 7. Paperless avionics work instruction system.

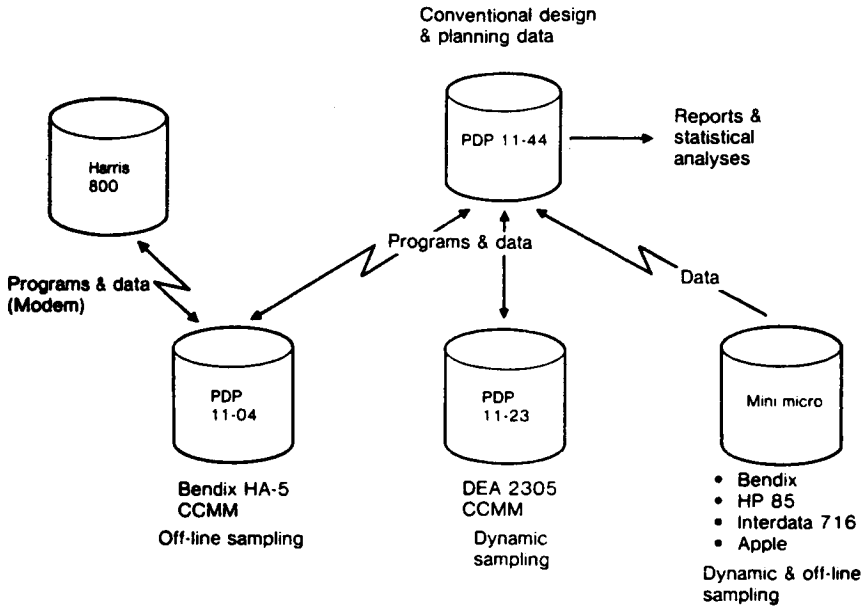

Figure 8. Near-term CAV computer network.

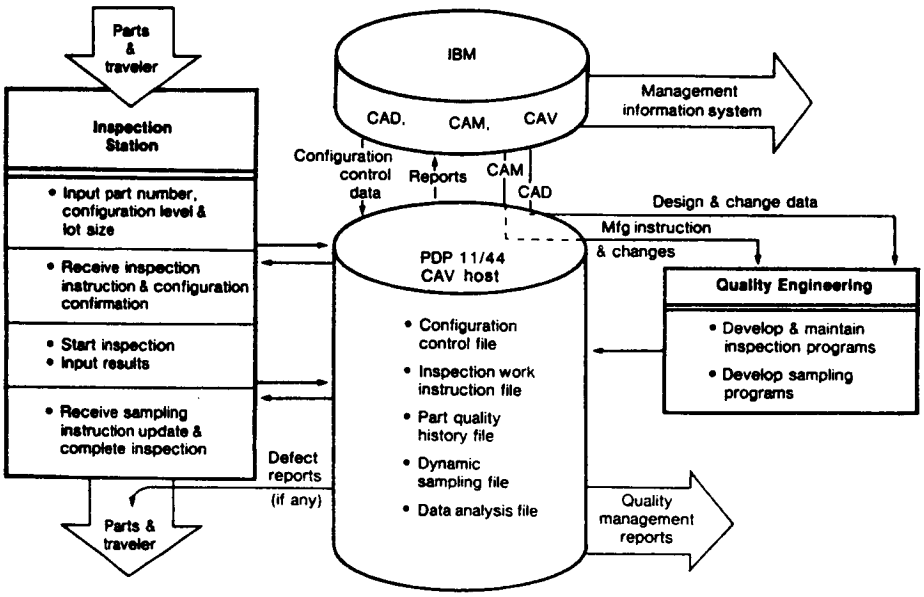

Figure 9. Planned CAV architecture.

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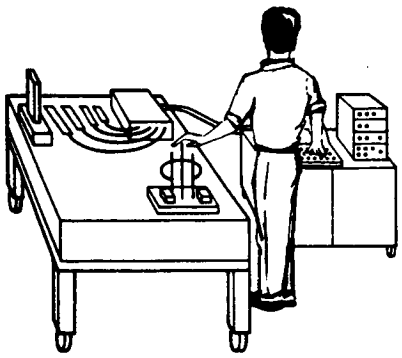

BENEFITS

- Preprogrammed inspection
- Statistical sampling
- Mobile
- Decreases inspection time for repetitive or complex parts
- Increased reproducibility of inspection
- Automatic documentation
- Produces accurate, error-free programs

- Planned implementation — late 1983

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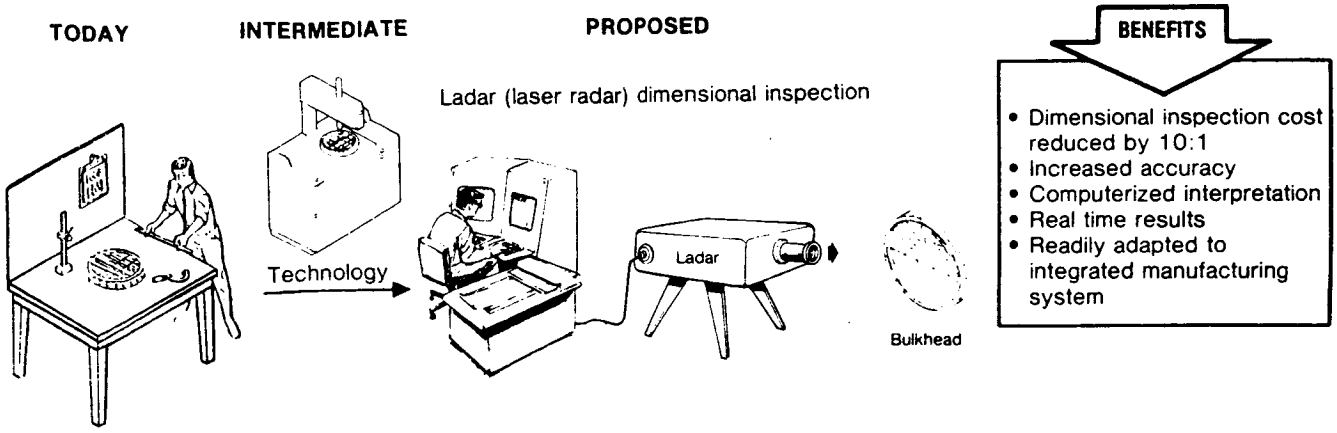
Figure 10. Precision-part computer-aided inspection center.



• Planned implementation — 1986

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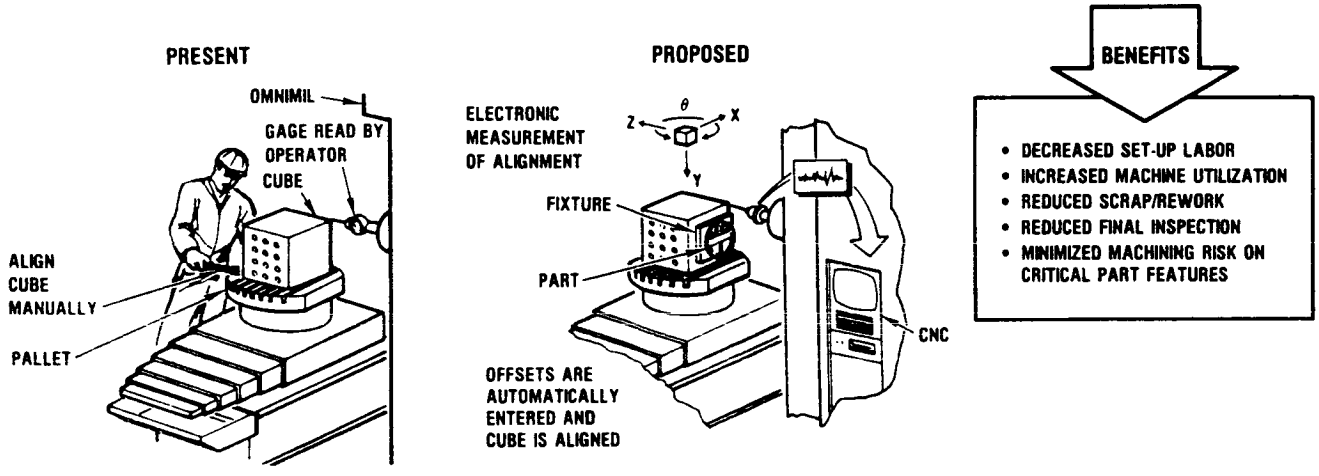
Figure 11. Automated dimensional inspection system.



• Planned implementation — 1985

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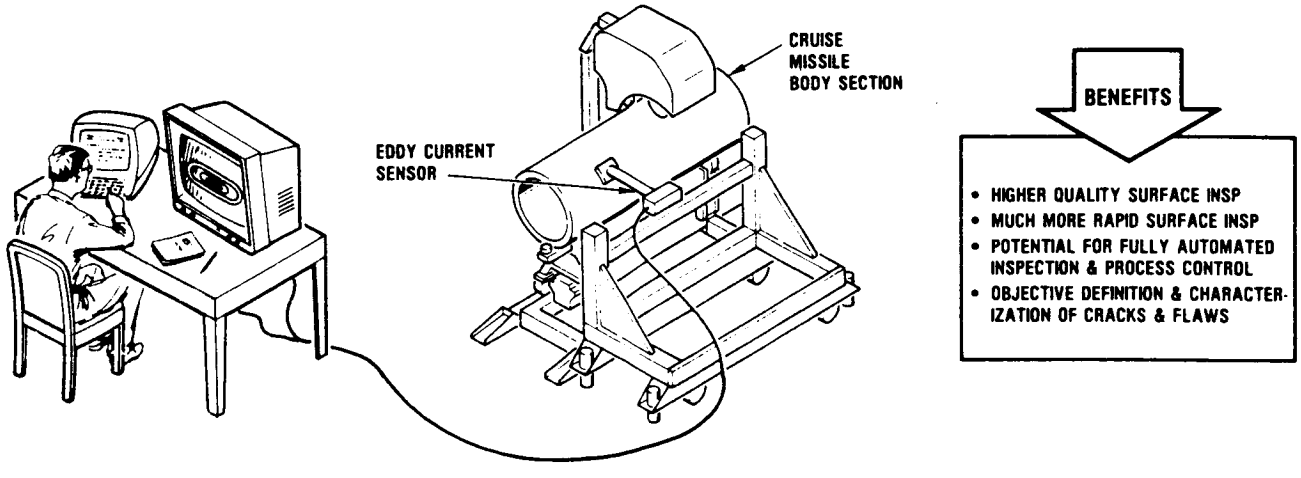
Figure 12. In-line probe inspection of machine parts.



• Planned implementation — 1985

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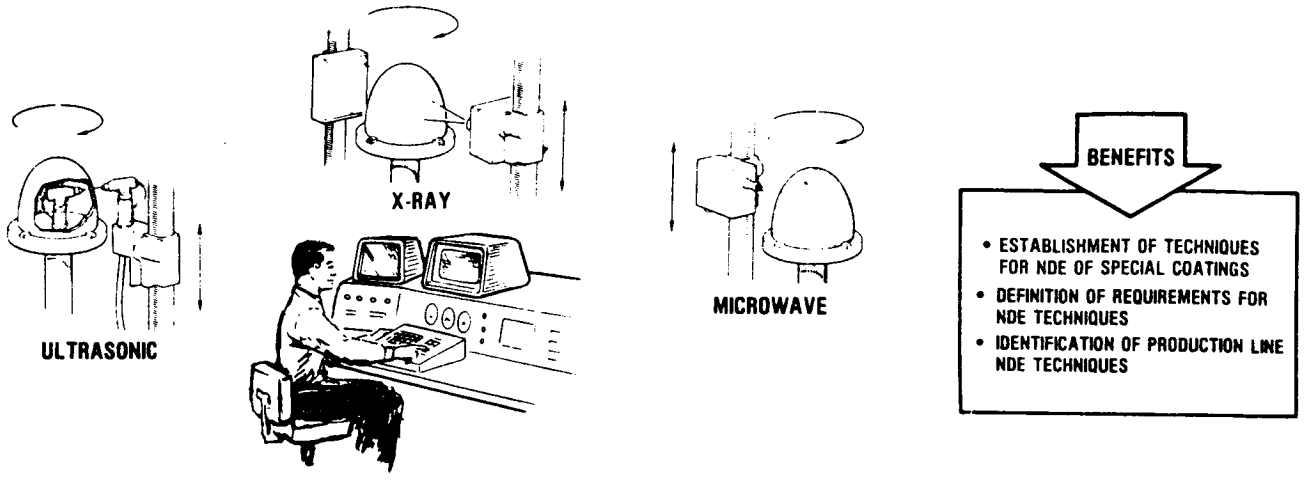
Figure 13. Eddy current phasography.



- Planned implementation — 1985

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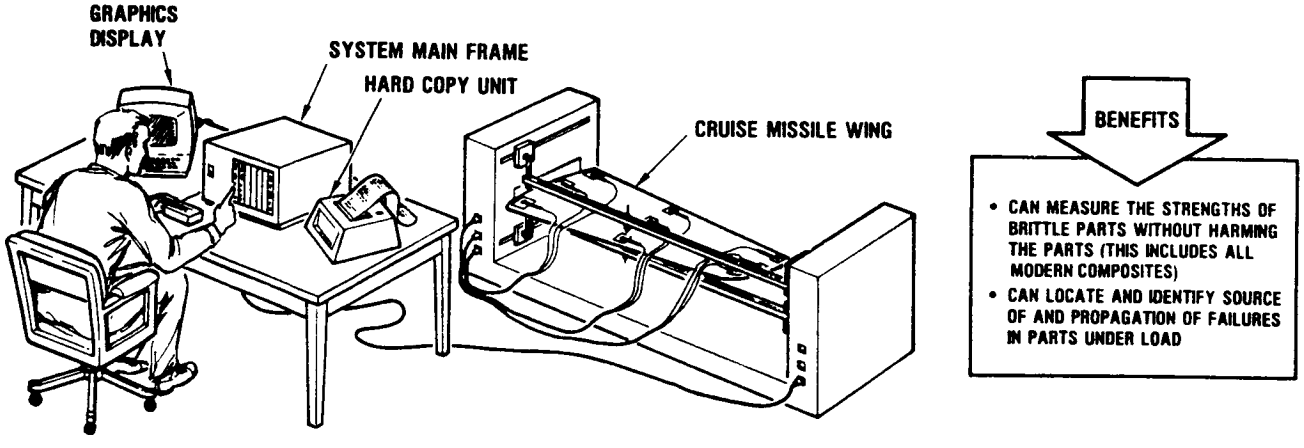
Figure 14. Automated NDE work cell.



- Planned implementation — late 1984

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Figure 15. Acoustic emission.

- Common language for inspection equipment
- Automated assembly verification techniques
- On-machine inspection techniques
- Automated NDT interpretation techniques
- Automated process control for low/medium rates production
- 3-D image analysis for noncontact inspection
- Qualify data processing system to allow automatic feedback to CAD/CAM

17053403-3

Figure 16. CAV developmental needs.

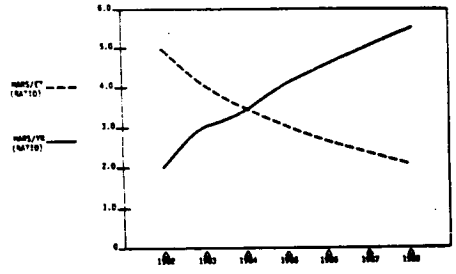
ANOMALY ANALYSIS AND PROCESSING PILOT PROGRAM UTILIZING A NETWORKED CAD SYSTEM.

The objective of the Anomaly Analysis and Processing Pilot Program is to determine the most effective level of utilizing a networked CAD system within the existing nonconformance system. Several CAD workstations will be placed in key locations within the factory and will be utilized as an anomaly analysis and processing network. A CAD workstation will also be placed in Liaison Engineering for MRB analysis.

The results of the Pilot Program will be a recommendation for the degree of implementation of a networked CAD system within the Manufacturing, Quality and Liaison Engineering environment.

ANOMALY ANALYSIS AND PROCESSING PILOT PROGRAM
UTILIZING A NETWORKED CAD SYSTEM

By: Mark Simmons
Martin Marietta Aerospace
Michoud Assembly Facility
New Orleans, Louisiana

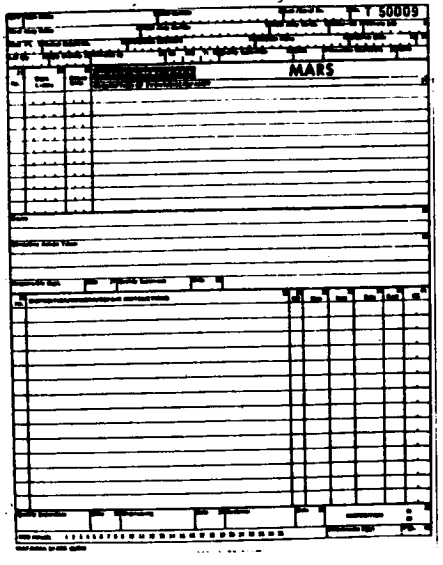


OBJECTIVE

TO SYSTEMATICALLY DETERMINE THE MOST EFFECTIVE LEVEL OF UTILIZING A NETWORKED CAD SYSTEM AS A NONCONFORMANCE PROCESSING AND ANALYSIS TOOL.

TWO AREAS OF STUDY

1) MARS PROCESSING CYCLE
   DISTRIBUTIVE PROCESSING FROM INITIATION TO CLOSURE
2) ANOMALY ANALYSIS
   TECHNICAL RMB ANALYSIS



GENERAL APPROACH TO MARS PROCESSING CYCLE

- o DETERMINE THE BASIC CAPABILITIES AND TECHNIQUES.
  - -- SYNTHETIC DEVIATIONS
  - -- VARIETY OF SITUATIONS
- o OPERATING PLAN
  - -- "HOW TO" WITH OPTIONS
- o PROCESS ACTUAL CLOSED MARS
  - -- SELECTED TO STRESS THE SYSTEM
  - -- RENUMBERED TO PREVENT LOOK-UP
  - -- INCREMENTAL DATA COLLECTION
- o PROCESS SAMPLE OF "NEW" MARS AS BASIS FOR COMPARISON
  - -- MATCHED SITUATIONS
  - -- INCREMENTAL DATA COLLECTION

GENERAL APPROACH TO ANOMALY ANALYSIS

- o DETERMINE THE BASIC CAPABILITIES AND TECHNIQUES
  - -- FINITE ELEMENT MODELING
  - -- NEXT ASSEMBLY ANALYSIS
  - -- CENTER OF GRAVITY DETERMINATION
  - -- MASS PROPERTIES
  - -- STRESS ANALYSIS
  - -- MARGIN OF SAFETY
- o OPERATING PLAN
  - -- COMPUTERVISION VERSUS VAX UTILITIES
- o PROCESS ACTUAL ANOMALIES
  - -- SELECTED TO STRESS THE SYSTEM
  - -- UAI VERSUS REPAIR

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MICHOUD DIVISION

ANOMALY ANALYSIS AND PROCESSING

CHART NO. 6
DATE JUNE 1983
SPEAKER M. SIMMONS

COMPUTERVISION

SEVEN INSTAVIEW WORKSTATIONS

- CRT
- DIGITIZING PEN
- IMAGE CONTROL UNIT
- GRAPHIC TABLET AND MENU
- KEYBOARD
- HARDCOPY PRINTER

TWO GRAPHICS PROCESSOR UNITS

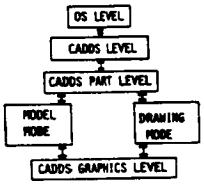
MICHOUD DIVISION

ANOMALY ANALYSIS AND PROCESSING

CHART NO. 7
DATE JUNE 1983
SPEAKER M. SIMMONS

SOFTWARE

CADDS-4 INTERACTIVE GRAPHICS SYSTEM

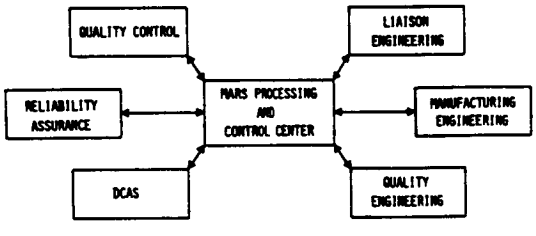


MICHOUD DIVISION

ANOMALY ANALYSIS AND PROCESSING

CHART NO. 8
DATE JUNE 1983
SPEAKER M. SIMMONS

GENERAL MARS NETWORK



MICHOUD DIVISION

ANOMALY ANALYSIS AND PROCESSING

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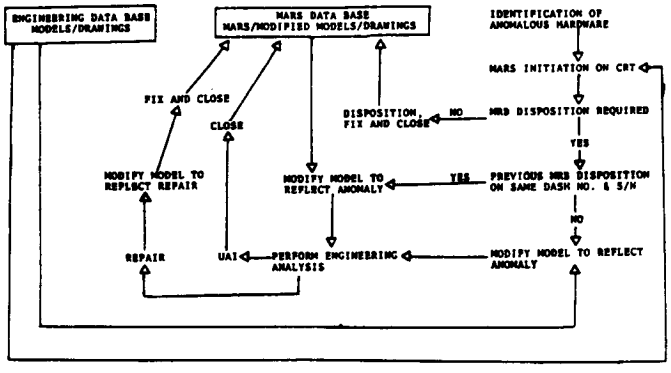
SPEAKER M. SIMMONS



MICHOUD DIVISION

ANOMALY ANALYSIS AND PROCESSING

CHART NO. 10
DATE JUNE 1983
SPEAKER M. SIMMONS

POTENTIAL AREAS OF BENEFIT

1) IMPROVED FLOW TIME OF NONCONFORMING FLIGHT HARDWARE.
2) DECREASE IN TOTAL PROCESSING TIME FOR NONCONFORMANCE DOCUMENTATION.
3) REDUCTION IN OPERATING COST OF THE TOTAL NONCONFORMANCE SYSTEM.
4) REDUCED QUANTITY OF NONCONFORMANCE PAPER.
5) NONCONFORMANCE HISTORY IN GRAPHICAL TERMS.
6) GRAPHICAL ANNOTATION OF ANOMALY FOR ANALYSIS.
7) INHERENT ANALYTICAL UTILITIES.

PAPERLESS QUALITY ASSURANCE OPERATIONS

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INTRODUCTION

For some time we have been thinking about, talking about, and in many instances doing something about the *"paperless factory"* concept, utilization of robots, and other innovations associated with the application of computers in the factory for the end purpose of improving productivity. Some systems are now available - and more are evolving - which offer many opportunities for automating quality assurance-related operations. Many of the advantages to be realized by implementation of automation in the factory are obvious. For example, the immediate availability of test and inspection data that results from the automatic real time collection along with historical data contained in the test and inspection data base for comparison can provide an extremely clear picture of a developing quality problem. The information can be easily accessed by the quality assurance engineer in a variety of different forms such that he is not only advised that a problem exists within minutes, but can be provided with a good idea as to where to start looking for the source of the problem, and may even be given good hints as to what to do about it. Thus, corrective action can be taken immediately, perhaps preventing production of a large number of faulty units. But even more valuable is the availability of trend data which allow corrective action to be taken before a real problem develops.

At the Aerospace Electronic Systems Department (AESD) of General Electric's Aircraft Equipment Division, we initiated a program aimed at automating test and inspection several years ago. This paper discusses and describes some of the *"paperless factory"* (that is, direct electronic quality data collection) aspects of that program. It is divided into three major sections:

- Our products and our factory
- In-roads to a paperless factory (i.e., progress to date)
- Challenges of the future.

OUR PRODUCTS AND OUR FACTORY

AESD can be characterized as a medium sized producer of sophisticated custom electronic systems. Our customer is the military, and the platform for our electronic systems ranges from artillery (for which we provide a radar system that accurately measures the velocity of a projectile as it leaves the muzzle) to ships, airplanes, and space vehicles. For example, AESD provides the Navy with the Surveillance Radar System for the E-2C airplane manufactured by the Grumman Aircraft Corporation. This radar, designated the AN/APS-125, consists of 41 individual units and contains in excess of 28,000 piece parts, most of which are mounted on 97 multilayer boards (MLBs). The total system weighs approximately one ton. We have been producing this system and similar systems preceding it for the last several years, at a rate of 10 to 15 systems per year.

We also produce the AN/AYA-8 Data Processing System for the P-3C airplane. Like the AN/APS-125 radar system, we manufacture this equipment at a fairly low rate — 18 to 24 systems per year — and have been supplying it to the Navy for the last 20 years. The multilayer assembly being used on the latest version of this system is very similar to the AN/APS-125; however, the units (black boxes) are very different. This system contains approximately 21,000 parts, mounted on 105 MLBs.

I could cite other examples of electronic systems, totally different from these in outward appearance, that we manufacture at fairly low rates. The point is that, at system and unit (black box) level, there is very little in common among the electronic systems that we manufacture. In addition, the annual production of each system is relatively small.

Military Requirements

Our primary customer is the military and so we live with restrictions that are not required of nonmilitary producers. Such things as data availability, both now and for future reference, are very important, as is a large category of documentation requirements in general. All of the equipment that we produce must not only survive a broad range of environmental exposures (e.g., temperature, vibration, humidity) but must function reliably for several years. To meet these requirements, our equipment is processed through comprehensive test and inspection operations which, when combined with low production rates, present a formidable challenge to automation.

Common Building Blocks and Standardization

We have taken several actions over recent years that have provided us with the benefits normally associated with high production rates. Probably the most significant single decision along this line was to standardize the basic building blocks of our equipment, the electronic module, or multilayer assembly (MLA). The configuration that

we are using in today's designs is similar to the 3/4 ATR configuration common in airborne systems. It has dimensions of about 7 by 9 inches and contains an MLB consisting of up to 16 layers. The assembly is made up of the MLB, to which an anodized aluminum heat sink is bonded using a resilient material that allows for the difference in thermal coefficient of expansion between the MLB and the aluminum plate. Microcircuits (DIPs) and discrete parts are soldered in place using the wave solder process. The development of this assembly — *today's standard* — was the product of a team of experienced representatives from Engineering, Manufacturing and the Reliability and Quality Assurance Sections. It represents an important departure from the days when Engineering did the design pretty much independently of the other functions. Incorporated in this design are features that are compatible with Engineering's design tools (interactive graphics, for example) and also compatible with Manufacturing's machines, tools, and processes and R&QA's test and inspection facilities. The process of developing this standard included environmental testing at high exposure/stress levels, as well as several hundred cycles of accelerated temperature cycling over the range between −65° and +125°C. The end result is a proven MLA that can be used in most of our systems (except where geometric limitations prevent its use) with an accurately predictable reliability. Since this MLA building block is used across all systems, the annual usage of MLAs is high, resulting in a fairly high production rate.

This means that we are able to implement a high degree of automation throughout the design, manufacturing, test and inspection operations.

Common Data Base

Another key to our success to date in automating our plant is shown in Figure 1, the CAD/CAM/CAQ System. At AESD, engineering design can be done manually or automatically by using the interactive graphics system which has been in place for 15 years or through the use of software programs developed for the completely automated design of multilayer boards. In all instances, the design data are entered into the common data base, placed under configuration control, and made available to the Manufacturing Section and to the Reliability and Quality Assurance (R&QA) section. As shown in Figure 1, both Manufacturing and R&QA can download data from the common data base to their own data bases and then utilize these data for many purposes including the generation of test and inspection software, drill tapes for multilayer boards and test fixtures, and programs to drive a variety of metal cutting machines. In addition, Manufacturing data can be extracted from the Manufacturing data base for use by R&QA and from the R&QA data base for use by Manufacturing. We have found that this easy transfer of data among data bases is a basic requirement for successful factory automation.

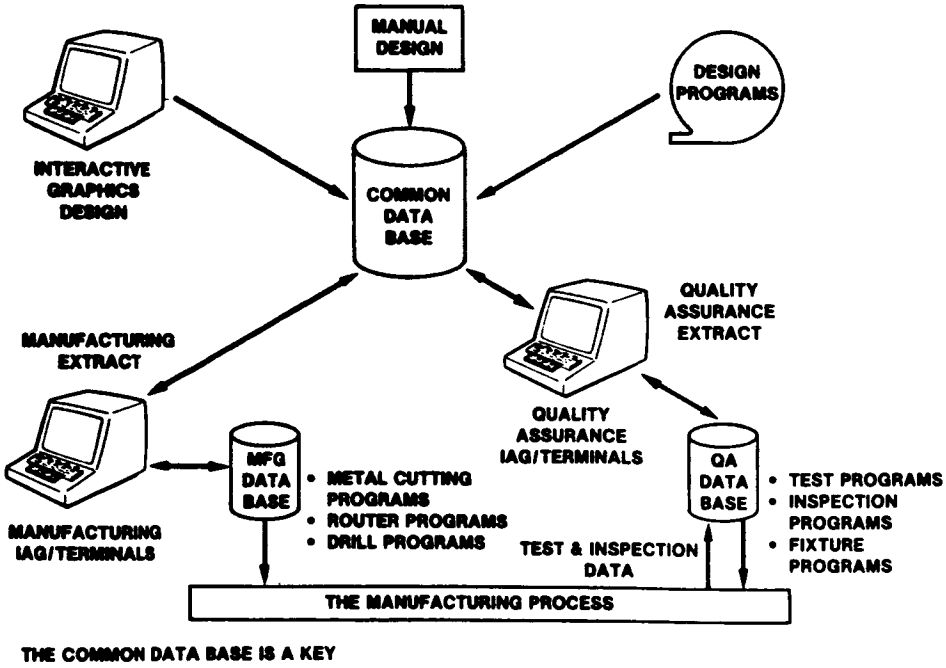

Figure 1. The CAD/CAM/CAQ System

INROADS TO A PAPERLESS FACTORY

In preparation for our inspection station automation program, we conducted a series of studies of several inspection stations representative of the approximately 150 operating stations in the factory. From these studies we concluded that 20 to 50 percent of an inspector's time is spent filling out inspection report forms. This is a laborious, error-prone, and much disliked aspect of an inspector's job. Obviously, the elimination of manual data recording on paper and processing (keypunch, etc.) held a significant productivity improvement potential. An important byproduct of this effort was recognized to be that data thus entered would be available immediately, as opposed to the time lag associated with paper reporting systems. The development of the hardware and software required to achieve our objective of replacing written inspection data by electronic collection of data would be expensive and time-consuming. Past experience indicated that our ability to plan, estimate and schedule even moderately complex software-intensive systems left a great deal to be desired. To tackle the whole factory at once would be forbidding. A step-by-step approach is, therefore, being taken so as to achieve results quickly with a reasonable expenditure of resources. We also decided to depend on off-the-shelf hardware and software to the degree possible, developing custom hardware only when none was readily available and there appeared to be a significant payback to warrant the use of in-house resources. As it has turned out, in all of the implementations attempted or achieved so far, a majority of the software required was developed by our own software engineers. This includes much of the executive and all of the applications software. This was not true in the test area where the producer of our test systems did a good job of developing basic software and making it available to us at a reasonable cost.

A review of the available technology revealed a limited number of concepts that would meet our needs. These were:

- OCR - Optical Character Recognition
- Bar Code
- Voice Input/Output
- Magnetic Card
- Function Keyboards

We had gained experience with magnetic cards while assisting another General Electric plant a few years ago. We felt that the kind of experience gained during the extensive experimenting with the magnetic card systems — that is, learning the characteristics of these systems, their strengths and weaknesses, and where pitfalls could be expected — was absolutely necessary.

The next step was to acquire data collection hardware/software systems that showed promise for meeting our diverse needs, and to gain enough hands-on experience to give us a high degree of confidence that we could successfully place these systems in the factory. Over a period of about two years we purchased, for experimentation and pilot runs, an optical character recognition system, a bar code system, and a voice input/output system.

The remainder of this paper is devoted to descriptions of three implementations in the factory, where the traditional handwritten inspection reports and inspection log sheets were replaced with some form of electronic data entry, accompanied by computer processing of the data and computer generated reports. At the present time we have automated, to some degree, a total of eight stations using OCR, Voice Data Entry, and Function Keyboards. All employ, or will employ, a dedicated microcomputer for real time support.

Standard Electronic Module Inspection Station

AESD has been in the business of manufacturing the Navy Standard Electronic Module (SEM) for several years. This product, a printed circuit assembly, represents a very small part of our total business, which mainly comprises large and relatively complex custom electronic systems. The SEM is an end product. That is, we sell these small (about 1 inch by 1 1/2 inches) low-complexity modules directly to a variety of customers. The relatively high production quantity of up to 10,000 per year, the competitiveness of the market, and the simplicity of this product made it an obvious candidate for our first electronic quality data collection project.

Figure 2 is a simplified flow of the product through the factory before we completely eliminated paper reporting by adapting the inspection station to utilization of an optical character recognition wand reader system for collection of all quality data. A computer-generated traveler card accompanied each lot (of 50 modules) through the factory. The traveler, along with the material for each lot, progressed through various manufacturing operations to the final inspection station. The traveler contained product information (program and drawing number), and a SLACS (Schedule Loading and Control System) number which related all product information to a manufacturing production control data base. This number was to play a key role in automating the inspection station. The inspector began his inspection by filling out the header section of the IDR (Inspection Defect Report) by copying the required information, which included such elements as a drawing number, revision number and reference designator, from the traveler card

to the IDR. He then performed the required inspection of the lot and completed the body of the IDR. This involved writing in a narrative description of any defects, the defect code (a five-digit code consisting of two alpha characters and three numeric characters), the reject quantity and his pay number.

The lot then went to the repair station, where the repairs were accomplished using the information contained on the IDR (e.g., defect description and defect location). The assemblies were reinspected for the repairs and, if no defects were found, the lot was accepted and moved to the next operation.

A copy of the completed IDR was provided to a keypunch operator, who entered the inspection results into the quality data base. These inspection data, appropriately sorted and summarized, were not available for review by the product line quality engineer for three to four days following the inspection.

To automate as much of the data entry as possible, it was decided that either an Optical Character Recognition (OCR) system or a bar code system would meet our needs. The ultimate decision to use OCR was based on the fact that the printers associated with our host computer already printed an OCR readable font on the traveler card. This eliminated the need to purchase a new piece of hardware for printing the code and eliminated a separate printing operation.

Figure 3 shows the factory flow in use today. The equipment at the station consists of an OCR wand reader and a CRT terminal tied to a host computer. A traveler still accompanies the material through the several factory operations; however, it now contains a SLACS number in OCR font.

The inspector is now prompted through the inspection operation by a form flash that appears on the screen of the CRT. The required data are entered as follows:

- Using the OCR wand to read the SLACS number causes a transfer of all of the header data from the manufacturing data base to the quality data base.
- The inspector's pay number is entered using the OCR wand to read the number from a preprinted sheet that contains the pay numbers of all certified inspectors.
- The defect codes are read from preprinted sheets, one reading for each defect, again using the wand.

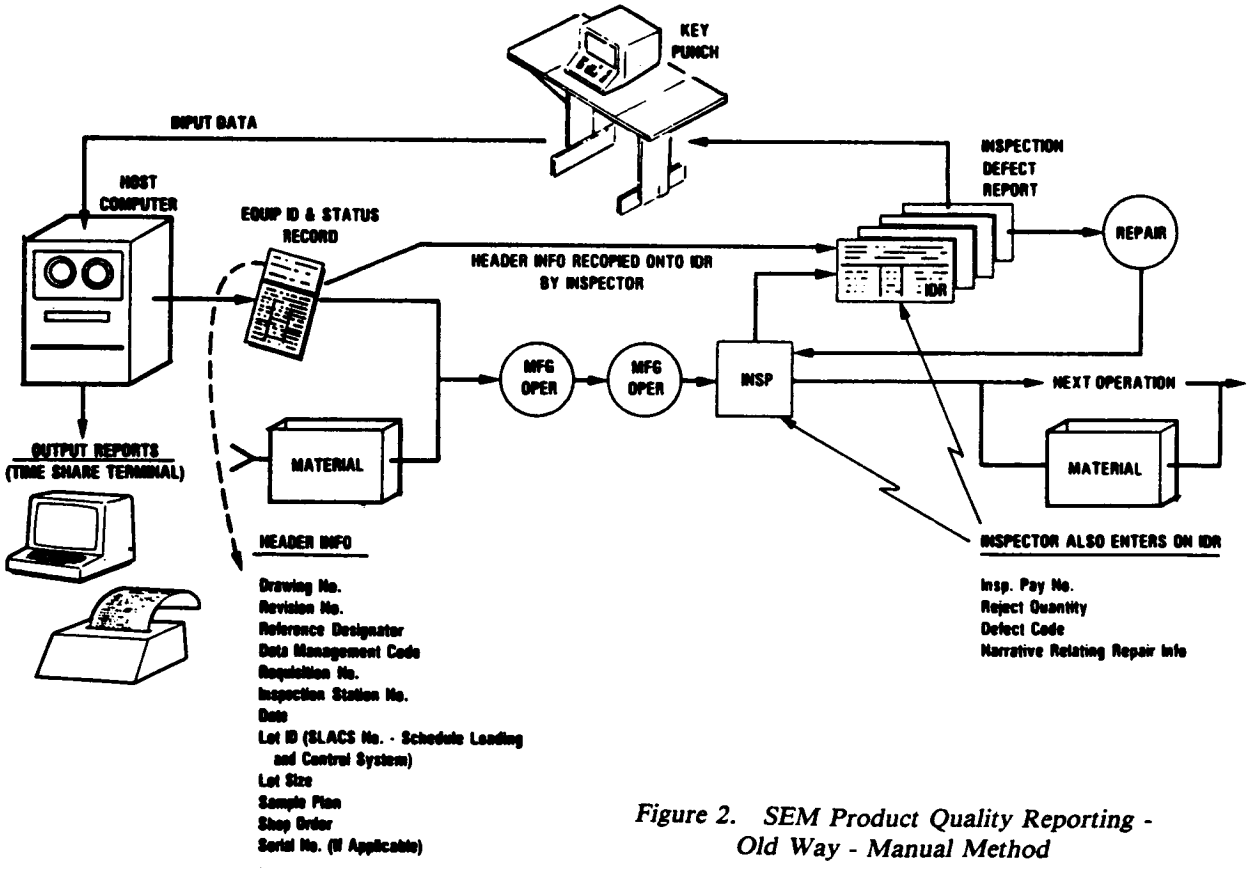

Figure 2. SEM Product Quality Reporting - Old Way - Manual Method

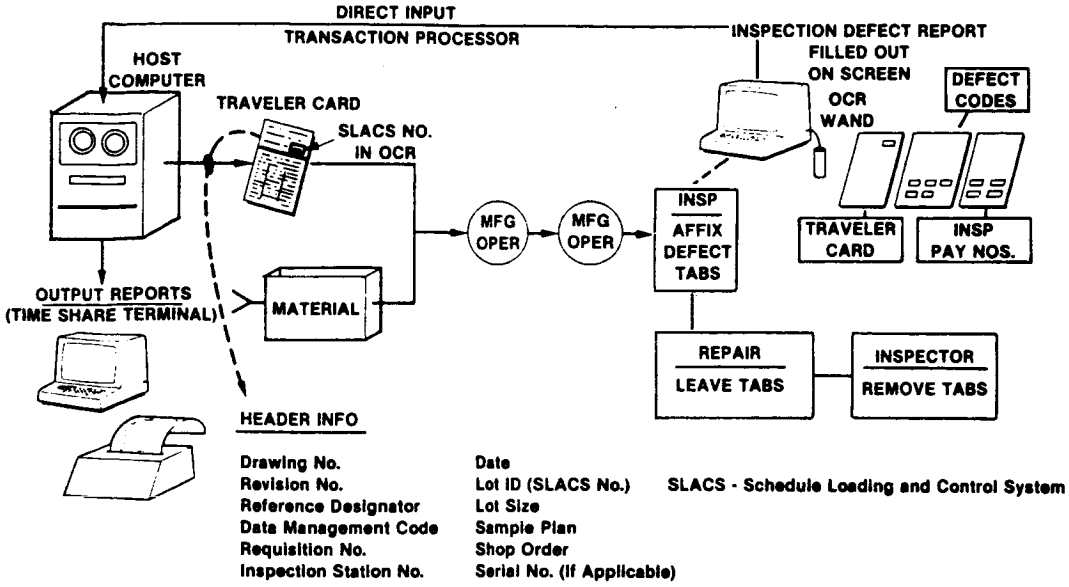

Figure 3. SEM Product Quality Reporting - New Way - Optical Character Recognition

The total reject quantity is computed by the microcomputer, which controls data for the whole inspection operation. The narrative which had been entered on the IDR previously is no longer used. During the studies that preceded implementation of the OCR station, it was found that the repair person did not need the narrative but was able to understand defect descriptions using the defect codes. This was possible because of the relatively small number of defect codes associated with this low-complexity product. Defects are identified by attaching a preprinted adhesive tab adjacent to the defect. This tab is left on the module until the module has passed reinspection. The tab is then removed by the inspector.

Following each inspection the inspector is able to review the complete inspection report on the CRT screen. If satisfied with the report, the inspector uploads it to the host computer, where it is immediately available to the product line quality control engineer in a variety of formats, including several different trend reports.

Computerized Measuring Microscope - Multilayer Board Cross Section Analysis

The microscope used at this inspection station is the typical metallographic microscope used for this type of inspection, but with a linear transducer added to measure and digitize the filar location. The remaining components of the inspection station consist of a keyboard, a CRT, a manual switch for entering the digitized data from the microscope, and a minicomputer for real time control of the station.

At the point in the printed wiring board fabrication cycle following chemical processing (i.e., etchback and copper and solder deposition) each lot of MLBs is sent to the Materials and Processes Laboratory for inspection. Preparation for inspection consists of removing from the border of one or more boards inspection coupons, which are then cast in transparent plastic, cross-sectioned, polished, and visually inspected under medium magnification. The inspection consists of positioning the measuring microscope filar at a reference location, recording the reading, repositioning the filar and recording the next reading. This process continues, requiring up to 150 separate readings for a 10-layer MLB. These measurements are then used to calculate summary data for a particular cross section, involving such measurements as maximum, minimum and average etchback, thickness of copper and lead plating and plated-through hole dimensions.

Prior to automating this inspection station, all readings were recorded on a log sheet. Then, depending on the magnification power of the optics being used, the readings were converted to dimensions which were computed by manually performing a series of arithmetic operations. These data were also recorded on the log sheet. In total, manual recording of detail data, manual calculations and manual entry of summary data consumed 50 percent of the operator's time. The continual looking away from the eyepiece to record detail data during the lengthy measuring sequence caused operator fatigue. At best, only six *"jobs"* (six plastic casts) could be completed in an eight-hour day. Frequently, it was necessary to work overtime to complete the eight to twelve jobs representing production MLBs awaiting release.

At the completion of inspection, chemical processing data (e.g., tank temperature, amperage and processing time) were copied from log sheets kept by Manufacturing in the chemical processing area of the factory. The microscope readings calculations, summary of dimensions and the chemical processing data constituted the required quality data for the particular lot from which the inspection coupons were obtained.

The operator is now guided through the inspection procedure in the required sequence by prompting on the CRT screen. The microscopic inspection is conducted as previously described (i.e., by mounting the inspection coupon and lining up the filar). However, now the required readings are entered into the computer memory by depressing a foot switch. A *"beep"* provides the operator with feedback, thereby eliminating the fatiguing *"look away"* problem described earlier. The readings are converted to appropriate dimensions from a table residing in the computer. This is accomplished by entering the magnification of the optics via the keyboard with the required dimensions and averages calculated by the computer.

As part of this project, the chemical processing data are entered into a manufacturing data base immediately following the processing of each lot of MLBs. At the time of the inspection, these data are entered into the quality data base by keying in the proper code at the inspection station keyboard.

The cost of automating the data collection was approximately $5,000 for hardware and six man-months of programming. The benefits include a doubling of operator throughput. (Twelve jobs can now be completed on one shift.) This eliminated a requirement to purchase additional equipment for another station and the hiring and training of additional inspectors to meet increased production in the MLB shop.

In addition, the data from each inspection are available immediately, directly, and in trend form. This very trend information, not previously available without manually tabulating data from log sheets, is being used to more effectively control the MLB manufacturing process.

Microcomputer Controlled Multifunction Keyboard System

The last system that will be described has been given the name Multifunction Keyboard Inspection System. We have established three identical inspection stations for the P-3C Data Processing System, at each of which 90 separate inspections are performed. Hardware inspected ranges from small cable assemblies to large electronic units. At these stations, no inspection paperwork is generated. Inspection data are available at any time share terminal throughout the plant immediately following the inspection. This multifunction keyboard system overcame the shortcomings of the aforementioned OCR system. The complex products being inspected on this line require a broad spectrum of defect codes. Narrative for repair is also required. The keyboard and printer meet these needs.

Figure 4 contains a block diagram of the system. It is made up of a CRT and a printer — both purchased — and a custom keyboard and a microcomputer — both built at AESD. The keyboard is a simple assembly which we designed to serve each individual need. It is used in a much reduced configuration at other inspection stations. The microcomputer, based on Intel's 8080 microprocessor chip, was developed several years ago at AESD as part of an in-plant microprocessor training course. The course is still taught; and through the years the hardware and software have continuously been upgraded. It has become one of the standards at AESD, not only because of its designed-in capabilities, but also because of the large number of people who are familiar with it, the constant upgradings that are being incorporated in its design, and the large amount of software that is available for it.

The function keyboard used at the three inspection stations is shown in Figure 5. These keyboards all contain numbers from 0 to 9, the full alphabet, some often used phrases (pressing the SOH key, for example, enters *"START OF HEADER"*) and the two alphas and three numerics that make up the mechanical defect codes that are required at these stations.

The information inputted to the system when any key is depressed is controlled by the system software. The number keys are single function and will always enter the number printed on them. The key below the *"O"* is a multifunction key and will enter either the letter *"O,"* the defect code prefix *"DD,"* or the defect code suffix *"016,"* again depending on the software.

To illustrate the system, it is first necessary to say a few words about the defect codes. The general-use mechanical defect codes are shown in Figure 6. Each code comprises two alpha and three numeric characters in a wide range of combinations. For example, CH means *"Component (hardware)",* 002 means *"damaged,"* the code CH002, therefore, means *"damaged hardware"*. CH177 means *"broken hardware"*.

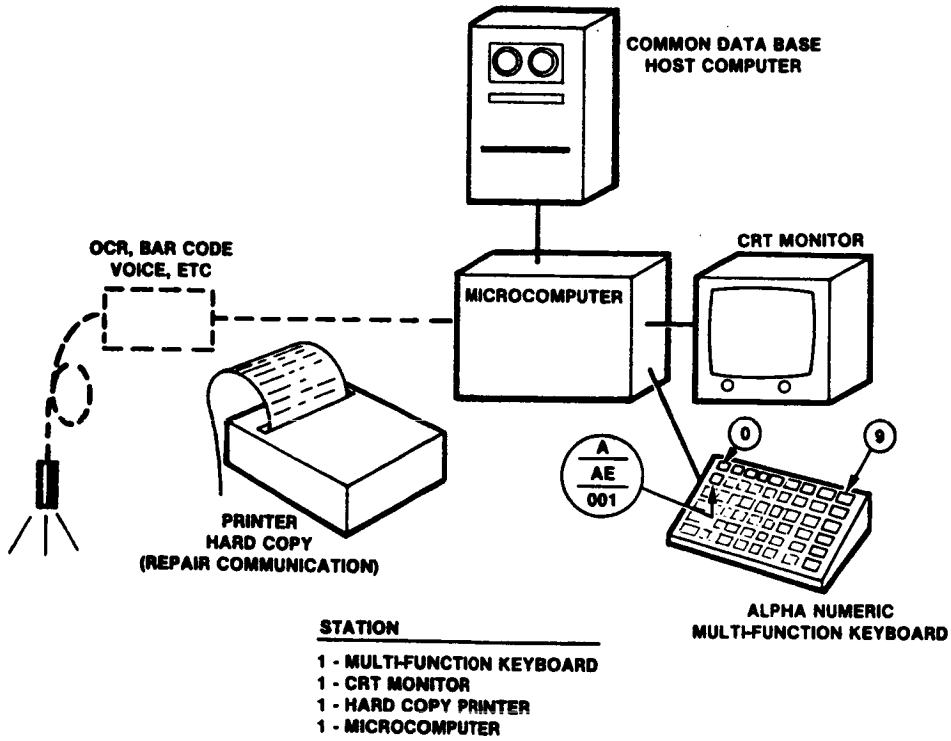

Figure 4. Function Keyboard System Block Plan

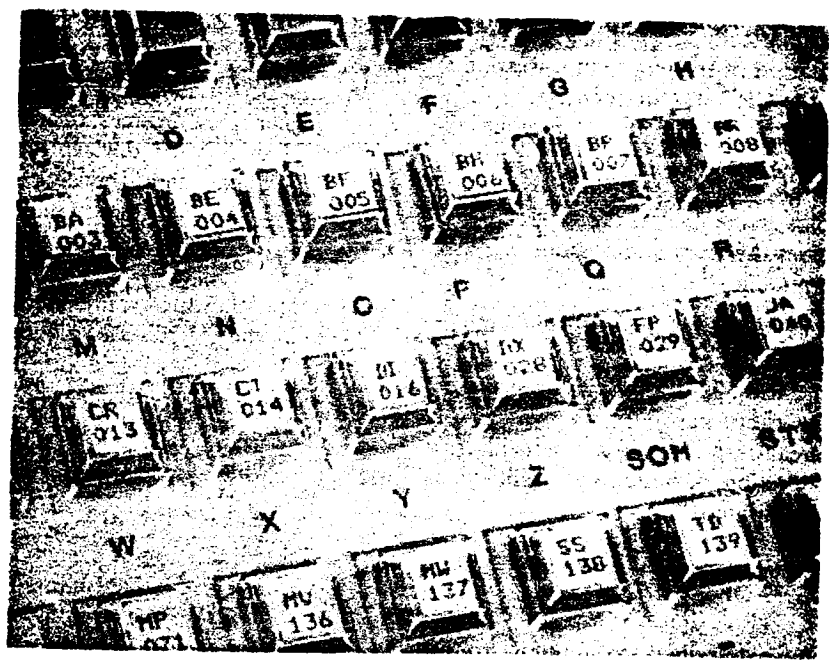

Figure 5. Function Keyboard

GENERAL-USE MECHANICAL DEFECT CODES

NUMERICAL INDEX BY DEFECT DESCRIPTION AND NUMERIC CODE

Mechanical Codes Consist of Two Alpha and Three Numeric Characters, e.g., CH002 = Component Hardware Damaged

ALPHA CHARACTERS

AE	Assembly (Electrical)
AM	Assembly (Mechanical)
BA	Boards (Printed, Molded)
BE	Hole Plated
BF	Fingers
BH	Internal Cond Pattern
BP	Pads (Terminal Area)
BR	Run Conductor
CE	Component (Electrical)
CH	Component (Hardware)
CM	Component (Mechanical)
CP	Connector Pin
CR	Connector
CT	Terminal
DD	Dimensions (Mechanical)
DX	Mechanical Test (Pull, Pressure, Etc)
FC	Finish (Chemical)
FP	Finish (Paints)
JA	Adhesives / Bonding
JM	Mask
JP	Encapsulation / Potting
MP	Braze
ML	Material
MP	Welding (Projection)
MV	Weld (Wire)
MW	Weld
PP	Preservation / Packaging
SS	Solder
TD	Documentation
TM	Marking-Decal / Stencil / Nameplate
TS	Acceptance Stamp
WC	Wire-Cable / Lacing / Dress
WL	Wire (Insulation / Sleeving)
WR	Wire (Termination / Wrap / Crimp)
WT	Wire (Twist)
XC	Configuration (Conforming)

NUMERIC CODE

001	Illegible
002	Damaged
003	Missing (Part / Operation)
004	Incomplete / Insufficient
005	Extra / Excessive
006	Wrong (Material, Size, Type, Color)
007	Loose
008	Out of Tolerance
009	Foreign Material / Dirty
010	Incorrect Connection / Position
011	Not to Revision
012	Not to Specification
013	Corroded / Pitted
014	Cracked
016	Delaminated
028	Height / Length OHL
029	Height / Length ULL
040	Not Flush
041	Inadequate Adhesion
045	Not Seated
046	Burrs
063	Voids
071	Defective
091	Early Cut-In (CIDN Supersedure)
092	Late Cut-In (CIDN Supersedure)
136	Embedded
137	Bridge / Splash (Solder)
138	Cold Joint (Solder)
139	Poor Wetting (Solder)
141	Birdcaging
142	Lifted
143	Measled
144	Recessed
146	Exposed Copper
148	Lead Exceeds Max Dimension After Clipping
149	Lead Contour Not Visible
150	Electrical (or Potential) Short Due to Position
151	Preform Improper
177	Broken
201	Bent
202	Binding
205	Burned / Carboned / Melted / Overheated
207	Contamination
212	Dented / Punctured
217	Leakage (Gas / Fluid)
220	Nicked
223	Pinched
224	Reversed / Backward
252	Flux Not Removed
554	Specification Error
716	Taut

Figure 6. General-Use Mechanical Defect Codes

For the P-3C DPS application, the inspector has a choice of *"filling out"* (electronic flash form - displayed on the CRT) an Inspection Defect Report (IDR), a Test/Inspection Pass Report (TIPR) or an IDR closeout. The time and date are automatically entered into the report file at the time of initiation of the inspection. Responding to prompting on the CRT, the inspector completes the inspection and builds the IDR, TIPR, or closeout record. The microcomputer automatically assigns a record number, causes the printing of a repair feedback ticket, contacts the host, uploads the inspection record to the host, and finally receives the record back from the host for review, closeout, and final storage at the host.

This basic function keyboard system, utilizing a much simpler keyboard, has been successfully used on an earlier automated inspection station involving microelectronics hybrid inspection. The use of keyboards is planned for expansion into other areas of the factory where its utilization for factory data collection, in addition to quality data reporting, will be incorporated.

CHALLENGES OF THE FUTURE

The systems that I have described are stepping stones to the true *"paperless factory"*. We are in the midst of a movement toward increased productivity in our factory through the application of electronic data collection, communication, processing, reporting, and storage. As we look into the future, some fundamental changes in the traditional ways we have done things become more evident. Some of the more significant are:

In the product:

- Smaller dimensions, increased complexity and higher speeds. Circuit boards will be populated with LSI and VLSI devices in hermetic chip carrier (HCC) packages. Device speeds as well as assembly speeds will continue to increase, impacting testing and inspection at all levels.
- New materials and new application of existing materials. For example, the high stresses that result when HCCs are soldered to a commonly used glass epoxy MLB and then the assembly is temperature cycled are causing many users to search for a different material for fabricating MLBs. Quality Assurance will play a major role in the selection, implementation, and process control of these materials.
- Standardization of designs and design features. In order to insure that tomorrow's designs can be fabricated using the very sophisticated, high priced, automated machines, processes, and test and inspection tools that are being implemented today, it is absolutely essential to ensure that the design is compatible with the factory. Therefore, the manufac-

turing and quality organizations are having a much greater influence on design than ever before.

In the factory:

- More automated work centers with computer controlled machines which receive their control instruction from common data bases. The availability of this kind of equipment will increase in the future, as will built-in in-process test and inspection sensors, some with self-correcting feedback capability.
- A new breed of equipment maintenance personnel accompanied by a higher level of training programs for these people.
- Less reliance on visual inspection. The number of solder joints on a chip carrier assembly will make visual inspection very difficult. More emphasis will be placed on automated screening tests to detect faults at all levels; and more environmental cycling (temperature and vibration) to allow the early detection of defects.
- More reliance on software to be used for development of application software.

Conclusion

All of this will require streamlined methods of capturing, processing and presenting data. Computers, peripherals, and software are the tools by which productivity gains can be realized in the Quality Assurance function. Inspection operations can become more productive when not encumbered by stifling paperwork requirements. This paper has illustrated that the *"paperless factory"* is near at hand. The challenge of the quality function is to wisely match needs to the available technologies.

AUTOMATED INSPECTION IN AN UNMANNED FLEXIBLE MACHINING CELL ENVIRONMENT

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ABSTRACT

The assurance of product quality for a large part mix and high production rate of an eight machining center unmanned FMC imposes complex demands on the inspection process. Definition of an inspection philosophy in an unmanned manufacturing environment dictated a departure from traditional operating methods. As part of the flexible machining cell concept, Vought structured an unmanned in-line (serial) inspection system. System operating software within the Vought FMC was structured with provisions for interfacing to existing Quality Assurance systems. FMC system controlled multi-level inspection part programs are being established that are automatically implemented based on inspection results. Unmanned inspection system hardware is to operate in a factory shop environment.

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Mission Assurance Conference

June 1983

CAD/CAM/CAV

Vought

Vought

QUALITY ASSURANCE

FMC at Vought

Vought

QUALITY ASSURANCE

FLEXIBLE MACHINING CELL

Vought

QUALITY ASSURANCE

- Background - Justification
- General Description of System
- Benefits
- What's New?
- Operating Philosophy (CAV)
- Present Status

Vought

QUALITY ASSURANCE

OPPORTUNITY

- Approximately 450 aluminum machined parts
- 90 + ship sets
- 36-in. cube work area

Vought

QUALITY ASSURANCE

An FMC of 8 automated machines equivalent to 5 hydrotels, 8 mills, 4 3-axis profilers and 1 standard machining center

Vought

QUALITY ASSURANCE

FLEXIBLE MACHINING CELL - GENERAL CAPABILITIES

- MACHINING, EQUIPMENT: Single Spindle CNC Machining Centers To Perform Profile Milling, Drilling, Boring, Reaming and Tapping Operations
  - Automatic cutting tool storage, selection and change
  - Automatic pallet (work piece) shuttle received and discharge system
  - High speed machining of aluminum parts
  - Prismatic work area up to 32 in. L x 32 in. W x 36 in. H
  - 3 and 4 axis simultaneous contouring X, Y, Z (and B)
  - Part/fixture weight up to 5,000 lb
  - Chip conveyor and coolant chip shield
  - Part surface sensing probe
  - Broken tool detection

Vought

QUALITY ASSURANCE

FLEXIBLE MACHINING CELL DESCRIPTION

- Complete computer control
- Automated (hands-off) machining (drilling, boring and tapping) in one setup
- Automated (hands-off) pallet transport - machine load/unload system
- In-line part cleaning
- In-line inspection capability
- Mechanized chip collection system
- Computerized cell loading, scheduling, simulation and cutting tool control
- Palletized - parts loaded/unloaded in central area
- Cutting tools set up in central crib area
- No assigned machine operators

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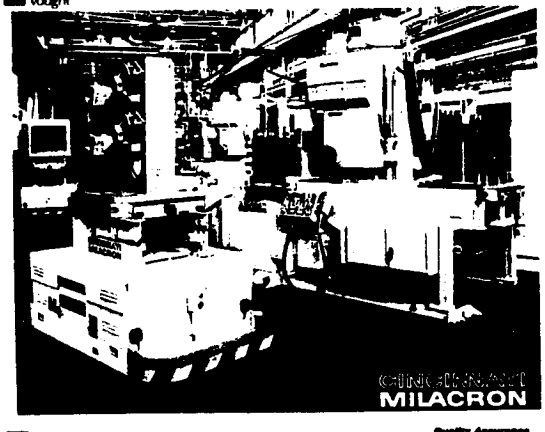
Vought

Quality Assurance

FMC

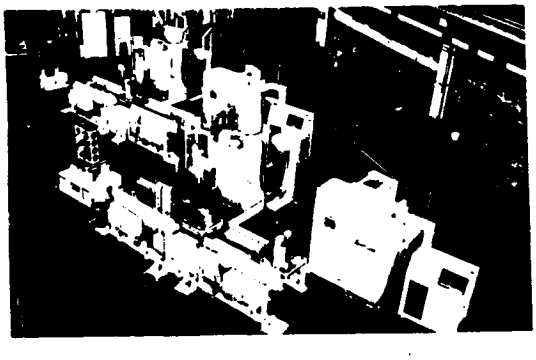
Vought

Quality Assurance



Vought

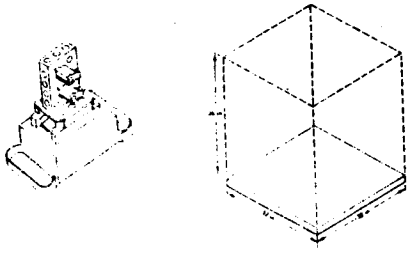
Quality Assurance



Vought

Quality Assurance

FMC WORK CUBE

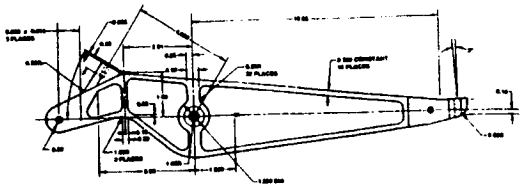


Vought

Quality Assurance

TYPICAL WORKPIECE CANDIDATE FOR FMC

(Part Number L5226070-005)



QUALITY ASSURANCE

Vought

ADVANTAGES OF FMC

- Unmanned — 6 people versus 18 per shift
- Flexible — Multiple machining functions per single load
- Variable mission — Traffic system with all machines capable of performing same task
- Maximum cutting time due to negated setup
- Control of schedule and cost
- Tool management through wear program

Vought

QUALITY ASSURANCE

BENEFITS

- Significant cost savings through improved productivity
  - Hours to make conventional; to make FMC (3 to 1)
- Maximum recovery of equipment cost over 92 ship sets
- Improved program control
- Enhanced Vought machining capacity and capability
- Improved quality
- Initial step toward Factory of the Future

Vought

QUALITY ASSURANCE

So What's New?

On-Line Inspection

Vought

QUALITY ASSURANCE

WHY ON-LINE INSPECTION?

- Traditional off-line inspection costs would have offset most of manufacturing savings
  - Loss of economies from batch production via sampling
  - Additional setup time caused by serial (1 at a time) production
- On-machine verification (while being produced) not available

Vought

QUALITY ASSURANCE

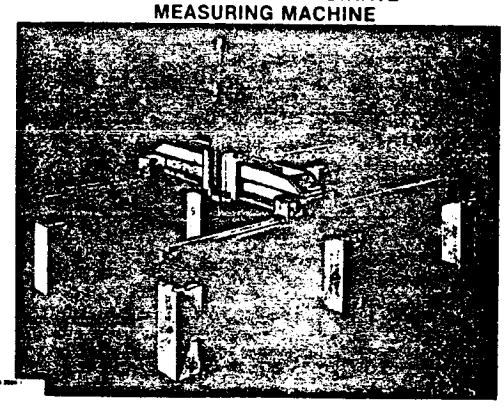
COORDINATE MEASURING MACHINE TYPICAL SYSTEM COMPONENTS

- MEASURING RANGE
  - x = 72 in.
  - y = 72 in.
  - z = 54 in.
- ACCURACY
  - x = ±0.0007 in.
  - y = ±0.0007 in.
  - z = ±0.0004 in.
- REPEATABILITY

  ± 0.00012
- READOUTS
  - Microprocessor Based
  - 0.0001 in. Resolution
- DRIVE SYSTEM
  - Direct Computer Control
  - Joystick Motor Drive for Programming

Vought

DEA GANTRY COORDINATE MEASURING MACHINE



Vought

QUALITY ASSURANCE

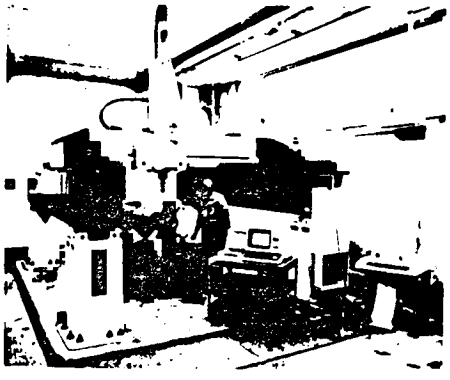
COORDINATE MEASURING MACHINE TYPICAL SYSTEM COMPONENTS (cont)

- Computer
  - DEC PDP 11/24 (CMM host) with 256K bytes memory
  - DEC PDP 11/23 (CMM controllers) with 96K bytes memory
  - Dual RL02 disk drives
  - VT-100 CRT
  - LA-120 DEC writer
- Software
  - DEA HELP-11
  - User-friendly, geometric-based learning program
  - RSX11-M multiuser-based operating system for multiple CMM operation
- Probe
  - DEA TF-58B 5-way electronic touch-trigger

Vought

Quality Assurance

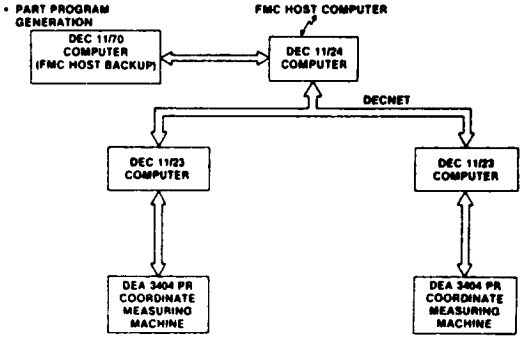
DEA COORDINATE MEASURING MACHINE



Vought

QUALITY ASSURANCE

CMM NETWORK



INSPECTION PHILOSOPHY

- Inspection data derived directly from engineering
  - Dimensioned drawing
  - Master dimension data
- Inspection program independent of cutting program but with visibility of what cutting program is
- Inspection program produced via interactive graphics and/or APT
- Two levels of inspection programs
  - 100% of all features on first article
  - Critical/major characteristics after first article
  - With capability to expand to variable sampling (T-N-R)
- Configuration control via direct QA/engineering interface

MANNING REQUIREMENTS

- Manager (1) 3 shifts
  - Monitors activity - cell control room
  - Schedules unplanned events
- Load/unload operator (4) 2 shifts
  - Load/unload fixtures
  - Load blank material
  - Unload parts
- Tool attendent (1) 2 shifts - available to cell as required
  - Support machining centers tool requirements
- Quality assurance (1) 2 shifts
  - Clear acceptable parts/work orders
  - Process rejected parts/work orders via discrepancy report
- Maintenance representatives (2) 2 shifts - available to cell as required
  - Support mechanical requirements
  - Support electrical requirements

INSPECTION, DATA ACQUISITION AND REPORTING

- Part inspected after each pass through FMC
  - Average 2½ passes per part
  - Data subsets stored for final part definition
- Accept - reject identification
  - Unload station after each inspection
  - Accept - go to next operation
  - Reject - hard copy data printout - go to MRB
- Inspection data interface to existing defect reporting system
- Trend analysis via part data
  - Monitor cell performance - machines and CMMs
- Calibration standard
  - Periodic preventative maintenance - scheduled
  - Troubleshooting - unscheduled

CURRENT STATUS

- Consignment CMM and machine modules on line July 1983
  - Machine module delivered
  - CMM in transit
- Tool design
  - Concept started
  - Initial designs by end July 1983
- NC programming started May 1983
- Inspection programming start July 1983
- First production modules on line February 1984
- Final production modules on line May 1984
- FMC debug and on line July 1984

ABSTRACT

The Role of Computer-Aided Design, Verification, and Manufacturing in the Development of Integrated Circuits

Q. C. Cassen
J. N. Culliney
The Aerospace Corporation

Integrated circuit manufacturing has progressed to the point where tens, and even hundreds, of thousands of transistors are being fabricated on a single integrated circuit chip. Manual methods are no longer sufficient to handle this degree of complexity in a reasonable period of time or with a reasonable expectation of success. Indeed, for large integrated circuits, computer-aided design (CAD) and computer-aided verification (CAV) tools are indispensable, and computer-aided manufacturing (CAM) tools are essential to keeping production costs down by increasing yields while shortening fabrication times.

This presentation first outlines the integrated circuit design, verification, and manufacturing process, and then attempts to convey an appreciation of the developing circuit complexity problem. Emerging strategies, heavily reliant on CAD and CAV tools, for dealing with modern integrated circuit complexities are then examined. Finally, several unresolved issues in the areas of integrated circuit design and verification are presented.

The challenge for the future is the achievement of increased productivity and reliability through innovation. CAD, CAV, and CAM will play an increasingly important role in the continuing pursuit of this goal.

The Role of Computer-Aided Design, Verification and Manufacturing in the Development of Integrated Circuits

D. C. Cassen

J. N. Culliney

The Aerospace Corporation

El Segundo, California

Mission Assurance Conference,

Los Angeles, California

June 7, 1983

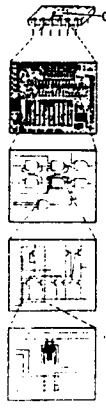
Outline

- BACKGROUND
- INCREASING IMPORTANCE OF CAD/CAV/CAM
- CAD METHODOLOGIES
- ISSUES

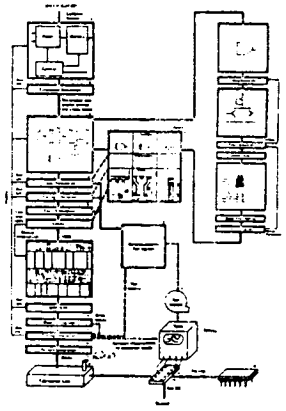
CAD / CAV / CAM

- DESIGN
  - THE PROCESS OF CONSTRUCTION
  - THE "CREATION" PROCESS
- VERIFICATION
  - TECHNIQUES TO ENSURE THE CORRECTNESS OF THE DESIGN
- MANUFACTURE
  - TRANSLATION OF A VERIFIED DESIGN INTO AN OPERATIONAL IC

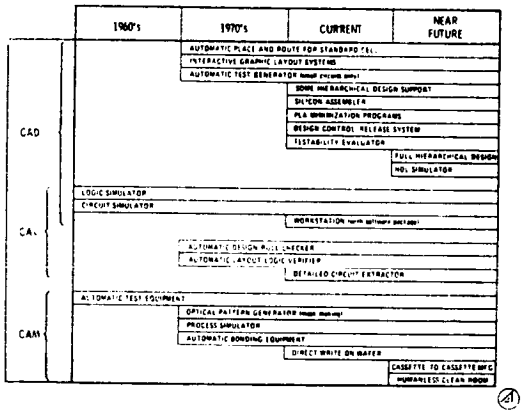
Hierarchical Decomposition of an Integrated Circuit



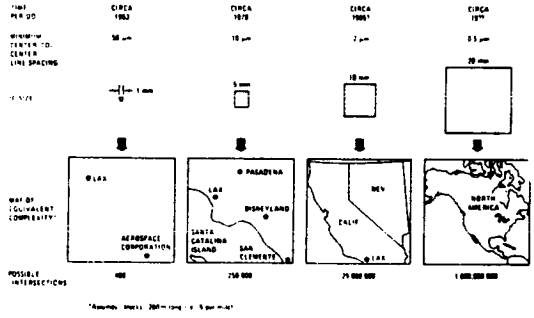
Integrated Circuit Design, Verification and Manufacture



Increasing Influence of CAD / CAV / CAM



Complexity Growth with Increasing IC Size and Density



Computer-Aided Design Methodologies

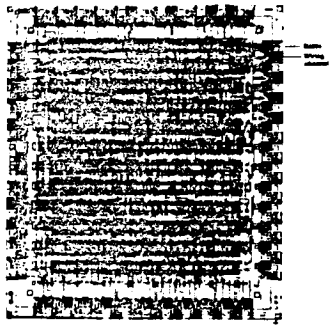
- STANDARD CELL
- GATE ARRAY
- SYMBOLIC LAYOUT
- SILICON COMPILER

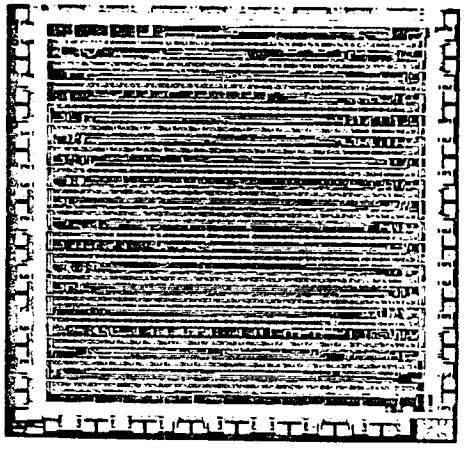
Standard Cell

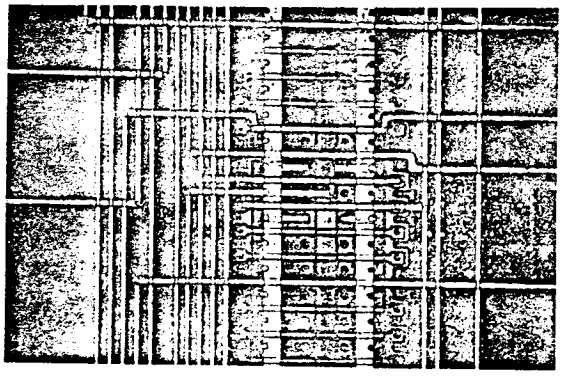
- LIBRARY OF CELLS REPRESENTS PREDEFINED LOGIC FUNCTIONS, USUALLY AT THE LOGIC GATE LEVEL
- CELL DIMENSIONS, PERFORMANCE AND ELECTRICAL CHARACTERISTICS OPTIMIZED AND RECORDED IN ADVANCE OF SPECIFIC APPLICATION
- CELLS PLACED IN ROWS WITH THE NECESSARY AMOUNT OF SPACE RESERVED BETWEEN THE ROWS FOR WIRING CHANNELS
- ADVANTAGES
  - RAPID DESIGN TURNAROUND TIME
  - FLEXIBILITY (large libraries available/new cells easily created)
- DISADVANTAGES
  - WASTED CHIP AREA
  - NO SAVINGS IN FABRICATION TIME

Gate Array

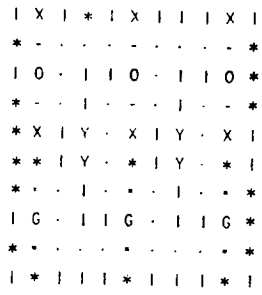
- GATE ARRAY CONTAINS REPEATED CELLS INDEPENDENT OF ANY PARTICULAR CIRCUIT IMPLEMENTATION
- MANUFACTURER USES IDENTICAL GATE PATTERN FOR ALL CHIPS, REGARDLESS OF END USE
- INTERCONNECTIONS FOR PARTICULAR CIRCUIT IMPLEMENTATION SPECIFIED IN THE LAST LAYER OR TWO
- ADVANTAGES
  - RAPID DESIGN TURNAROUND TIME
  - LOW COST
  - SHORT FABRICATION TIME
- DISADVANTAGES
  - WASTED CHIP AREA
  - DECREASED FLEXIBILITY
  - POSSIBLE WIRING RESTRICTIONS



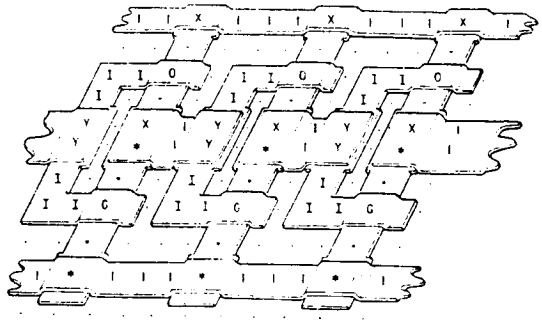




Symbolic Layout of Typical Design

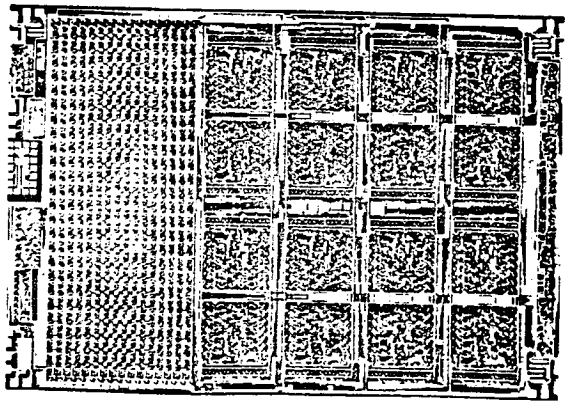


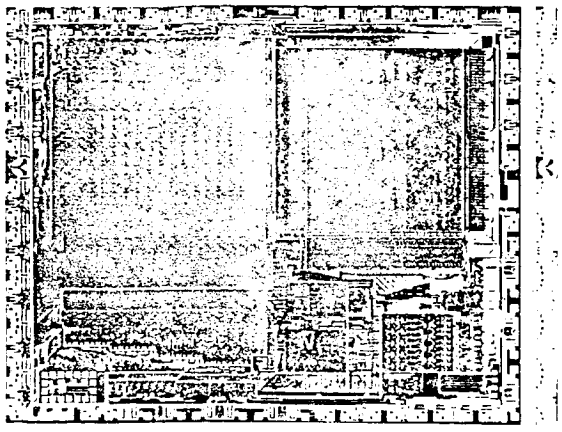
Perspective Drawing of Typical Design



Symbolic Layout

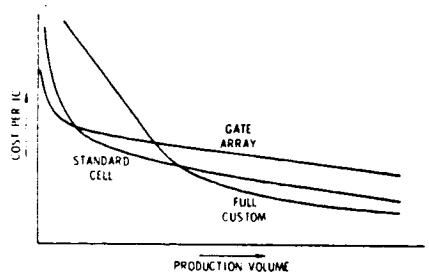
ADVANTAGES	DISADVANTAGES
• HIGH FUNCTIONAL DENSITY	• LONGEST DEVELOPMENT TIME
• LOWEST MANUFACTURING COST IN HIGH VOLUMES	• SEVERAL DESIGN ITERATIONS MAY BE NECESSARY
• MUCH INNOVATION POSSIBLE	• HIGHEST DESIGN DEVELOPMENT COST
• MASKS EASILY MODIFIED AS DESIGN RULES CHANGE (second sourcing)	• MAY ONLY BE ECONOMICAL AT HIGH VOLUMES





Silicon Compiler

IC Implementation Costs



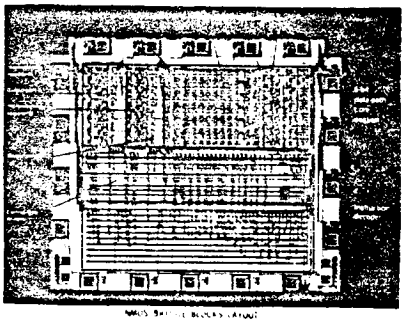
- A SOFTWARE PACKAGE THAT TRANSLATES A HIGH-LEVEL FUNCTIONAL DESCRIPTION TO A MASK LAYOUT
- GOAL IS TO DESCRIBE A COMPLETE DESIGN WITH SEVERAL DAYS WORTH OF INPUTS. THE PROCESS REQUIRED TO GENERATE A MASK-READY LAYOUT WOULD TAKE AN ADDITIONAL DAY AT MOST

ADVANTAGES

- WHEN AVAILABLE, WILL PUT CUSTOM ICS WITHIN THE GRASP OF A WIDE SPECTRUM OF ENGINEERS
- DESIGN IS "CORRECT BY CONSTRUCTION"

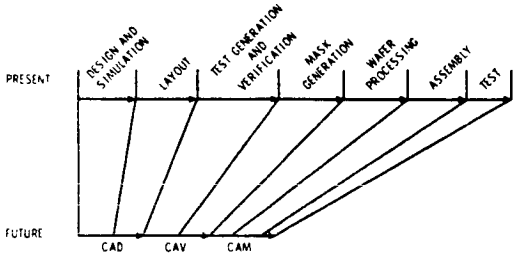
DISADVANTAGES

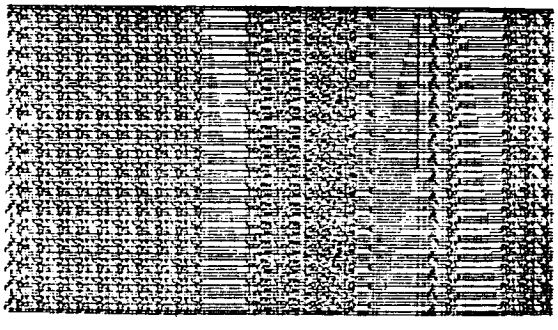
- NOT AVAILABLE TODAY
- MAY NOT BE EFFICIENT WITH RESPECT TO SILICON AREA



MASS SYNTHESIZED LAYOUT

Effect of Automation on Integrated Circuit Development Time





Issues

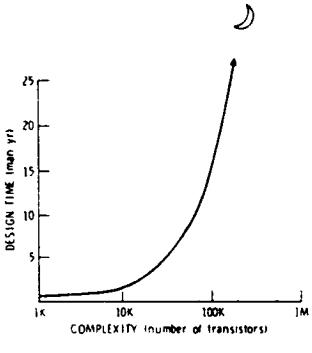
What do we need to know for the future?

Computer Aided Engineering Workstation

- ENABLES THE ENGINEER TO TAKE AN IDEA AND ADVANCE IT TO A SILICON FOUNDRY-READY MASK FILE
- USUALLY BASED ON A 16-BIT PROCESSOR ARCHITECTURE
- TYPICAL FUNCTIONS
  - LOGIC DESIGN CAPTURE
  - TRANSIENT ANALYSIS
  - LOGIC-LEVEL TIMING ANALYSIS
  - COLOR IC LAYOUT EDITING
  - AUTO-ROUTER
  - INTERACTIVE DESIGN RULE CHECKER
- USUALLY COST LESS THAN $100,000

Design Time vs Complexity

- DESIGN TIME IS INCREASING EXPONENTIALLY AS CIRCUIT COMPLEXITY INCREASES
- CAD IS ESSENTIAL IN THE DESIGN OF VLSI



Design Issues

- DESIGN IS BECOMING ASTRONOMICALLY EXPENSIVE, TIME-CONSUMING AND ERROR PRONE
- MANUAL IMPLEMENTATION IS IMPRACTICAL
- ENGINEERS ARE ASKED TO DESIGN NEXT GENERATION PARTS WITH TOOLS OF THE CURRENT GENERATION
- MANUFACTURERS ARE FOREGOING RIGOROUS DESIGN TECHNIQUES ENABLING AN IC TO BE COMPLETELY TESTED AND ARE ACCEPTING THE RISKS OF SHIPPING A DEFECTIVE PRODUCT
- SHORTAGE OF DESIGNERS IS A CRITICAL PROBLEM. INCREASED PRODUCTIVITY IS THE MOST OBVIOUS SHORT-TERM SOLUTION

Verification Issues

- EVEN THE SMALLEST ERROR IN AN IC DESIGN CAN REQUIRE A REDESIGN CYCLE WHICH IMPACTS BOTH SCHEDULE AND COST
- TEST GENERATION AND VERIFICATION CAN CONSUME 30% TO 50% OF THE COST OF IMPLEMENTING A CUSTOM INTEGRATED CIRCUIT
- AS CIRCUIT COMPLEXITY GROWS, DESIGN-FOR-TESTABILITY, TEST VERIFICATION AND IC TESTING NECESSITATE THE GENERATION OF NEW CAD/CAV/CAM TOOLS
- STATE-OF-THE-ART IC SPEED AND/OR PIN-COUNT ALREADY EXCEEDING TESTER CAPABILITIES

Challenge

- TO CAUSE DESIGN AUTOMATION TO BE ADVANCED BY THE VLSI PRODUCTS WHICH IT CREATES

Acknowledgements:

1. Science Magazine, April 1983
2. Science Magazine, April 1983
3. Proceedings, CALTECH Conference on VLSI, January 1979
4. IEEE Spectrum/ZyMOS Corporation, June 1982
5. IEEE Spectrum/Digital Equipment Corporation, June 1982
6. Rockwell International
7. Rockwell International
8. Rockwell International
9. IEEE Spectrum/California Institute of Technology, June 1982
10. Matheus Corporation
11. Industrial Circuit Engineering
12. Strategic Inc.

CAD/CAM/CAV SYSTEMS FOR M&P LABORATORY

The M&P Laboratory at the Marshall Space Flight Center has approval to procure two separate CAD/CAM systems for Laboratory utilization. One system will be the Intergraph Color Design Station as is currently utilized by other Laboratories at MSFC. The other system will be the Computervision Designer "M" series currently being implemented at the New Orleans Michoud Assembly Facility for the External Tank. Both systems are expected to be operational this year. Projected uses include robotic simulation for shuttle processes development/enhancement, tooling improvements identification for inhouse evaluation,and design of test apparatus.

	MARSHALL SPACE FLIGHT CENTER	
EH44	PLANNED CAD/CAM/CAV FOR M&P LABORATORY AT MSFC	NAME: EHL DATE: JUNE 1983

- FUNDED SYSTEMS
  - COMPUTERVISION - DESIGNER M SERIES
    - INSTAVIEW C COLOR WORK STATION (PS-H23-03)
    - PRINTER
    - PEN PLOTTER P1000
    - 8" X 8" HARD COPY UNIT
    - GRAPHICS ROBOTICS INTERFACE (M4647)
    - COMPUTER AIDED MANUFACTURING SOFTWARE PACKAGE (PS-S47-07)
  - EXPECTED OPERATIONAL CY 1983

	MARSHALL SPACE FLIGHT CENTER	
EH44	PLANNED CAD/CAM/CAV FOR M&P LABORATORY AT MSFC	NAME: EHL DATE: JUNE 1983

- FUNDED SYSTEMS
  - INTERGRAPH
    - COLOR DESIGN STATION (DSP037)
    - PLOTTER (PLT032)
    - PRINTER (PLT046)
    - DISCK STORAGE
    - EXPANSION RACK
    - MEMORY MODULES
  - EXPECTED OPERATIONAL CY 1983

ORGANIZATION	MARSHALL SPACE FLIGHT CENTER	NAME
EH44	PLANNED CAD/CAM/CAV FOR M&P LABORATORY AT MSFC	EHL
		DATE JUNE 1983

- INTERGRAPH

DESIGN STATION BUILDING 4711 → CPU BUILDING 4487

- COMPUTERVISION

DESIGN STATION BUILDING 4711 → CPU BUILDING 4202 → CAD/CAM/CAV MAF

ORGANIZATION	MARSHALL SPACE FLIGHT CENTER	NAME
EH44	PLANNED CAD/CAM/CAV FOR M&P LABORATORY AT MSFC	EHL
		DATE JUNE 1983

- PLANNED UTILIZATION OF CAD/CAM SYSTEMS
  - TOOL DESIGN CHANGES - LARGE VPPA WELD TOOLING
  - DESIGN OF NEW TOOLS FOR PROCESS CHANGES
    - OUTSIDE WELDING FOR ET BARREL ASSEMBLIES
    - NEW MANDREL DESIGNS FOR ET SUBASSEMBLY WELD STATIONS
  - ROBOTIC SIMULATION FOR:
    - ET WELDING & REPAIR
    - SSME WELD DEVELOPMENT
    - TPS REMOVAL FROM SRB
    - SOFI APPLICATION
  - DRAWING RETRIEVAL
  - SPECIFICATION RETRIEVAL
  - CRITICAL PROCESS CONTROL

ORGANIZATION	MARSHALL SPACE FLIGHT CENTER	NAME
EH44	PLANNED CAD/CAM/CAV FOR M&P LABORATORY AT MSFC	EHL
		DATE JUNE 1983

- ANTICIPATED FUTURE UTILIZATION
  - AUTOMATIC VERIFICATION OF MIS MATCH AND PEAKING FOR ET
  - WELD QUALITY VERIFICATION FOR SSME, ET & SRB
  - ROBOTIC SIMULATION & VERIFICATION OF PROGRAMMING BEFORE PROCESS APPLICATION

PAPERLESS QUALITY ASSURANCE OPERATIONS

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Thomas J. Nolan
Robert V. Caine
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Aerospace Electronic Systems Department
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INTRODUCTION

For some time we have been thinking about, talking about, and in many instances doing something about the "*paperless factory*" concept, utilization of robots, and other innovations associated with the application of computers in the factory for the end purpose of improving productivity. Some systems are now available - and more are evolving - which offer many opportunities for automating quality assurance-related operations. Many of the advantages to be realized by implementation of automation in the factory are obvious. For example, the immediate availability of test and inspection data that results from the automatic real time collection along with historical data contained in the test and inspection data base for comparison can provide an extremely clear picture of a developing quality problem. The information can be easily accessed by the quality assurance engineer in a variety of different forms such that he is not only advised that a problem exists within minutes, but can be provided with a good idea as to where to start looking for the source of the problem, and may even be given good hints as to what to do about it. Thus, corrective action can be taken immediately, perhaps preventing production of a large number of faulty units. But even more valuable is the availability of trend data which allow corrective action to be taken before a real problem develops.

At the Aerospace Electronic Systems Department (AESD) of General Electric's Aircraft Equipment Division, we initiated a program aimed at automating test and inspection several years ago. This paper discusses and describes some of the "*paperless factory*" (that is, direct electronic quality data collection) aspects of that program. It is divided into three major sections:

- Our products and our factory
- In-roads to a paperless factory (i.e., progress to date)
- Challenges of the future.

OUR PRODUCTS AND OUR FACTORY

AESD can be characterized as a medium sized producer of sophisticated custom electronic systems. Our customer is the military, and the platform for our electronic systems ranges from artillery (for which we provide a radar system that accurately measures the velocity of a projectile as it leaves the muzzle) to ships, airplanes, and space vehicles. For example, AESD provides the Navy with the Surveillance Radar System for the E-2C airplane manufactured by the Grumman Aircraft Corporation. This radar, designated the AN/APS-125, consists of 41 individual units and contains in excess of 28,000 piece parts, most of which are mounted on 97 multilayer boards (MLBs). The total system weighs approximately one ton. We have been producing this system and similar systems preceding it for the last several years, at a rate of 10 to 15 systems per year.

We also produce the AN/AYA-8 Data Processing System for the P-3C airplane. Like the AN/APS-125 radar system, we manufacture this equipment at a fairly low rate — 18 to 24 systems per year — and have been supplying it to the Navy for the last 20 years. The multilayer assembly being used on the latest version of this system is very similar to the AN/APS-125; however, the units (black boxes) are very different. This system contains approximately 21,000 parts, mounted on 105 MLBs.

I could cite other examples of electronic systems, totally different from these in outward appearance, that we manufacture at fairly low rates. The point is that, at system and unit (black box) level, there is very little in common among the electronic systems that we manufacture. In addition, the annual production of each system is relatively small.

Military Requirements

Our primary customer is the military and so we live with restrictions that are not required of nonmilitary producers. Such things as data availability, both now and for future reference, are very important, as is a large category of documentation requirements in general. All of the equipment that we produce must not only survive a broad range of environmental exposures (e.g., temperature, vibration, humidity) but must function reliably for several years. To meet these requirements, our equipment is processed through comprehensive test and inspection operations which, when combined with low production rates, present a formidable challenge to automation.

Common Building Blocks and Standardization

We have taken several actions over recent years that have provided us with the benefits normally associated with high production rates. Probably the most significant single decision along this line was to standardize the basic building blocks of our equipment, the electronic module, or multilayer assembly (MLA). The configuration that

we are using in today's designs is similar to the 3/4 ATR configuration common in airborne systems. It has dimensions of about 7 by 9 inches and contains an MLB consisting of up to 16 layers. The assembly is made up of the MLB, to which an anodized aluminum heat sink is bonded using a resilient material that allows for the difference in thermal coefficient of expansion between the MLB and the aluminum plate. Microcircuits (DIPs) and discrete parts are soldered in place using the wave solder process. The development of this assembly — *today's standard* — was the product of a team of experienced representatives from Engineering, Manufacturing and the Reliability and Quality Assurance Sections. It represents an important departure from the days when Engineering did the design pretty much independently of the other functions. Incorporated in this design are features that are compatible with Engineering's design tools (interactive graphics, for example) and also compatible with Manufacturing's machines, tools, and processes and R&QA's test and inspection facilities. The process of developing this standard included environmental testing at high exposure/stress levels, as well as several hundred cycles of accelerated temperature cycling over the range between −65° and +125°C. The end result is a proven MLA that can be used in most of our systems (except where geometric limitations prevent its use) with an accurately predictable reliability. Since this MLA building block is used across all systems, the annual usage of MLAs is high, resulting in a fairly high production rate.

This means that we are able to implement a high degree of automation throughout the design, manufacturing, test and inspection operations.

Common Data Base

Another key to our success to date in automating our plant is shown in Figure 1, the CAD/CAM/CAQ System. At AESD, engineering design can be done manually or automatically by using the interactive graphics system which has been in place for 15 years or through the use of software programs developed for the completely automated design of multilayer boards. In all instances, the design data are entered into the common data base, placed under configuration control, and made available to the Manufacturing Section and to the Reliability and Quality Assurance (R&QA) section. As shown in Figure 1, both Manufacturing and R&QA can download data from the common data base to their own data bases and then utilize these data for many purposes including the generation of test and inspection software, drill tapes for multilayer boards and test fixtures, and programs to drive a variety of metal cutting machines. In addition, Manufacturing data can be extracted from the Manufacturing data base for use by R&QA and from the R&QA data base for use by Manufacturing. We have found that this easy transfer of data among data bases is a basic requirement for successful factory automation.

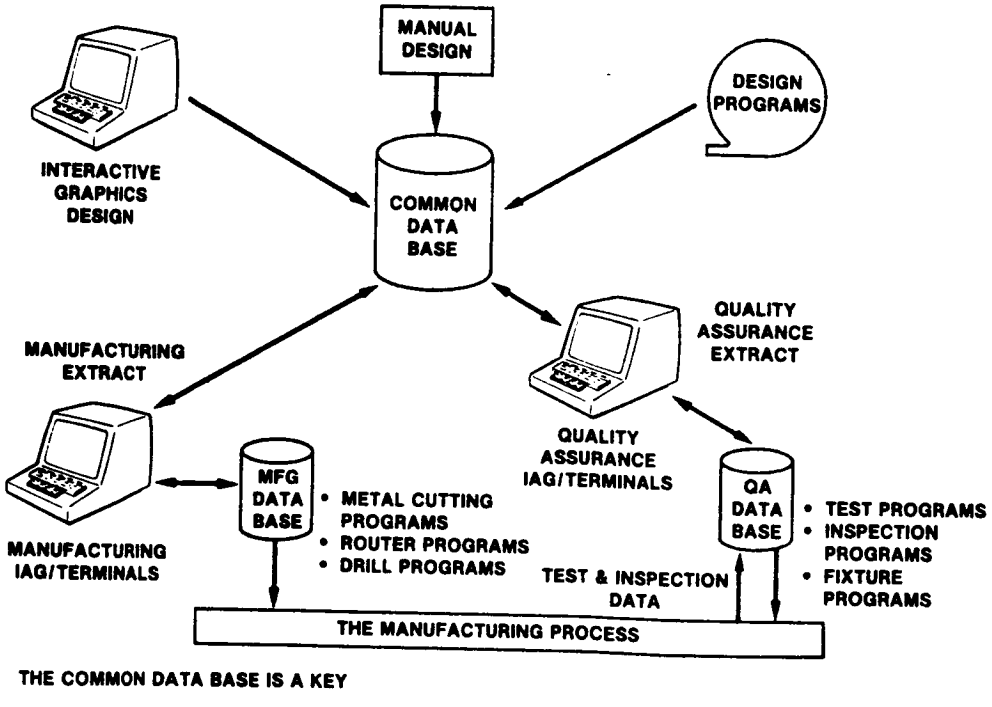

Figure 1. The CAD/CAM/CAQ System

INROADS TO A PAPERLESS FACTORY

In preparation for our inspection station automation program, we conducted a series of studies of several inspection stations representative of the approximately 150 operating stations in the factory. From these studies we concluded that 20 to 50 percent of an inspector's time is spent filling out inspection report forms. This is a laborious, error-prone, and much disliked aspect of an inspector's job. Obviously, the elimination of manual data recording on paper and processing (keypunch, etc.) held a significant productivity improvement potential. An important byproduct of this effort was recognized to be that data thus entered would be available immediately, as opposed to the time lag associated with paper reporting systems. The development of the hardware and software required to achieve our objective of replacing written inspection data by electronic collection of data would be expensive and time-consuming. Past experience indicated that our ability to plan, estimate and schedule even moderately complex software-intensive systems left a great deal to be desired. To tackle the whole factory at once would be forbidding. A step-by-step approach is, therefore, being taken so as to achieve results quickly with a reasonable expenditure of resources. We also decided to depend on off-the-shelf hardware and software to the degree possible, developing custom hardware only when none was readily available and there appeared to be a significant payback to warrant the use of in-house resources. As it has turned out, in all of the implementations attempted or achieved so far, a majority of the software required was developed by our own software engineers. This includes much of the executive and all of the applications software. This was not true in the test area where the producer of our test systems did a good job of developing basic software and making it available to us at a reasonable cost.

A review of the available technology revealed a limited number of concepts that would meet our needs. These were:

- OCR - Optical Character Recognition
- Bar Code
- Voice Input/Output
- Magnetic Card
- Function Keyboards

We had gained experience with magnetic cards while assisting another General Electric plant a few years ago. We felt that the kind of experience gained during the extensive experimenting with the magnetic card systems — that is, learning the characteristics of these systems, their strengths and weaknesses, and where pitfalls could be expected — was absolutely necessary.

The next step was to acquire data collection hardware/software systems that showed promise for meeting our diverse needs, and to gain enough hands-on experience to give us a high degree of confidence that we could successfully place these systems in the factory. Over a period of about two years we purchased, for experimentation and pilot runs, an optical character recognition system, a bar code system, and a voice input/output system.

The remainder of this paper is devoted to descriptions of three implementations in the factory, where the traditional handwritten inspection reports and inspection log sheets were replaced with some form of electronic data entry, accompanied by computer processing of the data and computer generated reports. At the present time we have automated, to some degree, a total of eight stations using OCR, Voice Data Entry, and Function Keyboards. All employ, or will employ, a dedicated microcomputer for real time support.

Standard Electronic Module Inspection Station

AESD has been in the business of manufacturing the Navy Standard Electronic Module (SEM) for several years. This product, a printed circuit assembly, represents a very small part of our total business, which mainly comprises large and relatively complex custom electronic systems. The SEM is an end product. That is, we sell these small (about 1 inch by 1 1/2 inches) low-complexity modules directly to a variety of customers. The relatively high production quantity of up to 10,000 per year, the competitiveness of the market, and the simplicity of this product made it an obvious candidate for our first electronic quality data collection project.

Figure 2 is a simplified flow of the product through the factory before we completely eliminated paper reporting by adapting the inspection station to utilization of an optical character recognition wand reader system for collection of all quality data. A computer-generated traveler card accompanied each lot (of 50 modules) through the factory. The traveler, along with the material for each lot, progressed through various manufacturing operations to the final inspection station. The traveler contained product information (program and drawing number), and a SLACS (Schedule Loading and Control System) number which related all product information to a manufacturing production control data base. This number was to play a key role in automating the inspection station. The inspector began his inspection by filling out the header section of the IDR (Inspection Defect Report) by copying the required information, which included such elements as a drawing number, revision number and reference designator, from the traveler card

to the IDR. He then performed the required inspection of the lot and completed the body of the IDR. This involved writing in a narrative description of any defects, the defect code (a five-digit code consisting of two alpha characters and three numeric characters), the reject quantity and his pay number.

The lot then went to the repair station, where the repairs were accomplished using the information contained on the IDR (e.g., defect description and defect location). The assemblies were reinspected for the repairs and, if no defects were found, the lot was accepted and moved to the next operation.

A copy of the completed IDR was provided to a keypunch operator, who entered the inspection results into the quality data base. These inspection data, appropriately sorted and summarized, were not available for review by the product line quality engineer for three to four days following the inspection.

To automate as much of the data entry as possible, it was decided that either an Optical Character Recognition (OCR) system or a bar code system would meet our needs. The ultimate decision to use OCR was based on the fact that the printers associated with our host computer already printed an OCR readable font on the traveler card. This eliminated the need to purchase a new piece of hardware for printing the code and eliminated a separate printing operation.

Figure 3 shows the factory flow in use today. The equipment at the station consists of an OCR wand reader and a CRT terminal tied to a host computer. A traveler still accompanies the material through the several factory operations; however, it now contains a SLACS number in OCR font.

The inspector is now prompted through the inspection operation by a form flash that appears on the screen of the CRT. The required data are entered as follows:

- Using the OCR wand to read the SLACS number causes a transfer of all of the header data from the manufacturing data base to the quality data base.
- The inspector's pay number is entered using the OCR wand to read the number from a preprinted sheet that contains the pay numbers of all certified inspectors.
- The defect codes are read from preprinted sheets, one reading for each defect, again using the wand.

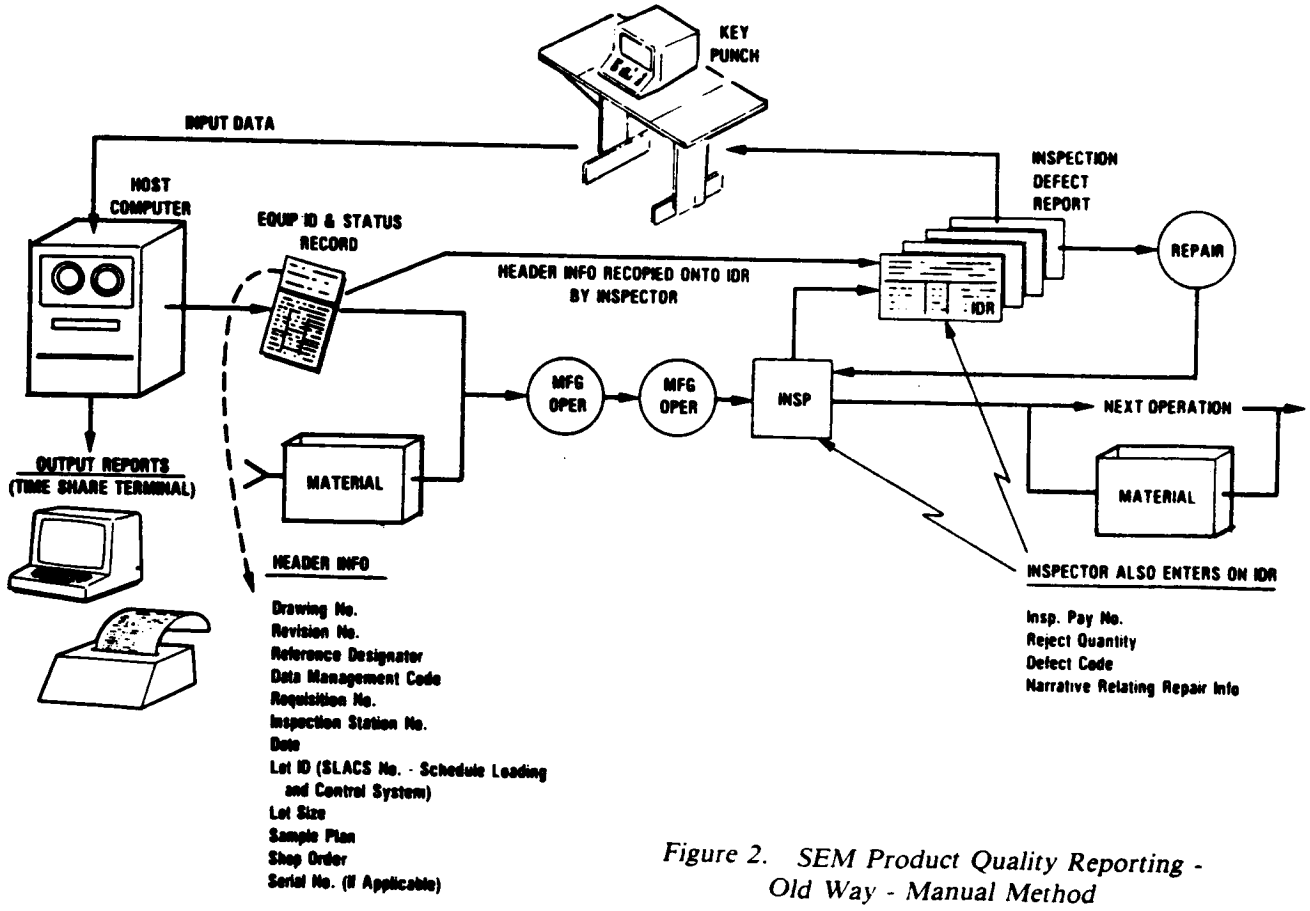

Figure 2. SEM Product Quality Reporting - Old Way - Manual Method

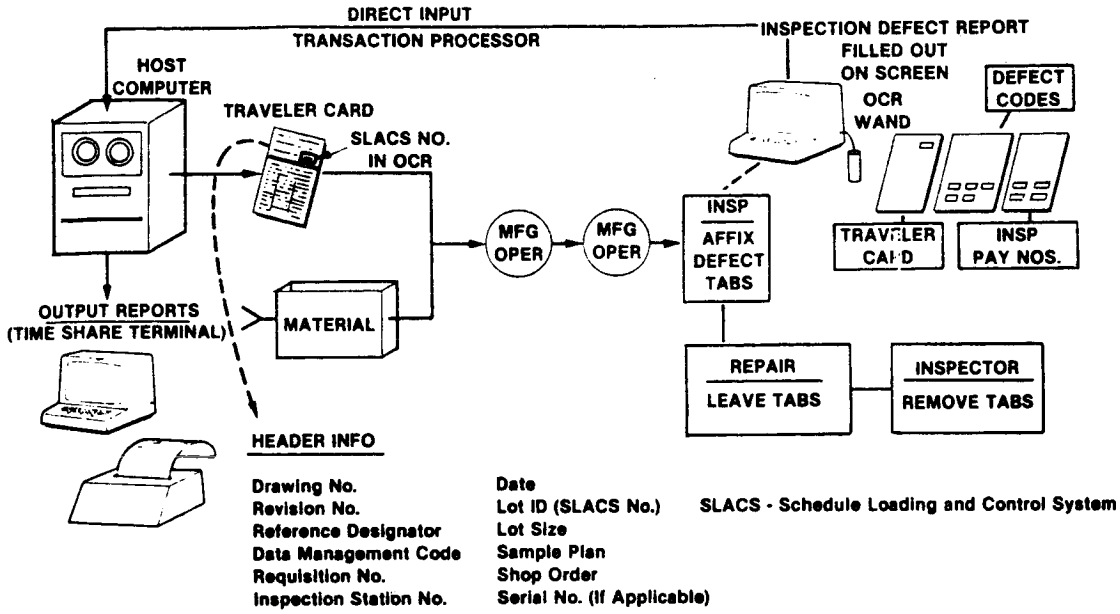

Figure 3. SEM Product Quality Reporting - New Way - Optical Character Recognition

The total reject quantity is computed by the microcomputer, which controls data for the whole inspection operation. The narrative which had been entered on the IDR previously is no longer used. During the studies that preceded implementation of the OCR station, it was found that the repair person did not need the narrative but was able to understand defect descriptions using the defect codes. This was possible because of the relatively small number of defect codes associated with this low-complexity product. Defects are identified by attaching a preprinted adhesive tab adjacent to the defect. This tab is left on the module until the module has passed reinspection. The tab is then removed by the inspector.

Following each inspection the inspector is able to review the complete inspection report on the CRT screen. If satisfied with the report, the inspector uploads it to the host computer, where it is immediately available to the product line quality control engineer in a variety of formats, including several different trend reports.

Computerized Measuring Microscope - Multilayer Board Cross Section Analysis

The microscope used at this inspection station is the typical metallographic microscope used for this type of inspection, but with a linear transducer added to measure and digitize the filar location. The remaining components of the inspection station consist of a keyboard, a CRT, a manual switch for entering the digitized data from the microscope, and a minicomputer for real time control of the station.

At the point in the printed wiring board fabrication cycle following chemical processing (i.e., etchback and copper and solder deposition) each lot of MLBs is sent to the Materials and Processes Laboratory for inspection. Preparation for inspection consists of removing from the border of one or more boards inspection coupons, which are then cast in transparent plastic, cross-sectioned, polished, and visually inspected under medium magnification. The inspection consists of positioning the measuring microscope filar at a reference location, recording the reading, repositioning the filar and recording the next reading. This process continues, requiring up to 150 separate readings for a 10-layer MLB. These measurements are then used to calculate summary data for a particular cross section, involving such measurements as maximum, minimum and average etchback, thickness of copper and lead plating and plated-through hole dimensions.

Prior to automating this inspection station, all readings were recorded on a log sheet. Then, depending on the magnification power of the optics being used, the readings were converted to dimensions which were computed by manually performing a series of arithmetic operations. These data were also recorded on the log sheet. In total, manual recording of detail data, manual calculations and manual entry of summary data consumed 50 percent of the operator's time. The continual looking away from the eyepiece to record detail data during the lengthy measuring sequence caused operator fatigue. At best, only six "*jobs*" (six plastic casts) could be completed in an eight-hour day. Frequently, it was necessary to work overtime to complete the eight to twelve jobs representing production MLBs awaiting release.

At the completion of inspection, chemical processing data (e.g., tank temperature, amperage and processing time) were copied from log sheets kept by Manufacturing in the chemical processing area of the factory. The microscope readings calculations, summary of dimensions and the chemical processing data constituted the required quality data for the particular lot from which the inspection coupons were obtained.

The operator is now guided through the inspection procedure in the required sequence by prompting on the CRT screen. The microscopic inspection is conducted as previously described (i.e., by mounting the inspection coupon and lining up the filar). However, now the required readings are entered into the computer memory by depressing a foot switch. A *"beep"* provides the operator with feedback, thereby eliminating the fatiguing *"look away"* problem described earlier. The readings are converted to appropriate dimensions from a table residing in the computer. This is accomplished by entering the magnification of the optics via the keyboard with the required dimensions and averages calculated by the computer.

As part of this project, the chemical processing data are entered into a manufacturing data base immediately following the processing of each lot of MLBs. At the time of the inspection, these data are entered into the quality data base by keying in the proper code at the inspection station keyboard.

The cost of automating the data collection was approximately $5,000 for hardware and six man-months of programming. The benefits include a doubling of operator throughput. (Twelve jobs can now be completed on one shift.) This eliminated a requirement to purchase additional equipment for another station and the hiring and training of additional inspectors to meet increased production in the MLB shop.

In addition, the data from each inspection are available immediately, directly, and in trend form. This very trend information, not previously available without manually tabulating data from log sheets, is being used to more effectively control the MLB manufacturing process.

Microcomputer Controlled Multifunction Keyboard System

The last system that will be described has been given the name Multifunction Keyboard Inspection System. We have established three identical inspection stations for the P-3C Data Processing System, at each of which 90 separate inspections are performed. Hardware inspected ranges from small cable assemblies to large electronic units. At these stations, no inspection paperwork is generated. Inspection data are available at any time share terminal throughout the plant immediately following the inspection. This multifunction keyboard system overcame the shortcomings of the aforementioned OCR system. The complex products being inspected on this line require a broad spectrum of defect codes. Narrative for repair is also required. The keyboard and printer meet these needs.

Figure 4 contains a block diagram of the system. It is made up of a CRT and a printer — both purchased — and a custom keyboard and a microcomputer — both built at AESD. The keyboard is a simple assembly which we designed to serve each individual need. It is used in a much reduced configuration at other inspection stations. The microcomputer, based on Intel's 8080 microprocessor chip, was developed several years ago at AESD as part of an in-plant microprocessor training course. The course is still taught; and through the years the hardware and software have continuously been upgraded. It has become one of the standards at AESD, not only because of its designed-in capabilities, but also because of the large number of people who are familiar with it, the constant upgradings that are being incorporated in its design, and the large amount of software that is available for it.

The function keyboard used at the three inspection stations is shown in Figure 5. These keyboards all contain numbers from 0 to 9, the full alphabet, some often used phrases (pressing the SOH key, for example, enters *"START OF HEADER"*) and the two alphas and three numerics that make up the mechanical defect codes that are required at these stations.

The information inputted to the system when any key is depressed is controlled by the system software. The number keys are single function and will always enter the number printed on them. The key below the *"O"* is a multifunction key and will enter either the letter *"O,"* the defect code prefix *"DD,"* or the defect code suffix *"016,"* again depending on the software.

To illustrate the system, it is first necessary to say a few words about the defect codes. The general-use mechanical defect codes are shown in Figure 6. Each code comprises two alpha and three numeric characters in a wide range of combinations. For example, CH means *"Component (hardware)",* 002 means *"damaged,"* the code CH002, therefore, means *"damaged hardware"*. CH177 means *"broken hardware"*.

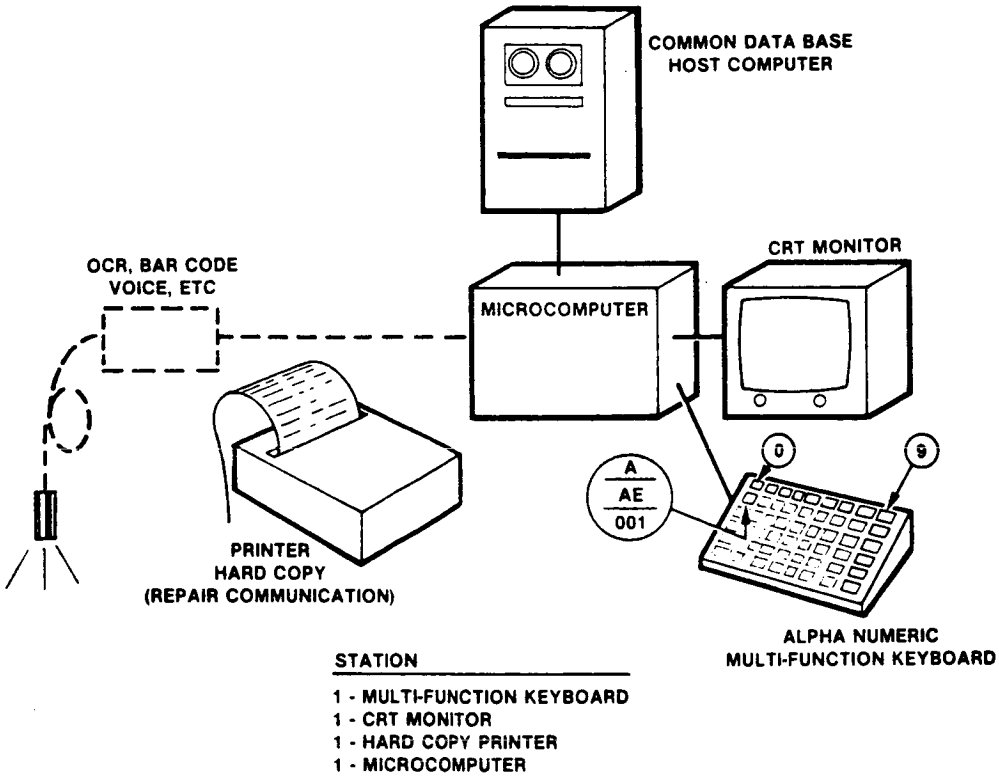

Figure 4. Function Keyboard System Block Plan

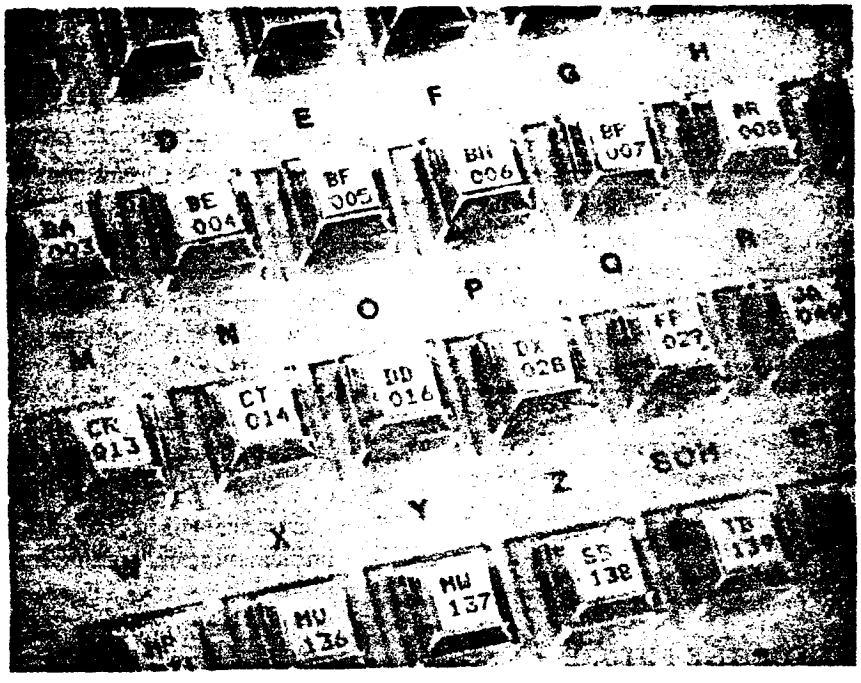

Figure 5. Function Keyboard

GENERAL-USE MECHANICAL DEFECT CODES

NUMERICAL INDEX BY DEFECT DESCRIPTION AND NUMERIC CODE

Mechanical Codes Consist of Two Alpha and Three Numeric Characters, e.g., CH002 = Component Hardware Damaged

ALPHA CHARACTERS

AE	Assembly (Electrical)
AM	Assembly (Mechanical)
BA	Boards (Printed, Molded)
BE	Hole Plated
BF	Fingers
BH	Internal Cond Pattern
BP	Pads (Terminal Area)
BR	Run Conductor
CE	Component (Electrical)
CH	Component (Hardware)
CM	Component (Mechanical)
CP	Connector Pin
CR	Connector
CT	Terminal
DD	Dimensions (Mechanical)
DX	Mechanical Test (Pull, Pressure, Etc)
FC	Finish (Chemical)
FP	Finish (Paints)
JA	Adhesives / Bonding
JM	Mask
JP	Encapsulation / Potting
MP	Braze
ML	Material
MP	Welding (Projection)
MV	Weld (Wire)
MW	Weld
PP	Preservation / Packaging
SS	Solder
TD	Documentation
TM	Marking-Decal / Stencil / Nameplate
TS	Acceptance Stamp
WC	Wire-Cable / Lacing / Dress
WL	Wire (Insulation / Sleeving)
WR	Wire (Termination / Wrap / Crimp)
WT	Wire (Twist)
XC	Configuration (Conforming)

NUMERIC CODE

001	Illegible
002	Damaged
003	Missing (Part / Operation)
004	Incomplete / Insufficient
005	Extra / Excessive
006	Wrong (Material, Size, Type, Color)
007	Loose
008	Out of Tolerance
009	Foreign Material / Dirty
010	Incorrect Connection / Position
011	Not to Revision
012	Not to Specification
013	Corroded / Pitted
014	Cracked
016	Delaminated
028	Height / Length OHL
029	Height / Length ULL
040	Not Flush
041	Inadequate Adhesion
045	Not Seated
046	Burrs
063	Voids
071	Defective
091	Early Cut-In (CIDN Supersedure)
092	Late Cut-In (CIDN Supersedure)
136	Embedded
137	Bridge / Splash (Solder)
138	Cold Joint (Solder)
139	Poor Wetting (Solder)
141	Birdcaging
142	Lifted
143	Measled
144	Recessed
146	Exposed Copper
148	Lead Exceeds Max Dimension After Clipping
149	Lead Contour Not Visible
150	Electrical (or Potential) Short Due to Position
151	Preform Improper
177	Broken
201	Bent
202	Binding
205	Burned / Carboned / Melted / Overheated
207	Contamination
212	Dented / Punctured
217	Leakage (Gas / Fluid)
220	Nicked
223	Pinched
224	Reversed / Backward
252	Flux Not Removed
554	Specification Error
716	Taut

Figure 6. General-Use Mechanical Defect Codes

For the P-3C DPS application, the inspector has a choice of *"filling out"* (electronic flash form - displayed on the CRT) an Inspection Defect Report (IDR), a Test/Inspection Pass Report (TIPR) or an IDR closeout. The time and date are automatically entered into the report file at the time of initiation of the inspection. Responding to prompting on the CRT, the inspector completes the inspection and builds the IDR, TIPR, or closeout record. The microcomputer automatically assigns a record number, causes the printing of a repair feedback ticket, contacts the host, uploads the inspection record to the host, and finally receives the record back from the host for review, closeout, and final storage at the host.

This basic function keyboard system, utilizing a much simpler keyboard, has been successfully used on an earlier automated inspection station involving microelectronics hybrid inspection. The use of keyboards is planned for expansion into other areas of the factory where its utilization for factory data collection, in addition to quality data reporting, will be incorporated.

CHALLENGES OF THE FUTURE

The systems that I have described are stepping stones to the true *"paperless factory"*. We are in the midst of a movement toward increased productivity in our factory through the application of electronic data collection, communication, processing, reporting, and storage. As we look into the future, some fundamental changes in the traditional ways we have done things become more evident. Some of the more significant are:

In the product:

- Smaller dimensions, increased complexity and higher speeds. Circuit boards will be populated with LSI and VLSI devices in hermetic chip carrier (HCC) packages. Device speeds as well as assembly speeds will continue to increase, impacting testing and inspection at all levels.
- New materials and new application of existing materials. For example, the high stresses that result when HCCs are soldered to a commonly used glass epoxy MLB and then the assembly is temperature cycled are causing many users to search for a different material for fabricating MLBs. Quality Assurance will play a major role in the selection, implementation, and process control of these materials.
- Standardization of designs and design features. In order to insure that tomorrow's designs can be fabricated using the very sophisticated, high priced, automated machines, processes, and test and inspection tools that are being implemented today, it is absolutely essential to ensure that the design is compatible with the factory. Therefore, the manufac-

turing and quality organizations are having a much greater influence on design than ever before.

In the factory:

- More automated work centers with computer controlled machines which receive their control instruction from common data bases. The availability of this kind of equipment will increase in the future, as will built-in in-process test and inspection sensors, some with self-correcting feedback capability.
- A new breed of equipment maintenance personnel accompanied by a higher level of training programs for these people.
- Less reliance on visual inspection. The number of solder joints on a chip carrier assembly will make visual inspection very difficult. More emphasis will be placed on automated screening tests to detect faults at all levels; and more environmental cycling (temperature and vibration) to allow the early detection of defects.
- More reliance on software to be used for development of application software.

Conclusion

All of this will require streamlined methods of capturing, processing and presenting data. Computers, peripherals, and software are the tools by which productivity gains can be realized in the Quality Assurance function. Inspection operations can become more productive when not encumbered by stifling paperwork requirements. This paper has illustrated that the *"paperless factory"* is near at hand. The challenge of the quality function is to wisely match needs to the available technologies.

MISSION ASSURANCE CONFERENCE
PRODUCT RECORDS PANEL
JUNE 1983

TECHNIQUES USED TO PROCESS, STORE AND RETRIEVE COMPLETED PRODUCT RECORDS

D. J. CLEMENS
GENERAL DYNAMICS
CONVAIR DIVISION

PRODUCT RECORD RETENTION REQUIREMENTS AND RESPONSIBILITIES

- PROCUREMENT RECORDS, MANUFACTURING/TESTING RECORDS, DISCREPANCY RECORDS, AND OTHER MISCELLANEOUS RECORDS CONSIDERED TO BE THE OBJECTIVE EVIDENCE OF QUALITY (FIG. 1) ARE RETAINED FOR A PERIOD SPECIFIED BY CONTRACT.
- QUALITY ASSURANCE DATA SYSTEMS (QADS) IN THE CONVAIR QUALITY ASSURANCE FUNCTION HAS THE RESPONSIBILITY TO PROCESS AND RETAIN COMPLETED PROCUREMENT RECORDS, MANUFACTURING RECORDS, TESTING RECORDS AND DISCREPANCY RECORDS (FIG. 1).
  - -- DISCREPANCY RECORDS AND OPERATIONS PLANNING RECORDS MAKE UP 90% OF RECORDS PROCESSED IN QADS.

DISCREPANCY RECORDS

- ONE FORM (FIG. 2) USED TO DOCUMENT VARIOUS CATEGORIES OF DISCREPANCIES.
  - -- FORM IDENTIFIED AS A QUALITY ASSURANCE REPORT (QAR).
  - -- FORM IS A 5-PAGE MANIFOLD (COPY NUMBERS 1, 2/B, 3, 4, 5).
  - -- SUPPLEMENTS ARE ADDED WHEN NECESSARY.
- COMPLETED MANIFOLD COPIES AND SUPPLEMENTS SENT TO QADS FOR INCREMENTAL COMPUTER ENTRY (FIG. 3).
  - -- ALL QAR DATA, INCLUDING NARRATION, ENTERED INTO ON-LINE COMPUTER SYSTEM
  - -- DATA ENTERED BY TERMINAL OPERATORS USING FORMATED CRT SCREEN.
- REMOTE TERMINALS LOCATED THROUGHOUT FACTORY AND OFF-SITE (FIG. 4) FOR COMPUTER ENTRY AND INQUIRY.
  - -- IMMEDIATE ON-LINE RESPONSE
  - -- ON-LINE SEARCH AND PRINTOUT CAPABILITY (FIG. 5)
- SPECIAL AND SCHEDULED REPORT CAPABILITY TO SUPPORT CORRECTIVE ACTION SYSTEM AND QUALITY PERFORMANCE REPORTING (FIG. 6).

DISCREPANCY RECORDS (CONTINUED)

- DISCREPANCY RECORDS MICROFILMED FOR PERMANENT STORAGE (COPIES 1, 2/B AND SUPPLEMENTS.
  - -- SATISFIES CONTRACTUAL RETENTION REQUIREMENTS
  - - RECORD SERIAL NUMBERS INDEXED AGAINST MICROFILM REEL AND FRAME FOR EASY RETRIEVAL (FIG. 7).
  - -- RECORDS ARE RETRIEVED USING MICROFILM VIEWER WITH PRINTER.
  - -- VIEWERS LOCATED AT FACTORY LOCATIONS.
  - -- DISCREPANCY RECORD DISCARDED AFTER MICROFILMING AND INDEXING.

OPERATION PLANNING RECORDS

- ALL COMPLETED PLANNING RECORDS SENT TO QADS FOR RETENTION.
- ASSEMBLY LEVEL PLANNING RECORD SERIAL NUMBERS ENTERED BY QADS INTO SCORE (STATUS AND CONTROL OF RELEASABLE ENGINEERING) SYSTEM.
- SCORE (PRINTOUT, FIG. 8) PROVIDES:
  - -- CONTINUOUS CONFIGURATION ACCOUNTABILITY DURING THE MANUFACTURING PROCESS.
  - -- STATUS OF RELEASABLE DESIGN.
  - -- STATUS OF RELEASABLE PLANNING.
  - -- STATUS OF RELEASED PLANNING (COMPLETED PLANNING NOTED AS "SOLD" IN FIG. 8).
- PLANNING RECORDS ARE MICROFILMED AND RECORD SERIAL NUMBERS ARE INDEXED AGAINST PART NUMBER AND THE MICROFILM FRAME AND REEL NUMBER (FIG. 9).
- VIEWING CAPABILITY SAME AS FOR DISCREPANCY RECORDS.
- PLANNING RECORDS DISCARDED AFTER MICROFILMING AND INDEXING.

OTHER QUALITY RECORDS

- MOST RECORDS RETAINED BY QADS FOR OBJECTIVE QUALITY EVIDENCE PURPOSES ARE MICROFILMED, INDEXED (FIG. 9) AND DISCARDED.
- RECORDS NOT MICROFILMED ARE BOXED AND SENT TO ARCHIVES WITH INSTRUCTIONS FOR RETENTION TIME. A MANIFEST IS PREPARED FOR RETRIEVAL PURPOSES.

PRODUCT RECORD MANAGEMENT SYSTEM PLANS

- PAPERLESS PLANNING SYSTEM IN CONCEPTUAL STAGES (FIG. 10).
- SYSTEM WILL REPLACE MANUFACTURING BUILD RECORDS, MANUFACTURING INSPECTION RECORDS AND DISCREPANCY RECORDS.
- SYSTEM WOULD PROVIDE REAL TIME END ITEM DELIVERY STATUS AND WILL HAVE SUFFICIENT DATA TO PRINT DD250 AT TIME OF DELIVERY.

Table 7-1. Quality Records

Records	Initiator	Maintainer	Retainer
Procurement Records			
Purchase Orders	Procurement	Procurement	Procurement
Receiving Inspection Material Record	Rec Insp	Rec Insp	Rec Insp
Receiving Inspection Serialization Record	Rec Insp	Rec Insp	Rec Insp
First Article Inspection Reports	R1/S1	R1/S1	QADS
Certificates of Compliance	Supplier	Rec Insp	QADS
Physical/Chemical Reports	Supplier	Rec Insp	QADS
IAT Data Sheets	Supplier	S1/R1	QADS
Source Quality Assurance Reports	Source Insp	Source Insp	QADS
Documentation Evaluation Records	Supplier	Data Mgt	Data Mgt
Supplier Capability Surveys/Audits	PQE/S1/QA Audit	PQE	PQE
Manufacturing/Testing Records			
Operations Planning	Planning	Inspection	QADS
Operations Inspection Logs	Planning	Inspection	QADS
Parts Control Index	Planning	Inspection	QADS
Acc Test Procedures/Data Sheets/PHSs	Operations	Inspection	QADS
QAR-To (Test Prep Sheets	User	Inspection	QADS
X-Ray Reports/Films	Supplier/PC	Supplier/PC	QADS/PC
Quality Yard Test Requests/Reports	User	QVL	QVL
Operations and Life Record (OLR)	Shop/Rec Insp	Inspection/Rec Insp	QADS
Assembly Line Shortage Logs (ALSLs)	Prod Control	Inspection	QADS
Calibration Curves (Transducers)	Supplier/Cal Lab	Inspection	QADS
Transducer Serialization Logs	Inspection	Inspection	QADS
Serialization Logs	Inspection	Inspection	QADS
Inspection Dimensional Check Sheets	Inspection	Inspection	Inspection
Engine Log Books	WRC	Inspection	QADS
Discrepancy Records			
Problem Reports (QAR-P)s	Any Dept	CA-PQE	QADS
Nonconformances (QAR-Ds)	Inspection	Insp-CA-PQE	QADS
Break-Of-Inspection (QAR-Bs)	Inspection	Inspection	QADS
Cleanups (QAR-Ms)	Inspection	Inspection	QADS
Quality Requirements Sheets (QAR-Zs)	User	Inspection	QADS
Functional Test Requests (QAR-Ps)	User	Inspection	QADS
Government Reported Deficiencies (QAR-Ys)	Customer	Inspection	QADS
Major Waivers (QAR-Rs)	MRB	Config Management	Config Mgt/QADS
Waiver Approval Request Forms (WARFs)	Supplier	Data Management	QADS
Alerts	Government	Parts Engineering	Parts Engineering
Customer Deficiency Reports	Customer	Corrective Action	Corrective Action
Survey Instructions	QADS	QADS	QADS
QAR/BOI Index	Inspection	Inspection	QADS
SEDB Data (GLCM)	Inspection	Inspection	QADS
Discrepancy Summary Reports (4404)	QADS	QADS	QADS
Discrepancy Trend Reports (4407)	QADS	QADS	QADS
Microfilm Index	QADS	QADS	QADS
Miscellaneous Records			
Personnel, Process, Equip Certifications	Proc Control	Proc Control	Proc Control
Process Records (Solutions, Heat Treat, Etc)	Proc Control	Inspection	Proc Control
Tool Orders	Tooling	Tool Insp	Tooling
Calibration Reports	Cal Lab	Cal Lab	Cal Lab
Audit Reports	QA Audit	QA Audit	QA Audit
Special Test Equipment Orders	STECC	Inspection	STECC
Mockup Tags/Mockup Orders	Planning	Inspection	Planning

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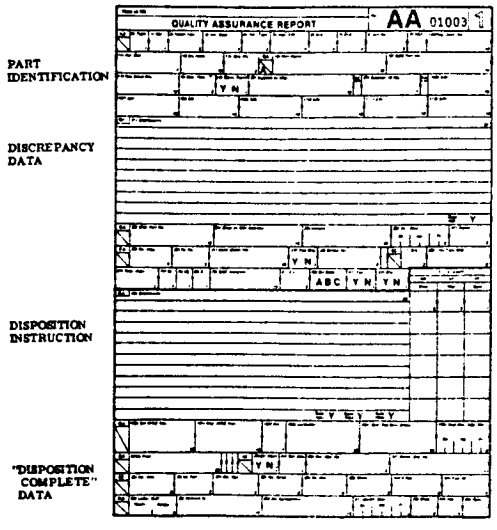
QUALITY ASSURANCE REPORT
NONCONFORMANCE (FAILURE) RECORD



NONCONFORMANCE DEFINITION - LACK OF A UNIT-OF-PRODUCT TO CONFORM TO REQUIREMENTS SPECIFIED IN THE CONTRACT, SPECIFICATIONS, DRAWINGS, OR OTHER APPLICABLE PRODUCT DESCRIPTION.

NONCONFORMANCE TYPES - 1) DISCREPANCY, 2) FAILURE, 3) FUNCTIONAL FAILURE.

GENERAL DYNAMICS CONVAIR

ART NO 28ACH18JCACH — REPT NO 2A457189 — VEN TYPE [redacted] — SYSTEM=030 — PPT CAT 20AR — FILM NO 9247
ART-NAME=NUT — DATE INT=550416 — GOVT PT CH — IHSP 101400 — FAIL CD 2HIMOR — DISP DATE 4884231
SUPPLIER AEROSPACE — RES DEPT=992 — SFTY IYMSH — REJECT=101400 — W/O NO 9679999888 — C/A CLOSED=884424
RFT FAC ELF-359 — CAUSE IMAN — P/O NO 489635-32835 — COMP DATE 4824582
CLASS NO=0A881830 — DIS CO=PAP — SUPPLR NO 2G25881
REC RPT 5306311

DISCREPANCY *
RAYMAR CERTS STATE AXIAL STRENGTH OF 4500 PER MIL-N-25027D. BOEING SPEC BPS-N-78 AXIAL STRENGTH TO BE 3940 MIN PER BOEING PRIME IHSP COMP-DIM MEET SPEC. HOWEVER PTS HAVE NOT BEEN TESTED FOR LOCKING TORQ OR AXIAL STRENGTH PER BIBS. NOTE-PTS MFG BY RAYMAR-AEROSPACE IS VEND
INITIATOR : STOVER
CORRECTIVE ACTION *
SEE AA57188 APP C/A
C/A ASSIGN -3266 MADDEN — STATUS PK
DISPOSITION INSTRUCTION * USE AS IS 101400
CORRECTED CERTIFICATION ATTACHED PROCESS AS PAPERWORK PROBLEM PER QAM 1-101 MADDEN 23 APR 88 PROBLEM PER QAM 1-101 MADDEN 23 APR 88

ART NO 28ACH18JCACH — REPT NO 2A457172 — VEN TYPE [redacted] — SYSTEM=030 — PPT CAT 20AR — FILM NO 9247
ART-NAME=NUT — DATE INT=501197 — GOVT PT CH — IHSP 180824 — FAIL CD 2HIMOR — DISP DATE 4884213
SUPPLIER AEROSPACE — RES DEPT=992 — SFTY IYMSH — REJECT=101400 — W/O NO 9679999888 — C/A CLOSED=884221
RFT FAC ELF-359 — CAUSE 2MAI — P/O NO 489635-33277 — COMP DATE 4884215
CLASS NO=0A881830 — DIS CO=1A1 — QAR COMP=ADAMS — SUPPLR NO 2G25881
REC RPT 5375473

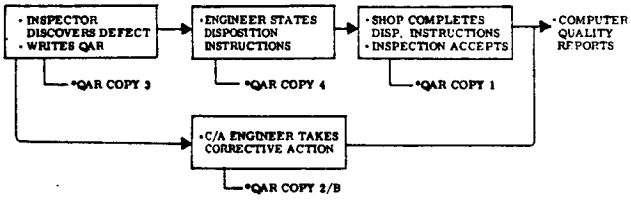
DISCREPANCY *
PARTS FAILED AXIAL TENSILE STRENGTH COPY OF DUTR/R ATTACHED
INITIATOR : GOEAL
CORRECTIVE ACTION *
PARTS WILL BE RETURNED TO VENDOR. NONREPETITIVE DISCREPANCY. NO FURTHER CORRECTIVE ACTION REQUIRED.
C/A ASSIGN -3280 KELSTRUP — STATUS PK
DISPOSITION INSTRUCTION * RTN VENDOR=81888
REFER TO DUTR/R FOR RETURN TO VENDOR KELSTRUP 3/9/88 RETURNED ON REJECTION NOTICE 81A1985
QUALITY RECORDS — BUYER=3551

THIS REPORT IS ISSUED MONTHLY AND LISTS THE PAST SIX MONTHS OF QUALITY ASSURANCE REPORTS IN PART NUMBER ORDER.

FAILURE TRENDS REPORT 81187 — PAGE NO. 107

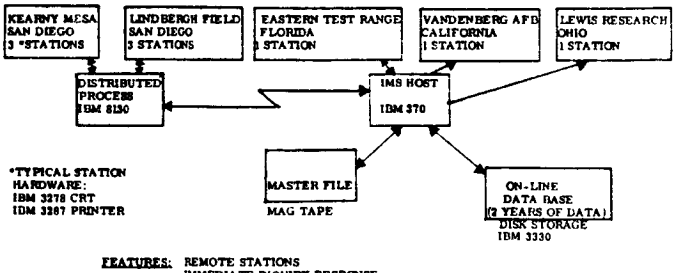
PART NUMBER	TYP	DEFECT CODE	DATE INIT	REPORT CATEGORY	DISP REPT	REPORT FACILITY	RES DEPT NO.	SUPPLIER CODE	REF	PART S/N OR LOT NO	QAR NUMBER	FILM NUMBER	DISP CODE
55-08383-001		3C8	761315	180	991	CA-CA1	510	B0001	B0001		A2B5885		1SP
55-09505-002	2	2E9	761018	00	992	EM-1A8	480	B0001	B0001	2	A2B0486	0012	0U1
55-08481-001	1		760681	00	992	EM-1A8	480	B0001	B0001	100	A2B0114	0012	0U1
55-04385-002	1		760594	180		EM-1A8	480	B0001	B0001	101	A2B0113	0012	0U1
55-04385-002			760593	00	992	EM-1A8	480	B0001	B0001	101	A2B0113	0012	0U1
55-03111-008	2	6AL	770117	180	991	CA-3A8	510	B0001	B0001		A2A1375		
55-03081-001	1	3D7	760826	180	994	EM-7A	100	B0001	B0001	7000A09013	A2B0488		0U0
55-08394-007			760815	0		EM-8A8	800			3113367010	A2B7832	0001	
55-09539-007		1PM	760815	180	991	EM-1A4	100	B0001	B0001	3113367010	A2B7833	0001	0U0
55-20821-007			760816	180	991	EM-1A4	100	B0001	B0001	3113673001	A2B7834	0001	0U0
55-8484-007		1A8	761101	180	990	EM-1A4	100	B0001	B0001	3113673010	A2B7834		
55-04484-7-32	1		760833	0	994	EM-1A4			B0001		A2B7833	0002	
55-08313-002	1		761111	180	992	LP-1B	800	B0001	B0001	7000114008	A2A1808		0TP
55-06426-001	1	3AA	761031	180	992	EM-8A1	100	B7001	B0001	7100114018	A2A8433		0TP
55-09322-001	1	4AE	760828	180	993	EM-7A1	210	B0001	B0001	1818133	A2B7781	0001	0U0
55-08321-001		4AE	760826	180	993	EM-7A1	210	B0001	B0001		A2B7537	0001	0U0
55-08321-001		3A1	761178	180	994	EB-2A1	100	B0001	B1001	478	A2B4811		0U0
55-09374-001	1	3D7	760822	00	992	EM-7A	100	B0001	B0001	3118673037	A2B6838		0TP
55-09374-001		3B7	761171	180	992	EM-7A	100	B0001	B3001	3118673029	A2B6847		0TP
55-08537-301	2	3D7	761001	00	992	EM-7A	100	B0001	B0001	7000118113	A2B6859		
55-08537-301		3D7	761002	180	992	EM-7A	100	B0001	B0001	7100118113	A2B6831		
55-09353-001	2	3D7	761013	00	992	EM-7A	100	B0001	B0001	7101373018	A2B6834		0TP
55-04318-001		3D7	761102	180	992	EM-7A	100	B0001	B0001	7101373008	A2B6842		0TP
55-08548-002	2	3D7	761120	00	992	EM-7A	100	2P001	B0001	7101373001	A2B6843		
55-08548-002		3D7	761121	180	992	EM-7A	100	2P001	B0001	7101373002	A2B6844		
55-08437-002	1	4CC	760917	180	991	EB-2A1	510	B0001	B0001	3181193002	A2B7142	0001	0U0
55-09801-001		9CC	763772	180	8U00	EB-3A8	400	B0001	B0001		A2B6193	0001	0TP
55-09801-001		9CC	763773	180	8U00	EB-3A8	400	B0001	B0001		A2B6193	0001	0TP
55-8434-001	1	3A1	760814	180	991	EB-1A1	400	B0001	B0001	13257	A2B6417		
55-16440-002	1	1PM	761120	180	991	EM-2A1	111	B0001	B0101	1H0002001	A2A1903		
55-7844-040		1AB	760810	00	99	EM-1B	401	B0001	B0001	21B18	A2B7181	0001	0U0
55-13216-001	1	3CL	760818	180	8U01	EM-2B	211	2P001	B0001		A2B7898	0001	0U0
55-11401-001	1	4CC	760804	00	991	EM-7A1	100	B0001	B0001		A2B7833		0TP
55-13491-007		1CA	761206	00	992	LP-1A	113	B0001	B0001	3187167	A2B7813		0U0
55-13482-001	1	8CA	760731	180	992	EM-1A1	110	B0001	B0001	3113001001	A2B7807	0001	0U0
55-13472-01	1	4CA	760804	180	992	EM-7A1	811	B0001	B0001	3113137	A2B8519	0001	0U0

DATA COLLECTION PROCESS



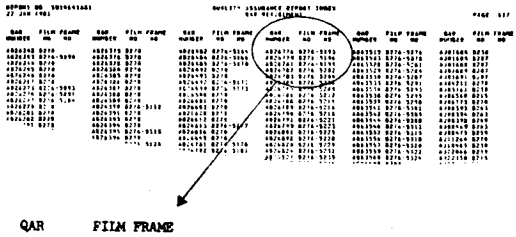
*COPY GOES TO TERMINAL OPERATOR FOR COMPUTER INPUT.

QAR SYSTEM HARDWARE



*TYPICAL STATION HARDWARE:
IBM 3278 CRT
IBM 3287 PRINTER

FEATURES: REMOTE STATIONS
IMMEDIATE INQUIRY RESPONSE
ON-LINE DOCUMENT INQUIRIES
ON-LINE DATA FIELD SEARCHES
PERIODIC REPORT CAPABILITY
SPECIAL REPORT CAPABILITY



QAR NUMBER	FILM FRAME NO.	NO.
AB26776	B276-5193	
AB26779	B276-5196	
AB26781	B276-5199	
AB26782	B276-5202	

SCORE B/D CONVAIR [redacted]-PSM 67PL/PR-001 RPT NO. 1572A61-386 PAGE

CHANGE STATUS REPORTING TOTAL EID/CIC SEQUENCE DATE 12-19-80

MOD NO	TCR NO	ENGR GROUP	R E SUPV	EID-ART	ENGR SCH DATE	I C	ENGR CEL DATE	SITE PLNG RESP	I C	PLNG REL DATE	INSTALLATION PLNG CARDS	CMO LTR CMO	ITEM	STA	E V T	REMARKS
51	00000	-076-13	-767	67PL 01		C	5210		C	7290						R-HPAR
51	00000	-076-14	-767	67PL 01		C			C	H100	311T3000-9021	A	351	01		SOLD
51	00000	-076-14	-767	67PL 01		C			C	9290	311T3000-9021	01	351	01		SOLD
51	00000	-076-14	-767	67PL 01		C	5290		C	6100	311T3100-905	R	347	01		SOLD
51	00000	-076-15	-767	67PL 01		C	7100		C	0220						R-BOL
51	00000	-078-00	-767	67PL 01		C	6169		C	0299						R-BOL
51	00000	-078-01	-767	67PL 01		C	0299		C	H149						R-BOL
51	00000	-078-02	-767	67PL 01		C	3130		C	3260						R-BOL
51	00000	-078-04	-767	67PL 01		C	4220		C	7290						R-BOL
51	00000	-078-08	-767	67PL 01		C	0810		C	H020						R-HPAR
51	00000	-078-09	-767	67PL 01		C	H240		C	D040						R-BOL
51	00000	-079-00	-767	67PL 01		C	6169		C	9289						R-BOL
51	00000	-079-02	-767	67PL 01		C	H249		C	D030						R-BOL
51	00000	-080-00	-767	67PL 01		C	9149		C	0299						R-BOL
51	00000	-080-01	-767	67PL 01		C	1140		C	2140						5-TCR-080-00
51	00000	-0C0-02	-767	67PL 01		C	5130		C	7290						R-BOL
51	00000	-081-00	-767	67PL 01		C	0239		C	U299						R-BOL
51	00000	-081-01	-767	67PL 01		C	1140		C	2140						R-HPAR
51	00000	-081-02	-767	67PL 01		C	2250		C	3260						R-BOL
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51	00000	-082-00	-767	67PL 01		C	8319		C	0299						R-BOL
51	00000	-032-02	-767	67PL 01		C	2250		C	3260						R-BOL
51	00000	-0C2-03	-767	67PL 01		C	3030		C	3260						5-TCR-082-02
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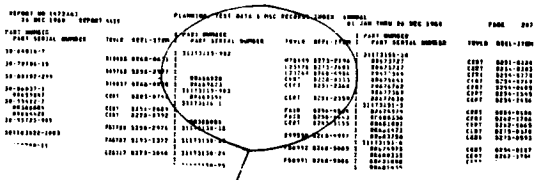
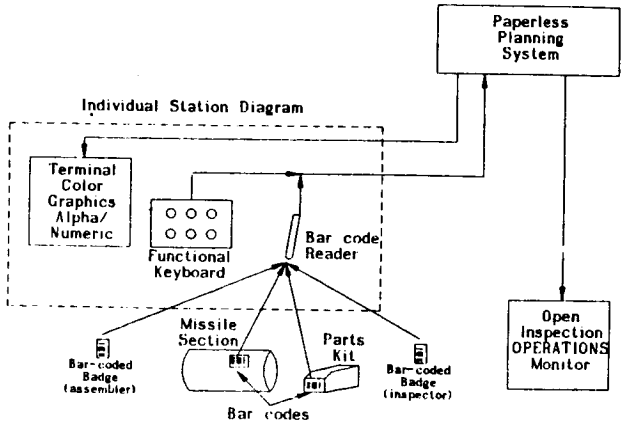


PART NUMBER
PART SERIAL NUMBER TRVLR REEL-ITEM

311T3115-902

H78499 B273-2196
L23176 B273-2601
L23260 B268-4986
RR666028 CERT B228-0333
RR669823 CERT B251-2360

Paperless Planning Project



MISSION ASSURANCE CONFERENCE

ASSURANCE TECHNOLOGY WORKSHOP

PRODUCT RECORDS PANEL

JUNE 1983

LOCKHEED
SPACE SYSTEMS DIVISION

J. H. TILTON

CURRENT ENVIRONMENT

- 0 DESIGN AND MANUFACTURE AEROSPACE SPACE HARDWARE
  - LOW VOLUME
  - ADVANCED TECHNOLOGY
  - HIGH RELIABILITY
  - LONG LIFE
  - NON MANNED
  - NON-REPAIRABLE
  - HIGH UNIT VALUE
- 0 PRODUCT MIX CHANGING
  - 1975 - PREDOMINANTLY FLIGHT HARDWARE
  - 1985 - EQUAL MIX:FLIGHT, GROUND, SOFTWARE
- 0 RESIDENT APPRO
- 0 MATRIX MANAGEMENT ORGANIZATION STRUCTURE
- 0 TRADITIONAL CENTRALIZED DATA PROCESSING ORGANIZATION
- 0 LONG ESTABLISHED PRACTICES AND PROCEDURES
- 0 STD. MFG./QA ORGANIZATION BOUNDARIES

RECORD EVOLUTION

- 0 HISTORIC - MANUAL
- 0 CURRENT - MIXED
  - MANUAL
  - VARIETY OF AUTOMATED AND SEMI-AUTOMATED SYSTEMS
- 0 FUTURE - INTEGRATED PAPERLESS SYSTEM

RECORDS OF INTEREST TO QUALITY

- 0 ENGINEERING/DESIGN
  - DRAWINGS
  - SPEC'S
  - CONF. MANAGEMENT
  - OPERATING TIME/LIFE
- 0 SUPPLIER/SUB-CONTRACTOR
  - SUPPLIER BUILD/DELIVERY
  - RECEIVING
- 0 IN PLANT MANUFACTURING AND TEST
  - SHOP DOCUMENTATION
  - TEST DATA
  - PROCESS CONTROL/YIELD
- 0 ACCEPTANCE/REJECTION/CORRECTION
- 0 DELIVERY DOCUMENTATION
- 0 SOFTWARE

RECORD CONCERNS

- 0 DATA EXPLOSION - LOSS OF CONTROL
- 0 COST
  - PREPARATION
  - TRACKING/STATUSING
  - HANDLING
  - STORAGE
- 0 TIMELINESS
- 0 LOSS
- 0 USER AVAILABILITY/ACCESS
- 0 LIMITED USER INPUT, DESIGN & CONTROL
- 0 FRAGMENTED SYSTEMS

AUTOMATED TOOLS CURRENTLY IN USE

- 0 CADAM - HARDCOPY ONLY
- 0 COMPUTER VISION - HARDCOPY ONLY
- 0 COMPUTER AUTOMATED TEST SYSTEMS - MANUAL PROGRAMMING
- 0 NUMERICAL CONTROL MACHINES - MANUAL PROGRAMMING
- 0 COORDINATE MEASURING MACHINES - INTEGRATED WITH CADAM
- 0 COMPUTER GENERATED SHOP ORDERS/STANDARD PLANNING - HARDCOPY ONLY
- 0 REAL-TIME AUTOMATED DISCREPANCY/FAILURE REPORTING/ANALYSIS SYSTEM - MANUAL INPUT FROM HARDCOPY
- 0 REAL-TIME AUTOMATED SAMPLING SYSTEM (RECEIVING TEST/INSP.)
- 0 THERMAL PROTECTION SYSTEM - AUTOMATED INSPECTION SYSTEM
- 0 PRODUCT ASSURANCE NATIONAL TELEDATA SYSTEM - TELEPHONE REPLACEMENT
- 0 REMOTE TERMINALS - STRUCTURED OUTPUT

OTHER AUTOMATED TOOLS

- 0 ACTIVE DEVELOPMENT
  - VOICE INTERACTION PROGRAM (VIP) - PROTOTYPE OPERATIONAL
  - INTEGRATED ELECTRONICS DESIGN/MFG. FACILITY
  - COMPUTER DRIVEN INSPECTION RECORDS SYSTEM (FOR NON-FLIGHT CIRCUIT BOARDS) ON-LINE 1 AUGUST
  - NON CENTRALIZED - REMOTE WORD PROCESSING
  - ROVONICS BOARD LOADER
- 0 EXPLORATION
  - ROBOTS - BOARD LOADING
  - SENSORS
  - DIGITIZED VISION SYSTEMS
  - OPTICAL CHARACTER READERS
  - LIGHT PEN READERS

PAPERLESS SYSTEM - REAL-TIME MANAGEMENT

- 0 INTEGRATED DESIGN, PLANNING, MANUFACTURING, TEST, OPERATIONS, INSPECTION, DELIVERY, INVENTORY/MATERIAL RECORD SYSTEM
- 0 AVAILABLE TO ALL USERS THROUGH VIDEO TERMINALS
- 0 GRAPHICS AND HARDCOPY CAPABILITY
- 0 INTEGRATED MANUFACTURING/INSPECTION
- 0 CORPORATE COMPUTER NETWORK CONTROLLING INDEPENDENT SYSTEMS

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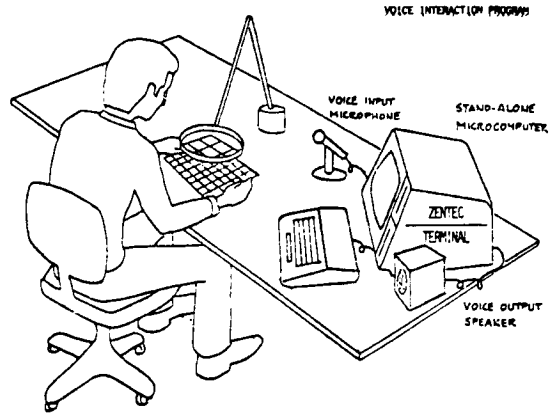
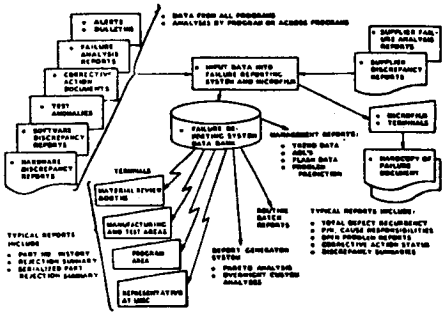
POTENTIAL PROBLEMS

- O GOVERNMENT SPEC'S REQUIRING OBJECTIVE EVIDENCE
- O CONFIGURATION MANAGEMENT/CHANGE CONTROL/SECURITY
- O DEVELOPMENT COST
- O INDUSTRY AVAILABILITY OF WORKING SYSTEMS
- O IN-HOUSE DEVELOPMENT CONTRAINTS - EXPERTISE
- O WORKER ACCEPTANCE - CAN YOU TYPE?
- O MANAGEMENT PAY-BACK REQUIREMENTS
- O STANDARD IDENTIFICATION OF PARTS REQUIRED
- O OVERCOME CLASSIC ORGANIZATIONAL BOUNDARIES/PREROGATIVES
- O IMPACT ON GOVERNMENT APPROVED ACCOUNTING STRUCTURES
  - REDUCED DIRECT LABOR
  - INCREASED OVERHEAD COSTS

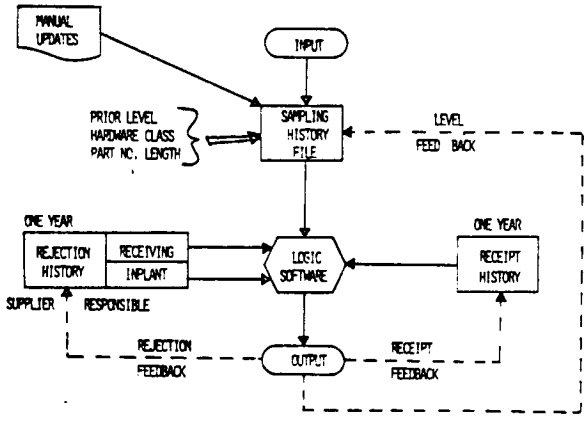
INTERCONNECT WORKSTATION



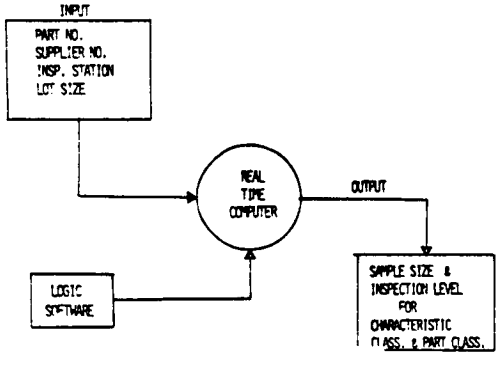


Product Assurance Realtime Direct Access Data System

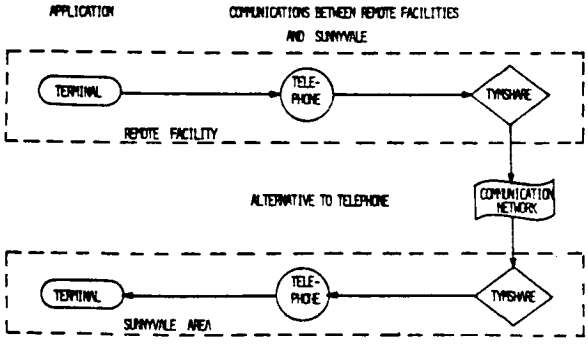
SAMPLING UPDATE LOGIC



SYSTEM OPERATION AUTOMATED SAMPLING



PRODUCT ASSURANCE NATIONAL TYMSHARE SYSTEM (PANTS)



MARTIN MARIETTA MICHOUD DIVISION | EXTERNAL TANK RECORDS RETENTION PROGRAM | CHART NO. | DATE | SPEAKER L. HERKES

EXTERNAL TANK

RECORDS RETENTION PROGRAM

MARTIN MARIETTA MICHOUD DIVISION | EXTERNAL TANK RECORDS RETENTION PROGRAM | CHART NO. 2 | DATE | SPEAKER L. HERKES

RECORDS RETENTION REQUIREMENTS

- NHB 5300.4 (10-2) --- SRM & Q PROVISIONS FOR THE SPACE SHUTTLE PROGRAM

  1D502-7 - RETENTION OF RECORDS. RETENTION OF ARTICLES AND MATERIALS WHICH HAVE BEEN DESIGNATED FOR IDENTIFICATION AND DATA RETRIEVAL SHALL BE RETAINED IN A SAFE, ACCESSIBLE LOCATION BY THE CONTRACTOR FOR THE PERIOD SPECIFIED IN THE CONTRACT, UNLESS RELEASED PRIOR TO THE TIME BY CONTRACTURAL AUTHORIZATION. THE CONTRACTOR SHALL ALSO INVOKE THIS SAME REQUIREMENT ON THE SUBCONTRACTORS AND SUPPLIERS. THE PRIME CONTRACTOR SHALL BE RESPONSIBLE FOR ASSURING THAT APPLICABLE RECORDS ARE NOT DESTROYED, UNLESS AUTHORIZED BY THE CONTRACTING OFFICER.

- NASA PROCUREMENT REGULATION M.202 --- RECORD RETENTION REQUIREMENTS

  M.201 - RETENTION PERIODS. CONTRACTORS AND SUBCONTRACTORS SHALL RETAIN THE RECORDS DESCRIBED IN THE CONTRACT OR SUBCONTRACT RECORDS CLAUSES, AND SHALL MAKE THEM AVAILABLE TO THE COMPTROLLER GENERAL OF THE UNITED STATES, THE CONTRACTING OFFICER, OR THEIR AUTHORIZED REPRESENTATIVES (I) UNTIL EXPIRATION OF THREE YEARS AFTER FINAL PAYMENT, OR FOR CERTAIN RECORDS, FOR THE PERIOD SPECIFIED IN THIS PARAGRAPH M.201, WHICHEVER EXPIRES EARLIER, AND (II) FOR WHATEVER LONGER PERIOD, IF ANY, IS SPECIFIED IN THE GENERAL REQUIREMENTS OF THE APPLICABLE CONTRACT OR SUBCONTRACT RECORDS CLAUSE.

MARTIN MARIETTA MICHOUD DIVISION | EXTERNAL TANK RECORDS RETENTION PROGRAM | CHART NO. 3 | DATE | SPEAKER L. HERKES

RECORDS RETENTION PROCEDURE (MMC STANDARD PROCEDURE ET 7.8)

- RESPONSIBILITIES
  - CONTRACTS
    - DEFINES RETENTION PERIODS
    - MANAGES OVERALL RETENTION PROGRAM
  - DEPARTMENTAL RECORD COORDINATORS
    - COORDINATES RETENTION REQUIREMENTS WITH CONTRACTS
    - ADMINISTERS RECORDS PROGRAM WITHIN RESPECTIVE DEPARTMENTS
  - DEPARTMENTAL FUNCTIONS
    - GENERATES/PROCESSES RECORDS TO MEET CONTRACTURAL REQUIREMENTS
    - MAINTAINS "ACTIVE" RECORD FILES
  - MATERIEL INVENTORY MANAGEMENT
    - MAINTAINS RECORD CENTER FOR "NON-ACTIVE" RECORDS
    - COORDINATES DESTRUCTION OF RECORDS WITH RECORD COORDINATORS

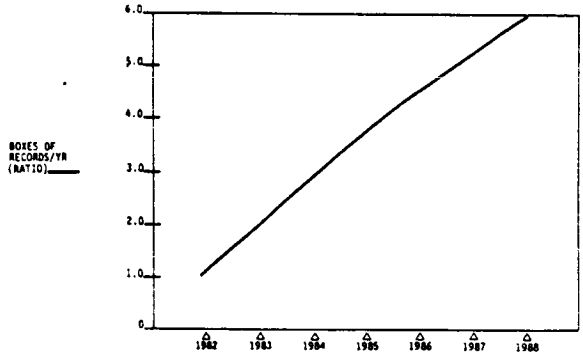
MARTIN MARIETTA MICHOUD DIVISION | EXTERNAL TANK RECORDS RETENTION PROGRAM | CHART NO. 4 | DATE | SPEAKER L. HERKES

RECORD RETENTION PROCEDURE

- PROCESSING EXAMPLE (PRODUCT BUILD RECORDS)
  - PRODUCT BUILD RECORD CATEGORIES
    - VENDOR DATA PACKAGES
    - SHOP FOLDERS (COMPONENT BUILD RECORDS)
    - SHOP LOGS (ASSEMBLY BUILD RECORDS)
    - TEST PROCEDURES
  - QUALITY DATA CENTER
    - RECEIVES CLOSED RECORDS
    - PREPARES ACCEPTANCE DATA PACKAGES (ADP) FOR E.T. DELIVERIES
    - MAINTAINS "ACTIVE" RECORD FILES
    - FORWARDS RECORDS TO MATERIEL RECORD CENTER (90 DAYS AFTER FLIGHT)
  - MATERIEL RECORD CENTER
    - MAINTAINS CLOSED RECORDS (3 YRS. AFTER FINAL PAYMENT OF CONTRACT)

MARTIN MARIETTA MICHOUD DIVISION | EXTERNAL TANK RECORDS RETENTION PROGRAM | CHART NO. 5 | DATE | SPEAKER L. HERKES

PROJECTED VOLUME OF PRODUCT RECORDS AS
EXTERNAL TANK PROGRAM APPROACHES RATE PRODUCTION



MARTIN MARIETTA MICHOUD DIVISION | EXTERNAL TANK RECORDS RETENTION PROGRAM | CHART NO. 6 | DATE | SPEAKER L. HERKES

SOME THINGS BEING EVALUATED:

- RE-ASSESS NEED TO RETAIN SOME RECORDS WITH NON-ESSENTIAL DATA
- CONSIDER VARIABLE RETENTION PERIODS FOR DIFFERENT CATEGORIES OF RECORDS (E.G., TRACEABLE vs. NON-TRACEABLE RECORDS)
- RESIDENT PLANS BY "BLOCK" EFFECTIVITY WITH BUY-OFF SHEETS FOR EACH EFFECTIVITY
- PAPERLESS RECORD SYSTEM (PILOT PROGRAM FOR NON-CONFORMANCE RECORD ON CAD/CAM EQUIPMENT)
- MICROFILM/MICROFICHE SYSTEMS WITH DESTRUCTION OF ORIGINAL RECORDS

OMEX

OMEX
2323 OWEN STREET
SANTA CLARA, CA 95051
(408) 727-5801

ELECTRONIC FILING IN THE '80s

John McAfee
OMEX
Santa Clara, California

This year alone, American business will buy an estimated 320,000 electronic typewriters; purchase, rent and lease a half a million copiers, and invest in 1.8 million print and display desk top calculators. The drive to thwart trends in declining white collar productivity has captured the interest of the entire nation, thrusting it toward computer automation in the office environment.

Americans are rushing to subscribe to a new and wide-ranging selection of automation equipment designed to extend worker potential, relieve tedium, and quicken the pace in which we produce and disseminate information. Ranging from typewriters which, in the wink of an eye, correct spelling errors to word processors and sophisticated data processing equipment, today's office manager need only sign up for the expressway bound for tomorrow's "office of the future" to experience the vast plethora of devices available to enhance productivity in the office.

Yet, despite the recent impact computer-based office equipment has had on our ability to manufacture new information, the productivity improvements once boldly touted by proponents of the "paperless office of the future" have yet to materialize for the vast majority of us. At best we seem to have arrived at some kind of stand-off between office automation and declining white collar productivity. And I'm afraid to say this stand-off may continue as we just now begin to face the fact the "paperless office of the future" isn't going to be an overnight event. The fact is, paper, in volumes greater than we have ever before imagined, will be with us for quite some time. The volume of documents produced each day by lightning-quick copiers, word processors and advanced data processing equipment continues to

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aggravate statistics which pin the annual growth of paper in offices across the United States at roughly 20%. As a result, we should anticipate a temporary drop in office productivity as we rush to increase our ability to create paper-based information and do nothing to increase our ability to manage it all.

To fully appreciate the role turnkey document storage and retrieval systems are destined to play in our quest for improved office efficiency, it is worthwhile to take a moment to discuss a few of the problems triggered by the recent onslaught of paper in the office. For purposes of this presentation, I divide these problems into four major categories: growing requirements for real estate space to store ever greater volumes of paper, crude indexing systems currently used to identify paper files, slow manual methods of distributing paper to multiple employees and, finally, manual procedures for storing and retrieving large quantities of documents.

To get a clear picture of exactly how big the paper problem is, I'd like to begin by pointing out during 1982 an average of four file drawers were attributable to every office worker in the United States. Multiply this figure by a total of 18 million office workers and we can estimate no less than 72 million filing drawers occupying expensive office real estate space during 1982 alone.

If this figure seems a bit dumbfounding, consider the fact 20% more paper is being stored each year in offices across the country. And, as electronic copiers, typewriters, word processors and data processing equipment escalate our output of paper, this figure is destined to climb.

A common solution to ever-increasing requirements for storage real estate space has been to reduce, or "shrink", the size of 8-1/2" x 11" documents to the size of a piece of microfilm or microfiche. Yet, despite inroads made recently by the micrographics industry, 90% of information stored in offices across the U.S. still remains on paper. This is, to a large extent, due to the fact that micrographics does not solve other problems associated with the proliferation of paper-based information.

One of the problems which, until recently, has been ignored by the micrographics industry involves manual procedures for indexing both film and paper documents. Most manual filing systems rely on a single index to identify a document. In cases where single indices are not sufficient, several copies of a document may be stored within multiple files.

The problem with single indices is that they restrict access to a document by requiring a person who needs a document to know the precise index associated with it. If the single index is not known, the document may not be retrieved by any other known information.

Many offices attempt to safeguard against the hazards of single indices by storing duplicate copies of a document under several file names. However, over prolonged periods of use, this process has a tendency to backfire as it increases the overall volume of paper stored, dilutes the identity of individual files by including copies of documents not directly relevant to the file and, finally, hinders the document retrieval process.
Recently, the micrographics industry has turned to computers to combat problems associated with single indices. Leaders in micrographics technology pioneered computer-assisted retrieval systems during the late seventies: systems which use sophisticated database management systems to determine the physical location of a document as well as to identify it by several logical indices. At the time a document is stored, logical and physical indices are entered into a computer's database. Later, when an individual needs to view a document he need only enter any one of several indices to determine the location of the document. From here the individual need only go to the designated carousel, cartridge or fiche card specified by the computer to locate his document.

Yet, even with sophisticated indexing capabilities, CAR systems have scarcely penetrated the market for office automation equipment. This is in part due to the fact that CAR systems require manual intervention to retrieve a document and do not successfully address document distributrion.

All paper filing systems, as well as most CAR systems, require some form of manual distribution processes. Generally speaking, a file requestor will retrieve a document, make a copy of it, and return the original file to the central file area. However, while the file or document is being copied it is unavailable to other individuals who may also require the information contained in the file. Furthermore, should the file inadvertently be returned to an incorrect location or be damaged while in use, the file may become unavailable forever.

Clearly, what is needed is an automatic method of distributing and copying documents which does not require removing them from storage. Recently, digital scanning technology, combined with communications technology, has provided the mechanism for distributing an accurate digital reproduction of a document without removing it from storage. This is

achieved by reducing each piece of paper or film to a series of microscopic dots called pixels. Each tiny pixel appears as part of a mark on the paper or part of the blank portion of a page. Pixels, in turn, are converted into digital electronic signals which can be distributed over local area networks and reconstructed as images on high-resolution video terminals and printers.

While scanning technology has been with us for some time, its use in computer-assisted retrieval systems has been a relatively new phenomenon--and one which has laid an important stepping stone for turnkey document storage and retrieval systems.

To successfully solve growing problems associated with the proliferation of paper in the office environment much more than a component or piece-meal approach is needed. A full systems approach is needed.

To solve the growing need for storage real estate, a dense, economical storage media is required. To solve access restrictions caused by single indexing, sophisticated database management systems which permit rich indexing are needed. To solve problems associated with manually distributing information, optical scanners and digital communications technology are required. And finally, to implement a full systems approach to automatic storage and retrieval, the rapid processing power of the computer is needed.

Driven by other market demands, several new technologies have materialized which, for the first time, can be combined to produce complete turnkey document storage and retrieval systems. The computer-aided design and facsimile industries have produced economical, high-resolution raster video monitors and on-line raster printers. The market for office automation equipment has manufactured high-speed local area networks. The facsimile industry has produced a wide variety of digital scanners and finally, the computer memory market has given rise to semiconductor, magnetic tape, magnetic disk and optical memory technologies.

Each of these technological breakthroughs plays a vital part in a full systems approach to document storage and retrieval. Low-cost high-resolution terminals--an outgrowth of the CAD/CAM and facsimile industries--are used for viewing documents, while high-speed communications resulting from the office automation marketplace are used to distribute documents to a wide number of system users simultaneously. Raster printers are used to produce hard copies of documents. Digital scanners are used to convert paper and microform documents into digital form. And,

finally, magnetic and optical memory provides the most dense, economical method of storage available to date.

In the final analysis, the technology required to address the full scope of the document storage and retrieval problem exists today for the first time.

Let us take computer memory as an example. Yesterday's CAR systems depended on film as the primary storage media, whereas today's turnkey systems efficiently meld semiconductor, magnetic disk and film memory for an economical, more responsive document management system. The marriage of these three storage medias permits today's new turnkey filing systems to accommodate the way documents function in a typical office environment.

For instance, every document has a life cycle during which its frequency of access rises and declines. If we use a bill as an example of a typical document, the bill might have a life cycle of 45 days during which it must be paid.

Following the initial 45-day period, the rate at which the bill needs to be referenced diminishes considerably unless, of course, many months later there is a question regarding the bill. When the bill is retrieved several months later, it assumes a new life cycle enjoying a new period of high or "active" access.

An ideal turnkey filing system must accommodate the waxing and waning life of any document, not just bills. This is accomplished brilliantly using moderately expensive magnetic disks to store new incoming documents which require high access. Archived documents are stored on less expensive media such as film and optical memory. Finally, expensive semiconductor memory is employed at video screens where the document is viewed, enabling several pages of a document to be stored locally at the terminal. Local semiconductor memory permits system users to page instantaneously backward and forward through several pages at a time. As you can see, the technology which permits us to take advantage of expensive semiconductor memory, moderately priced magnetic disk and inexpensive film exists today for the very first time.

Ladies and gentlemen, I have spent some time describing the problems brought about by the recent growth of office automation equipment; I have also described some of the technological phenomena which make today's document storage and retrieval systems possible. I'd like to take a minute now to walk you through the Omex approach to turnkey filing systems.

The Omex InfoView system employs three types of peripherals: input, output and memory. Input peripherals can be further segmented into two categories: input peripherals for new documents and peripherals for archived documents. New incoming documents are scanned, converted into a digital signal, indexed and temporarily stored on magnetic disk for immediate availability to system users. Magnetic disk is used because most new documents have an active access period from the time they come in the door. Once documents have been scanned and stored on disk they can be microfilmed or transferred to inexpensive optical memory for long term storage.

The second type of input peripheral is that designed to house long-term or archival documents. These peripherals include carousels designed to mechanically retrieve 16mm film cartridges and optical mass memory storage.

When a document is requested from an archival peripheral it is mechanically selected, digitized and sent over a local area network to a magnetic buffering disk. From the buffer disk the document can be distributed to a multitude of system users without tying up any of the archival storage devices which are designed to store many millions of documents within a small storage area.

It is worthwhile noting here, whether new or old documents are selected, the system automatically retrieves and distributes document images without requiring manual intervention of any kind. Retrieval is mechanically as well as electronically controlled and this is precisely what distinguishes today's turnkey filing systems from yesterday's CAR systems.

Once input, a document can be requested by multiple indices and output to either high-resolution video screens for viewing or high-speed raster printers for hard copy. Furthermore, depending on the lifespan of the document, the option to retain the document on disk for immediate retrieval is always available to the system user.

Each time a document is requested the original remains intact in the storage device. Only an accurate digital reproduction of the document is distributed to the requestor, thereby assuring the availability of all documents to all system users at all times.

Ladies and gentlemen, I began this presentation by describing a trend toward modernization which is taking place in offices across the globe--modernization aimed exclusively at our ability to create new information. I

would like to conclude now by pointing to the inevitable growth of turnkey document storage and retrieval systems as a vital part of that modernization process. Hard earned productivity improvements in the office are on a collision course with our inability to manage, to store, to distribute and control paper.

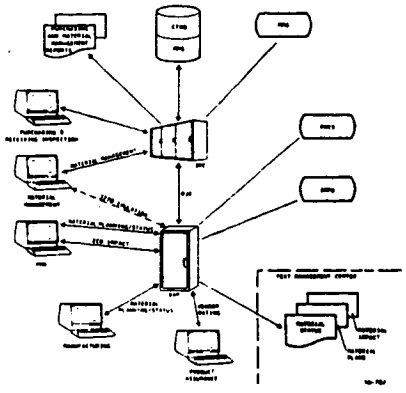
What is needed to change the course is a fresh look at office automation: a holistic approach which covers the life of information from beginning to end, from its inception to its use many, many years later. When today's pioneers of the "office of the future" begin to adopt a holistic approach to problems they are attempting to solve with office automation technology, turnkey document storage and retrieval systems will be there to answer the question, "What now?"

A HARRIS CORPORATION APPROACH TO THE IDEA OF "PAPERLESS FACTORY":

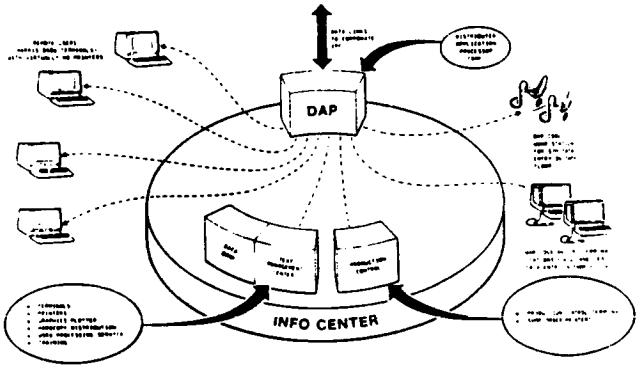
B-1B EMUX PROGRAM
INFORMATION CENTER CONCEPT

PRESENTED BY:
LAWRENCE A. BAUGHER
HARRIS CORPORATION
GOVERNMENT AEROSPACE SYSTEMS DIVISION

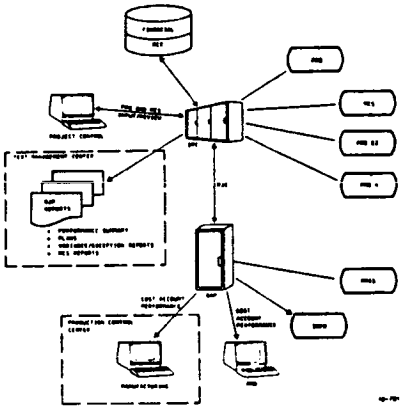
MATERIAL MANAGEMENT



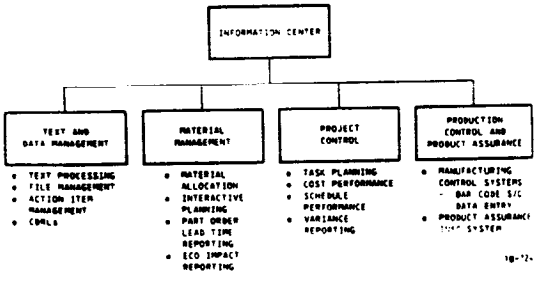
INFORMATION CENTER CONCEPT



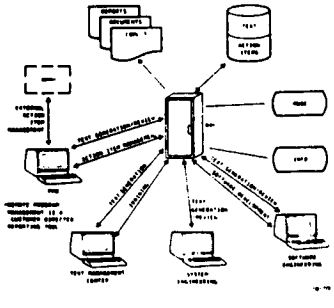
PROJECT CONTROL



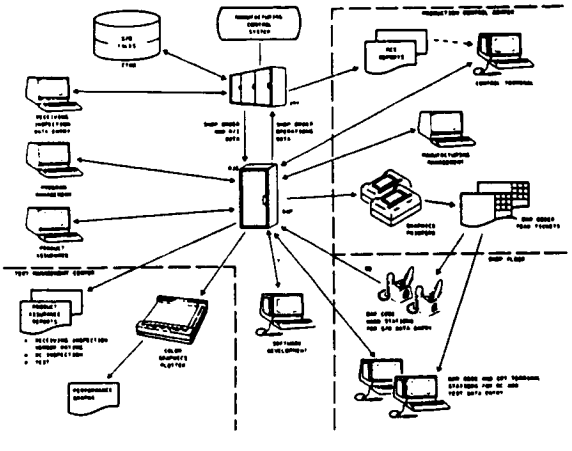
INFORMATION CENTER FUNCTIONS



TEXT AND DATA MANAGEMENT



PRODUCTION CONTROL AND PRODUCT ASSURANCE



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CURRENT STATISTICS

1	H-800 COMPUTER WITH 3 MBYTE MOS MEMORY
2	300 MBYTE DISC DRIVES
33	HARRIS "BEEHIVE" TERMINALS WITH DIRECT LINES TO H-800
2	HARRIS "BEEHIVE" TERMINALS WITH DIAL-UP ACCESS TO IPC/H-800
6	HARRIS "BEEHIVE" TERMINALS WITH SWITCH TO IPC/H-800
1	9600 BAUD RJE LINK TO CORPORATE IPC
1	3270 EMULATION LINK TO CORPORATE IPC
3	HIGH SPEED LINE PRINTERS
3	LETTER QUALITY PRINTERS
1	SPECIAL PURPOSE GRAPHICS PRINTER
4	1200 BAUD DIAL-IN LINES TO H-800
1	PROTOCOL CONVERTER LINK TO IPC FOR 8 ASYNC DEVICES
4	BAR CODE READERS
NO	PERSONAL COMPUTERS

RESULTS TO DATE

TEXT MANAGEMENT

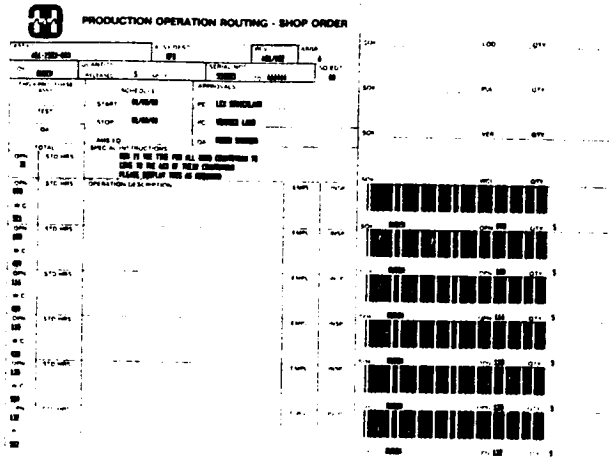
- 247 DOCUMENTS ON FILE
- 1200 VIEWGRAPHS ON FILE
- 18 TRAINED MUSE OPERATORS
- 32 ENROLLED IN MUSE TRAINING
- 3 ENROLLED IN INFO TRAINING

CHALLENGES

- DAP RJE LINK TO IPC
- SPOOLING TO LETTER QUALITY PRINTERS
- HANDLING OF SENSITIVE DATA
- MINIMIZATION OF SPECIALIZED HARDWARE
- FREQUENCY OF REBOOTS

PLANS FOR FUTURE

- EXPANSION OF SHOP FLOOR BAR CODE DATA ENTRY STATIONS
- ADDITION OF INTER-OFFICE ELECTRONIC MAIL
- PRODUCT ASSURANCE INFORMATION SYSTEM
- INTEGRATION WITH GOVERNMENT SECTOR LOCAL AREA NETWORK
- 3270 EMULATION CAPABILITY



PRODUCT RECORDS IN THE AEROSPACE FIELD

EXPENDABLE LAUNCH VEHICLES

EASTERN SPACE AND MISSILE CENTER

BY A.A. MACIAS

AREAS TO BE COVERED:

I. OPERATIONS AND MAINTENANCE RECORDS - TITAN

II. IUS LAUNCH OPERATIONS RECORD SYSTEM
- o HARDWARE DATA PACKAGE
- o ACCEPTANCE DATA PACKAGE
- o SOFTWARE CONTROL

III. TITAN AND IUS RECORDS:
- o WORK AUTHORITY -
- o DISCREPANCY AND PROBLEM REPORTING -
- o CORRECTIVE ACTION -

IV. CALIBRATION RECORDS

V. CONFIGURATION STATUS AND ACCOUNTABILITY RECORDS

VI. FLIGHT TEST READINESS REVIEWS

I. OPERATION AND MAINTENANCE RECORDS - TITAN

o	COMPONENT HISTORICAL RECORD	- AFTO FORM 2E
o	SIGNIFICANT HISTORICAL RECORD	- AFTO FORM 95
o	COMPONENT REPLACEMENT RECORD	- AFTO FORM 208
o	MAINTENANCE RECORD	- AFTO FORM 209
o	STATUS AND OPERATIONAL RECORD	- AFTO FORM 207

II. IUS LAUNCH OPERATIONS RECORD SYSTEM
- o HARDWARE DATA PACKAGE
- o ACCEPTANCE DATA PACKAGE
- o SOFTWARE CONTROL

III. TITAN & IUS RECORDS
- o WORK AUTHORITY
- o DISCREPANCY AND PROBLEM REPORTING
- o CORRECTIVE ACTION
  - o VEHICLE IMPACT STATUS

IV. CALIBRATION RECORDS
- o MIL-C-45662 CALIBRATION SYSTEM REQUIREMENTS
- o AFTO FORM 136-PRECISION MEASUREMENT EQUIPMENT RECORD

V. CONFIGURATION STATUS AND ACCOUNTABILITY RECORDS
- o TITAN
- o IUS

VI. FLIGHT TEST READINESS REVIEWS
- o INCREMENTAL REVIEWS DURING VEHICLE PROCESSING
- o VSSR (VEHICLE STATUS SUMMARY REPORT)
- o PEDIGREE PROGRAM
- o DATA PACKAGES

I OPERATIONS AND MAINTENANCE RECORDS - TITAN

Contractural Requirement on Titan Program - Not IUS

Component Historical Record - AFTO Form 2E

a) Prepared for each time/cycle critical item at the component level.

b) Initiated by the responsible contractor for hardware and spares shipped to the launch sites.

c) Used to record modifications, maintenance actions and operational time/cycle data for the designated components.

d) Upon installation of a time change item into a higher assembly, the information is transcribed into the next higher assembly AFTO Form 208 (Component Replacement Record).

Significant Historical Record - AFTO Form 95

a) Provides the contractor and Air Force a record of all approved Class I ECPs (Engineering Change Proposals), Waivers, Deviations, and other significant historical information from the time a CI (Configuration Item)/CPCI (Computer Program Configuration Item) becomes an identity.

b) Initiated by the appropriate contractor, subcontractor, vendor, and/or supplier for each program related CI/CPCI not later than the time of acceptance testing of the item, upon contractural implementation of CF-82-66-1 document, or upon receipt of a CI/CPCI from another agency.

c) The AFTO Form 95 will accompany the item throughout its useful life.

d) Form DD 829-1 originally accomplished the same function as AFTO Form 95 and can be utilized until existing supplies are expended.

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Component Replacement Record - AFTO Form 208

a) Provides a means of maintaining a current record of components or items requiring replacement at a specified calendar time, operating time, or cycles.

b) Initiated prior to shipment of vehicle, component, or item to the launch site.

c) Maintained only on equipment which contains time change items.

Maintenance Records - AFTO Form 209

a) Used to record all maintenance actions, discrepancies, and retest requirements on Airborne CIs and AGE (Aerospace Ground Equipment).

b) Initiated after complete assembly of the end item by the responsible contractor or by the first receiving organization of AGE items.

c) Records are maintained from the time of end item assignment or delivery until the items are expended in use or transferred for disposal.

Status and Operational Record - AFTO Form 207

a) Used to record system level time/cycle data for functional areas of Airborne and AGE systems.

1) Start, stop and cumulative total of system operating time (power-on time).

2) Operational status, inspection due dates and exceptional releases for all designated AGE selected end items.

b) Initiated prior to shipment of the end item to launch site or by the first receiving organization for the items of AGE.

c) Records are maintained from time of delivery to the launch site until the end item is expended or transferred for disposal.

d) This document is in the process of being phased out.

HARDWARE DATA PACKAGE

(HDP)

The Hardware Data package (HDP) is a system used to account for and maintain control of the records required to assemble, test, checkout, modify, repair, retest and maintain hardware in an assigned work area.

Hardware Data Packages are located in areas designated as Records Control Areas (RCAs).

Each HDP is sub-divided to provide a separate section for IRSOs, UERs, UEPs, PRR and non-operational streamers. Each section of the HDP Log contains an Accountability Log. All planned and unplanned events are logged into the applicable log. Upon completion or closure of the item, it is logged out by Quality Assurance Inspection stamping and dating the Q.C. Acceptance block on the log.

ACCEPTANCE DATA PACKAGES

(ADP)

Acceptance Data packages (ADPs) are also considered part of the ELS/IUS Launch Operations Record System. ADPs are the supplier records that are received with the hardware. Included are records of tests, inspections drawings, certificates of compliance, etc. After part acceptance in receiving, ADPs are filed and retained by Quality Assurance for future reference, or until contract closeout.

SOFTWARE CONTROL

The control and handling of software at ELS is extremely important since all software used at ELS has either a direct or indirect interface with the IUS vehicle. Inadvertent alteration of the software contents due to improper storage, handling or use could adversely affect the IUS mission.

The software may be in the form of tape reels, tape cassettes, keyboard entry or punched cards.

All software is received from Boeing - Kent by ELS stores. Receiving Inspection is performed by QA and a tape compare performed at the COS per a resident IRSO prior to placing in QA files.

It is necessary to provide a high level of confidence in the integrity of software placed in temporary or permanent storage. This is accomplished by the use of an integrity seal. The integrity seal is placed over the retaining ring clasp in such a manner that, when the ring is opened to gain access, the seal must be broken. While this does not preclude unauthorized access to a respository of data or computer program, it provides an indication of whether or not the canister was tampered with.

Software (tapes, punched cards, etc.) is issued as required to support scheduled testing and/or troubleshooting. The software is issued to an individual on the sign-out log.

III. WORK AUTHORITY/DISCREPANCY & PROBLEM REPORTING - TITAN

MARS - Used to document discrepancies, rework, rejection, work authority, work orders and approved modifications involving airborne, AGE and facility hardware, and test tools. Entered into computer data system for record purposes and use in other quality/reliability functions.

Two types of MARS:

1. System
2. Component

Examples of versatility of MARS:

1. Replacement of components/parts/assemblies.
2. Troubleshooting
3. Retest requirements.
4. Material Review Board Action
5. Return to Vendor
6. Scrap
7. Rework, repair, reinspection.
8. Corrective Action
9. Integrity Control
10. Investigation and/or disposition
11. Deviations (Affects safety, interchangeability, specified reliability, or performance. Contract coverage required prior to acceptance.)
12. Variations (Does not affect safety, interchangeability, specified reliability, or performance.)
13. System Failure Analysis authority. Triggers FA and FA Report attached to MARS.

14. Unverified Failure - Any system or component which has exhibited a functional failure during testing for which no reasonable explaination or conclusive cause can be found. Engineering analysis is prepared. Unverified failures are reviewed and approved by the Manager of Mission Success and is not for flight usage without approval of Space Division.

15. Break of Inspection (BOI) - An action against the vehicle or its associated GSE which removes the vehicle from an operational status.

SYSTEM MARS

Nonconformances occuring at system level are recorded on Systems MARS and logged at the Quality Data Center. All system MARS are inputted to the Open Items Status Summary. The OISS is reviewed for open items or incomplete work accomplishment prior to each scheduled milestone.

COMPONENT MARS

Nonconforming components (not installed in a system or after removal from system) are recorded on component MARS. A "Withheld for Material Review" stamp is applied to the item or a tag, label, or bag attached to the item until disposition by Material Review Board action.

WORK AUTHORITY - IUS

Work authority forms are used to provide work instructions for planned events and provide the means for recording work accomplishment and acceptance. Planned events will be based on released engineering and contractual requirements. Detailed Operating Procedures (DOPs) will be released and documented as planned events. This is accomplished by use of the Work Increment System and the IRSO Integrated Record System Order.

WORK INCREMENT SYSTEM

The Work Increment System is intended to provide a method by which Manufacturing Planning can be requested to release an IRSO. IRSOs required for Site Activation, Vehicle Processing, and special tests are requested by Work Increment Memos. Originals of the Work Increment are maintained by Test Integration.

IRSO

All planned work which affects/verifies configuration or performance of hardware or services are documented on IRSOs.

IRSOs provide detailed instructions for work to be performed and a record of work accomplishment/acceptance. IRSOs consist of a combination of forms.

IRSOs are issued to support change committments, in-sequence installation or testing, fabrication, assembly, maintenance, or unplanned events as authorized by CBCR, work increment, Maintenance Requirement, Shop Aid Request, or Supplement unplanned event disposition.

DISCREPANCY AND PROBLEM REPORTING - IUS

Boeing records all nonconformances and deviations from planned events. The following are considered unplanned events:

(1) Hardware, engineering, physical, and functional nonconformances.

(2) Discrepancies or conditions noted on planned inspection shakedowns, work area surveys, and investigations.

(3) Parts that are removed and reinstalled to facilitate the accomplishment of unplanned events. This is accomplished by use of the UER or UEP.

UNPLANNED EVENT PICKUP

The Unplanned Event Pickup (UEP) is used to record nonconforming conditions which can be corrected to drawing configuration without specific written instructions, and which do not require a record of non-recurrence action.

UNPLANNED EVENT RECORDS

The Unplanned Event forms are used to record all discrepancies and errors occurring after a plan has been released into work. These forms are also used to obtain disposition and nonrecurrence action, record removals and reinstallations, travel incomplete items, to accomplish troubleshooting in the resolution of equipment problems, and Materiel Review Actions.

DOP HISTORY SHEET

(DHS)

The DOP History Sheet (DHS) is used to provide a real time historical record of all unplanned changes to the procedure encountered during the accomplishment of a Detailed Operating procedure. The DHS form is used to record all DOP discrepancies, errors, deviations, test interruptions and corrective actions occurring after the DOP has been placed in work.

DHS items are reviewed at the DOP post test review and classified into one of the following categories:

a) Hardware Nonconformance, UER No.

b) Software Nonconformance, SPR No.

c) Permanent DOP change, (explain)

d) One time DOP change, (explain)

e) Test Termination, (reason)

f) Test Interruption, (reason)

CORRECTIVE ACTION - TITAN

Originated by MARS, MRB action, failure analysis or significant problems recorded in historical data files.

Denver Mission Success is notified by telephone of all significant impact or potential impact problems. A Corrective Action Problem Summary (CAPS) is prepared and tasks assigned. Other Corrective Action traceability and follow-up by Failure Analysis Reports, Corrective Action Directive, Corrective Action Directive Reply and Supplier Corrective Action Request.

CORRECTIVE ACTION - IUS

Copies of all UERs are forwarded to Quality Data Systems at Kent. The Corrective Action Board, also located at Kent, reviews all UERs for trends and/or significant problems and prepares Problem Packages for those items requiring follow-up and corrective action.

Potential launch on time and flight impact problems occuring during IUS processing at ELS are coordinated with the Corrective Action Board via telecon.

Vendor corrective action is implemented from Boeing/Kent.

VEHICLE IMPACT STATUS

A listing of all flight impact problems which must be resolved prior to entering the launch Flight Test Readiness Review. These impacts are significant problems which are regarded to be mission critical. The items which are classified as flight impacts are placed on the Vehicle Impact Status Report after a thorough review and evaluation of the problem by representatives of SD/Aerospace and the Boeing Failure Review Board or Martin Mission Success group.

The Vehicle Impact Report is updated every two weeks during vehicle processing and daily as the launch date draws near.

IV. CALIBRATION

Calibration of tools and precision measuring and test equipment is performed, maintained and verified in accordance with MIL-C-45662, Calibration System Requirements and other sub-tier documents.

Martin Calibration Lab calibrates those Titan program items which cannot be processed through the Range Precision Measurement Equipment Lab due to schedule or technical requirements. The Martin Cal Lab maintains a file of calibration procedures and the AFTO Form 136 for each item requiring calibration.

Boeing has no calibration lab at ELS, and all items requiring calibration are sent out to the PMEL facility. Boeing supply keeps a copy of the calibration record and maintains the recall system.

The basic record system for calibration management consists of the AFTO Form 136, Precision Measurement Equipment Record. These cards provide equipment nomenclature, tolerance capability, cal cycle requirements, maintenance and repair history.

A "No Cal Required" sticker is applied to all indicating devices and equipment not requiring calibration. All calibrated equipment must exhibit a calibration certification sticker which indicates the day, month, and year the calibration was accomplished, and the calibration expiration date.

All equipment calibrated by Martin or the PMEL is traceable to the National Bureau of Standards.

V. CONFIGURATION STATUS AND ACCOUNTABILITY - TITAN

The Titan configuration accountability system is maintained on all deliverable/non-deliverable end items and test tools in accordance with the Configuration and Data Management Plan.

All modifications to airborne and ground equipment are performed in accordance with approved Change Operations Directives received from Denver. Local authorization to perform the modification is by Modification Authorization MARS.

The Operations Planning Group schedules the mod incorporation and the Mod Installation Group prepares the MARS with all the applicable incorporation information (Mod instructions, engineering drawings, retest required).

Mod incorporation accountability is by Quality and Air Force Acceptance stamping on the MARS.

Applicable logs and historical records are updated by QA to relfect the latest configuration status and concurrence obtained from AFQA.

Paper Change Only mods are accounted for by QA acceptance on a Change Accountability Completion Input Card.

A Configuration and Data Management tab run showing the mod status is updated daily and printed weekly.

Martin ELS has a computer and terminal which is used to record configuration status. The Martin ELS Configuration Data System has the capability to querie the Denver Configuration Management Data System for status but does not input to that computer.

A tab run listing of all the Martin ELS completed mods is forwarded to Denver Configuration Management on a weekly basis.

IUS CONFIGURATION MANAGEMENT RECORDS

Provides accountability for the engineering requirements of a committed change.

All configuration changes reviewed, approved and directed by the ELS Change Board.

The following forms are utilized in the implementation and documentation of committed changes at ELS:

CHANGE BOARD COMMITMENT RECORD

The ELS Change Board prepares and authorizes an ELS Change Board Commitment Record (CBCR) which includes schedule commitments and resource identification for implementation of the change as scheduled.

DOCUMENT RELEASE COMPLETION RECORD (DRCR)

Document Release Completion Record (DRCR) forms are used at ELS only to record the release of a document required by a committed change.

DRCRs shall be used for the following types of committed releases:

(1) Complete DOP revisions.

(2) DOP APCN releases.

(3) Test Report completions.

(4) Other documentation releases identified by ELS CBCR commitments.

ENGINEERING RELEASE COMPLETION RECORD (ERCR)

ERCR is used to record the release of a hardware committed change. This document is a Boeing/Seattle engineering initiated document.

PLANNING ACCOUNTABILITY RECORD (PAR)

The Planning Accountability Record (PAR) provides cross-referenced accounting of Engineering Drawing Data Required (ERCR) to the Manufacturing Planning released to incorporate a specific controlled or committed Engineering Change and Work Increments (WIs). The PAR provides accountability of the complete change incorporation.

VI. TITAN & IUS

FLIGHT TEST READINESS REVIEWS

Readiness Review - A detailed presentation to Government and contractor agencies which provides the status of the launch vehicle, associated AGE, launch crews, schedule, mission success problems, design, logistics and limited life/cycle components. The review will assess the readiness to proceed to the next scheduled milestone or launch.

INCREMENTAL REVIEWS

At selected key incremental review points during the launch processing of each vehicle the Readiness Review Team Members convene to review the status of the launch vehicle testing to that point.

Technical concurrence by the Readiness Review Team Members constitutes test readiness to that point and authorizes continuation of the testing, and in the final analysis, the authority to proceed with the launch activity.

VEHICLE STATUS SUMMARY REPORT - VSSR

The Vehicle Status Summary Report (VSSR) defines the condition and status of the vehicle as it exists at the completion of Acceptance Testing. It contains a listing of conditions for movement of the vehicle, contractor certification, and Acceptance Team recommendation.

The signing of the VSSR authorizes the vehicle to move from the subsystem testing phase of the acceptance activity to the testing phase directly associated with the launch preparation activity, i.e., move to the pad or move to Vertical Processing Facility (IUS).

PEDIGREE PROGRAM

Pedigree - Special reviews conducted at the component and/or device subsystem and system level to ensure a flight worthiness of the airborne hardware and its spares, and to support vehicle acceptance.

Airborne components are considered critical to mission success. These components are approved for flight usage after a review of the build, test, and failure data of each component by serial number. SD/Aerospace data review and approval prior to launch is required.

The Component Pedigree Status list contains a listing of designated critical components approved for use at ELS.

The pedigree of a component is voided whenever a pedigree component is rejected, modified, or returned to the vendor for modification or retest, etc.

DATA PACKAGES

Prior to each Readiness Review, a Quality and Reliability Subworking Group reviews and evaluates the Readiness Review Data Package prepared by each contractor. The Data Package contains data concerning vehicle shortages, component replacements, time/cycle sensitive components, pedigree and qualification status, open waivers, failure analysis status, test procedure status, vehicle and AGE modification status, corrective action problem status, open items status, identification of any launch/test restraints, and a listing of key personnel.

At the conclusion of the Data Package review and evaluation, the Quality and Reliability Subworking Group determines if there are any restraints to proceeding with the next major event and notifies the Air Force Vehicle Test Controller of its decision prior to the Readiness Review.

NDE FOR FIBER REINFORCED COMPOSITES
STANDARDS/CRITERIA/APPROACHES

Presented by Alex Vary
NASA Lewis Research Center
Cleveland, Ohio

To Composites Technology Workshop
Mission Assurance Conference
Los Angeles, California, 7-8-9 June 1983

ABSTRACT

An overview is given on problem areas involved in extablishing meaningful nondestructive evaluation (NDE) approaches for aerospace composites. The questions of unassailable accept/reject criteria and standard reference materials for NDE calibrations are invoked. The focus is on filament-wound casings for reusable space shuttle boosters. Current NDE approaches are reviewed and critiqued. A new approach is described and examples of its potentials are given. The new approach, termed acousto-ultrasonics, goes beyond flaw detection and characterization by attempting to assess the mechanical/dynamic response of the material environment in which the flaws reside.

NASA Lewis Research Center MATERIALS DIVISION – NDE

CURRENT GAPS : CHALLENGES FOR NDE

EFFECTS OR CRITICALITY OF READILY-FOUND FLAWS ARE OFTEN UNKNOWN

TECHNIQUES FOR MECHANICAL PROPERTY & DEGRADATION ASSESSMENT ARE LACKING

FUNDAMENTAL MODELS TO EXPLAIN EMPIRICAL CORRELATIONS ARE NEEDED

NASA Lewis Research Center MATERIALS DIVISION – NDE

EXAMPLES OF CRITICAL AND NON-CRITICAL FACTORS FOR INTERNALLY PRESSURIZED FILAMENT-WOUND ROCKET CASES

CRITICAL

- CUT, BROKEN FIBERS (IMPACT DAMAGE)
- DELAMINATIONS AT KNUCKLES, REINFORCEMENTS
- DELAMINATIONS, CRACKS AT EDGES, NEAR HOLES
- GROSS, GLOBAL NONUNIFORMITIES (CURE STATE)

NON-CRITICAL

- POROSITY, MATRIX CRAZING
- MIDCASE, WEB DELAMINATIONS
- LOCAL RESIN, FIBER RICHNESS
- FOREIGN INCLUSIONS, DEBRIS

NASA Lewis Research Center MATERIALS DIVISION – NDE

FIBER REINFORCED COMPOSITE NDE PROBLEM AREAS

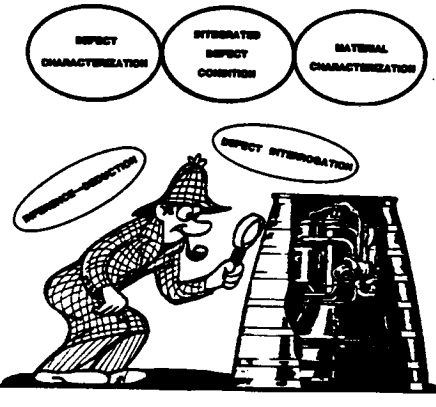
I. REFERENCE-CALIBRATION STANDARDS

II. ACCEPT-REJECT-REPAIR CRITERIA

III. MECHANICAL PROPERTIES VERIFICATION

IV. DEGRADATION-REUSABILITY ASSESSMENT

NASA Lewis Research Center MATERIALS DIVISION – NDE



NASA Lewis Research Center MATERIALS DIVISION – NDE

COMPARISON OF FILAMENT-WOUND AND AUTOCLAVE-CURED COMPOSITES

FILAMENT-WOUND (ROCKET REQUIREMENTS)	AUTOCLAVE-CURED (AIRCRAFT REQUIREMENTS)
• GOOD PRESSURE-VESSEL PERFORMANCE	• GOOD STRUCTURAL PROPERTIES
• LOW FATIGUE CYCLE EXPOSURE	• HIGH FATIGUE CYCLE EXPOSURE
• MODERATE-HIGH ELONGATION	• LOW ELONGATION RESIN
• LOW CURE TEMPERATURE RESIN	• HIGH CURE TEMPERATURE RESIN
• HIGH FIBER VOLUME	• MODERATE FIBER VOLUME
• MINIMAL CURE PRESSURE	• HIGH CURE PRESSURE
• MODERATE TO HIGH VOID CONTENT	• LOW VOID CONTENT

(AFTER: S. B. KULKARNI, NOV. 11, 1982 MACHINE DESIGN)

NASA Lewis Research Center MATERIALS DIVISION – NDE

CANDIDATE NDE TECHNIQUES

- RADIOGRAPHY (FILM, COMPUTER TOMOGRAPHY)
- THERMOGRAPHY (INFRARED STRAIN IMAGING)
- HOLOGRAPHY (& OTHER OPTICAL METHODS)
- ELECTROMAGNETICS (CONDUCTIVITY, MICROWAVE)
- ULTRASONICS (TRANSMISSION, PULSE-ECHO)
- ACOUSTO-ULTRASONICS (TAP TEST)

CORRELATION OF STRESS WAVE FACTOR WITH MECHANICAL BEHAVIOR OF COMPOSITE LAMINATES

The acousto-ultrasonic approach was introduced at the Lewis Research Center to handle nondestructive evaluation requirements peculiar to composite laminates. Acousto-ultrasonics overcomes difficulties associated with the high degree of anisotropy and pronounced attenuation exhibited by fiber reinforced composites. The primary objective of acousto-ultrasonics is to assess morphological variations that govern extrinsic properties and, hence, mechanical behavior.

The acousto-ultrasonic approach is based on measuring the propagation of simulated stress waves primarily along the major load directions in fiber reinforced laminates. This is accomplished by measuring a quantity called the stress wave factor (SWF). The SWF provides a means for rating the efficiency of dynamic strain energy transfer in a material. If a given composite material exhibits efficient stress wave energy transfer, then it is likely to have a greater strength. That is, better stress wave energy transmission means better transmission of dynamic stress and load distribution. Conversely, low values of SWF would indicate places where dynamic strain energy is likely to concentrate and promote fracture.

The purpose of the study reported in this highlight was to determine how stress wave factor (SWF) measurements relate to mechanical behavior exhibited by composite laminates subjected to mild tensile loading (i.e., loading just short of inducing fracture). To accomplish this, SWF measurements were made on virgin specimens of a glass/epoxy laminate. A grid system was used to subdivide the lateral surface of the specimens. Using the grid as a guide, a series of 51 overlapping SWF readings were made to create a topological mapping of variations in the SWF. These variations corresponded to nonuniformities in material morphology due, for example, to slight differences in microvoid content, cure state, and fiber/resin ratio from point to point. An example of the SWF topology is illustrated in the accompanying figure. All the SWF measurements are directional and parallel to the major axis of the laminate. Subsequently, the specimens were incrementally loaded and lateral tensile displacements of the specimens were recorded by Moiré interferometry, as illustrated in the accompanying figure.

Variations in lateral displacements and, by inference, local variations in stiffness correlate well with the SWF topology. This correlation helps establish the viability of the acousto-ultrasonic approach in assessing the potential mechanical behavior of composite laminates and thus predicting their dynamic response.

REFERENCES:

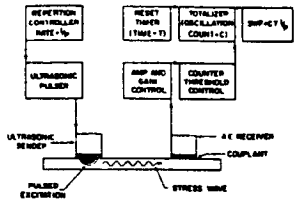
A. Vary, "Acousto-Ultrasonic Characterization of Fiber Reinforced Composites," Materials Evaluation, Vol. 40, No. 6, May 1982, pp. 650-654, 662.

E. G. Henneke, II, et al., " A Study of the Stress Wave Factor Technique for the Characterization of Composite Materials," NASA Contractor Report 3670 (1983).

J. H. Williams, Jr., et al., "Ultrasonic Input-Output for Ttransmitting and Receiving Longitudinal Transducers Coupled to the Same Face of Isotropic Elastic Plate," Materials Evaluation, Vol. 40, No. 6, May 1982, pp. 655-662.

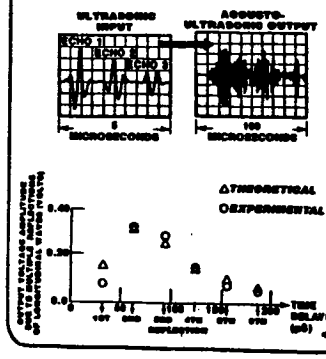
NASA Lewis Research Center MATERIALS DIVISION – NDE

DIAGRAM OF ACOUSTO-ULTRASONIC NDE METHOD
FOR STRESS WAVE FACTOR MEASUREMENT



NASA Lewis Research Center MATERIALS DIVISION – NDE

THEORETICAL PREDICTION OF THE ACOUSTO-ULTRASONIC WAVEFORM



★ THE ACOUSTO-ULTRASONIC WAVEFORM IS A COMPLEX INTERFERENCE OF MULTIPLE REFLECTIONS OF SHORT TRAIN ULTRASONIC WAVES

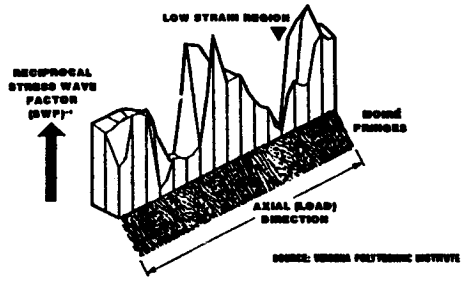
★ THE ACOUSTO-ULTRASONIC WAVEFORM CHARACTERIZES MECHANICAL PROPERTIES OF THE MATERIAL TRAVERSED

★ ANALYSIS OF THE MATERIAL FACTORS INFLUENCING THE WAVEFORM YIELDED GOOD AGREEMENT BETWEEN THE THEORETICALLY PREDICTED AND EXPERIMENTAL VALUES ON THE WAVEFORM ENVELOPE FOR AN ISOTROPIC MEDIUM

SOURCE: MASSACHUSETTS INSTITUTE OF TECHNOLOGY

NASA Lewis Research Center MATERIALS DIVISION – NDE

CORRELATION OF SWF TOPOLOGY AND MOIRÉ PATTERN INDICATING MECHANICAL PROPERTY VARIATIONS



SOURCE: VIRGINIA POLYTECHNIC INSTITUTE

HIGH SWF AND LOW STRAIN REGIONS EXHIBIT GREATER STRENGTH FOR THE GLASS/EPOXY COMPOSITE LAMINATES TESTED

NASA Lewis Research Center MATERIALS DIVISION – NDE

THEORETICAL PREDICTION OF THE ACOUSTO-ULTRASONIC WAVEFORM

FEATURES

- ANALYSIS OF WAVE PROPAGATION AND MATERIAL FACTORS THAT GOVERN THE ACOUSTO-ULTRASONIC WAVEFORM YIELDED GOOD AGREEMENT BETWEEN THEORETICALLY PREDICTED AND EXPERIMENTAL VALUES ON THE WAVEFORM ENVELOPE FOR AN ISOTROPIC MEDIUM.

STATUS

- THEORETICAL AND EXPERIMENTAL INVESTIGATIONS ARE CONTINUING.
- THE EFFECTS OF SPECIMEN BOUNDARY CONDITIONS AND NATURAL FREQUENCIES ARE BEING EVALUATED.
- THE EFFECTS OF MATERIAL ANISOTROPIES AND INHOMOGENEITIES ARE ALSO BEING EVALUATED.

BENEFITS

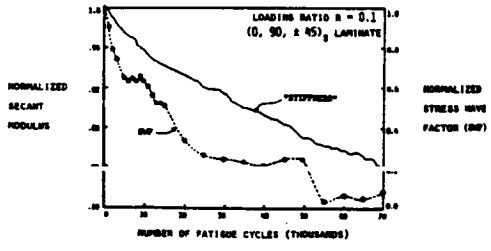
- IMPROVED UNDERSTANDING OF THE BEST METHODS OF APPLICATION OF ACOUSTO-ULTRASONICS AS A NONDESTRUCTIVE EVALUATION TECHNIQUE FOR A VARIETY OF STRUCTURAL MATERIALS IS BEING REALIZED.

RESEARCHERS

- JAMES H. WILLIAMS, JR., ET AL. (MASSACHUSETTS INSTITUTE OF TECHNOLOGY)

NASA Lewis Research Center MATERIALS DIVISION – NDE

COVARIATION OF STRESS WAVE FACTOR (SWF)
AND LONGITUDINAL SECANT MODULUS WITH
FATIGUE DAMAGE IN GRAPHITE/EPOXY LAMINATE



SOURCE: VIRGINIA POLYTECHNIC INSTITUTE

NASA Lewis Research Center MATERIALS DIVISION – NDE

CORRELATION OF STRESS WAVE FACTOR WITH MECHANICAL
BEHAVIOR OF COMPOSITE LAMINATES

FEATURES

- IT WAS DEMONSTRATED THAT ACOUSTO-ULTRASONIC STRESS WAVE FACTOR MEASUREMENTS CAN PREDICT NONUNIFORMITIES IN LATERAL STRAIN WHEN COMPOSITE LAMINATES ARE LOADED IN TENSION.
- A DIRECT CORRELATION WAS FOUND BETWEEN STRESS WAVE FACTOR TOPOLOGICAL MAPPINGS AND MOIRÉ FRINGE PATTERNS ON A SET OF GLASS/EPOXY FIBER COMPOSITE LAMINATE TENSILE SPECIMENS.

STATUS

- CONTINUING STUDIES ARE FOCUSING ON ASSESSMENT OF STRESS WAVE FACTOR MEASUREMENTS FOR PREDICTING WEAK ZONES AND POTENTIAL FAILURE LOCI IN COMPOSITE LAMINATES.

BENEFITS

- CONCLUSIVE EVIDENCE IS BEING COMPILED DEMONSTRATING THE VIABILITY OF NONDESTRUCTIVE STRESS WAVE FACTOR MEASUREMENTS FOR ASSESSING MECHANICAL PROPERTY VARIATIONS CORRESPONDING TO PRINCIPAL LOAD DIRECTIONS IN FIBER COMPOSITE LAMINATE STRUCTURES.

RESEARCHERS

- EDMUND G. HENNEKE, ET AL. (VIRGINIA POLYTECHNIC INSTITUTE)

NASA Lewis Research Center MATERIALS DIVISION – NDE

SUMMARY

NEEDS FOR COMPOSITE STRUCTURES NDE

- CREDIBLE CRITERIA FOR REJECTION, REPAIR
- MATERIALS STRENGTH VERIFICATION
- DEGRADATION, DAMAGE ASSESSMENT
- DYNAMIC RESPONSE PREDICTION

BEST FIT PROGRAM FOR DIMENSIONAL REFERENCE ADJUSTMENT

ABSTRACT

The Lockheed-Georgia Company has developed a "Best Fit" program which works in conjunction with a CCMM. When measuring complex aircraft parts there is often no accurate method of aligning the part references to the measuring machine. This required re-measuring the part with references manually shifted until a best fit was obtained. Using the "Best Fit" program references are automatically shifted in 6 degrees of freedom to reduce the out of tolerance wherever possible.

C. F. (Bud) Nix, Jr.
Lockheed-Georgia Co.
Marietta, Georgia

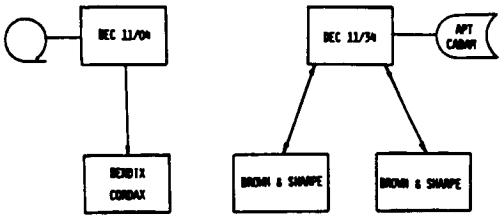
BEST FIT PROGRAM FOR DIMENSIONAL REFERENCE ADJUSTMENT

CLAUDE F. (BUD) RIX, JR.

JUNE 1983

Lockheed-Georgia Company

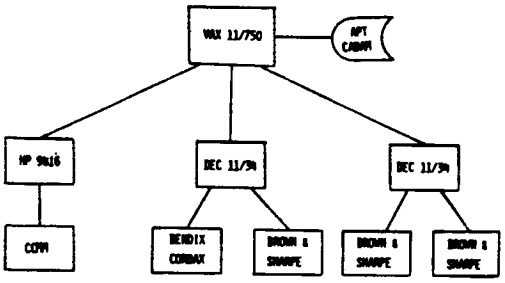
LOCKHEED-GEORGIA PRESENT CDM SYSTEM



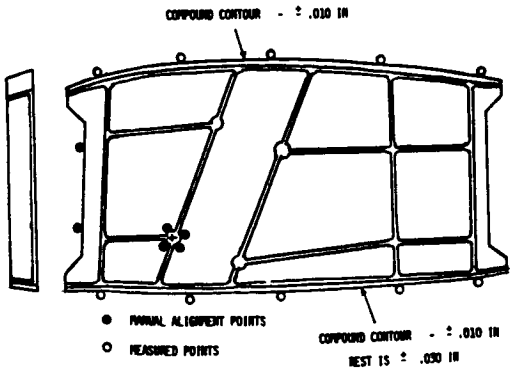
Lockheed-Georgia Company

LOCKHEED-GEORGIA FUTURE

CDM SYSTEM

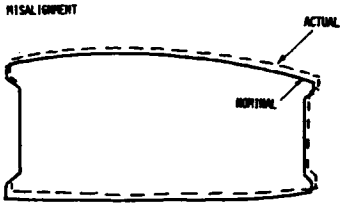


Lockheed-Georgia Company



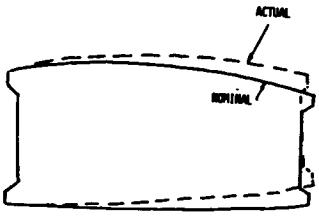
Lockheed-Georgia Company

POSSIBLE X-Y MISALIGNMENT



Lockheed-Georgia Company

POSSIBLE ROTATIONAL MISALIGNMENT



Lockheed-Georgia Company

3397E07 SRSH-7084J41339 103A E CHIN 39-11 9-29-82 1

LOC	NOMINAL	+ TOL	- TOL	MEASURED	DEVIATION	OUT/TOL
70						
X	30.7497	0.0100	0.0100	30.7514	0.0016	0.0000
Y	7.4097	0.0100	0.0100	7.4271	0.0172	0.0172
Z	0.0000	0.0100	0.0100	0.0000	0.0000	0.0000
LOC	NOMINAL	+ TOL	- TOL	MEASURED	DEVIATION	OUT/TOL
80						
X	30.7390	0.0100	0.0100	30.7380	-0.0010	0.0000
Y	8.6488	0.0100	0.0100	8.6412	-0.0073	0.0000
Z	0.0000	0.0100	0.0100	0.0000	0.0000	0.0000
LOC	NOMINAL	+ TOL	- TOL	MEASURED	DEVIATION	OUT/TOL
90						
X	30.7731	0.0100	0.0100	30.7712	-0.0097	0.0000
Y	9.4772	0.0100	0.0100	9.4610	-0.0162	0.0062
Z	0.0000	0.0100	0.0100	0.0000	0.0000	0.0000
LOC	NOMINAL	+ TOL	- TOL	MEASURED	DEVIATION	OUT/TOL
100						
X	10.7806	0.0100	0.0100	10.7806	-0.0000	0.0000
Y	9.7710	0.0100	0.0100	9.7480	-0.0229	0.0129
Z	0.0000	0.0100	0.0100	0.0000	0.0000	0.0000
LOC	NOMINAL	+ TOL	- TOL	MEASURED	DEVIATION	OUT/TOL
110						
X	2.7931	0.0100	0.0100	2.7948	0.0018	0.0000
Y	9.9214	0.0100	0.0100	9.4941	-0.0272	0.0172
Z	0.0000	0.0100	0.0100	0.0000	0.0000	0.0000
LOC	NOMINAL	+ TOL	- TOL	MEASURED	DEVIATION	OUT/TOL
120						
X	2.7711	0.0100	0.0100	2.7730	0.0017	0.0000
Y	-4.9163	0.0100	0.0100	-4.9499	-0.0336	0.0236
Z	0.0000	0.0100	0.0100	0.0000	0.0000	0.0000

Lockheed-Georgia Company

LOC	NOMINAL	+ TOL	- TOL	MEASURED	DEVIATION	OUT/TOL
130						
X	10.7717	0.0100	0.0100	10.7742	0.0025	0.0000
Y	-4.4893	0.0100	0.0100	-4.5330	-0.0437	0.0337
Z	0.0000	0.0100	0.0100	0.0000	0.0000	0.0000
LOC	NOMINAL	+ TOL	- TOL	MEASURED	DEVIATION	OUT/TOL
140						
X	30.7725	0.0100	0.0100	30.7727	0.0002	0.0000
Y	-3.9382	0.0100	0.0100	-3.9428	-0.0045	0.0000
Z	0.0000	0.0100	0.0100	0.0000	0.0000	0.0000
LOC	NOMINAL	+ TOL	- TOL	MEASURED	DEVIATION	OUT/TOL
150						
X	30.7742	0.0100	0.0100	30.7745	0.0004	0.0000
Y	-3.4312	0.0100	0.0100	-3.4379	-0.0068	0.0000
Z	0.0000	0.0100	0.0100	0.0000	0.0000	0.0000
LOC	NOMINAL	+ TOL	- TOL	MEASURED	DEVIATION	OUT/TOL
160						
X	30.7723	0.0100	0.0100	30.7726	0.0004	0.0000
Y	-2.9672	0.0100	0.0100	-2.9742	-0.0070	0.0000
Z	0.0000	0.0100	0.0100	0.0000	0.0000	0.0000

END OF ORIGINAL MEASUREMENT

TRANSLATION VECTOR IS (0.00047 -0.01521 0.00000)

Lockheed Georgia Company

COORDINATES AFTER TRANSLATION ONLY

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
70						
X	30.7497	0.0100	-0.0100	30.7507	0.0010	0.0000
Y	7.4099	0.0100	-0.0100	7.4423	0.0324	0.0324
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
80						
X	30.7590	0.0100	-0.0100	30.7573	-0.0017	0.0000
Y	8.4485	0.0100	-0.0100	8.4564	0.0079	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
90						
X	20.7721	0.0100	-0.0100	20.7705	-0.0015	0.0000
Y	9.4772	0.0100	-0.0100	9.4762	-0.0010	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
100						
X	10.7906	0.0100	-0.0100	10.7799	-0.0007	0.0000
Y	9.7710	0.0100	-0.0100	9.7633	-0.0077	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
110						
X	2.7931	0.0100	-0.0100	2.7942	0.0011	0.0000
Y	9.5214	0.0100	-0.0100	9.5093	-0.0120	-0.0020
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

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ROTATION IN XY,ZX&YZ PLANES:

-0.86521E-03 0.00000E+00 0.00000E+00

COORDINATES AFTER TRANSLATION AND ROTATION

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
70						
X	30.7497	0.0100	-0.0100	30.7549	0.0052	0.0000
Y	7.4099	0.0100	-0.0100	7.4247	0.0148	0.0048
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
80						
X	30.7590	0.0100	-0.0100	30.7626	0.0036	0.0000
Y	8.4485	0.0100	-0.0100	8.4478	-0.0008	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
90						
X	20.7721	0.0100	-0.0100	20.7744	0.0045	0.0000
Y	9.4772	0.0100	-0.0100	9.4762	-0.0010	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
100						
X	10.7906	0.0100	-0.0100	10.7862	0.0055	0.0000
Y	9.7710	0.0100	-0.0100	9.7719	0.0009	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
110						
X	2.7931	0.0100	-0.0100	2.8003	0.0072	0.0000
Y	9.5214	0.0100	-0.0100	9.5249	0.0035	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

Lockheed-Georgia Company

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
120						
X	2.7711	0.0100	-0.0100	2.7723	0.0012	0.0000
Y	-4.9163	0.0100	-0.0100	-4.9346	-0.0184	-0.0084
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
130						
X	10.7717	0.0100	-0.0100	10.7734	0.0018	0.0000
Y	-4.4093	0.0100	-0.0100	-4.5178	-0.0285	-0.0185
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
140						
X	20.7725	0.0100	-0.0100	20.7720	-0.0004	0.0000
Y	-3.9382	0.0100	-0.0100	-3.9274	0.0107	0.0007
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
150						
X	30.7742	0.0100	-0.0100	30.7738	-0.0003	0.0000
Y	-3.4312	0.0100	-0.0100	-3.4227	0.0085	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
160						
X	30.7723	0.0100	-0.0100	30.7719	-0.0003	0.0000
Y	-2.9672	0.0100	-0.0100	-2.9670	0.0002	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

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LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
120						
X	2.7711	0.0100	-0.0100	2.7659	-0.0052	0.0000
Y	-4.9163	0.0100	-0.0100	-4.9191	-0.0028	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
130						
X	10.7717	0.0100	-0.0100	10.7675	-0.0043	0.0000
Y	-4.4093	0.0100	-0.0100	-4.4091	-0.0198	-0.0098
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
140						
X	20.7725	0.0100	-0.0100	20.7665	-0.0060	0.0000
Y	-3.9382	0.0100	-0.0100	-3.9274	0.0107	0.0007
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
150						
X	30.7742	0.0100	-0.0100	30.7687	-0.0055	0.0000
Y	-3.4312	0.0100	-0.0100	-3.4314	-0.0002	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

LOC	NOMINAL	+TOL	-TOL	MEASURED	DEVIATION	OUT/TOL
160						
X	30.7723	0.0100	-0.0100	30.7672	-0.0051	0.0000
Y	-2.9672	0.0100	-0.0100	-2.9746	-0.0074	0.0000
Z	0.0000	0.0100	-0.0100	0.0000	0.0000	0.0000

TT4 -- STOP

OUT OF TOLERANCES	ORIGINAL MEASUREMENT	AFTER TRANSLATION	AFTER TRANSLATION AND ROTATION
	6	5	3

Lockheed Georgia Company

SUMMARY OF ISSUES AND RECOMMENDATIONS

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Use of P95 Monitored Line System

Issue

Use of P95 monitored line system by NASA.

Recommendations

NASA management establish system interface with Lockheed which will permit use of the P95 monitored line system on NASA projects. (Provides high reliability nonstandard parts when "S" level MIL spec parts do not exist.)

Suggested OPR

NASA

2. MIL-Spec System

Issue

Irregularities in the microcircuit MIL-Spec system have caused a loss in confidence that might affect the Aerospace industry's ability to procure quality assurance microcircuits, especially for the new microcircuit families now appearing.

Recommendations

The panel recognizes the value and utility of the MIL-Spec system to the procurement of quality assured microcircuits. It recommends that the Mission Assurance Conference endorse the need for action to restore confidence in the quality assurance controls of the MIL-Spec system. (Only 48% of CMOS devices are qualified to "S" level. High speed CMOS are the next generation of parts prior to LSI, VLSI, and VHSIC availability. Steps need to be taken to ensure qualification of high speed CMOS to "S" level requirements.)

Suggested OPR

Space Division

3. Planning for Use of Microcircuits

Issue

Adequacy of overall Assurance Technology planning for military and space use of VLSI and VHSIC microcircuits.

Recommendations

Major problem areas associated with:

a) Present methods of internal visual and burn-in requirements may no longer be adequate.

b) Current density design criteria is suspect.

c) Latent defect identification is a problem.

d) MIL-M-38510 qualification and lot acceptance criteria are not compatible with VLSI and VHSIC.

It is recommended that a task force be established to address possible approaches for the following key areas:

a) Use of test pattern testing philosophy to supplement/replace internal visual inspections and tests.

b) Inclusion of more extensive evaluation/verification of device design and processes.

c) Incorporation of testability into design criteria.

d) Development of new test/screening philosophies.

This would ultimately lead to a MIL-M-38510 equivalent for VLSI and VHSIC products.

Suggested OPR

AIA/NSIA/SD/NASA

4. Microelectronic Device Physics

Issue

Microelectronic device physics associated with the causes of radiation effects are not understood in depth.

Recommendations

Endorse the development of a research program to analyze the device physics involved in radiation effects towards identification of fundamental physical characteristics which lead to radiation degradation and the physical and electrical alterations caused by both total dose radiation exposure and high energy single event strikes.

Suggested OPR

AIA/NSIA/SD/NASA (Government Lead)

5. Radiation Hazards

Issue

Impact of single event radiation hazards on VLSI and VHSIC.

Recommendations

A technical education project be undertaken to describe the current known risks of single event upsets (SEU) and their serious potential risks for the more complex, smaller geometry devices of the future. Emphasis should be placed upon the probable need for both device and system level solutions to the problems.

Suggested OPR

AIA/NSIA/SD/NASA

6. Test and Verification of VLSI and VHSIC Parts

Issue

Independent test and verification of VLSI and VHSIC parts subsequent to manufacturer test and delivery.

Recommendations

Establish a procurement philosophy for VLSI and VHSIC that a copy of source codes and test software be made available to the customer or delivered with each procurement so independent testing can be accomplished at a reasonable cost when such tests are appropriate.

Suggested OPR

NSIA/AIA
Microelectronics Committee

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Lack of Standard Data

Issue

There is a lack of standardized quantitative data to assess current software assurance technology, identify future needs, and motivate new development.

Recommendations

Industry should develop a system for defining, collecting, and sharing data on the effectiveness of software assurance technology. The effectiveness of this data needs to be well thought out. The voluntary participation of the community in this issue is important. Comparative evaluation, like the AIA cost data, is the proper way to achieve this.

Suggested OPR

AIA/NSIA

2. Multiple Software Requirements

Issue

Software Quality Program requirements are currently defined in several government specifications and standards (e.g., MIL-STD-1679, MIL-S-52779A, MIL-STD-1644A). The multiple requirements cause confusion in both industry and government procurement offices. Current action being taken by the JLC in developing MIL-STD-SDS and MIL-STD-SQAM only partially resolves this issue.

Recommendations

Software quality program requirements should be defined in only one document. This document should include multidiscipline requirements covering the entire software development and support process. It should standardize terminology, define documentation, and include provision for tailoring.

Suggested OPR

Space Divison

3. STARS Program and JLC Initiative

Issue

The STARS Program and the JLC initiative to develop MIL-STD-SDS and MIL-STD-SQAM share common objectives, but they are being implemented in an independent fashion.

Recommendations

The STARS Program and the JLC initiative to develop MIL-STD-SDS and MIL-STD-SQAM should increase current coordination activities. This should include multidisciplined industry participation and other non-DOD agencies. Technical committees from industry should establish liaison with the STARS Program Office.

Suggested OPR

AIA/NSIA/SD

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Interface Between CAD/CAM/CAV Systems

Issue

There is no common language or interface between CAD/CAM systems and computer controlled verification tools.

Recommendations

Government and industry should support the related projects to develop such a common language or interface which would allow verification tools of various manufacturers to be integrated into a CAD/CAM/CAV system without the need to develop special software for each application. At the present time, CAM-I has a project addressing the problem and strong sponsorship is recommended.

Suggested OPR

AIA/NSIA

2. Machine Inspection

Issue

Post machine inspection permits production of defective parts. For significant improvements in product quality and its assurance and productivity, verification must occur in real time on the machine during processing.

Recommendations

a) Development studies should be conducted to identify effective monitoring approaches for machine tool systems.

b) The equipment manufacturers should be provided incentives to include the required in-process verification capabilities as part of the basic equipment.

Suggested OPR

AIA/NSIA/SD/NASA

ADVANCED ASSURANCE TECHNOLOGY - PRODUCT ASSURANCE RECORDS

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Records Management Systems

Issue

Government contractors should evaluate their existing records management systems and develop state-of-the-art approaches.

Recommendations

An NSIA/AIA Panel should study the above issue and present specific recommendations.

Suggested OPR

AIA/NSIA

2. Traditional CDRL and SDRL

Issue

The necessity for some traditional/historical government CDRL and prime contractor SDRL is questionable and not considered cost effective in today's environment.

Recommendations

A joint NASA/DOD/Industry team should be established to draft new specifications to standardize, improve the effectiveness, and reduce deliverable data requirements.

Suggested OPR

AIA/NSIA/SD/NASA - Government Lead

3. Data/Records Systems

Issue

There is a lack of coordinated government interaction with industry to improve or automate data/records systems.

Recommendations

Establish a NASA/DOD funded study effort to evaluate the benefits and costs associated with improving record management systems. This study effort should cover all operations associated with the management, design, procurement, build inspection, test acceptance, and operational use of aerospace and military equipment.

Suggested OPR

SD/NASA

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Defect Monitoring

Issue

Presently NDE only finds abnormalities. No effort is made to determine defect characteristics or material properties.

Recommendations

a) Improve quantitative NDE technology to enhance interpretability.

b) Laboratory methods exist or are emerging that will allow defect characterization. Further, these methods produce documented results that may be obtained later. This would promote defect monitoring and growth tracking without regard to knowledge of previous equipment settings. This equipment is cost effective because it would use existing handling equipment.

Suggested OPR

AIA/NSIA/SD/NASA

2. Equipment and Technology for Field Use

Issue

a) NDE equipment and techniques for field use have not kept pace with available equipment on the market.

b) Failure data and service history data is not readily available to the manufacturer.

Recommendations

Extend NDE improvements to field applications and improve failure analysis documentation for feedback.

Suggested OPR

AIA/NSIA/SD/NASA - Government Lead (AFLC)

3. Laboratory Equipment

Issue

Laboratory equipment is developed and does not gain production acceptability. Production problems are not brought to the attention of the researchers.

Recommendations

a) Encourage two-way technology transfer between research labs and users.

b) Techniques for solving production problems are known, and some production assurance problems exist that the researchers were not aware of.

Suggested OPR

AIA/NSIA/SD/NASA

4. Process Control

Issue

Process control methods could be improved to provide data and feedback that would automate composite cure cycles with a resulting improvement in material properties, producibility, and repeatability.

Recommendations

Promote the assurance technology of real time process control and feedback, e.g., cure monitoring.

Suggested OPR

AIA/NSIA/SD/NASA - Mantech Lead

5. Parts Inspection

Issue

There is still insufficient dialogue between designer, stress analysis, NDE, and production to ensure that parts are adequately inspected, produced, and have satisfactory accept/reject criteria. Additionally, a conservative design often results.

Recommendations

a) Require inspectability/producibility evaluation at the time of design.

b) NDE Board consists of design, stress, NDE, and production. When a design drawing is ready to be released, a review board convenes to review producibility, inspectability, defect allowables, etc., and then the drawing is signed by these reviewers.

Suggested OPR

AIA/NSIA

ADVANCED ASSURANCE TECHNOLOGY - CLOSE TOLERANCE MEASUREMENTS OF LARGE SCALE STRUCTURES

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Measuring Large Structures in Space

Issue

Need to develop a design approach to measure large structures erected or deployed in space.

Recommendations

Study contracts for design and fabrication of structures in space should include technologies for measurement in space which are compatible with design requirements.

Suggested OPR

Contracting Agencies (NASA, AF Space Division)

2. Measurement Handbook

Issue

A measurement handbook is needed to provide measuring techniques and accuracies attainable for measuring length/diameters of large structures. Large structures were defined as any size larger than 8 to 10 feet.

Recommendations

A capabilities handbook should be developed by the National Bureau of Standards (NBS), or by industry with the cooperation of the NBS, to describe existing accuracies/uncertainties associated with measurands related to large scale structures. Techniques for achieving cost-effective measurements should be described.

This information should be disseminated to:

a) Design functions, to provide state-of-the-art capability data.

b) Quality/Product Assurance functions, to provide methods/techniques for measurement of large scale structures to various accuracies.

Suggested OPR

The National Conference of Standards Laboratories (NCSL) and/or AIA Quality Assurance Committee

3. Attachment Methods

Issue

Hard point attachments of large scale structures require high cost tooling and complex inspection methods to verify design requirements and to ensure trouble-free, interchangeable assembly. This problem is compounded in the case of large scale structures.

Recommendations

Feasibility studies should be performed and testing accomplished to qualify new designs for flexible/adjustable attaching methods.

Suggested OPR

AF Wright Patterson Materials Laboratory

4. Verification of Large Structures

Issue

Verification or re-verification of large structures, including tooling, is time consuming and interrupts the production process.

Recommendations

Study and formulate new or improved techniques for improving productivity of inspection/verification processes, especially those related to large structures.

Suggested OPR

Dual industry-government responsibility - industry (unsolicited proposals), AFSC, and NASA

WORKSHOP E

ELECTRONIC PARTS WORKSHOP

Chairmen:

Lt. Col. S. Hunter
USAF Space Division

Lanny Schooler
Martin Marietta Aerospace

Don Moore
Defense Logistics Agency (DLA)

Coordinators:

Ralph Enz
The Aerospace Corporation

Paul Dick
General Electric

SESSION 1 — PARTS MANAGEMENT SUBWORKSHOP

DoD Standardization and Specification Program	R. Kunihiro, OASD
Hi-Rel Parts Management Considerations	Keeney/Campbell, Boeing
Parts Management Project Office Viewpoint	R. Moorehead, JSC
Parts Management Workshop, Vendor Viewpoint	D. Lambert, Signetics
Government Source Quality Assurance	D. Moore, DLA

SESSION 2 — PARTS AVAILABILITY/COST SUBWORKSHOP

Present Status of Space Grade Parts	J. McGuirk, Honeywell
Availability of Parts for Space Systems/Costs	B. Evans, TRW
Monitored Line Approach	W. Geller, LSMC
Microcircuit Qualifications	R. E. Depp, DESC
VLSI Design, Reliability, Quantity, Qualification, Logistics Supportability	E. J. Wescott, RADC
Microprocessors and VLSI Devices Availability for Space Use	L. Hamiter, Parts Tech Inc.

SESSION 3 — SPACE QUALITY OF NEW PART TECHNOLOGIES SUBWORKSHOP

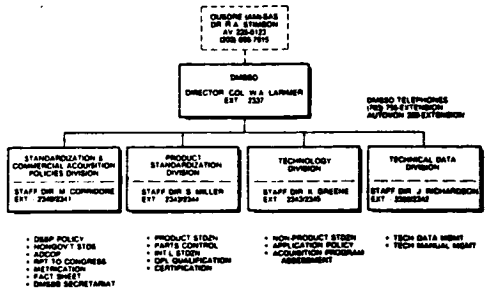
Workshop Focus	R. Lambert, Signetics
Advanced NMOS Process Characterization and Control	D. Meyer, IBM
Manufacturing Considerations	E. R. Wolfe, T.I.
Technology Insertion for Space Applications	K. D. Lemon, National Semiconductor

DEPARTMENT OF DEFENSE

STANDARDIZATION & SPECIFICATION PROGRAM

PRESENTER:
RONALD A. KUNIHIRO
DEFENSE MATERIEL SPECIFICATION AND STANDARDS OFFICE

DMSSO ORGANIZATION



DEFENSE STANDARDIZATION AND SPECIFICATION PROGRAM (DSSP) REQUIRED BY LAW

DEFENSE CATALOGING & STANDARDIZATION ACT
TITLE 10, U.S. CODE CHAPTER 145
SECTIONS 2451-2456

- DIRECTED DEVELOPMENT OF THE PROGRAM
- REQUIRES ACHIEVEMENT OF HIGHEST PRACTICABLE DEGREE OF STANDARDIZATION OF ITEMS & PRACTICES USED THROUGHOUT DOD

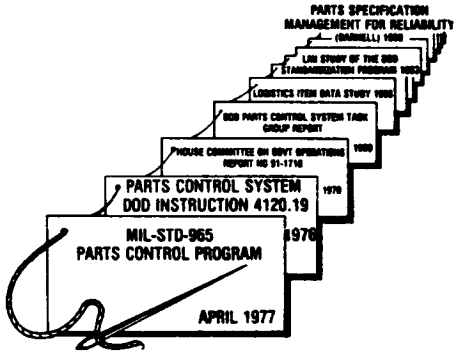
DEPARTMENT OF DEFENSE

PARTS CONTROL PROGRAM

DSSP OBJECTIVES

- IMPROVE OPERATIONAL READINESS OF MILITARY SERVICES
- MINIMIZE VARIETY OF ITEMS, PROCESSES AND PRACTICES USED IN ACQUISITION AND LOGISTIC SUPPORT
- ENHANCE INTERCHANGEABILITY, RELIABILITY AND MAINTAINABILITY OF MILTIARY EQUIPMENTS AND SUPPLIES

"STANDARDIZE DURING DESIGN"



OBJECTIVE OF DSSP ACHIEVED BY:

- PREVENTING DUPLICATIVE AND OVERLAPPING SPECIFICATIONS AND STANDARDS.
- USING EXISTING TECHNOLOGY TO SATISFY NEW EQUIPMENT AND SYSTEM REQUIREMENTS.
- ESTABLISHING AND USING STANDARD TYPES AND SIZES OF ITEMS AND EQUIPMENTS.
- REVIEWING ITEMS IN THE INVENTORY TO LIMIT VARIETIES AND SIZES TO THE MINIMUM NUMBER NEEDED.

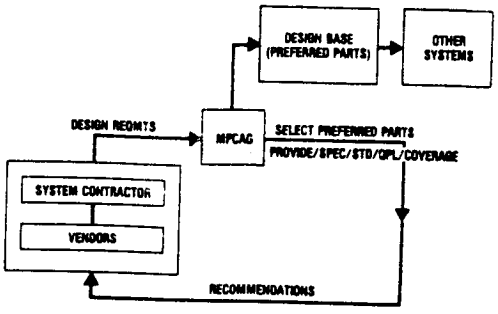
PROBLEMS DRIVING THE NEED FOR PARTS CONTROL

- DIMINISHING ACQUISITION DOLLARS VS. INCREASING EQUIPMENT COMPLEXITY
- COST OF OWNING EQUIPMENT/SYSTEMS
- DEMANDS FOR IMPROVING:
  - RELIABILITY/MAINTAINABILITY
  - QUALITY
  - PERFORMANCE
  - READINESS
  - INDUSTRIAL BASE/PRODUCTIVITY
  - DIMINISHING SOURCES

THE EQUIPMENT DESIGNER WILL USE STANDARD PARTS IF HE

1. KNOWS WHAT IS AVAILABLE
2. CAN COMMUNICATE HIS PARTS NEEDS
3. MAY USE CURRENT TECHNOLOGY PARTS
4. IS ASSURED DESIGN FREEDOM

DESIGN SELECTION CONSULTING SYSTEM

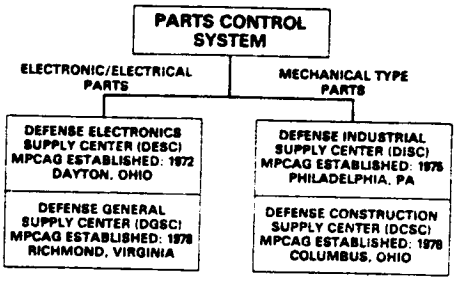


DOD PARTS CONTROL PROGRAM POLICY

DOD INSTRUCTION 4120.19 June 1981

- SINGLE INTEGRATED PROGRAM
- ADVISORY ENGINEERING SUPPORT SERVICES MILITARY PARTS CONTROL ADVISORY GROUPS (MPCAG)
- PROGRAM APPLICATION
  - DESIGN
  - DEVELOPMENT
  - PRODUCTION
  - MODIFICATION
- REQUIRE JUSTIFICATION WHEN THE PROVISIONS OF THE INSTRUCTION ARE NOT APPLIED

DLA MPCAGS



MIL-STD-965

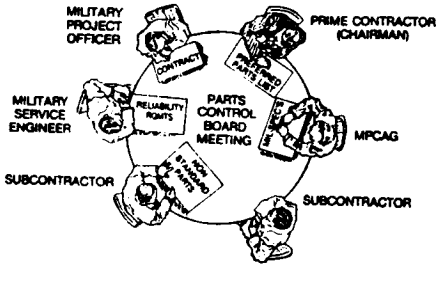
INTENDED FOR:

- MAJOR WEAPON SYSTEMS
- EQUIPMENT REQUIRING PROVISIONING & LOGISTIC SUPPORT
- OTHER CONTRACTS OR INTERNAL GOVERNMENT PROGRAMS IN WHICH LIFE CYCLE BENEFITS CAN BE DERIVED

MAIN PURPOSE

PROVIDE ENGINEERING RECOMMENDATIONS TO EQUIPMENT DESIGNERS IN SELECTION AND USE OF STANDARD PARTS

PARTS CONTROL BOARD (SYSTEM CONTRACTS)



PRODUCTS FOR MPCAG SUPPORT

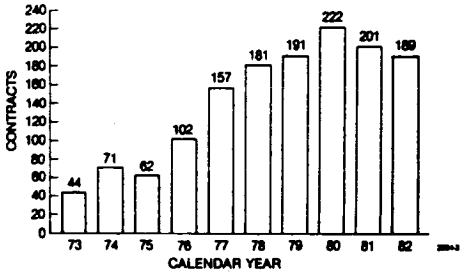
ELECTRICAL/ELECTRONIC PARTS		MECHANICAL PARTS	
DESC DAYTON	DGSC RICHMOND	DISC PHILADELPHIA	DCSC COLUMBUS
RESISTORS CAPACITORS FILTERS FUSES CIRCUIT BREAKERS SWITCHES CONNECTORS (ELEC) RELAYS TRANSFORMERS CRYSTALS TUBES (ELEC) TRANSISTORS/DIODES MICROCIRCUITS AUDIO WAVEGUIDES SYNCHROS MISC ELEC WIRE & CABLES METERS (PANEL) FIBER OPTICS	TERMINALS, LUGS INSULATORS ELEC CABLE ASSY'S LIGHTING DEVICES LAMPS TIME TOTALIZING METERS LUBRICANTS BATTERIES	BEARINGS FASTENERS SEALS MISC HARDWARE KNOBS SPRINGS RINGS, SHIMS CABLE FITTINGS (MECH)	GEARS BELTING PIPE & TUBES TUBE FITTINGS VALVES

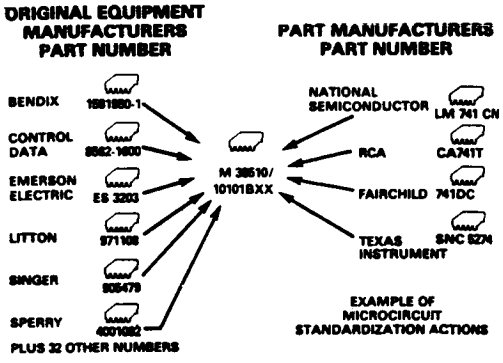
MPCAG SERVICES TO THE PROCURING ACTIVITY INCLUDE

- EQUIPMENT SPECIFICATION REVIEW
- BID EVALUATION REVIEW
- PARTS CONTROL
- SPECIFICATION PREPARATION

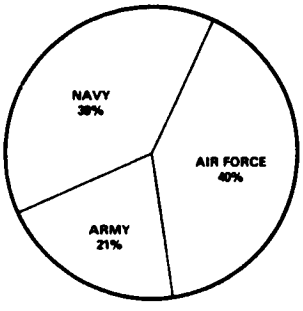
DOD PARTS CONTROL PROGRAM

MILITARY PARTS CONTROL ADVISORY GROUP (MPCAG)
NUMBER OF NEW CONTRACTS ASSIGNED FOR MPCAG SUPPORT DURING YEAR





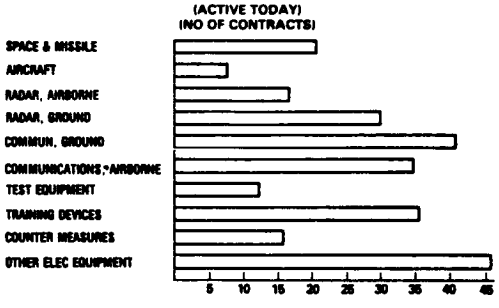
CURRENT CONTRACT DISTRIBUTION



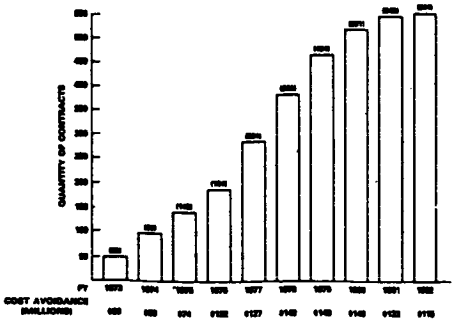
MAJOR SYSTEMS USING PARTS CONTROL PROGRAMS

F-15	XM-1 TANK
F-16	GPS
F-18	MAVERICK
B-52-OAS	AAH
AWACS	LAMPS
AMRAAM	MINUTEMAN
ALCM	MX
618A MODEM	SHUTTLE IUS
TADS/PNVS	AN/UYK-43,44
PERSHING	RPV
SEEK IGLOO	E4B
A-10	

TYPES OF CONTRACTS SUPPORTED



MPCAG SUPPORT TO EQUIPMENT/SYSTEM CONTRACTS



THE VALUE OF PARTS STANDARDIZATION

VALUE OF DESIGN DOCUMENTATION COST AVOIDANCE (ONE TIME)

PLUS

VALUE OF TESTING COST AVOIDANCE (ONE TIME QUALIFICATION)

PLUS

VALUE OF SUPPLY MANAGEMENT COST AVOIDANCE

PLUS

VALUE OF MAINTENANCE COST AVOIDANCE

HI-REL PARTS MANAGEMENT CONSIDERATIONS

J. H. KEENEY
SYSTEM ASSURANCE MANAGER

S. S. CAMPBELL
PARTS, MATERIALS & PROCESSES MANAGER

IUS PROGRAM
BOEING AEROSPACE COMPANY
KENT, WASHINGTON

INTRODUCTION - The charts in this section reflect a historical look at the management challenge involved in obtaining extremely high-reliability parts for the IUS program. The parts requirements laid down for the IUS program were the most stringent requirements issued by government and accepted by industry in the 1978-1980 time frame.

The presentors expect to stimulate participant interaction and hopefully conclude with solid recommendations through this material. This presentation is the prime contractor's view; the government and parts supplier views follow. The written material that follows is in the form of explaining the message and any clarifications required to understanding the charts. It is believed that each chart is basically self explanatory and detailed written material was not requested nor is it necessary.

Chart 1 - This chart explains the presentation organization from the contractor's view and carries the participants through acquisition, problem resolution, program experience and conclusions and recommendations.

Chart 2 - Section Divider for Parts Acquisition

Chart 3 - A pictorial representation of the parts acquisition flow process. The example is for a microcircuit but the process is the same for other part types.

Chart 4 - This chart shows the procurement tracking process detailing the type of data tracked and the responsible organizations for each. This information was posted on wall displays and viewed by management weekly until the parts acquisition process was well under control, e.g., until at least 30% of a range of parts was in stores.

Chart 5 - Shows the technical and business decisions that have to somehow fit together to arrive at the decision point on which part to use in a high reliability design.

Chart 6 - Presents four possible options for obtaining high-reliability parts, once the part type has been selected. There are other options but these were those considered prime for the IUS program.

Chart 7 - Shows the magnitude of the Parts Management task, that is, the total number of part types and quantities per vehicle that had to be specified, procured and delivered. This chart reflects electronic/electrical parts only. There were, of course, many additional mechanical/structural parts which were no small management task in themselves.

Chart 8 - Once the best schedules were negotiated with the suppliers, program schedules could be solidified. This chart shows what was negotiated with the suppliers by part class and set the stage for the original program schedules.

Chart 9 - Shows concerns, both real and imaginary, exhibited by the suppliers when faced with building to the high reliability requirements. These concerns served as the technical justification for the schedules the parts suppliers claimed were needed. As shown, some of these concerns proved to be unfounded.

Chart 10 - The contractor also had concerns, three of which are shown on this chart. The focus of some of these concerns were made known through the parts suppliers and subcontractors.

Chart 11 - Presents the fallout during receiving inspection, DPA and data review after all the high reliability controls were implemented upstream of receipt. While the data is for Boeing make items only, it is believed to be representative of IUS subcontractors as well.

Chart 12 - Section divider for Problem Resolution.

Chart 13 - Presents the pros and cons of six different management approaches for avoiding parts problems. Most of these approaches were used on the IUS program for at least several part types.

Chart 14 - Shows, in order of priority (acceptance), what was ultimately negotiated with SD/NASA for parts substitutions on the IUS Program.

Chart 15 - Shows most of the ways problems can be identified to parts management and those organizations that must be brought into the problem for ultimate resolutions.

Chart 16 - Presents the management tiering of part problems and the responsibility for each level of problem.

Chart 17 - Section Divider for Program Experience

Chart 18 - Shows some examples of how custom high-reliability procurement can overshadow mil-spec parts costs. Also shown is how procurement quantity drastically affects the cost of these high-reliability parts.

Chart 19a through h - Show the actual delivery schedules by parts vendor for the various parts classes vs. the schedules committed at negotiations.

Chart 20 - Lays out in summary form the actual performance of suppliers vs. that negotiated. This chart also shows how much schedule a contractor needs to set aside just for high-reliability parts acquisition.

Chart 21 - Shows the experience to date on part failures including both qualification and acceptance testing.

Chart 22 - Outlines some lessons learned from the parts acquisition process on the IUS program.

Chart 23 - Section Divider for Conclusions & Recommendations

Chart 24 & 25 - Self explanatory management conclusion & recommendations for future high-reliability parts contracts.

Prime Contractors View

- Parts Acquisition
- Problem Resolution
- Program Experience
- Conclusions & Recommendations

Chart 1. Hi-Reliability Parts Management

- Selection
- Specification/Procurement
- Build Surveillance
- Acceptance

Chart 2. Parts Acquisition

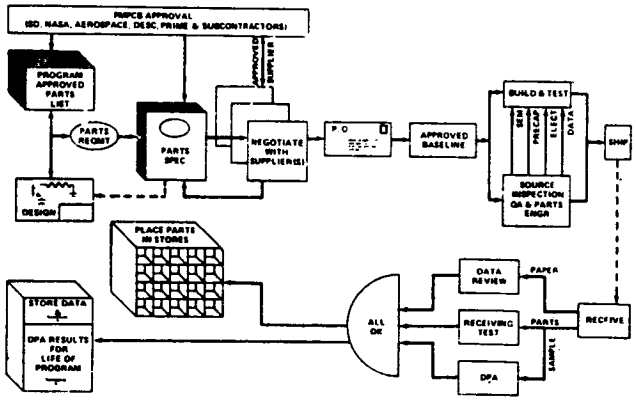


Chart 3. IUS Parts Flow Microcircuits

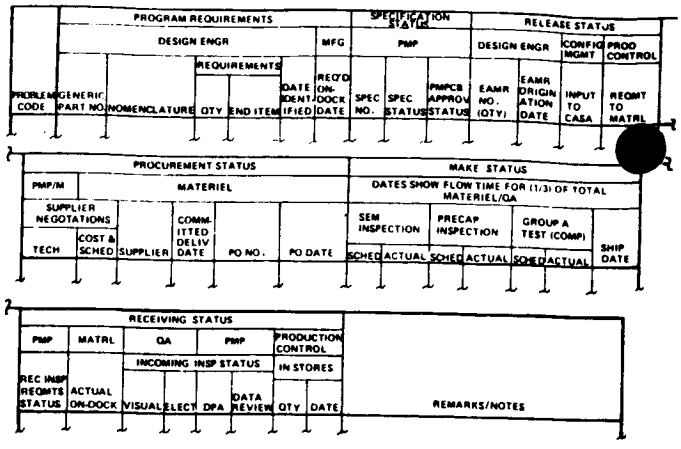


Chart 4. Procurement Tracking

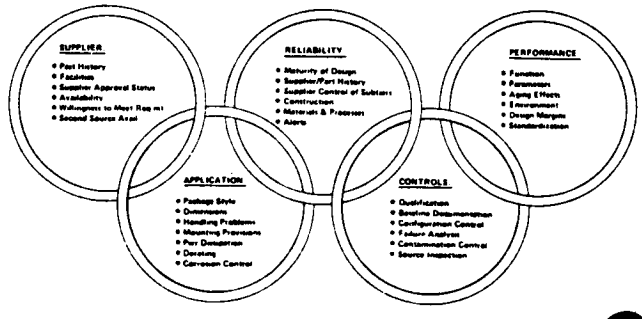


Chart 5. High Reliability Parts Selection Olympics

Option	Pro	Con
• Class S (QPL)	• Gov't source inspection • No spec prep maint • No qualification hassle	• Minimum buy & long lead time • Limited part types
• Procurement Control Drawing	• Procurement flexibility • All part types	• Minimum buy & long lead time • Qual & baselining required • Source inspection required • Spec prep maint • Risk that vendor will no bid
• Monitored Line (ICs & Transistors)	• Gov't source inspection • No spec prep maint • No qualification hassle	• Minimum buy & long lead time • Limited part types & sources • SD approval required (SD Costs) • Priority risk
• Upgrade Screening (MIL-SPEC or MIL-GRADE parts)	• Low initial procurement cost • Shorter lead time	• Questionable lot traceability • Low Yield risk • High risk for lot rejection

Chart 6. Options for High Reliability

Part Name	Types	Quantity
Capacitors	30	5,261
Connectors	33	1,490
Crystals	7	14
Diodes	58	3,468
Fuses	6	42
Magnetics	115	643
Microcircuits	135	8,638
Relays	11	178
Resistors	20	10,022
Transistors	41	1,673
Switches	10	153
Misc.	48	293
Total	514	31,875

Chart 7. IUS Parts Summary

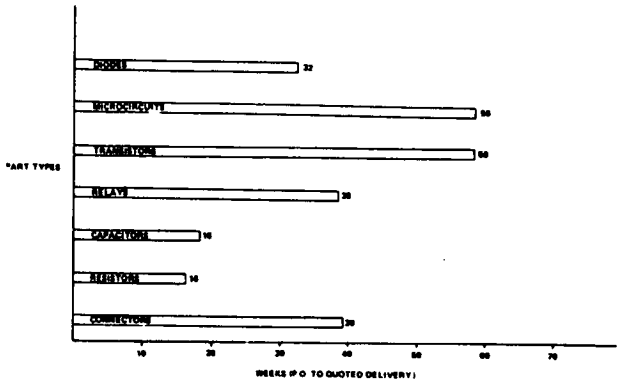


Chart 8. Negotiated Procurement Schedules

New/Special Requirement	Concern	Outcome
• 100% Non-destructive bond pull test	• Possible damage to good part • No production experience • Test equipment • Labor intensive	• Good test • Standard for Class "S"s
• PIND Test	• Reject good parts • No production experience • Test equipment • Labor intensive	• Good but not 100% effective • Vendors oppose "5 passes" • Standard for Class "S"
• Wafer Fab Requirements (IC's)	• Increased wafer lot jeopardy • Access to proprietary data	• Lot jeopardy concern valid for dual-level metallization • Standard for Class "S"
• Inspection Lot Definitions (IC's)	• Limited lot sizes • Destruct Test sample qty	• Relaxed for Class "S"
• Lead Braze Packages	• No production experience • Non-standard package	• DIP's application limited • Removed as Class "S" requirement

Chart 9. Vendor Build Concerns

Item	Concern
• Lack of Government standardization on various SD NASA programs	• Parts procured for one program likely cannot be used for another
	• Multiple procurement specifications required for same part type
	• Equipment selections affected by parts requirement differences
• Program unique requirements tailoring	• Breeds requirement creep
	• "Special requirements" affect cost & delivery, benefits are often subjective
	• Changes subsequent to vendor selection negotiations drive costs out of sight
• Emphasis on microcircuits and semiconductors	• Class "S" QPL's for other part types (connectors, relays, etc.) are also needed

Chart 10. Parts Management Concerns

• Lots received		183
• Lots Rejected		26 (14%)
Data Review	3	
Failed subsequent lot tests	3	
DPA	18	
Receiving test	2	

Chart 11. Microcircuit Lot Summary

- Options available
- Part substitution policy
- Problem management

Chart 12. Problem Resolution

Option	Pro	Con
• Dual source procurement	• Reduces impact of lot failure vendor slides	• Increases qty of lots • Added sources require qual
• Procure MIL Grade along with Class "S"	• Low cost back-up parts	• Upgrade screening is a risk • Government questions as an allowable contract charge
• Provide rework/repair capability	• Avoids schedule impact of reprocurement	• Risk of rework repair damage • Reliability may be compromised
• Force standardization	• Greater likelihood of subs & prime helping one another	• Could force redesigns of existing (proven) equipment
• Procure long lead well in advance (2X)	• Allows schedule slack for problems	• Risks for some part types if designs aren't proven
• Force government to agree on substitution policy	• Allows contractor to plan & implement in responsive manner	• None

Chart 13. Management Options For Avoiding Problems

In Order of Priority	Program Requirement
1. Use parts through Group "A" testing (not yet through Qual testing).	No deviation required
2. Other "Hi Rel" program sources with proposed screening upgrades if warranted. SAMSO, NASA, NSA, etc. Review requirements vs. condition	Deviation required
3. 883B or Class "B" upgrade. With stringent screening	Deviation required
4. 73-2C Lot rejection, rescreened.	Prog office approval plus Deviation required
5. Other	Prog office approval plus Deviation required

Chart 14. Parts Substition Policy

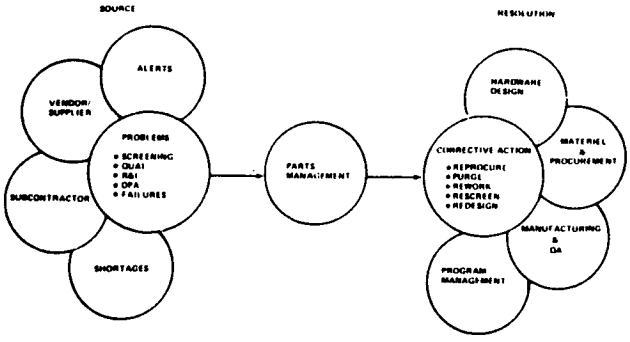


Chart 15. Problem Identification and Management

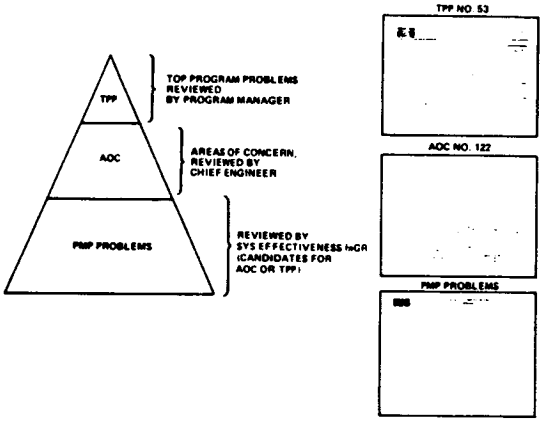


Chart 16. Problem Reporting and Review

- Parts Costs
- Actual Schedules Vs. Negotiated
- Parts Reliability
- Lessons Learned

Chart 17. Program Experience

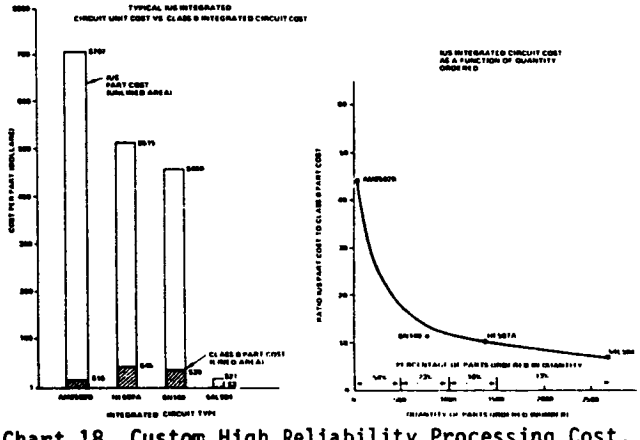


Chart 18. Custom High Reliability Processing Cost, IC's

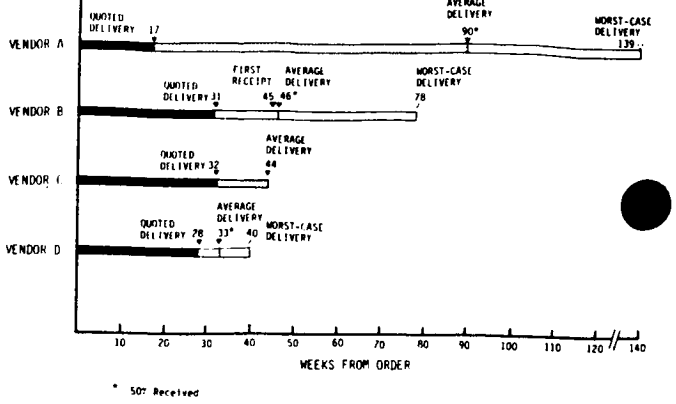


Chart 19a. Diodes

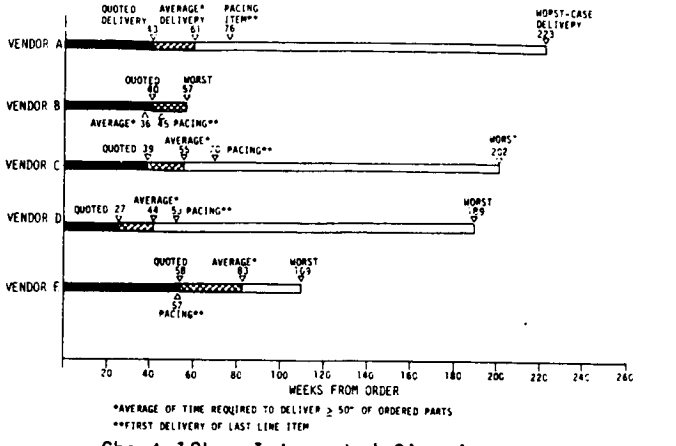


Chart 19b. Integrated Circuits

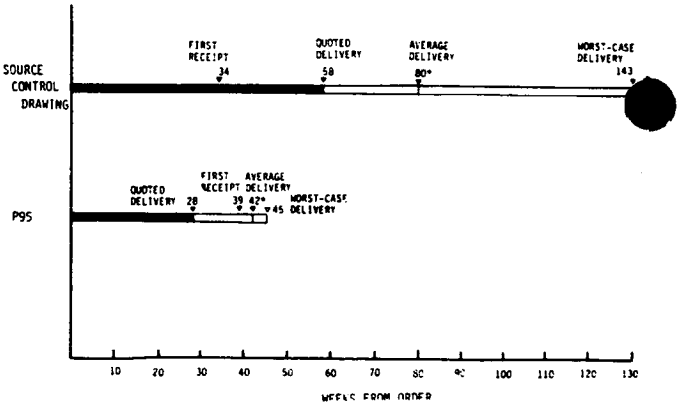


Chart 19c. Transistors

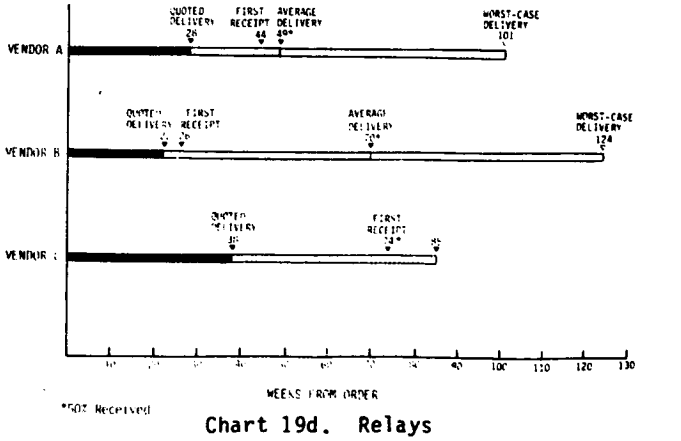


Chart 19d. Relays

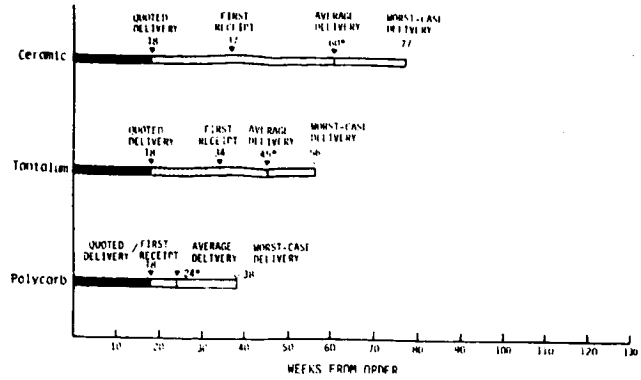
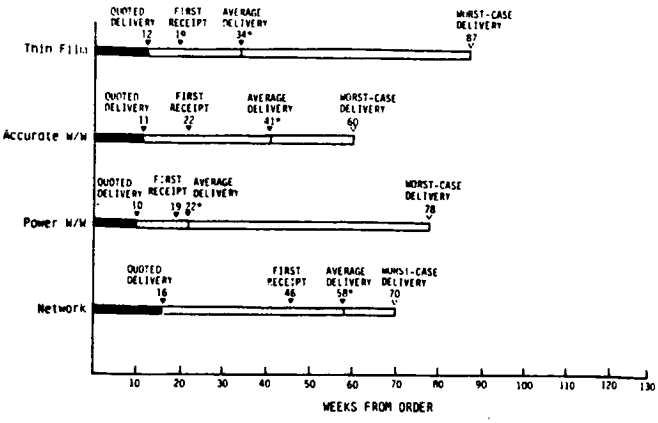


Chart 19e. Capacitors



*50% Received

Chart 19f. Resistors

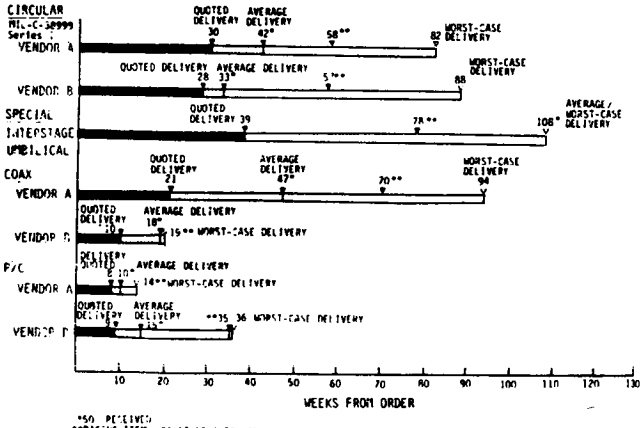


Chart 19g. Connectors

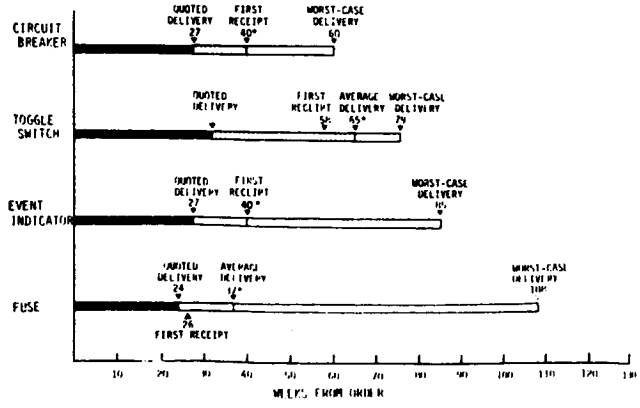


Chart 19h. Miscellaneous Types

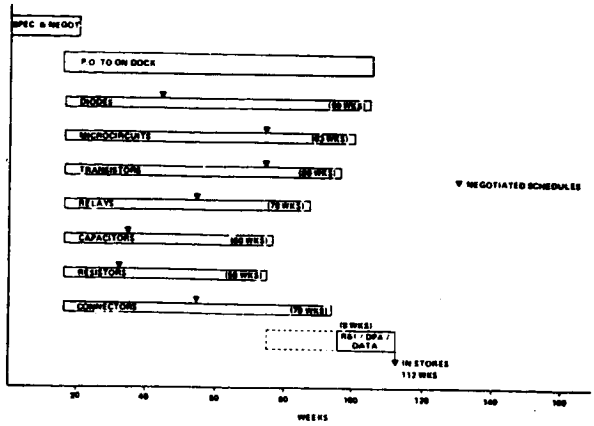


Chart 20. Parts Acquisition Summary

- Only 10% of failures are part related (111/1062)
- Broken down as follows:

Part Type	Failures	
Diodes	6	5
Microcircuits	39	35 (16/39 are memory devices)
Transistors	0	0
Relays	14	13
Capacitors	7	6
Resistors	7	6
Connectors	25	23
Miscellaneous*	13	12
	111	100

*Incl: Magnetics -9, Indicators -2, Fuse -1, Crystal -1

Chart 21. Part Failure History

- Vendors require frequent contractor attention to keep product "moving", even though already late.
- There is a need for QPL Class "S" electromechanical & passive parts.
- Adding special high reliability requirements on top of Sole Source supplier results in disproportionately high costs.
- Constant care-and-feeding of parts suppliers is required due to their reluctance to accept government special requirements.
- High-Reliability parts are paying off by reducing percentage of failures due to parts. (10% parts failures on IUS vs. 55% on a missile program)
- While contracts may emphasize on-shore build, essentially all Class "S" microcircuit packages are from Japan
- For minimum buy quantities, QPL Class "S" IC's cost 15% to 30% less than SCD parts

Chart 22. Lessons Learned

- Contractor conclusions
- Recommendations for:
  - Government
  - Contractors
  - Suppliers

Chart 23. Conclusions and Recommendations

Misconceptions

- Government believes that contractors/suppliers can always find a few extra parts when problems develop
- Government has impression that contractors will trade off reliability if not watched
- Government believes that parts suppliers are at their beck and call

Facts

- Receiving test, inspections and DPA are weeding out some potential failures even with high reliability requirements
- Schedule commitments from parts suppliers are of little value
- Lack of government standardization along with small quantities is too costly
- High reliability requirements are generally working, fewer failures due to parts are noted
- Requirements have no "sunset" laws

Chart 24. Conclusions (Contractors View)

- For Government –
  - Standardize reqts. (use & expand class "S" specs as required)
  - Don't invent in mid stream
  - Utilize technical advisors to refine specs, not to manage real time
  - Don't negotiate contractors into corner with no provisions for backout
- For Contractors –
  - Believe in seriousness of requirements
  - Put more faith in track records and less in promises when selecting subs & suppliers
  - Don't trade off R&I and DPA
- For Parts Suppliers –
  - Put more production management in negotiations & less marketing management
  - Don't promise something you can't do or haven't done
  - Develop product description information system for Class "S" equivalent parts

Chart 25. Recommendations

PARTS MANAGEMENT PROJECT OFFICE VIEWPOINT

R. W. Moorehead

NASA LBJ Space Center

SCOPE OF BRIEFING

- O OVERALL PROJECT OFFICE VIEWPOINT OF PARTS MANAGEMENT
- O SPACE SHUTTLE ORBITER PROJECT PARTS MANAGEMENT EXPERIENCE
- O SPACE SHUTTLE ORBITER PROJECT PARTS MANAGEMENT LESSONS LEARNED
- O CONCLUSIONS

OVERALL PROJECT OFFICE VIEWPOINT OF PARTS MANAGEMENT

The project office objective is to convert project design concepts into delivered hardware that will accomplish the defined tasks. The total project effort is driven by the defined task, available budget, and required schedule.

The criticality of mission objectives is the major factor in defining the system architecture and parts management approaches. For most of the current projects, electrical, electronic, and electromechanical parts are major building blocks in the fabrication of the required hardware. The success of a project, which depends on the ability to accomplish the defined tasks within the budget and on schedule, can hinge on parts management decisions. Project office parts management decisions should be made to minimize the project's "cost of parts ownership." This cost not only includes the initial procurement cost but costs for documentation, costs incurred for any delays caused by parts unavailability, costs resulting from buildup and operational failures, and costs resulting from lost operating time.

Project parts documentation requirements should provide management with early visibility of the parts being selected and used, the extent of their compliance with established controls, and the information necessary for supporting logistics in the operational phase. It is important that the project office understand at the preaward stage how the potential contractors "do business" to assure that their systems are compatible with the project approach. Significant costs can be incurred when the contractor's in-place system is not compatible with the established project approach.

SPACE SHUTTLE ORBITER PROJECT PARTS MANAGEMENT EXPERIENCE

The project office experience will cover the Space Shuttle Orbiter design concepts, baseline level of parts, documentation, parts deviation requests, and significant parts failure experience.

- O PROJECT OFFICE OBJECTIVES ARE TO CONVERT DESIGN CONCEPTS INTO HARDWARE THAT WILL DO THE DESIRED TASKS.
- O COMPLETION OF THESE EFFORTS IS LIMITED BY PROJECT BUDGETS AND SCHEDULES.
- O CONTROLS OF SELECTED PROJECT PARTS STRONGLY INFLUENCED BY SYSTEM AND EQUIPMENT REDUNDANCY AND ACCESSIBILITY AND MAINTENANCE CONCEPT.
- O EEE PARTS ARE A MAJOR BUILDING BLOCK IN THE DESIGN OF MOST SYSTEMS AND THEREFORE REQUIRE MANAGEMENT ATTENTION TO THEIR SELECTION AND CONTROL.
- O PARTS AVAILABILITY AND RELIABILITY CAN HAVE SIGNIFICANT IMPACT ON PROJECT SCHEDULES AND COSTS.
- O PROJECT OFFICE DECISIONS SHOULD MINIMIZE "COST OF PARTS OWNERSHIP."
- O PROJECT PARTS DOCUMENTATION NEEDS TO PROVIDE EARLY UNDERSTANDING OF RISKS; E.G., EARLY IDENTIFICATION OF PARTS USAGE AND WAIVERS.
- O SPECIFIC METHODS USED BY SUPPLIERS NEED EARLY IDENTIFICATION; E.G., AT PREAWARD STAGE (UNDERSTAND HOW THEY DO BUSINESS).

SPACE SHUTTLE ORBITER PROJECT PARTS MANAGEMENT EXPERIENCE

The project office experience will cover the Space Shuttle Orbiter design concepts, baseline level of parts, documentation, parts deviation requests, and significant parts failure experience.

- O ORBITER DESIGN CONCEPT
- O ORBITER BASELINE LEVEL OF PARTS
- O ORBITER PARTS DOCUMENTATION
- O ORBITER PARTS DEVIATION REQUESTS
- O SIGNIFICANT ORBITER PARTS FAILURE EXPERIENCE

ORBITER DESIGN CONCEPT

In keeping with the overall Space Shuttle concept, the Orbiter Project was tailored to an airline concept. This concept assumed that (1) the project would use existing off-the-shelf equipment and designs to the maximum extent possible, (2) the avionics system designs would be redundant with fail operational/fail safe architecture, and (3) the Orbiter would be available for ground maintenance to the line replaceable unit level between flights.

The project parts management and control approach was to use controlled and readily available standard electrical, electronic, and electromechanical parts. To support this approach, problems encountered in the equipment design and development phase would be failure analyzed and corrective actions implemented to assure that mature hardware would be used in the operational vehicles.

Using this system architecture, parts not fully controlled to Orbiter Project requirements are not used in single failure point applications that would jeopardize vehicle safety or mission success.

- O USE OTS EQUIPMENT AND DESIGNS WHERE POSSIBLE.
- O PROVIDE SYSTEM AND EQUIPMENT REDUNDANCY-FAIL OPERATIONAL/FAIL SAFE.
- O PERFORM GROUND MAINTENANCE BETWEEN FLIGHTS.
- O USE CONTROLLED AND READILY AVAILABLE STANDARD EEE PARTS.
- O PERFORM FAILURE ANALYSES FOR ALL PROBLEMS AND IMPLEMENT CORRECTIVE ACTIONS.
- O NO UNCONTROLLED PARTS ARE USED IN SINGLE FAILURE POINT CRITICALITY 1 APPLICATIONS.

ORBITER BASELINE LEVEL OF PARTS

The level of parts control selected as Orbiter Project baseline is "ER" (established reliability) "P" failure rate military specification passive devices (resistors, capacitors, relays), MIL-S-19500 JANTXV semiconductors, and MIL-M-38510 level B microcircuits. Special controls include particle impact noise detection testing of both relay and hybrid microcircuits. The use of WTSC's (wet tantalum slug capacitors) requires special project approval to assure proper application with justification. WTSC's are very prone to failure if subjected to excessive a.c. ripple current or reverse voltage.

These baseline level parts were selected since (1) they were adequate for the Orbiter Project and were readily available devices that could be procured by numerous contractors and (2) they were the highest level readily available with acceptable usage history that could be procured by numerous contractors.

Parts not meeting baseline level must be approved so that risk assessment can be made prior to procurement or use.

PART TYPE	BASELINE LEVEL OF CONTROL
PASSIVE DEVICES	MILITARY SPECIFICATION ESTABLISHED RELIABILITY "P" FAILURE RATE DEVICE
SEMICONDUCTORS	MIL-S-19500 JANTXV DEVICES
MICROCIRCUITS	MIL-M-38510 CLASS B DEVICES

ORBITER PARTS DOCUMENTATION

To promote and enhance the use of standard parts, an OPPL (Orbiter Project parts list) has been established. The OPPL includes only devices that are qualified to a controlling specification, are suitable for Orbiter application, and are readily available. The OPPL also includes the requirements and controls for selecting and using parts not contained in the standard OPPL.

Where-used parts lists submitted at preliminary and critical design reviews provide the visibility of the parts being selected for use. This visibility can assure the project office that only approved parts are being used. When parts are selected for use that do not meet OPPL requirements, the contractor prepares a part waiver in the form of an IPAR (irregular part approval request). The IPAR, which provides the rationale why the parts is required and why an approved OPPL part will not perform the required function, is submitted to the project office for approval prior to the part's procurement. This procedure provides the project office with the opportunity to participate in the selection and use of all irregular parts, to recommend alternative parts, to recommend that additional qualification or screening requirements be imposed, or to accept the part's use as documented in the IPAR.

Contractor parts specifications are required for all selected parts not controlled by an acceptable military-NASA specification. The specification controls the identification, physical, environmental, functional, qualification, screening, baselining, and data retention requirements. When irregular parts are projected to have high usage or to be used in critical applications, the qualification requests, plans, and reports for these parts are provided for project office approval. The project office uses this qualification documentation to assure the usage or application warrents the expenditure to perform a formal qualification of the manufacturing process. In addition, this procedure reduces the duplication of qualification testing and maximizes the use of existing data.

Parts application stress analyses are provided at the critical design reviews. The stress analyses provide the visibility necessary to assure that the parts selected are being used within the project's derating guidelines. To minimize operational equipment problems, GIDEP (Government-Industry Data Exchange Program) ALERTS are assessed for potential project impact. This process provides the project office with early visibility of problems being experienced by other Government-industry projects and assesses any risk for a common problem.

Equipment as-built records are provided in the acceptance data pack when the unit is delivered. The as-built records are audited to assure that the actual parts used in equipment fabrication are the ones that were selected for use during the design phase. These as-built records are also used when assessing the project impact for the GIDEP ALERTS.

ORBITER PARTS DOCUMENTATION

- O PROJECT PARTS LIST
- O WHERE-USED PARTS LISTS
- O IRREGULAR PART APPROVAL REQUESTS
- O PARTS APPLICATION ANALYSES
- O PARTS SPECIFICATIONS
- O PARTS QUALIFICATION REQUESTS, PLANS, AND REPORTS
- O ALERT DOCUMENTATION
- O AS-BUILT RECORDS

ORBITER PARTS DEVIATION REQUESTS

The Orbiter Project has reviewed numerous deviation requests submitted in the form of irregular approval requests. The typical deviation request is for (1) use of off-the-shelf equipment that does not meet all Orbiter requirements, (2) use of parts that lack manufacturer's formal qualification, (3) use of equipment for which traceability data are not documented as required, (4) use of semiconductor devices that lack internal visual examination, or (5) use of unapproved parts when approved parts are not available to support fabrication and testing schedules.

Approval of the deviation requests involves accepting reasonable risks based upon rationale provided with the requests. The rationale provides information on available parts data to support usage such as alternate screens or test results for limited qualification. Additional information may be provided on hardware fault tolerance, redundancy, and overall criticality. An engineering review of the rationale supplied provides the ability to adequately assess the risks being taken.

ORBITER PARTS DEVIATION REQUESTS

- O VOLUME OF DEVIATION REQUESTS
- O TYPICAL DEVIATION REQUESTS
  - O USE OF OTS EQUIPMENT
  - O LACK OF QUALIFICATION
  - O LACK OF MAINTAINED TRACEABILITY
  - O LACK OF INTERNAL VISUAL EXAMINATION
  - O LACK OF AVAILABILITY

ORBITER PARTS FAILURE EXPERIENCE

The Orbiter Project has used approximately 5 million parts in the OV-102, spares, ground test articles and systems. Approximately 790 failures have been experienced with these parts. Considering the number of equipment operational hours and the number of parts used, the number of failures experienced is one-half that predicted using MIL-HDBK-217 failure rate formulas and factors.

Typical significant EEE (electrical, electronic, and electromechanical) parts failure problems have included the TI (Texas Instruments) Schottky microcircuit aluminum migration experienced in the GPC (general purpose computer); the MDM (multiplexer/demultiplexer) ceramic capacitor insulation resistance degradation; hybrid microcircuit contamination; and power transistor contamination.

A life issue problem was experienced with the TI 54S Schottky microcircuit digital logic family manufactured in the 1974-1976 time frame. This problem involved the migration of aluminum metallization which caused the formation of extruded aluminum whiskers. These whiskers would short to the adjacent conductive surfaces. The problem was not the classical open circuit problem caused by metallization migration, since the sublayer titanium tungsten metal continued to act as a conductor. These failures began to occur after approximately 15,000 hours of operation. GPC's using these devices were purged during equipment recycling. Continued failures experienced with ground test units proved this decision to be expedient.

Another life issue problem was experienced with ceramic capacitors used in MDM low-voltage applications. This problem, the degradation of insulation resistance, caused excessive leakage current. The problem devices, which were procured from three suppliers, were removed from the flight-critical MDM's. Continued failures experienced in the ground test MDM's proved this decision to be cost effective.

Early in the Orbiter Project, industry problems with hybrid microcircuit contamination were reported. PIND (particle impact noise detection) testing was imposed for hybrid microcircuits, which resulted in a rejection rate of approximately 15 percent. Within a year, the rejection rate had decreased to less than 3 percent. The particle contamination problem experienced with the RPC (remote power controller) resulted in the entire hybrid microcircuit being coated with parylene. By imposing PIND testing, the supplier had to clean up its process or take corrective actions. The Orbiter Project would not have been able to tolerate contaminated RPC's.

Another problem was experienced with power transistor contamination. During the Orbiter development cycle, industry started imposing PIND testing for power transistors. The suppliers stated, effectively, that if buyers wanted clean devices, they should impose PIND testing requirements. The result has been a contractual change to impose PIND testing.

Effective corrective action in each of the previous examples was possible only because a complete system of EEE parts traceability was imposed for the Orbiter Project. This allowed determination of exactly which LRU's (line replaceable units) contained parts that required retrofit and which LRU's were adequate to use as-is.

ORBITER PARTS FAILURE EXPERIENCE

- O OVERALL PARTS FAILURE EXPERIENCE
- O TYPICAL SIGNIFICANT EEE PARTS FAILURES
  - O MICROCIRCUIT ALUMINUM MIGRATION
  - O CERAMIC CAPACITOR INSULATION RESISTANCE
  - O CONTAMINATED HYBRID MICROCIRCUITS
  - O CONTAMINATED POWER TRANSISTORS
  - O PARTS TRACEABILITY ALLOWED EFFECTIVE CORRECTIVE ACTION

SPACE SHUTTLE ORBITER PROJECT PARTS MANAGEMENT LESSONS LEARNED

A few of the lessons learned have included learning the need for (1) early visibility of parts selection, (2) verifying that the delivered equipment configuration agrees with the approved design, (3) assuring that ALERT part problems have received generic assessments in lieu of specific lot date code comparisons, (4) being aware of parts obsolescence, and (5) establishing manufacturing controls.

Contractors and subcontractors have not been as responsive or as rigorous in submitting where-used parts lists and irregular part approval requests as desired. On numerous occasions, the documentation was not submitted until after the equipment had been fabricated. In those instances, project parts recommendations have had significantly greater cost impacts.

Audits of the as-built records verus the approved as-designed configuration indicate that undocumented substitutions and deviations have been made without project approval. When changes are made without documentation, the project loses configuration control and the true understanding of parts usage and associated risks. When assessing the project impact for Government-Industry Data Exchange Program ALERTS, the contractor has a tendency to limit the Orbiter review to the specific lot date codes with which the ALERT preparer has experienced problems. By the rules for submitting ALERTS, the preparer may document his factual experience. When assessing ALERT problems, the contractor's position should be "is the problem applicable to the device used in the equipment?" and not "I don't use that specific lot date code." This concern does not apply when the problem is truly a lot-related issue.

Problems with parts obsolescence are becoming more prevalent as suppliers phase out certain parts processing technologies that are used in fabricating unique special parts. Fast-moving microcircuit technology is driven by the commercial market, and the technology available in the early 1970's is now being phased out and replaced by newer processing technology. Suppliers are finding that it is not economically feasible to operate by past manufacturing technologies. Another problem is the incorporation of enhanced parts technologies developed to alleviate failure mechanisms. Examples of these types of enhanced parts are the all-tantalum devices that replaced the silver-cased wet tantalum slug capacitors, and the special screened ceramic capacitors that are used in low-voltage applications.

Parts suppliers have caused some significant concerns by supplying counterfeit parts, devices that have not been screened as required, and devices whose materials and processes have been changed after qualification; and by not meeting promised delivery dates, which has resulted in fabrication schedule impacts.

SPACE SHUTTLE ORBITER PARTS MANAGEMENT LESSONS LEARNED

- O PARTS USAGE - NEED MORE RAPID RESPONSE ON PARTS USAGE AND WAIVERS TO PROVIDE CAPABILITY OF ISSUE WORKAROUNDS PRIOR TO EQUIPMENT FABRICATION.
- O AS-BUILT VERSUS AS-DESIGNED COMPARISON - DEFINITE NEED TO ASSURE THAT THE DELIVERED EQUIPMENT CONFIGURATION AND PARTS USAGE AGREE WITH APPROVED AS-DESIGNED AND CERTIFIED CONFIGURATION.
- O ALERT RESPONSES - CONTRACTOR REVIEW OF ALERT ISSUES SHOULD INCLUDE MORE THAN THE SPECIFIC LOTS OF PARTS IDENTIFIED BY THE ALERT.
- O PARTS OBSOLESCENCE - DISCONTINUED SPECIAL PARTS, FAST-MOVING MICROCIRCUIT TECHNOLOGY, AND ENHANCED TECHNOLOGY.
- O PART MANUFACTURER PROBLEMS - COUNTERFEIT ISSUE; OMITTED SCREENING TESTING; PROCESS, MATERIAL, AND CONFIGURATION CHANGES; AND DELIVERY DELAYS

CONCLUSIONS

e overall Orbiter Project management and controls have been successful to date. oject office decisions on some key issues and concerns have proven to be cost fective in the overall "cost of parts ownership." Emphasis has been placed on proving the contractors' responsiveness to and compliance with contractual quirements through parts documentation audits and periodic electrical, ectronic, and electromechanical parts reviews.

- O ORBITER EXPERIENCE RELATIVE TO PARTS MANAGEMENT AND CONTROL FOR SPACE SHUTTLE ORBITER SUCCESSFUL TO DATE.
- O ORBITER PROJECT MANAGEMENT APPROACH AND DECISIONS HAVE PROVEN EFFECTIVE IN MINIMIZING OVERALL "COST OF PARTS OWNERSHIP."
- O MORE EMPHASIS NEEDED IN PARTS MANAGEMENT AND CONTROL TO UNDERSTAND PROBLEMS EARLY IN THE PROGRAM WHERE PREVENTATIVE ACTIONS CAN BE TAKEN TO MINIMIZE PROGRAM IMPACT.

MISSION ASSURANCE

PARTS MANAGEMENT WORKSHOP

VENDOR VIEWPOINT

DICK LAMBERT, SIGNETICS
7 JUNE, 1983

0 CURRENT MARKET

- MILITARY HERMETIC USAGE 1.1% OF TOTAL I.C. CONSUMPTION (UNITS)
- TOTAL SPACE USAGE 0.03% OF MILITARY (UNITS)
- JAN S DEMAND 0.0082 OF MILITARY (UNITS)
- ONE JAN S PART SHIPPED FOR EVERY 1.1 MILLION I.C.'S

0 STANDARDIZATION PROLIFERATION

- JAN S
- 003B510
- MONITORED LINE
- SCD'S
- B UPGRADE

0 NON - PROBLEMS

- SPECIFICATIONS
- PERFORMANCE TO SPEC
- RAW MATERIALS
- CAPACITY
- ABILITY
- GSI SUPPORT
- COMMITMENT

0 PROPOSALS

- ESTABLISH "MPCAG" SYSTEM FOR CLASS S
- CREATE DESC DRAWING SYSTEM TO ELIMINATE SCD'S
- ELIMINATE NON-STANDARD FLOWS AND LINES
- AGREE ON BASELINE REQUIREMENTS (ALL AGENCIES)
  - WAFER LOT ACCEPTANCE
  - NON-DESTRUCT BOND PULL
  - GSI VS CSI
  - DPA RESPONSIBILITY
  - RAD SCREENING
  - LOT QCI OR GENERIC DATA
- UPDATE MIL-SPEC TO PROVIDE FOR ABOVE
- FORECAST USAGE BY DEVICE TYPE AND SYSTEM
- REENFORCE POLICIES
- ESTABLISH SUBSIDIES FOR DISTRIBUTION STOCK
  - WITH MANUFACTURERS, OR
  - WITH AGENT/DEPOT

0 CURRENT PROBLEMS

- LACK OF MARKET VISIBILITY (FORECAST)
- SMALL QUANTITY DEMAND
- HIGH COST OF INVENTORY
- LACK OF STANDARDIZATION
- MULTIPLE AGENCY REQUIREMENTS
- AGENCY POLICY VIOLATIONS
- ADD-ON REQUIREMENTS (NON-STANDARD)
- NO DISTRIBUTION SYSTEM

GSQA

GOVERNMENT SOURCE QUALITY ASSURANCE

WHAT IT IS AND WHAT IT ISN'T

AND

RELATED PART ACQUISITION ACTIVITIES

PRESENTED AT THE 1983
MISSION ASSURANCE CONFERENCE
7 JUNE 1983
BY: D. E. MOORE
DEPUTY EXECUTIVE DIRECTOR
QUALITY ASSURANCE
DEFENSE LOGISTICS AGENCY

GSQA WHAT IT IS AND WHAT IT ISN'T

- THE ACQUISITION OF QPL ITEMS BY ORIGINAL EQUIPMENT MANUFACTURERS
- THE SEMICONDUCTOR MICROCIRCUIT EXAMPLE

GSQA AND HOW IT HAPPENED

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

- DCAS ROLE IN SUPPORT OF THE QPL SEMICONDUCTOR ACQUISITION ACTIVITY
  - IN SOME CASES - BY SECONDARY DELEGATION
  - INITIALLY LIMITED TO WITNESSING QUALIFICATION TESTS AND REPORTING RESULTS TO QUALIFYING ACTIVITY
  - IN 1977 DCAS ROLE WAS EXPANDED BY INCORPORATING GOVERNMENT SOURCE INSPECTION (GSI) REQUIREMENT IN MIL-S-19500 TO SOLVE A COUNTERFEITING PROBLEM
  - IN DECEMBER 1979 DCAS ROLE WAS FURTHER EXPANDED TO INCLUDE THE AUDITING OF ER DISTRIBUTORS
  - IN 1982 DCAS ROLE WAS AGAIN EXPANDED BY INCORPORATING GSI REQUIREMENT IN MIL-M-38510 TO SOLVE ANOTHER PROBLEM
  - DCAS ALSO SUPPORTS THE QPL PROGRAM BY EXECUTING SPECIAL TASKS DELEGATED BY THE QUALIFYING ACTIVITY
  - DCAS ALSO PERFORMS SPECIAL QUALITY ASSURANCE RELATED ACTIONS, E.G., RECENT SERIES OF QUALITY SYSTEM REVIEWS (QSRS) PERFORMED AT SEMICONDUCTOR MANUFACTURING FACILITIES.

SOME BASICS

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

- PRIME CONTRACTOR'S (OEM'S) RESPONSIBILITIES
  - THE CONTRACTOR (OEM) IS RESPONSIBLE FOR ASSURING THAT ALL SUPPLIES AND SERVICES PROCURED FROM HIS SUPPLIERS (SUB-CONTRACTORS AND VENDORS) CONFORM TO THE CONTRACT REQUIREMENTS." PARA 6.1, 6.2, MIL-Q-9858A; DAR 14-302; DAR 7-103.24; PARA 3. 11, MIL-I-45208.
  - "THE INCLUSION OF A PRODUCT ON THE QUALIFIED PRODUCTS LIST ONLY SIGNIFIES THAT AT ONE TIME THE MANUFACTURER MADE A PRODUCT WHICH MET SPECIFICATION REQUIREMENTS. IT DOES NOT RELIEVE THE CONTRACTOR (OEM) OF HIS RESPONSIBILITY FOR FURNISHING SUPPLIES THAT MEET ALL SPECIFICATION REQUIREMENTS OR FOR THE PERFORMANCE OF SPECIFIED INSPECTIONS AND TESTS FOR SUCH MATERIAL." PARA 5.1, MIL-Q-9858A; DAR 14-302; DAR 7-103.24 PARA 3.8, MIL-I-45208.
  - IT IS DOD POLICY THAT: "CONTRACTORS SHALL BE HELD RESPONSIBLE FOR THE QUALITY OF PRODUCTS AND SERVICES; AND CONTRACTORS SHALL BE HELD RESPONSIBLE FOR THE QUALITY OF PRODUCTS AND SERVICES FURNISHED BY THEIR SUPPLIERS AND GOVERNMENT INSPECTION AT SUPPLIER FACILITIES SHALL BE HELD TO AN ABSOLUTE MINIMUM." PARA C.3a AND d, DODD 4155.1.

SOME BASICS

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

PRIME CONTRACTOR'S (OEM'S) RESPONSIBILITIES

- "WHEN THE GOVERNMENT ELECTS TO PERFORM INSPECTION AT A SUPPLIER'S PLANT, SUCH INSPECTION SHALL NOT BE USED BY CONTRACTORS (OEM'S) AS EVIDENCE OF EFFECTIVE CONTROL OF QUALITY BY SUCH SUPPLIERS." PARA 6.1, MIL-Q-9858; DAR 14-302; DAR 7-103.24; DAR 7-103.5(a) (b), PARA 3.11, MIL-I-45208.
- "THE GOVERNMENT RESERVES THE RIGHT TO INSPECT AT SOURCE SUPPLIES OR SERVICES NOT MANUFACTURED OR PERFORMED WITH THE CONTRACTOR'S (OEM'S) FACILITY. GOVERNMENT INSPECTION SHALL NOT CONSTITUTE ACCEPTANCE; NOR SHALL IT IN ANY WAY REPLACE CONTRACTOR (OEM) INSPECTION OR OTHERWISE RELIEVE THE CONTRACTOR (OEM) OF HIS RESPONSIBILITY TO FURNISH AN ACCEPTABLE END ITEM." PARA 7.1, MIL-Q-9858A; DAR 14-302; DAR 7-103.8; PARA 3.11, MIL-I-45208.

A MISCONCEPTION

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

- EXTENT OF GOVERNMENT INVOLVEMENT AT QPL PRODUCERS' FACILITIES
  - INDUSTRY DESIRES INCREASED GOVERNMENT INVOLVEMENT AT QPL PRODUCERS.
    - "...(OEMS) NORMALLY RELY ON THE GOVERNMENT'S QUALITY AUDIT AND SURVEILLANCE AT THE COMPONENT MANUFACTURERS' FACILITIES AND DO NOT ATTEMPT TO DUPLICATE THIS EFFORT" NSIA, 23 JUNE 1982
  - DAR PLACES RESPONSIBILITY ON THE CONTRACTOR AND LIMITS FQA AT THE SUBCONTRACT LEVEL. PARA C3A&D, DODD 4155.1.
  - OEM RESPONSIBLE FOR PRODUCT QUALITY AND SURVEILLANCE OF SUBCONTRACTORS.
  - QPL PRODUCER RESPONSIBLE FOR COMPLYING WITH SPECIFICATION REQUIREMENTS.
  - LAX OEM/PRIME SURVEILLANCE OF SUBCONTRACTORS.

GSQA AND WHAT IT ISN'T

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

- EXTENT OF GOVERNMENT INVOLVEMENT AT QPL PRODUCERS' FACILITIES
  - FAST PROBLEMS WERE INDEPENDENT OF DCAS ACTIVITY
    - WEAK MANUFACTURER'S QUALITY PROGRAM
      - INADEQUATE IN-LINE QUALITY CONTROL
    - QUALITY SUBSERVIENT TO SCHEDULE
      - SPECIFICATION PROVISIONS IGNORED
  - GOVERNMENT QAR INVOLVEMENT UNIQUE
    - REQUIRED BY GSI INCLUSION IN PRODUCT SPEC
    - NO ACCEPTANCE REQUIRED
    - NO DD-250

GSQA AND WHAT IT MEANS

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

CERTIFICATION OF TRACEABILITY

1. NAME OF MANUFACTURER OF QUALIFIED PRODUCT:
2. DEVICE TYPE AND PRODUCT ASSURANCE LEVEL: JAN 2N3XXXX A
3. LOT DATE CODE AND ASSEMBLY PLANT CODE: 8148
4. INSPECTION DATE OR LATEST REINSPECTION DATE:
5. QUANTITY OF DEVICES IN SHIPMENT FROM MANUFACTURER:
6. NAME OF MANUFACTURER'S EMPLOYEE RESPONSIBLE FOR SHIPMENT: RICHARD DOE

SIGNATURE _____

DATE OF SHIPMENT:

ANOTHER MISCONCEPTION

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

SHARE THE WEALTH

- INDUSTRY PROPOSED A DAR CHANGE FOR THE GOVERNMENT TO SHARE "RISK OF QPL PARTS"
  - "7-X.X.X. PARTICIPATION IN GOVERNMENT INDUSTRY DATA EXCHANGE PROGRAM (GIDEP)"

    "(b) WITH RESPECT TO ANY PARTS ACQUIRED FROM THE QUALIFIED PRODUCTS LIST, ALL REQUIRED ACTION(S) SHALL BE SUBJECT TO AN EQUITABLE ADJUSTMENT AS CONTEMPLATED BY THE "CHANGES" CLAUSE." NSIA, 23 JUN 82; EIA, 23 AUG 82.
- MISINTERPRETATION OF OEM CONTROL OF QPL PARTS
- ABDICATION OF OEM RESPONSIBILITY
- RECENT QPL EXPERIENCE
  - OEMS RECEIVED WAIVERS/REPLACEMENT PARTS
  - OEMS ESCAPED IMPACT OF MONETARY CONSIDERATION

THE BOTTOM LINE FOR GSQA

- THE PRIME CONTRACTOR (OEM) IS RESPONSIBLE FOR THE QUALITY OF SUBCONTRACTORS'/VENDORS' QPL PRODUCTS.
- A MANUFACTURER (OEM) WHO DELIVERS A PRODUCT DESTINED FOR DELIVERY TO THE GOVERNMENT IS ABSOLUTELY RESPONSIBLE FOR THE QUALITY OF THAT PRODUCT.
- THIS RESPONSIBILITY IS NOT DIMINISHED OR AFFECTED BY A GSQA DELEGATION.

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

- DOD POLICY PROMOTES THE USE OF STANDARD PARTS TO MAXIMUM EXTENT PRACTICAL
- USE OF NONSTANDARD PARTS MUST BE APPROVED BY PROCURING ACTIVITY

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY AND NOBODY

REQUIREMENTS FOR USE OF NONSTANDARD PARTS IN ELECTRONIC EQUIPMENT

1. MIL-E-5400, ELECTRONIC EQUIPMENT, AEROSPACE, GENERAL SPECIFICATION FOR:

PARAGRAPH 3.1.1 - SELECTION OF PARTS AND MATERIALS. PARTS AND MATERIALS COVERED BY DOCUMENTS LISTED IN APPENDIX A ARE STANDARD AND SHALL BE USED WHENEVER THEY ARE SUITABLE FOR THE PURPOSE. PARTS AND MATERIALS SHALL BE PROCURED FROM QPL SOURCES WHEN QUALIFICATION IS A REQUIREMENT OF THE PART OR MATERIAL SPECIFICATION. NONSTANDARD PARTS AND MATERIALS MUST BE EQUIVALENT TO OR BETTER THAN SIMILAR STANDARD PARTS AND MATERIALS. PARTS SELECTION AND CONTROL SHALL BE IN ACCORDANCE WITH MIL-STD-454, REQUIREMENT 22.

PARAGRAPH 3.1.36 - MICROELECTRONIC DEVICES. MICROELECTRONIC DEVICES, INCLUDING HYBRIDS, SHALL BE IN ACCORDANCE WITH MIL-STD-454, REQUIREMENT 64. DEVICES SELECTED SHALL BE SOLDERED OR WELDED INTO THE CIRCUIT.

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY AND NOBODY

2. MIL-STD-454, STANDARD GENERAL REQUIREMENTS FOR ELECTRONIC EQUIPMENT:

REQUIREMENT 22 (PARTS SELECTION AND CONTROL):

PARAGRAPH 3. DATA. PREPARATION AND SUBMISSION OF DATA FOR PARTS SELECTION AND CONTROL, INCLUDING REQUESTS FOR APPROVAL OF NONSTANDARD PARTS, SHALL BE IN ACCORDANCE WITH MIL-STD-965 TO THE EXTENT SPECIFIED IN THE CONTRACT.

REQUIREMENT 64 (MICROELECTRONIC DEVICES):

PARAGRAPH 4. SELECTION. MICROELECTRONIC DEVICES SHALL CONFORM TO MIL-M-38510, PRODUCT ASSURANCE LEVEL CLASS B, AS A MINIMUM. UNLESS OTHERWISE SPECIFIED, THE ORDER OF PREFERENCE SHALL BE AS FOLLOWS:

A. MIL-M-38510 JAN MICROCIRCUITS LISTED IN MIL-STD-1562
B. OTHER MIL-M-38510 JAN MICROCIRCUITS.
C. OTHER MICROCIRCUITS (SEE 4.1), SUBJECT TO PROCURING ACTIVITY APPROVAL.

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY AND NOBODY

2. MIL-STD-454, STANDARD GENERAL REQUIREMENTS FOR ELECTRONIC EQUIPMENT: (CONT'D)

PARAGRAPH 4.1 NON-JAN DEVICES. FOR OTHER THAN JAN DEVICES, THE FOLLOWING INFORMATION SHALL BE INCLUDED IN THE NONSTANDARD PART APPROVAL REQUEST:

A. DEVICE NOMENCLATURE, MARKING, CONFIGURATION, FUNCTIONAL REQUIREMENTS, PARAMETERS AND LIMITS SUFFICIENT TO INSURE THE REQUIRED FORM, FUNCTIONS AND INTERCHANGEABILITY.
B. REQUIRED ENVIRONMENTAL, ENDURANCE (LIFE) AND OTHER DESIGN CAPABILITY TESTS.
C. QUALITY ASSURANCE REQUIREMENTS, INCLUDING SCREENING AND LOT QUALITY CONFORMANCE (ACCEPTANCE) TESTS. AS A MINIMUM, ALL DEVICES SHALL BE REQUIRED TO PASS THE MIL-STD-883 CLASS B REQUIREMENTS OF SCREENING IN ACCORDANCE WITH METHOD 5004 OR 5008, AS APPLICABLE, AND GROUPS A AND B LOT QUALITY CONFORMANCE IN ACCORDANCE WITH METHOD 5005 OR 5008, AS APPLICABLE, AND SHALL HAVE AT LEAST INITIAL VERIFICATION OF THE GROUP C AND D REQUIREMENTS OF METHOD 5005 OR 5008, AS APPLICABLE.

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

- TYPICAL LIMITATIONS ON OEMS' SPEC CONTROL DRAWINGS
  - THE DEVICE SHALL BE IN ACCORDANCE WITH MIL-M-38510 PRODUCT ASSURANCE LEVEL CLASS B OR EQUIVALENT AS SPECIFIED HEREIN.
  - COUNTRY OF MANUFACTURE, ASSEMBLY, AND TESTING NEED NOT BE CONFINED TO THE U.S. AND ITS TERRITORIES.
  - DESIGN DOCUMENTATION IN ACCORDANCE WITH MIL-M-38510 IS NOT REQUIRED.
  - BURN-IN PER MIL-STD-883, METHOD 1015, AS REQUIRED, BY PURCHASE ORDER.
  - THE SUPPLIER SHALL RETAIN COPIES OF ALL PERIODIC GROUP A, B, AND C DATA FOR REVIEW BY THE OEM.
    - AND WHAT ABOUT GROUP D

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

- TYPICAL LIMITATIONS ON OEMS' SCD PART SPECIFICATIONS
  - IN THE EVENT OF CONFLICT BETWEEN THE REQUIREMENTS OF THIS SPECIFICATION AND THE SPEC CONTROL DRAWING THE LATTER SHALL CONTROL.
  - MANUFACTURE, ASSEMBLY, AND TESTING WITHIN THE U.S. AND ITS TERRITORIES IS NOT REQUIRED.
  - WHEN GROUP B, C OR D TEST DATA IS REQUIRED BY P.O. SUMMARY DATA SHALL BE SUPPLIED WITH EACH SHIPMENT.
  - ONLY WHEN SPECIFICALLY CALLED OUT BY THE P.O. SHALL THE SUPPLIER BE OBLIGATED TO PERFORM THE LOT QUALIFICATION INSPECTIONS FOR GROUP B, C, AND D REQUIREMENTS.
  - WHEN APPLICABLE, GROUPS B, C, OR D SAMPLES SHALL BE SELECTED FROM SUB-LOTS THAT HAVE SUCCESSFULLY COMPLETED ALL OF THE 100% PROCESSING STEPS INCLUDING GROUP A LOT ACCEPTANCE.
  - THE SPECIFIC LEVEL OF PROCESS CONDITIONING, TESTING AND SCREENING SHALL BE SPECIFIED IN THE DETAIL SPECIFICATION IN THE SUPPLIER'S PART NUMBER TABLE.

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY AND NOBODY

RESULTS OF A SURVEY OF 8838 "LOOK-ALIKE" SUPPLIER'S

REGION	NUMBER OF PRODUCERS	MIL-M-38510 JAN QUALIFIED	PARA 1.2 OF 883
1	2	1	O.K.
2	7	2	NO COMMENT
3	2	0	NO COMMENT
4	1	1	MODIFY
5	8	5	O.K.
6	30	11	MODIFY
7	4	1	O.K.
8	1	0	MODIFY
9	3	1	ADD TO 454
	58	22	

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

SOME SURVEY FEEDBACK

- CONTRACTOR "A" SAID WE DON'T INSPECT QPL PARTS - IF NO GOVERNMENT STAMP WE REJECT.
- CONTRACTOR "B" MANUFACTURES NONSTANDARD PARTS AND OTHER PRODUCERS ARE NOT RECEPTIVE TO HIS VISIT.
- IN REGARD TO SEMICONDUCTOR DEVICES AND MICROCIRCUITS, CONTRACTOR "C" DOES NOT PERFORM SOURCE INSPECTION ON JAN OR SCD ITEMS.
- CONTRACTOR "D" PURCHASES OVER 50 PERCENT OF ITS JAN ITEMS FROM DISTRIBUTORS WHICH AUTOMATICALLY ELIMINATES THE POSSIBILITY OF PERFORMING SOURCE INSPECTION.
- ON PURCHASES FROM KNOWN PRODUCERS OF QPL PRODUCTS, MILITARY SPECIFICATIONS OR STANDARDS ARE NOT LISTED SINCE THE PRODUCER MUST MEET THE 19500 AND/OR 38510 REQUIREMENTS.
- CONTRACTOR "F" RELIES ALMOST TOTALLY ON THE GOVERNMENT TO INSURE THE QUALITY OF QPL PARTS IT PURCHASES.

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

SOME SURVEY FEEDBACK (CONT'D)

- PRODUCER "G" DOES NOT ALLOW OUTSIDERS ACCESS TO THEIR MANUFACTURING AREA SO SURVEYS ARE BASED ON THE PRODUCER'S RECORDS.
- CONTRACTOR "H's" POSITION IS THAT INCOMING INSPECTION/TESTING IS NOT ECONOMICALLY ADVANTAGEOUS. THEY FEEL THAT IT COSTS LESS TO REWORK DEFECTIVE COMPONENTS.
- CONTRACTOR "I's" PROCEDURES GOVERNING SOURCE INSPECTION FOR VENDOR ITEMS ARE SIMILAR TO THE PROCEDURES FOR HARDWARE EXCEPT THAT SOURCE INSPECTION OF THE FORMER MAY BE WAIVED WHEN GSI IS IMPOSED.
- CONTRACTOR "J" HAS A POLICY NOT TO DO ANY SOURCE INSPECTION AT SUBCONTRACTORS/VENDORS OR DISTRIBUTORS OF SEMICONDUCTOR OR MICROCIRCUIT QPL ITEMS.
- CONTRACTOR "K's" ACCEPTANCE OF SEMICONDUCTOR AND TRANSISTOR DEVICES IS BASED ON A CERTIFICATE OF CONFORMANCE OR CERTIFICATION OF TRACEABILITY.
- CONTRACTOR "L's" PROCEDURES PROVIDE FOR VENDOR APPROVAL EITHER BY SURVEY, BY PRODUCT QUALIFICATION, OR BY PAST HISTORY WITHOUT FURTHER GUIDANCE.

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

SOME SURVEY FEEDBACK (CONT'D)

- CONTRACTOR "M" DOES NOT VERIFY VALIDITY OF DATA FURNISHED WITH PROCURED ITEMS.
- CONTRACTOR "N" DOES NOT PROVIDE PROCEDURAL DIRECTION FOR SOURCE INSPECTORS CONCERNING RESPONSIBILITY FOR CORRECTIVE ACTION.
- CONTRACTOR "O" DID NOT HAVE ANY PROCEDURES TO IDENTIFY THE SCOPE, DEPTH, PERFORMANCE, OR RECORDS REQUIRED FOR VENDOR SURVEYS.
- CONTRACTOR "P" HAD NO PROCEDURAL GUIDANCE CONCERNING THE APPLICATION OF DESIGN, TECHNICAL OR QUALITY CONTROL REQUIREMENTS TO BE INCLUDED ON PURCHASE ORDERS.
- THE CONTRACTOR "Q's" QUALITY ASSURANCE PROCEDURES PROVIDE ONLY LIMITED TREATMENT TO PURCHASED MATERIAL AND INCOMING INSPECTION.
- CONTRACTOR "R" HAS NO BASIC POLICY OR PROCEDURE CONCERNING THE SELECTION AND QUALIFICATION OF VENDORS AND THE TRANSMISSION OF DESIGN REQUIREMENTS TO VENDORS.
- CONTRACTOR "S's" PROCUREMENT SYSTEM DOES NOT SUFFICIENTLY ADDRESS DEVELOPMENT OF PROCUREMENT SPECIFICATIONS AND SUBSEQUENT QUALIFICATION OF MICROELECTRONIC PARTS TO ENSURE REQUIRED EQUIVALENCY

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

SOME SURVEY FEEDBACK (CONT'D)

- CONTRACTOR "T's" PURCHASE ORDER AND SOURCE CONTROL DOCUMENT REQUIREMENTS FOR NONSTANDARD PARTS WERE INADEQUATE TO ENSURE THAT NONSTANDARD PARTS ARE EQUIVALENT TO QPL PARTS.
- CONTRACTOR "U's" SPECIFICATIONS/DRAWINGS FOR NONSTANDARD PARTS WERE LIMITED TO THE TESTING REQUIREMENTS OF MIL-STD-883 WITHOUT ADEQUATE CONSIDERATION OF THE REQUIREMENTS OF MIL-M-38510.
- CONTRACTOR "V" ATTESTED THAT SCD PARTS ARE LESS EXPENSIVE AND HAVE SHORTER LEAD TIMES THAN COMPARABLE JAN PARTS.

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

OVERALL CONCLUSIONS OF DLA SURVEYS CONCERNING SCD PARTS

- SCD PARTS:
  - GENERALLY DON'T MEET THE REQUIREMENTS OF MIL-M-38510.
  - PERHAPS CONFORM TO PART OF THE REQUIREMENTS OF MIL-STD-883B TEST METHODS
  - USUALLY ARE APPROVED BY PROCURING ACTIVITIES
  - SELDOM ARE CHALLENGED BY RESPONSIBLE DOD CONTRACT ADMINISTRATION ORGANIZATIONS AT OEM FACILITIES.
- COORDINATED EFFORT BY PROCURING ACTIVITIES AND CONTRACT ADMINISTRATION ORGANIZATIONS IS ESSENTIAL

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

A CHAIN IS NO BETTER THAN ITS WEAKEST LINK

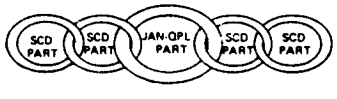
- RECENT DLA-Q SURVEYS IDENTIFIED THAT THERE ARE:
  - 58 883B "LOOK ALIKE" SCD PART PRODUCERS

    AND
  - 22 MIL-M-38510 QPL PART PRODUCERS
  - WHAT'S HAPPENING AT THE OTHER ≈ 36 FACILITIES - AND NOBODY KNOWS?

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

A CHAIN IS NO BETTER THAN ITS WEAKEST LINK



- SCD PARTS:
  - ARE INCORPORATED IN MOST MAJOR SYSTEMS
  - ARE NOT VERY WELL CONTROLLED - BY EVERYBODY
  - OVERWHELM JAN - QPL PARTS
    - BY A RATIO OF 4 TO 1

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

STANDARD CLASS S MICROCIRCUITS

- TWO MANUFACTURERS LISTED ON QPL 38510, PART I
  - 10 DEVICE TYPES QUALIFIED
- THREE MANUFACTURERS LISTED ON QPL 38510, PART II
  - 109 DEVICE TYPES QUALIFIED
- NONSTANDARD MICROCIRCUITS - NORM FOR SPACE APPLICATION
- FLOW DOWN REQUIREMENTS FOR CLASS S PARTS ARE NOT AS WEL DEFINED AS ARE THOSE FOR CLASS B PARTS
- NO REASON TO BELIEVE CONTROL OF CLASS S SCD PARTS IS DIFFERENT

THE SCD MYTH

EVERYBODY, SOMEBODY, ANYBODY, AND NOBODY

A CHAIN IS NO BETTER THAN ITS WEAKEST LINK

- JAN VS SCD - CONUS VS OFFSHORE
  - IS THIS REALLY CONTRACT COMPLIANCE?
- A RHETORICAL QUESTION
  - THE OBJECTIVE OF THIS WORKSHOP IS TO VENTILATE IMPORTANT ISSUES
- WE MUST WORK TOGETHER TO IDENTIFY ISSUES AND ACTIONS WHICH WILL CONTRIBUTE TO MISSION ASSURANCE

RESULTS OF SURVEYS OF PRIME CONTRACTORS' CONTROL OF SUBCONTRACTORS

REGION	VENDOR RATING	CONTRACTOR SOURCE INSPECTION	PREAWARD SURVEY	EVALUATION OF VENDOR PROCESS CONTROL	RECEIVING INSPECTION	TEST TO VERIFY CERTIFICATION	CONTRACTOR CORRECTIVE ACTION	DELD INSPECTION	VENDOR SURVEYS AND AUDITS	CONTROLLED PURCHASE ORDER REQUIREMENTS	GSI RELIED ON BY CONTRACTOR
1	X				X		X			X	
2	X	X			X	X	X		X	X	X
3					X	X	X		X	X	X
4	X								X		
5	X	X		X	X		X		X	X	
6					X				X	X	
7				X	X	X	X	X	X	X	X
8	X	X	X	X	X	X	X		X	X	X
9	X		X		X		X				X

SUMMARY

THIS IS A STORY ABOUT FOUR PEOPLE. EVERYBODY, SOMEBODY, ANYBODY AND NOBODY. THERE WAS AN IMPORTANT JOB TO BE DONE AND EVERYBODY WAS ASKED TO DO IT. EVERYBODY WAS SURE SOMEBODY WOULD DO IT. ANYBODY COULD HAVE DONE IT, BUT NOBODY DID IT. SOMEBODY GOT ANGRY ABOUT THAT BECAUSE IT WAS EVERYBODY'S JOB. EVERYBODY THOUGHT ANYBODY COULD DO IT, BUT NOBODY REALIZED THAT EVERYBODY WOULDN'T DO IT. IT ENDED UP THAT EVERYBODY BLAMED SOMEBODY WHEN ACTUALLY NOBODY ASKED ANYBODY.

A. N. ONYMOUS

LET'S JOIN TOGETHER AND MAKE THE JAN QPL PROGRAM WORK

Comments on Charts

by D. Moore

CHART 1

I WAS ASKED TO SPEAK ON THE SUBJECT OF GSI. I HAVE ELECTED TO DISCUSS GOVERNMENT SOURCE QUALITY ASSURANCE AND TO SHARE WITH YOU SOME OF OUR EXPERIENCE IN EVALUATING ACQUISITION ACTIVITIES RELATED TO TRANSISTORS AND MICROCIRCUIT DEVICES. I ALSO PLAN TO SHARE WITH YOU WHAT GSQA IS AND WHAT IT ISN'T.

CHART 3

THIS VUGRAPH RELATES THE HISTORY OF DCAS' INCREASING INVOLVEMENT IN THIS ACQUISITION ACTIVITY.

CHART 4

SINCE THE MAJORITY OF ORIGINAL EQUIPMENT MANUFACTURERS HAVE MIL-Q-9858A OR, AS A MINIMUM, MIL-I-45208 IN THEIR CONTRACTS, I HAVE DISPLAYED PERTINENT QUOTES TO ILLUSTRATE THE OEM'S RESPONSIBILITY WITH REGARD TO CONTROL OF PRODUCTS - INCLUDING QUALIFIED PRODUCTS - DELIVERED BY THEIR SUPPLIERS.

CHART 5

THIS VUGRAPH IS DIFFERENT FROM THE PRECEDING ONE IN THAT IT DISPLAYS PERTINENT QUOTATIONS FROM MIL-Q-9858 AND MIL-I-45208 WHICH INDICATE THAT GOVERNMENT QUALITY ASSURANCE ACTIVITY AT A SUPPLIER'S FACILITY IS THE PREROGATIVE OF THE GOVERNMENT AND DOES NOT RELIEVE THE OEM OF ANY OF HIS RESPONSIBILITY CONCERNING A SUPPLIER'S ACTIVITY.

CHART 6

THE THIRD BULLET ON THIS CHART GRAPHICALLY DISPLAYS THE EXTENT OF THE MISUNDERSTANDING CONCERNING GSQA AND AN OEM'S RESPONSIBILITY.

CHART 7

THE MOST SIGNIFICANT POINT TO BE MADE ON THIS VUGRAPH IS THE FACT THAT ACCEPTANCE IS NOT REQUIRED BY THE INCLUSION OF A SUBPARAGRAPH CONCERNING GSI IN MIL-S-19500. THOSE OF YOU WHO HAVE GOVERNMENT QUALITY ASSURANCE REPRESENTATIVES IN YOUR FACILITY - WITH ACCEPTANCE RESPONSIBILITY - CAN CERTAINLY APPRECIATE THE DIFFERENT LEVEL OF RESPONSIBILITY - ABSENT THE REQUIREMENT FOR A DD250.

CHART 8

THE CERTIFICATION OF TRACEABILITY SHOWN ON THIS CHART IS REPRESENTATIVE OF CERTS REQUIRED BY MIL-S-19500 AND YOU WILL OBSERVE THAT THERE IS NO ACCEPTANCE VERIFICATION INCLUDED ON THIS CERTIFICATION. THE SIGNATURE LINE IS TO BE FILLED IN BY A REPRESENTATIVE OF THE SUPPLIER.

CHART 9

AS DISCUSSED IN A PREVIOUS VUGRAPH, BULLET 2 ON THIS CHART FURTHER ILLUSTRATES THE EXTENT OF THE MISUNDERSTANDING CONCERNING AUTHORITIES AND RESPONSIBILITIES AN OEM HAS CONCERNING PROCUREMENT OF QUALIFIED PARTS.

CHART 11

OUR ACTIVITIES IN THE RECENT PAST HAVE NOT BEEN LIMITED TO ELECTRONIC PARTS FOR SPACE APPLICATIONS, NONETHELESS, I BELIEVE THAT THE INFORMATION WE HAVE ACQUIRED CONCERNING SCD PARTS OR 883B "LOOK ALIKES" IS SUFFICIENTLY PERTINENT TO WARRANT SHARING IT WITH YOU.

CHART 13

THE NEXT SEVERAL CHARTS ARE RATHER BUSY BUT THEY ESTABLISH SOME OF THE KEY REQUIREMENTS FOR THE USE AND SELECTION OF NONSTANDARD PARTS IN ELECTRONIC EQUIPMENT. THE KEY SENTENCE IN THIS VUGRAPH IS THAT "NONSTANDARD PARTS AND MATERIALS MUST BE EQUIVALENT TO OR BETTER THAN SIMILAR STANDARD PARTS AND MATERIALS."

CHART 14

THE KEY POINT ON THIS VUGRAPH IS THAT MICROELECTRONIC DEVICES SHALL CONFORM TO MIL-M-38510 AS A MINIMUM. IT ALSO IDENTIFIES THE ORDER OF PREFERENCE FOR OTHER THAN JAN MICROCIRCUITS.

CHART 15

THIS VUGRAPH INDICATES THAT NONSTANDARD PART APPROVAL REQUEST SHALL INCLUDE: THE DEVICE NOMENCLATURE, MARKING, CONFIGURATION, FUNCTIONAL REQUIREMENTS, PARAMETERS AND LIMITS SUFFICIENT TO INSURE THE REQUIRED FORM, FUNCTIONS AND INTERCHANGEABILITY. I MIGHT ADD THAT IN OUR REVIEWS WE HAVE DETERMINED THAT THE MARKING REQUIREMENTS ARE ALWAYS CLEARLY SPELLED OUT.

CHART 16

AS I HAVE INDICATED EARLIER, WE HAVE CONDUCTED A NUMBER OF REVIEWS OF OEM FACILITIES TO BETTER UNDERSTAND WHAT'S HAPPENING IN THE REAL WORLD. THIS VUGRAPH DISPLAYS SOME OF THE TYPICAL LIMITATIONS WHICH HAVE BEEN INCLUDED IN SPECIMENS OF CURRENT SPEC CONTROL DRAWINGS PREPARED BY OEMS. YOU WILL OBSERVE THAT SOME OF THESE LIMITATIONS ARE VERY SIGNIFICANT.

CHART 17

AS WITH THE PRECEDING VUGRAPH, THIS CHART DISPLAYS LIMITATIONS OBSERVED IN SCD PARTS SPECIFICATIONS. AGAIN YOU WILL OBSERVE THAT SOME OF THESE LIMITATIONS ARE VERY SIGNIFICANT.

CHART 18

AT A MEETING IN TUCSON EARLIER THIS YEAR, A CONCERN WAS VOICED THAT THERE WERE A NUMBER OF 883B "LOOK ALIKE" SUPPLIERS IN THE COMMUNITY WHO WERE NOT JAN QUALIFIED PRODUCERS. TO DETERMINE THE EXTENT OF THIS CONDITION, WE SOLICITED INPUT FROM THE NINE DCAS REGIONS. ALTHOUGH OUR DATA MAY NOT BE ALL INCLUSIVE, IT CONFIRMS THAT THERE ARE A SIZEABLE NUMBER OF SUPPLIERS MANUFACTURING "LOOK ALIKE" DEVICES WHO ARE NOT JAN QUALIFIED. I ALSO INVITE YOUR ATTENTION TO THE COLUMN WHICH REFERS TO PARA 1.2 OF MIL-STD-883C. I SUGGEST ANY OF YOU WHO REPRESENT "LOOK ALIKE" PRODUCERS SHOULD THOROUGHLY FAMILIARIZE YOURSELF WITH THE CONTENT OF THIS PARAGRAPH WHEN THE C REVISION IS PUBLISHED.

CHART 19

I INDICATED EARLIER THAT EACH OF OUR NINE REGIONS REVIEWED AT LEAST ONE PRIME CONTRACTOR'S PROCEDURES AND SYSTEM FOR CONTROL OF SUBCONTRACTOR ACTIVITY. THIS MATRIX GRAPHICALLY REPRESENTS THE DIFFERENT LEVELS OF EFFORT ACROSS THE COMMUNITY IT REPRESENTS.

CHART 20

SOME SPECIFIC FEEDBACK CONCERNING THE REVIEWS DEPICTED ON THE PREVIOUS SLIDE IS INCLUDED ON THE NEXT FOUR SLIDES. IN MY OPINION, THE OBSERVATIONS LISTED ON THESE SLIDES ARE NOT UNIQUE TO THE CONTRACTORS VISITED DURING OUR REVIEWS - BUT ENDEMIC TO THE COMMUNITY. THE OBSERVATIONS REPRESENT THE DIVERSE ATTITUDES AND ABSENCE OF CONTROL CONCERNING A VERY IMPORTANT COMMODITY WHICH IS THE SUBJECT OF OUR MEETING THIS WEEK. I AM SHARING THIS INFORMATION WITH YOU BECAUSE WE SHOULD ALL HAVE SOME CONCERN AND DEDICATE OURSELVES TO ESTABLISH BETTER CONTROL OF JAN QPL PRODUCTS.

CHART 23

THE SUM AND SUBSTANCE OF THE OBSERVATIONS YOU HAVE SEEN ON PRECEDING SLIDES IS BOILED DOWN TO THE FIRST TWO BULLETS OF THIS VUGRAPH. IN SUMMARY, IT WOULD APPEAR THAT SCD PARTS MAY MEET THE REQUIREMENTS OF MIL-STD-883 BUT CERTAINLY ARE NOT EQUAL TO OR BETTER THAN DEVICES MANUFACTURED IN ACCORDANCE WITH MIL-M-38510.

CHART 24

FROM OUR PERSPECTIVE, IT WOULD APPEAR THAT SCD PARTS FALL SHORT OF COMPLYING WITH THE REQUIREMENTS OF MIL-M-38510.

CHART 25

I MENTIONED PREVIOUSLY THAT IN A RECENT SURVEY, IT WAS DETERMINED THAT THERE WERE AT LEAST 58 883B "LOOK ALIKE" SCD PART PRODUCERS. CERTAINLY, WE SHOULD ALL BE CONCERNED WITH THE ACTIVITY AT THOSE FACILITIES THAT ARE NOT QUALIFIED TO PRODUCE MIL-M-38510 PARTS.

CHART 26

AS A MECHANICAL ENGINEER, SOMEONE ONCE TOLD ME THAT A CHAIN IS NO STRONGER THAN ITS WEAKEST LINK. I AM NOT SURE IF THAT ADAGE APPLIES HERE SINCE IT WOULD APPEAR THAT FOR EVERY STRONG LINK, WE HAVE FOUR LESSER LINKS. FROM THE DATA WE DEVELOPED, THERE APPEAR TO BE AN AVERAGE OF THREE OR FOUR NONSTANDARD PARTS FOR EVERY JAN PART INCLUDED IN WEAPON SYSTEMS MANUFACTURED BY OEMS.

CHART 28

AT AN EIA/JEDEC INDUSTRY/GOVERNMENT FORUM ON MICROELECTRONIC PRODUCT QUALITY CONVENED ON 20 JANUARY 1983 IN TUCSON, INDUSTRY REPRESENTATIVES OFFERED A NUMBER OF RECOMMENDATIONS TO IMPROVE THE JAN MICROCIRCUIT ELECTRONIC PROGRAM. ONE OF THE FINAL RECOMMENDATIONS OF THE INDUSTRY REPRESENTATIVES WAS BASED ON A PERCEIVED PROBLEM CONCERNING THE LACK OF TOTAL GOVERNMENT COMMITMENT TO SUPPORT THE JAN PROCUREMENT SYSTEM AS A RESULT OF OBSERVATIONS THAT BROAD USE OF SCD PRODUCTS WAS CIRCUMVENTING THE JAN QPL PROGRAM. INDUSTRY REPRESENTATIVES THUS RECOMMENDED STRICT ENFORCEMENT OF THE FLOW-DOWN REQUIREMENTS I DESCRIBED EARLIER. OUR OBSERVATIONS REINFORCE THAT INDUSTRY OBSERVATION AND I SUBMIT THAT ALL OF US IN THIS ROOM MUST WORK TOGETHER TO STRENGTHEN PROCUREMENT PRACTICES CONCERNING ELECTRONIC PARTS AND TO IDENTIFY ISSUES AND ACTIONS WHICH WILL CONTRIBUTE TO MISSION ASSURANCE.

CHART 29

IN MY OPINION, THE LITTLE STORY ABOUT FOUR PEOPLE SHOWN ON THIS SLIDE PRETTY WELL SUMS UP SOME RECENT HISTORY. LET'S JOIN TOGETHER AND MAKE THE JAN QPL PROGAM WORK.

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SPACE & STRATEGIC AVIONICS DIVISION CLEARWATER FLORIDA

PRESENT STATUS OF SPACE GRADE PARTS

JUNE, 1983

JOSEPH B. McGUIRK

PARTS MANAGEMENT

HONEYWELL SPACE AND STRATEGIC AVIONICS DIVISION

CLEARWATER, FLORIDA

THE SOURCE(s) OF REQUIREMENTS FOR SPACE GRADE PARTS ARE MIL-STD-1546 (USAF), MIL-STD-1547 (USAF), MIL-STD-975 (NASA), SAMSO-STD-77-7 AND THE ICBM PART AND MATERIALS STANDARDIZATION LIST FOR BMO. MIL-STD-1546 IS A MANAGEMENT STANDARD FOR SPACE GRADE PARTS AND REQUIRES USE OF JANS MICROCIRCUITS, SEMICONDUCTORS, AND QUALIFIED CLASS "S" PASSIVE DEVICES AS FIRST CHOICE. MIL-STD-1547 CONTAINS THE TECHNICAL REQUIREMENTS FOR PARTS WHEN JANS OR CLASS "S" PARTS ARE NOT AVAILABLE UPGRADING OF LOWER GRADE PARTS IS NOT ALLOWED BY SPACE DIVISION WITHOUT PROGRAM APPROVAL. MONITORED LINE PROGRAM DEVICES ARE ALLOWED AS SUBSTITUTE DEVICES WITH PROGRAM APPROVAL.

NASA's MIL-STD-975 CONTAINS LISTINGS OF NASA STANDARD PARTS AND PROVIDES FOR TWO GRADES OF PARTS. NAMELY, GRADE 1 FOR SPACE APPLICATIONS AND APPLICATIONS CONTAINING SINGLE POINT FAILURE MECHANISMS AND GRADE 2 FOR OTHER THAN SPACE APPLICATIONS. JANS MICROCIRCUITS, SEMICONDUCTORS AND QUALIFIED CLASS "S" PASSIVES ARE GRADE 1 DEVICES. SO ARE CLASS "B" MICROCIRCUITS, JANTXV SEMICONDUCTORS AND ESTABLISHED RELIABILITY PASSIVE DEVICES AFTER SUCCESSFULLY PASSING CLASS "S" SCREENING REQUIREMENTS AND DESTRUCTIVE PHYSICAL ANALYSIS. MIL-STD-976 CONTAINS REQUIREMENTS FOR MICROCIRCUIT MANUFACTURERS FOR CERTIFYING THEIR LINES.

USAF/BMO PARTS REQUIREMENTS IN SAMSO-STD-77-7 REQUIRE COMPLETELY SEPARATE PART DOCUMENTATION. HOWEVER, BMO's ICBM PMP LISTS DO REQUIRE USE OF JAN CLASS "S" DEVICES.

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SPACE & STRATEGIC AVIONICS DIVISION CLEARWATER FLORIDA

SOURCE(S) OF REQUIREMENTS FOR SPACE GRADE PARTS

USAF (SPACE DIVISION	NASA
MIL-STD-1546 (MANAGEMENT)	MIL-STD-975 (PREFERRED PARTS LIST)
MIL-STD-1547 (TECHNICAL)	MIL-STD-976 (LINE CERTIFICATION)

USAF (BALLISTIC MISSILE OPERATIONS)

SAMSO-STD-77-7 and ICBM PARTS, MATERIALS AND PROCESSING STANDARDIZATION LIST

THE MANUFACTURERS LISTED HAVE OBTAINED CLASS "S"/JANS LINE CERTIFICATION FROM AUDITS AND SURVEYS BY DESC AND OTHER GOVERNMENT AGENCIES. CLASS "S" LINE CERTIFICATION REQUIREMENTS IN MIL-STD-976 AND OTHER APPLICABLE DOCUMENTS ARE USED IN THE CERTIFICATION PROCESS.

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SPACE & STRATEGIC AVIONICS DIVISION CLEARWATER FLORIDA

CLASS "S" QUALIFICATION STATUS

MANUFACTURERS WITH CLASS "S" CERTIFIED LINES

MICROCIRCUITS

FAIRCHILD -- (PORTLAND, MAINE -- WAFER FAB, ASSEMBLY AND TEST)

NATIONAL SEMICONDUCTOR -- (SANTA CLARA, CALIFORNIA -- WAFER FAB)
(TUCSON, ARIZONA -- ASSEMBLY AND TEST)

SIGNETICS -- (OREM, UTAH -- WAFER FAB AND ASSEMBLY)
(SACRAMENTO, CALIFORNIA -- TEST)

RCA -- (SOMERVILLE, NEW JERSEY -- WAFER FAB)
(FINDLAY, OHIO -- ASSEMBLY AND TEST)

TRANSISTORS

MOTOROLA -- (PHOENIX, ARIZONA)

DIODES

MICROSEMICONDUCTOR CORPORATION -- (SANTA ANA, CALIFORNIA)

CERAMIC CAPACITORS (MIL-C-123)

SAN FERNANDO ELECTRIC COMPANY -- (SAN FERNANDO, CALIFORNIA)

THE NEXT FOUR (4) VIEWGRAPHS SHOW CLASS "S", JANS QUALIFICATION, DELIVERY, AND COST STATUS FOR MICROCIRCUITS, TRANSISTORS, DIODES AND CERAMIC CAPACITORS. THERE ARE OTHER TYPES OF PASSIVE DEVICES FOR WHICH CLASS "S" REQUIREMENT SPECIFICATIONS ARE IN PROCESS. SOME OF THESE ARE FOR MAGNETIC COMPONENTS, FILTERS, RESISTORS AND OTHER CAPACITORS AS WELL AS RELAYS AND THERMAL SWITCHES.

ALTHOUGH THE CLASS "S"/JANS MARKET IS SMALL COMPARED TO THE OVERALL DEVICE MARKET, THE NUMBER OF QUALIFIED CLASS "S" DEVICES IS GROWING; AND IN THE MICROCIRCUIT AREA THERE ARE NO CLASS "S" MICROPROCESSORS AND THEIR PERIPHERAL DEVICES, RAM's OR PROM's, AND NO JANS POWER SEMICONDUCTORS YET.

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SPACE & STRATEGIC AVIONICS DIVISION CLEARWATER FLORIDA

MICROCIRCUIT CLASS "S" QUALIFICATION/DELIVERY/COST/STATUS

PER QPL-38510-55 (14 MARCH 1983) AND DESC UPDATE 16 MAY 1983

QUALIFICATION

TOTAL DEVICES QUALIFIED = 107 DEVICE TYPES IN VARIOUS PACKAGES (FP, DIP, CAN)
QPL PART 1 QUALIFIED = 48 DEVICE TYPES
QPL PART 2 QUALIFIED = 59 DEVICE TYPES

LINEAR DEVICES = 3 TYPES ALL PART 2

DIGITAL DEVICES

TTL DEVICES	= 10 TYPES	-- 5 PART 1, 5 PART 2
LOW POWER SCHOTTKY	= 64 TYPES	-- 34 PART 1, 30 PART 2
SCHOTTKY	= 16 TYPES	-- 7 PART 1, 9 PART 2
CMOS	= 14 TYPES	-- 2 PART 1, 12 PART 2

DELIVERY -- OFF-THE-SHELF FOR SOME PART 1 DEVICES TO 42 WEEKS.

COST FACTOR -- APPROXIMATELY 10 TO 1 COMPARED TO JAN CLASS "B" DEVICES.

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SPACE & STRATEGIC AVIONICS DIVISION

TRANSISTORS

MIL-S-19500 JANS STATUS

QUALIFICATION

DEVICE TYPE	MIL-S-19500/SHEET	STATUS
JANS 2N2219AL	251	QUALED NOW
JANS 2N2222A	255	QUALED NOW
JANS 2N2369A	317	QUALED NOW
JANS 2N2905AL	290	QUALED NOW
JANS 2N2907A	291	QUALED NOW
JANS 2N918	301	QUALED NOW
JANS 2N2920	355	THIRD QUARTER, 1983
JANS 2N3810	336	THIRD QUARTER, 1983
JANS 2N3019	391	T.B.D.
JANS 2N3501	366	FIRST QUARTER, 1984
JANS 2N3700	391	FIRST QUARTER, 1984
JANS 2N4261	511	T.B.D.
JANS 2N3763	396	T.B.D.

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SPACE & STRATEGIC AVIONICS DIVISION

TRANSISTORS

MIL-S-19500 JANS STATUS

(CONTINUED)

DELIVERY -- QUALIFIED JANS DEVICES ARE OFF THE SHELF -- 36 TO 40 WEEKS IF NOT QUALIFIED YET.

COST FACTOR -- APPROXIMATELY 10 TO 1 COMPARED TO JANTXV.

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SPACE & STRATEGIC AVIONICS DIVISION

DIODES

MIL-S-19500 JANS STATUS

QUALIFICATION

MIL-S-19500 SLASH NUMBER	DEVICE TYPE	ESTIMATED QUAL. COMPLETION
116 (SWITCHING)	JANS 1N4148-1	JULY, 1983
117 (REGULATOR) 11V THROUGH 33V	JANS 1N962B-1 THROUGH 1N973B-1	JULY, 1983
127 (REGULATOR) 6.8V THROUGH 12V	JANS 1N754A-1 THROUGH 1N759A-1	JULY, 1983
411 (3 AMP. FAST RECOVERY POWER RECTIFIER)	JANS 1N5415 THROUGH 1N5420	JULY, 1983
427 (1 AMP. POWER RECTIFIER)	JANS 1N5614, 16, 18, 20 AND 22	JULY, 1983
477 (1 AMP. FAST RECOVERY (25ns) RECTIFIER)	JANS 1N5802, 04, AND 06	JULY, 1983
516 (BIPOLAR TRANSIENT VOLTAGE SUPPRESSOR) 500 WATT	JANS 1N6102 THROUGH 1N6137	JULY, 1983

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SPACE & STRATEGIC AVIONICS DIVISION

DIODES

MIL-S-19500 JANS STATUS

(CONTINUED)

DELIVERY -- ESTIMATED 20 WEEKS.

COST FACTOR -- NOT YET DEFINED.

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SPACE & STRATEGIC AVIONICS DIVISION

PASSIVES

QUALIFICATION

CERAMIC CAPACITORS		ESTIMATED QUAL. COMPLETION
MIL-C-123	CHIPS	JULY, 1983
	RADIAL LEADS	SEPTEMBER, 1983
	AXIAL LEADS	DECEMBER, 1983

NOTE: MIL-C-123 CAPACITORS ARE NOT DIRECTLY INTERCHANGEABLE WITH MIL-C-39014 OR MIL-C-20 CAPACITORS. IN SOME CASES, THERE ARE VOLTAGE RATING AND SIZE DIFFERENCES

DELIVERY -- ESTIMATED 18 TO 22 WEEKS.

COST FACTOR -- NOT YET DEFINED.

AVAILABILITY OF PARTS FOR SPACE SYSTEMS/COSTS

B. Evans
TRW Systems

I OVERVIEW - The use of Class S on new and follow-on projects is a topic that is much discussed. Rather than another discussion I have taken the Class S approach and applied it to a role model spacecraft reviewing availability of part numbers, schedule considerations and cost considerations for various procurement options. In addition I will briefly address product life cycle versus military space qualification time, discuss a survey of potential Class S suppliers and close with a summary and recommendations.

- CLASS S COST AND SCHEDULE - A MUCH CUSSED AND DISCUSSED ITEM
- APPLYING CLASS S TO A ROLE MODEL S/C
  - AVAILABILITY OF NEEDED PART NUMBERS
  - SCHEDULE CONSIDERATIONS
  - COST CONSIDERATIONS VERSUS PROCUREMENT OPTIONS
- CLASS S QUALIFICATION TIME VERSUS NEW PRODUCT LIFE CYCLE
- FINDING MORE SUPPLIERS FOR CLASS S
- SUMMARY AND RECOMMENDATIONS

II APPLYING CLASS S TO A ROLE MODEL SPACECRAFT - The program approved IC list from a major communication spacecraft was used for the model. The spacecraft was designed in the 72, 73 time period. The digital logic is 5400, 54L and 54H. The QPL used was 38510-54, 9-20-82. The data shows that the available S level part types would not support the needs of this spacecraft. This drives the spacecraft builder into alternate procurement approaches.

- CLASS S AVAILABILITY OF NEED PART NUMBERS

	PART NUMBERS NEEDED	PART NUMBERS ON QPLI	PART NUMBERS ON QPLII
DIGITAL IC's	46	1	2
LINEAR IC's	13	—	2
TOTAL IC's	59	1	4

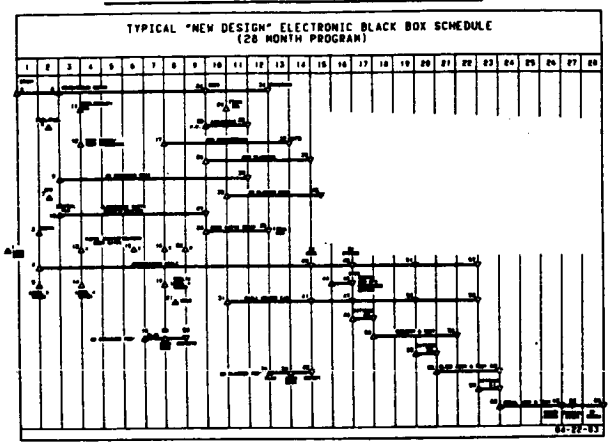
III SCHEDULES - This chart presents an integration of a Class S procurement schedule into a using project schedule. The Class S schedule is shown and the spacecraft builders in-house time necessary to place the P.O and get the parts into Kits. The schedule shows that under the best conditions the part could be used but if the part is a late identification or any of the schedules have slips the part will be late to Kits.

- FROM THE PROJECT CONTRACT AWARD DATE TO THE PART KITTING DATE IS 16 MONTHS.
- IN-HOUSE PART PROCESSING, WITHOUT UPGRADE, IS 16 WEEKS (4 MONTHS).
- QUOTED DELIVERY TIME FOR VARIOUS PARTS

	SUPPLIER TIME	IN-HOUSE	TOTAL
- JAN S	43-45 WKS [1]	14-21 WKS	57-66
- TRW PART NUMBER	33-35 THRU A 43-45 THRU B & C	16 WKS	49-51
- SUPPLIER CLASS S	33-35 THRU A 43-45 THRU B & C	16-21 WKS	49-56

1 SHIPMENT PRIOR TO COMPLETION OF B AND C NOT ALLOWED.

FRONT END SCHEDULE MANAGEMENT SYSTEM



IV COSTS - Competition is needed to reduce costs. The spacecraft builder is driven to buy the most cost - effective part meeting his contractual requirements. It is anticipated that we will see price reductions in the supplier S equivalent area due to competition.

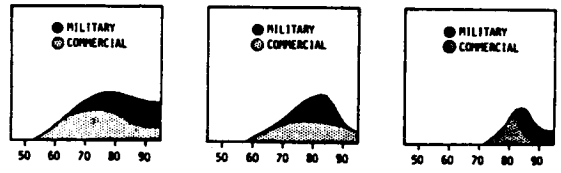
CLASS S COST COMPARISON

	SUPPLIER A	SUPPLIER B	SUPPLIER C
JAN S	49.75		
TRW PART NUMBER	47.00	35.22	
SUPPLIER CLASS S EQUIVALENT	52.00		62.00

EXAMPLE IS 54LS00

V PRODUCT LIFE CYCLE - When discussing with part suppliers the problems with procuring spacecraft parts several issues are commonly brought up. These are product life cycle and return on investment. In general a part types life cycle in the commercial world is becoming shorter due to new part development. As the part matures the need for military qualification arises and the part becomes fully qualified as the commercial volume drops significantly. To qualify at this point in time requires supplier investment in a part with reducing volume.

MILITARY PRODUCTS
PRODUCT LIFE CYCLE TRENDS



	DISCRETE	TTL	MOS
COMMERCIAL	20 YEARS	15 YEARS	5+ YEARS
MILITARY	30 YEARS	25+ YEARS	20+ YEARS

VI SUPPLIER INTEREST IN CLASS S - The suppliers are in business to make a profit. They are not unwilling to invest if a potential market exists, however if it is late in the product life cycle their enthusiasm will certainly be tempered.

SUPPLIER INTEREST IN CLASS S

- SUPPLIER A, D, E - QUALIFICATION COSTS CONSIDERED TOO HIGH FOR RETURN ON INVESTMENT.

  B - DOES NOT SEE SUFFICIENT BUYER/USER INTEREST TO WARRANT QUALIFICATION EXPENSE. FEELS THEIR 883S TO BE VIABLE ALTERNATIVE.

  C - QUALIFICATION TOO COSTLY. NOT ENOUGH RETURN ON SPACE BUSINESS. DEVELOPING S EQUIVALENT FLOW.

OVERALL - UNTIL MILITARY AND SPACE LEVEL BUYERS BECOME COMMITTED TO CLASS S MOST PART SUPPLIERS WILL NOT BEAR THE EXPENSE OF QUALIFICATION.

VII SUMMARY AND RECOMMENDATIONS - We must make Class S work. The part market is extremely difficult to deal in particularly for the spacecraft builder with his small quantities of parts. To make it work we must have many qualified suppliers with the part numbers qualified that we need. Class S must also be acceptable to the government customer without costly upgrading. When these things happen Class S will be the success that it can be.

- CLASS S HAS NOT YET ACHIEVED ITS GOAL OF MAKING HIGH QUALITY SPACE LEVEL PARTS AVAILABLE TO USERS.
- SEVERAL SUGGESTED ACTIONS INCLUDE

  a) LISTEN TO PART SUPPLIER CONCERNS ABOUT HIGH COST OF QUALIFICATION. IF THEY'RE REAL EXAMINE ALTERNATE APPROACHES, IF THEY'RE NOT SHOW THE SUPPLIERS THEY'RE NOT.

  b) DEVELOP A LIST BY PART NUMBER SHOWING THE USING SPACECRAFT AND QUANTITIES. DIRECT SUPPLIER EFFORTS TOWARD THE HIGHLY USED PARTS. CONSIDER SUBSIDIZING SUPPLIERS FOR QUALIFICATION OF NEEDED PARTS WITH MODERATE VOLUME.

  c) EXAMINE ALLOWING SHIPMENT OF JAN S PRIOR TO COMPLETION OF GROUP B.

Mission Assurance Conference
Electronic Parts Workshop

Parts Availability/Cost Subworkshop

Monitored Line Approach
A Solution to the Availability Problem

Warren Geller
Technical Director
Monitored Line Service Program

Lockheed Missiles & Space Co. Inc

INTRODUCTION

There has been much discussion regarding the definition of requirements for Space-Rated parts. All of these requirements are of little value if the availability of these parts is inadequate. Yet we do need parts, delivered on time, at a reasonable cost, with which to build our hardware.

Traditionally, we have looked to the Military specifications system to develop sources for the kinds of parts necessary for Military programs. At this point, we will show the Military system does not solve the availability problem for many classes of semiconductor parts.

In this discussion, we will try to look at the forest rather than at the trees. We will try to define in broad terms what we really need in Space-Rated parts and then look at alternative approaches that meet these broad goals rather than a specific list of requirements. By doing this, we will try to find means of relieving the Space-Rated part availability problem.

MONITORED LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROBLEM

OBJECTIVES OF SPACE-RATED PARTS PROGRAM

1) FAILURE-FREE LAUNCH AND ORBITAL OPERATIONS
2) FAILURE-FREE SYSTEM-LEVEL TESTING
3) NO IDENTIFIED LONG-LIFE FAILURE TENDENCIES DURING EQUIPMENT TESTING
4) TRACEABILITY RECORDS TO LIMIT THE SCOPE OF AFFECTED HARDWARE IF A PART FAILURE DOES OCCUR

OBJECTIVES OF SPACE-RATED PARTS PROGRAM

The fundamental objectives of a Space-Rated parts program are easily defined. We need failure-free performance in launch and orbital operations. We want as few failures as possible during the equipment build-up and test cycle—failures cost time and money. If we must have failures, we want them to occur early in the cycle where the cost impact is minimum.

In order to accomplish this, we need parts free from long-life failure tendencies.

In recognition that there will always be some failures, a successful program must maintain adequate records and make provisions to provide back-up data for each part and its related lot, so that the scope of a failure can be quickly identified and dealt with.

MONITORED LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROBLEM

SPACE-RATED PARTS CONCEPTS

"S" – PARTS WHOSE DESIGN, MATERIALS, MANUFACTURING OPERATIONS AND TEST SCHEDULES HAVE BEEN DEFINED AND CONTROLLED, TO ENSURE PARTS FREE OF DEFECTS WHICH COULD LIMIT THEIR PERFORMANCE IN SPACE SYSTEMS OPERATIONS

OTHER – WHERE THE ABOVE PARTS ARE NOT AVAILABLE – PARTS, (e.g., USUALLY WITH LIMITED MANUFACTURING AND TEST CONTROLS) THAT HAVE BEEN EXPOSED TO A RIGOROUS TEST REGIME DESIGNED TO REVEAL PART DEFECTS

SPACE-RATED PARTS CONCEPTS

For purposes of this discussion, it would appear to be adequate to define space parts in two categories.

1) Those that include in-process controls in addition to rigorious testing as "S" type.

2) Those that demonstrate their reliability primarily through test programs.

Although we would prefer to use "S" type parts, there are occasions where the availability problem forces us to use "tested parts". While there is considerable history that indicates "tested parts" are worthy of consideration, it is our belief that "S" parts will ultimately reward us with lower failure rates.

MONITORED LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROBLEM

SOURCES OF "S" PARTS

- MIL-M-38510 CLASS "S"
- MONITORED LINE SERVICE PROGRAM (MIL-STD-1546)
- USER – GENERATED SPECIFICATION PARTS (MIL-STD-1547)
- SUPPLIER "S" PARTS

SOURCES OF "S" PARTS

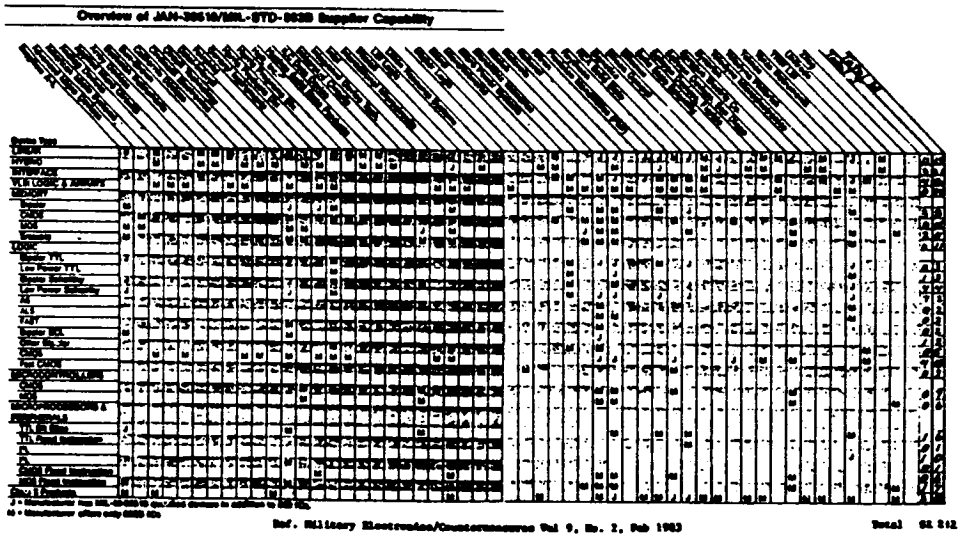
Of the listed sources, the MIL-M-38510 Class "S" (JANS) is preferred. Under this system, an extremely rigorous series of specifications define parts accepted in the field by the DCAS, a DoD agency. The specification requirements are established by another Military group with extensive inputs from suppliers and users. It is the DCAS responsibility to ensure that the supplier conforms to the requirements of the specification.

The Monitored Line Service Program is characterized by a single management and monitoring function controlling the entire system. Specifications and drawings are based closely to the requirements of JANS. Particular emphasis is given to supplier management (to be discussed in greater detail). This Program, with 11 years of maturity, has become a standardization program, having supplied parts to nearly 50 Aerospace users. The central management function has resulted in greater flexibility to support program needs for making new parts available.

User-generated specifications are necessary to relieve the total availability problem. They represent a best effort on the part of a single user to obtain needed parts. Low-volume usage of these specifications discourages suppliers. Some suppliers will not accept orders for user-generated specifications.

Supplier "S" parts utilize supplier management to control parts. While there is reluctance on the part of users to rely on supplier controls, there are some parts that are only available using this technique.

MONITORED LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROBLEM



AVAILABILITY OF MILITARY PARTS

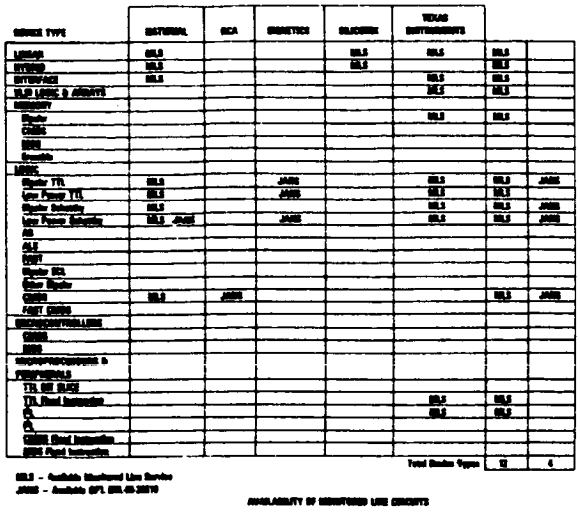
AVAILABILITY OF MILITARY PARTS

A review of this chart provides a measure of the availability problem.

The technology is advancing at an astounding rate. It is estimated that new parts will become obsolescent in as little as 5 years. We are experiencing a large influx of companies coming on line, many with proprietary products filling some space need. These small companies are reluctant to enter the MIL or "S" market.

As the chart shows, only a small fraction of the current technology is available as JAN and only a fraction of that is available as JANS.

MONITORED LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROBLEM



AVAILABILITY OF MONITORED LINE CIRCUITS

Even with the greater flexibility resulting from central management, the Monitored Line (as is shown on the chart) can currently supply parts from 12 of the 27 technologies listed. However, JANS only currently provides parts from 4 technologies.

It becomes obvious that Monitored Line rather than competing with JANS is really filling a vital need of supplementing JANS.

MONITORED LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROBLEM

OVERVIEW OF MONITORED LINE SERVICE PROGRAM

- CENTRAL (AF/LMSC) PROGRAM MANAGEMENT
- PROGRAM MATURITY (11 YEARS)
- LISTED AS SUBSTITUTE CLASS "S" MIL-STD-1546
- SUPPLIER MANAGEMENT
  RESIDENT TEAM ASSIGNED TO EACH SUPPLIER'S FACILITY
  SUPPLIER BASELINE MANAGEMENT
  IDENTIFIED PROCESS & TEST MONITORING POINTS
  MATERIAL REVIEW CAPABILITY FOR NON-CONFORMING PARTS

OVERVIEW OF MONITORED LINE SERVICE PROGRAM

The AF/LMSC managed Monitored Line Service Program, first established to support Lockheed Programs, currently makes the service available to non-Lockheed users through an AF Contract.

As a result of specification similarity to JANS, Monitored Line parts are listed as substitutes for JAN Class "S" in MIL-STD-1546, with using Program approval. A significant characteristic of the Program is the use of resident teams, a Reliability Engineer, a Quality Engineer, and one or more inspectors assigned to each facility, to manage the manufacturing, inspection and test of the parts. Many of the inspections are performed by the Locheed team as a check on supplier performance. This always includes 100% internal visual inspection performed by LMSC resident personnel. The supplier flow baseline, after review and approval by the resident personnel, is the basis for controlling the supplier operations.

Rigorous 100% inspections and tests have been incorporated into the program to preclude the need for costly lot sample testing. Justification for this is seen in the performance of these parts (to be discussed). As a result of having resident teams at the supplier's facility, real-time decision can be made and direct support to the user is available.

MONITORED LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROBLEM

OVERVIEW OF MONITORED LINE SERVICE PROGRAM (CONT'D)

- RIGOROUS MANAGED TEST PROGRAM
  100% SCREENING UNLESS DESTRUCTIVE
  TIGHT PARAMETER DRIFT REQUIREMENTS
  FAILURE ANALYSIS OF BURN-IN REJECTS
  REVIEW OF LOTS WITH SIGNIFICANT FAILURE RATES (2% PDA)
- REJECTION OF RELIABILITY HAZARD DEVICES
  (NOT DEFINED IN SPEC REQUIREMENTS)
- EXTENSIVE DATA PACKAGE SHIPPED WITH PARTS
- COORDINATED PROCUREMENT
- ABILITY TO ADD NEW PARTS IN RESPONSE TO PROGRAM NEEDS

OVERVIEW OF MONITORED LINE SERVICE PROGRAM (Cont'd)

Monitored Line resident personnel are striving constantly to identify non-conforming parts at the earliest step of the production cycle. This allows a maximum of time for the supplier to build a replacement lot if necessary. When delivery impact is anticipated, early detection of a problem allows the user to make a technical assessment of the discrepancy and decide if his application is affected by the non-conformance. When the Monitored Line Program Office finds that the non-conformance does not present a latent defect reliability hazard, the user is allowed to amend his purchase order and buy the non-conforming hardware. Non-conforming parts with interchangeability defects are marked so that they may be identified. When parts are identified having a defect that could present a reliability hazard, even though not rejectable to specification requirements, these parts are removed from the line with supplier and user concurrence.

Coordinated procurements have been performed for LMSC programs and subcontractors and are also available to non-Lockheed users.

MONITORED LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROBLEM

MLP PART FAILURES IN EQUIPMENT
ALL TEST LEVELS
ALL PROGRAMS

PART TYPE	QUANTITY RECEIVED	OXIDE FAULTS	OPEN METAL	CONDUCTIVE PARTICLES	OPEN BONDS	OTHER	TOTAL
Digital ICs	102,710	67	9	4	0	10	[illegible]
Linear ICs	51,054	5	4	0	0	7	25
Hybrid ICs	16,022	13	1	35	0	0	[illegible]
Large Scale ICs	200	0	0	0	0	0	0
Power Transistors	20,455	0	0	0	1	0	0
Field Effect Transistors	27,545	0	0	0	1	1	2
Signal Transistors	214,255	0	0	3	4	7	14
TOTAL	[illegible]	[illegible]	14	12	6	[illegible]	[illegible]

JUNE 1973 – MARCH 1983

MLP PART FAILURES IN EQUIPMENT JUNE 1973-MARCH 1983

One of the objectives of the Monitored Line Program has been to accumulate failure data with the interest of identifying assignable causes in order to eliminate them. Our success in accomplishing this objective can be observed with regard to two entries in the chart — 36 Hybrid IC Conductive Particle failures and 67 Digital Oxide Fault failures, accounting for nearly half of the failures.

The first problem was eliminated in 1976 by modifying the wire bonding and lid sealing processes, and maintaining those fixes. The second problem was more subtle since it involved flaws in the oxide under the metal where they could not be detected by visual inspection. After much analysis, we were able to develop an electrical test which provided failure precursor information. This test was incorporated into our specification in 1978.

It should be observed that through process control, we have not yet experienced a wire bond failure in any IC and have seen only 16 conductive particle failures other than the 36 discussed above.

The low failure rate shown here has been constantly decreasing as we eliminate problems and monitor to see that they remain eliminated.

MONITORED LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROBLEM

MLP PART FAILURES IN EQUIPMENT
ALL TEST LEVELS
ALL PROGRAMS

PART TYPE	QUANTITY RECEIVED	OXIDE FAULTS	BOND PLACEMENT SHORT	CONDUCTIVE PARTICLES	OPEN BONDS	OTHER	TOTAL
Digital ICs	63,302	2	0	0	0	4	6
Linear ICs	16,037	1	0	1	0	3	5
Hybrid ICs	2,002	0	0	0	0	3	3
Large Scale ICs	200	0	0	0	0	0	0
Power Transistors	8,765	0	0	0	0	1	1
Field Effect Transistors	4,744	0	0	0	0	0	0
Signal Transistors	88,102	0	2	1	2	1	6
TOTAL	145,013	3	2	2	2	12	21

JUNE 1980 THRU MARCH 1983

MLP PART FAILURES IN EQUIPMENT — JUNE 1980 — MARCH 1983

This matrix clearly shows that through Program maturity, and a constant striving to identify and eliminate failure mechanisms, a continuting lower failure rate can be achieved.

Even more significant, there are no concentrations of failures that can be readily associated with assignable causes.

MONITORED LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROGRAM

PERFORMANCE IN EQUIPMENT (10 YEARS OF DELIVERIES)

- APPROXIMATELY 5000 LOTS DELIVERED
- ONE KNOWN RETROFIT FOR LOT RELATED PROBLEM
  LOT PASSED SEM SAMPLE (METHOD 2018) BUT HAD BAD METAL COVERAGE
- MOST FAILURES OCCUR EARLY IN TEST PHASE
  INITIAL EXPOSURE TO NEW ENVIRONMENT
- SIGNIFICANT PROGRAM COST REDUCTION BECAUSE OF FEW TEST FAILURES AND THOSE, OCCURRING EARLY IN THE TEST CYCLE
- TWO REPORTED SYSTEM TEST LEVEL FAILURES
  CONCLUDED TO BE NON-LOT RELATED
- NO REPORTED OPERATIONAL FAILURES
  OPERATIONAL LIFE AS LONG AS 6 YEARS

PERFORMANCE IN EQUIPMENT (10 YEARS OF DELIVERIES)

Several conclusions can be drawn from this data justifying the Monitored Line approach.

1) It is possible, through a managed program, to essentially eliminate part failures, even on complex semiconductor devices.

2) Rigorous process control and maximum use of 100% screening can produce parts sufficiently failure-free and homogenious to preclude the need for costly and time consuming lot sample testing.

3) Utilizing the supplier baseline as the basis for supplier management is a viable approach.

MONITOR LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROBLEM

CONCLUSIONS

- RIGOROUS REQUIREMENTS FOR SPACE-RATED PARTS TEND TO SEVERELY LIMIT THEIR AVAILABILITY
- MIL-M-38510-CLASS "S" SOLVES A SMALL PORTION OF THE AVAILABILITY PROBLEM
- MANY SUPPLIER "S" QUALITY PARTS ARE AVAILABLE BUT USER CONFIDENCE IS LACKING
- MONITORED LINE, WITH DEMONSTRATED PERFORMANCE, SUPPLEMENTS MIL-M-38510 CLASS "S", TO HELP SOLVE THE AVAILABILITY PROBLEM

CONCLUSIONS

The lack of availability of space-rated parts poses a serious problem to the users.

We want the best parts, but are forced on occasions to use parts that are not all that we want, but appear to be adequate for the application.

Analysis of Monitored Line performance data should be sufficient to convince users that this is a viable supplemental approach to JANS, worthy of serious consideration for helping relieve the "S" part availability problem.

This approach is in keeping with the recent military re-emphasis of the OEM's responsibility for the reliability/quality of the parts used in his equipment.

1983 MISSION ASSURANCE CONFERENCE

ELECTRONIC PARTS WORKSHOP
PARTS AVAILABILITY/COST SUBWORKSHOP

MONITORED LINE APPROACH –
A SOLUTION TO THE AVAILABILITY PROBLEM

UNDERSTANDING SPACE-RATED PARTS

SOURCES OF "S" PARTS

AVAILABILITY OF MILITARY PARTS

MONITORED LINE AS A NEEDED MIL SUPPLEMENT

JUNE 1983

WARREN GELLER,
TECHNICAL DIRECTOR
MONITORED LINE SERVICE PROGRAM

SUNNYVALE, CA
(408) 742-6014

Lockheed Missiles & Space Company, Inc.

MONITORED LINE APPROACH – A SOLUTION TO THE AVAILABILITY PROBLEM

SOURCES OF "S" PARTS

- MIL-M-38510 CLASS "S"
- MONITORED LINE SERVICE PROGRAM (MIL-STD-1546)
- USER – GENERATED SPECIFICATION PARTS (MIL-STD-1547)
- SUPPLIER "S" PARTS

Monitored Line Service Program

Lockheed Missiles & Space Company, Inc.

MONITORED LINE APPROACH – A SOLUTION TO THE AVAILABILITY PROBLEM

OBJECTIVES OF SPACE-RATED PARTS PROGRAM

1) FAILURE-FREE LAUNCH AND ORBITAL OPERATIONS

2) FAILURE-FREE SYSTEM-LEVEL TESTING

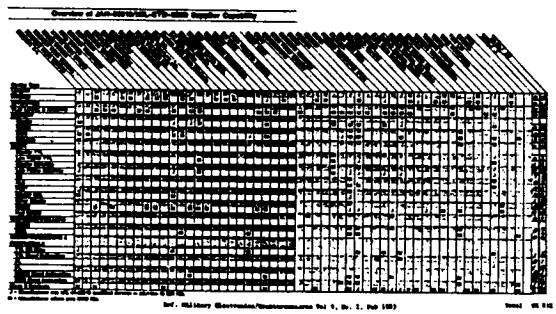
3) NO IDENTIFIED LONG-LIFE FAILURE TENDENCIES DURING EQUIPMENT TESTING

4) TRACEABILITY RECORDS TO LIMIT THE SCOPE OF AFFECTED HARDWARE IF A PART FAILURE DOES OCCUR

Monitored Line Service Program

Lockheed Missiles & Space Company, Inc.

MONITORED LINE APPROACH – A SOLUTION TO THE AVAILABILITY PROBLEM



AVAILABILITY OF MILITARY PARTS

Monitored Line Service Program

Lockheed Missiles & Space Company, Inc.

MONITORED LINE APPROACH – A SOLUTION TO THE AVAILABILITY PROBLEM

SPACE-RATED PARTS CONCEPTS

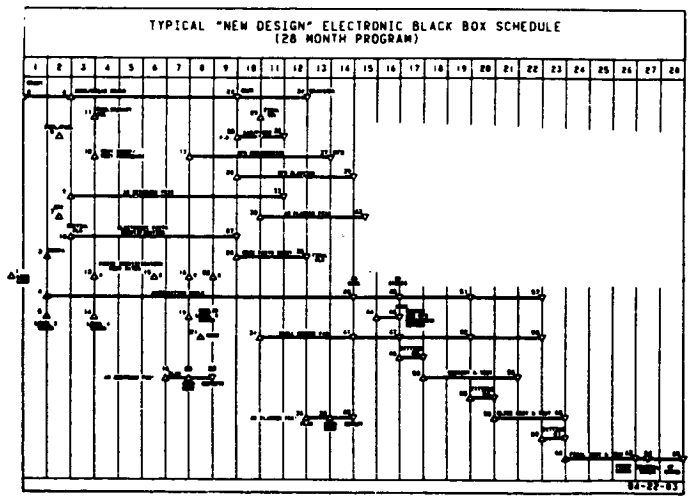
"S" – PARTS WHOSE DESIGN, MATERIALS, MANUFACTURING OPERATIONS AND TEST SCHEDULES HAVE BEEN DEFINED AND CONTROLLED, TO ENSURE PARTS FREE OF DEFECTS WHICH COULD LIMIT THEIR PERFORMANCE IN SPACE SYSTEMS OPERATIONS

OTHER – WHERE THE ABOVE PARTS ARE NOT AVAILABLE – PARTS, e.g., USUALLY WITH LIMITED MANUFACTURING CONTROLS THAT HAVE BEEN EXPOSED TO A RIGOROUS TEST REGIME DESIGNED TO REVEAL PART DEFECTS

Monitored Line Service Program

Lockheed Missiles & Space Company, Inc.

FRONT END SCHEDULE MANAGEMENT SYSTEM



MONITORED LINE APPROACH – A SOLUTION TO THE AVAILABILITY PROBLEM

OVERVIEW OF MONITORED LINE SERVICE PROGRAM

- CENTRAL (AFLMSC) PROGRAM MANAGEMENT
- PROGRAM MATURITY (11 YEARS)
- LISTED AS SUBSTITUTE CLASS "S" MIL-STD-1546
- SUPPLIER MANAGEMENT
  - RESIDENT TEAM ASSIGNED TO EACH SUPPLIER'S FACILITY
  - SUPPLIER BASELINE MANAGEMENT
  - IDENTIFIED PROCESS & TEST MONITORING POINTS
  - MATERIAL REVIEW CAPABILITY FOR NON-CONFORMING PARTS

MONITORED LINE APPROACH – A SOLUTION TO THE AVAILABILITY PROBLEM

MLP PART FAILURES IN EQUIPMENT
ALL TEST LEVELS
ALL PROGRAMS

PART TYPE	QUANTITY RECEIVED	OXIDE FAULTS	BOND PLACEMENT SHORT	CONDUCTIVE PARTICLES	OPEN BONDS	OTHER	TOTAL
Digital ICs	93,302	2	0	0	0	4	6
Linear ICs	16,037	1	0	1	0	3	5
Hybrid ICs	2,802	0	0	0	0	3	3
Large Scale ICs	259	0	0	0	0	0	0
Power Transistors	6,765	0	0	0	0	1	1
Field Effect Transistors	4,344	0	0	0	0	0	0
Bipolar Transistors	88,102	0	2	1	2	1	6
TOTAL	165,013	3	2	2	2	12	21

JUNE 1980 THRU MARCH 1982

MONITORED LINE APPROACH – A SOLUTION TO THE AVAILABILITY PROBLEM

OVERVIEW OF MONITORED LINE SERVICE PROGRAM (CONT'D)

- RIGOROUS MANAGED TEST PROGRAM
  - 100% SCREENING UNLESS DESTRUCTIVE
  - TIGHT PARAMETER DRIFT REQUIREMENTS
  - FAILURE ANALYSIS OF BURN-IN REJECTS
  - REVIEW OF LOTS WITH SIGNIFICANT FAILURE RATES (2% PDA)
- REJECTION OF RELIABILITY HAZARD DEVICES (NOT DEFINED IN SPEC REQUIREMENTS)
- EXTENSIVE DATA PACKAGE SHIPPED WITH PARTS
- COORDINATED PROCUREMENT
- ABILITY TO ADD NEW PARTS IN RESPONSE TO PROGRAM NEEDS

MONITORED LINE APPROACH – A SOLUTION TO THE AVAILABILITY PROBLEM

PERFORMANCE IN EQUIPMENT (10 YEARS OF DELIVERIES)

- APPROXIMATELY 5000 LOTS DELIVERED
- ONE KNOWN RETROFIT FOR LOT RELATED PROBLEM
  - LOT PASSED 2010 SAMPLE (METHOD 2010) BUT HAD BAD METAL COVERAGE
- MOST FAILURES OCCUR EARLY IN TEST PHASE
  - INITIAL EXPOSURE TO NEW ENVIRONMENT
- SIGNIFICANT PROGRAM COST REDUCTION BECAUSE OF FEW TEST FAILURES AND THOSE, OCCURRING EARLY IN THE TEST CYCLE
- TWO REPORTED SYSTEM TEST LEVEL FAILURES
  - CONCLUDED TO BE NON-LOT RELATED
- NO REPORTED OPERATIONAL FAILURES
  - OPERATIONAL LIFE AS LONG AS 8 YEARS

MONITORED LINE APPROACH – A SOLUTION TO THE AVAILABILITY PROBLEM

MLP PART FAILURES IN EQUIPMENT
ALL TEST LEVELS
ALL PROGRAMS

PART TYPE	QUANTITY RECEIVED	OXIDE FAULTS	OPEN METAL	CONDUCTIVE PARTICLES	OPEN BONDS	OTHER	TOTAL
Digital ICs	102,210	57	0	4	0	10	69
Linear ICs	51,454	5	4	0	0	7	26
Hybrid ICs	10,022	13	1	26	0	0	50
Large Scale ICs	259	0	0	0	0	0	0
Power Transistors	26,455	0	0	0	0	0	0
Field Effect Transistors	27,645	0	0	0	1	1	2
Bipolar Transistors	214,520	0	0	3	4	7	14
TOTAL	432,622	55	14	32	5	50	200

JUNE 1973 – MARCH 1982

MONITORED LINE APPROACH – A SOLUTION TO THE AVAILABILITY PROBLEM

CONCLUSIONS

- RIGOROUS REQUIREMENTS FOR SPACE RATED PARTS TEND TO SEVERLY LIMIT THEIR AVAILABILITY
- MIL-M-38510-CLASS "S" SOLVES A SMALL PORTION OF THE AVAILABILITY PROBLEM
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MICROCIRCUIT QUALIFICATION

By

Robert E. Depp

Defense Electronics Supply Center

I would like to discuss with you our Microcircuit Qualification Program at the Defense Electronics Supply Center, Dayton, OH. We have approximate 200 personnel dedicated to the Engineering Standardization Program. These personnel are charged with four (4) major functions:

1. We are responsible for managing the Department of Defense (DoD) Standarization Program for electronic parts.
2. We develop as agent for the military services specifications and standards.
3. We administer the qualification program for most electronic parts.
4. We provide parts control recommendations for DoD systems to the system program managers.

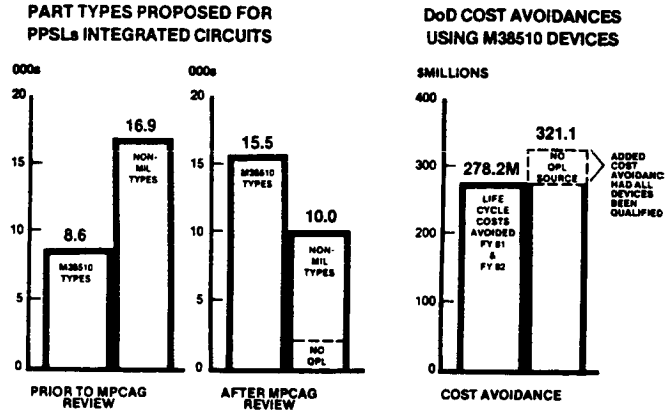
In support of the preparation of specifications and standards we do approximately 1200 projects per year; this equates to 95% of all electronics parts projects conducted within the DoD. We are also responsible for 150 Qualified Products Lists (QPLs).

The value of parts standardization is rather straightforward and we continuously compute the cost avoidance of the parts standardization action program using the following criteria:

1. Value of the design documentation cost avoidance (one time).
   PLUS
2. Value of testing cost avoidance (one time).
   PLUS
3. Value of supply management cost avoidance.
   PLUS
4. Value of maintenance actions cost avoidance.

The past year the cost avoidance was sufficient to yield an 88.1 ratio of benefit to cost. The Mililtary Parts Control Advisory Program (MPCAP) is a system where our engineers meet with the program manager of the system, the prime contractors, all subcontractors and the military reliability engineers and determine the level of parts to be used in the system design. The military specification preparation is a vital element in the parts control program if the specification is timely and a qualified source is obtained.

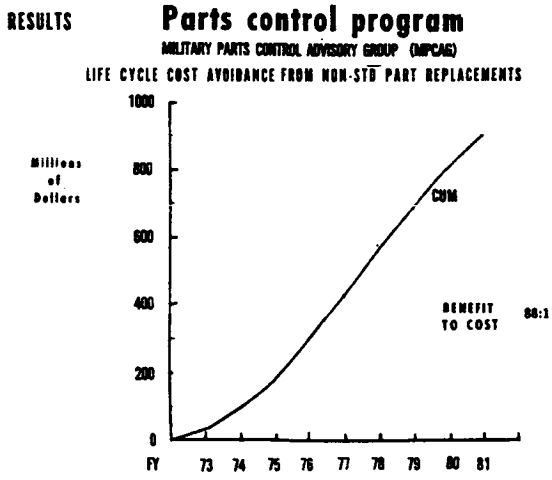
A list of some of the typical systems for which we have provided parts recommendation is contained below:



ALL DATA FOR FY 1981 AND FY 1982

MAJOR SYTEMS USING PARTS CONTROL PROGRAMS

AH-64 (AAH)	E-4B	MLRS
AEGIS SHIPS	F-15	MRASM
ALCM	F-15 msip	MX
AMRAAM	F-16	NGT (T46A)
AN/SPS-48 RADAR	F-16 MSIP	PATRIOT
AN/UYK-43,44	F-18	PAVE TACK
ASPJ	GLCM	PERSHING II
AV8-B	GPS	PLSS
AWACS	JTIDS	ROLAND
BISS	LAMPS	SEEK IGLOO
BLACKHAWK	LANTIRN (HUD), (POD)	SHUTTLE IUS
B-1B	LASER HELLFIRE	SLCM
B-52 OAS	M-1 TANK	SOTAS
ELF	MAVERICK	TADS/PNVS
EF-111A	MINUTEMAN III	



For the fiscal years 81 and 82, figure 1 indicates our before and after results for MPCAG microcircuit recommendations. The Preferred Parts Selection Lists (PPSLs) are a shopping list that the design engineer may use in the design of the system. After our Military Parts Control Advisory Group (MPCAG) has reviewed the parts to be used in the design of a system we use the previously mentioned cost avoidance criteria to determine cost avoidance. The cost avoidance from the MPCAG program for the past two fiscal years was 278 million dollars for microcircuits.

Figure 2 shows our cost avoidance for the past 10 years. The MPCAG Program started in 1973 and the cost avoidance is approaching one billion dollars.

The problems associated with MIL-M-38510 program take many forms. We have been able to help reduce the nonavailability of a fully qualified source by using DESC drawings for the interim period between issuance of the M38510 specification and when a manufacturer obtains a QPL listing. Many of the problems are caused by a lack of attention to the details of initial drafts of specifications by manufacturers. Manufacturers have supplied drafts to be used in the coordination process and later been unable to qualify to their own draft. Another major problem is a lack of high-level management commitment to the JAN program by the manufacturers. It appears to us they do testing when it can be fitted in between other work or there is nothing else to do of higher priority. There is also a lag between the development of state-of-the-art specifications and the purchase of parts for production use. Thus problems are created when orders do not rapidly follow the dating of a specification.

The MIL-M-38510 program has a lengthy qualification cycle and in most cases it exceeds a year. This is frequently brought about by manufacturers not being prepared for our audits. We feel that a self-audit requirement, imposed on a periodic basis, would be one solution to that problem. We also find that in many cases line certification does not lead to qualification of devices. This, we believe, is caused by some manufacturers primarily wanting a DESC certified line to sell "883 equivalent" devices. To solve this problem, we propose that milestone and schedules be developed and a firm commitment from a responsible company management official to indicate that they intend to follow up on qualifying JAN devices after a DESC certification. The Program management also must share some of the blame since they do not aggressively use JAN M38510 devices in military systems. We are getting increasing numbers of complaints from manufacturers that "883 equivalents" are being used while JAN MIL-M-38510 devices set in Manufacturers' inventory. It is hard to encourage manufacturers to pursue an aggressive qualification program with this situation existing.

Figure 3 below contains features that show the best and average time to complete certain phases of the qualification process we are currently attempting to streamline that process.

MIL SPEC	GENERIC uP	LERT	ATT	UPL II	UPL I	REMARKS
48001-03	280	YES	YES	YES		UPL-I IN PROGRESS
48101-02						
48201-02	NO INTEREST					
48301-02	EXPRESSED BY					
48401-02	MANUFACTURER					
49001-02	8048, 8035					
52001-04	20000	YES	YES	YES(2)		UPL-I FOR U2/U4 IN PROGRESS
53001	8086	YES	YES	YES		UPL-I PENDING (JAN 83)
TOTAL	uP 16			TOTAL PERIPHERALS		26
	UPL II 10			UPL II		0
	UPL I 1 (6 IN PROCESS)			UPL I		0

MIL-M-38510
LENGTHY QUALIFICATION CYCLE

	BEST	AVERAGE
MANUFACTURER REQUEST FOR ATT	2 DAYS	44 DAYS
ATT APPROVAL TO PART I REPORT	21 DAYS	11.3 MONTHS
QUALIFICATION REPORT INITIAL REVIEW	2 DAYS	16.5 DAYS
COMPLETION OF PART I QUAL	0 DAYS	1.6 MONTHS

MIL SPEC	GENERIC uP	LERT	ATT	UPL II	UPL I	REMARKS
46001	2901	YES	YES	YES		UPL IN PROGRESS
46101-06	NO INTEREST					
46201	EXPRESSED BY					
	MANUFACTURER					
46301	9900	YES	YES	YES		UPL DROPPED
46401	9809	YES	YES	YES		UPL I IN PROGRESS
47001	1802	NO				AUDITED - LOST INTEREST
47101	NO INTEREST					
47201-02	EXPRESSED BY					
47301	MANUFACTURER					
47501						
47601-02						

Recently, we have encountered a number of problems during our DSCC audits. They have consisted of incomplete or inaccurate record keeping or deviation from specification requirements. Consequently, we are unsure of the quality/reliability of the devices produced at that facility which usually results in removal from the QPL. We have also encountered numerous cases of where the line procedures were not accurately documented or kept up to date. Finally, we encountered outright alteration of records. Some were obliterated , others entailed the use of white-out. The above problems resulted in removal from the QPL and a series of audits until the problems were corrected.

Another important issue is that qualifications are lagging by 3+ on the specifications that are available for sources. This directly relates to the microprocessor and peripheral availability question. This lag of qualification and the rapid moving of the technology causes a number of Diminishing Manufacturer Sources (DMS). DMS is one of our major problems at DESC and a number of the cases are in microcircuits.

We have had some success in qualification of the microprocessors but NO success in the qualification of the associated peripheral devices. No peripherals have ever been qualified nor have any manufacturers expressed an interest in qualifying.
Figures 4-6 show the problem encountered on a type by type basis:

MIL SPEC	GENERIC uP	LERT	ATT	UPL II	UPL I	REMARKS
40001	6800	YES	YES	YES	NO	DROPPED COUNDN'T AGREE ON ELECTRICAL TABLE III CHANGES WITH DSCC
40101	NO INTEREST					
40201	EXPRESSED BY					
40301	MANUFACTURER					
42001	8080A	YES	YES	YES	YES	NO'S COMPLAINING ABOUT NO BUYERS
42101	NO INTEREST					
42201	EXPRESSED BY					
42301	MANUFACTURER					

We recommend that the DOD continue to cover microprocessors with military specifications and actively pursue qualification. However, for microprocessor peripheral, we recommend that no MIL-M-38510 specifications be prepared and the peripheral should be covered with a DESC drawing. To be eligible for a DESC drawing a manufacturer must be qualified to a basic microprocessor. MIL-M-38510 specifications will be issued to some type of family qualification.

MICROCIRCUIT QUALIFICATION

by

ROBERT E. DEPP
DEFENSE ELECTRONICS SUPPLY CENTER
DAYTON, OHIO

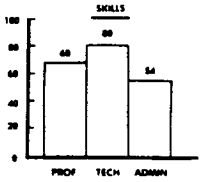
WHO IS DESC ENGINEERING STANDARDIZATION AND WHAT DO WE DO

- WHAT IS OUR OBJECTIVE
- HOW DOES PARTS CONTROL FIT IN
- QPL PROGRAM WITH FOCUS ON MIL-M-38510
- FUTURE INITIATIVES
- SUMMARY

BACKGROUND

WHAT WE DO

- DoD STANDARDIZATION MANAGER FOR ELECTRONIC PARTS
- MILITARY DEPARTMENT AGENT FOR MIL SPECS AND STDS
- ADMINISTERS QUALIFICATION PROGRAMS QPLs
- PROVIDE PARTS CONTROL SUPPORT FOR DoD SYSTEMS PROGRAMS MANAGERS



BACKGROUND

THE VALUE OF PARTS STANDARDIZATION

Value of design documentation cost avoidance (one time)

plus

Value of testing cost avoidance (one time)

plus

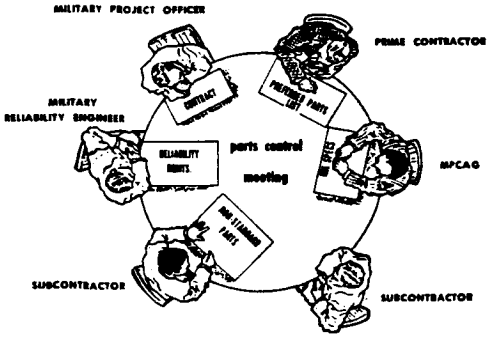
Value of supply management cost avoidance

plus

Value of maintenance cost avoidance

FUNCTIONS

PARTS CONTROL PROGRAM



MAJOR SYTEMS USING PARTS CONTROL PROGRAM

AH-64 (AAH)	E-4B	MLRS
AEGIS SHIPS	F-15	MRASM
ALCM	F-15 msip	MX
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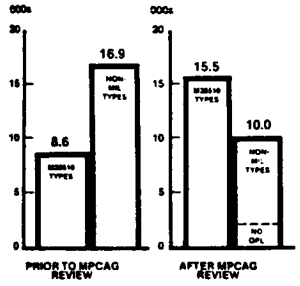
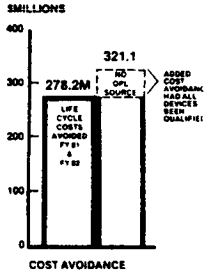
AN/UYK-43,44	F-18	PAVE TACK
ASPJ	GLCM	PERSHING II
AV8-B	GPS	PLSS
AWACS	JTIDS	ROLAND
BISS	LAMPS	SEEK IGLOO
BLACKHAWK	LANTIRN (HUD), (POD)	SHUTTLE IUS
B-1B	LASER HELLFIRE	SLCM
B-52 OAS	M-1 TANK	SOTAS
BLF	MAVERICK	TADS/PNVS
EF-111A	MINUTEMAN III	

PART TYPES PROPOSED FOR PPSLs INTEGRATED CIRCUITS



DoD COST AVOIDANCES USING M38510 DEVICES



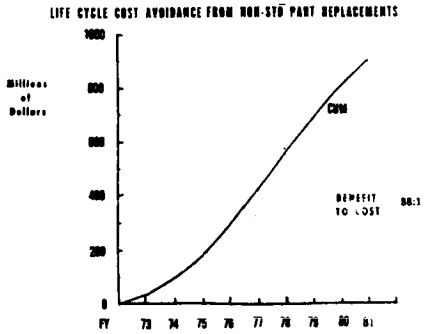
ALL DATA FOR FY 1981 AND FY 1982

RESULTS

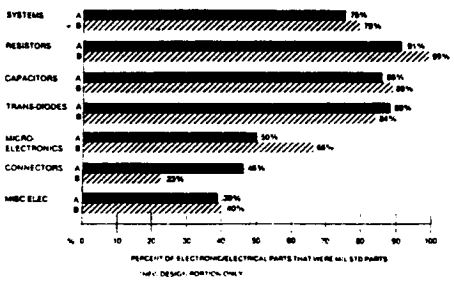
Parts control program

MILITARY PARTS CONTROL ADVISORY GROUP (MPCAG)

LIFE CYCLE COST AVOIDANCE FROM NON-STD PART REPLACEMENTS



STANDARD ELECTRONICS PARTS USED IN AIRCRAFT SYSTEMS



MIL-M-38510
LENGTHY QUALIFICATION CYCLE

PROBLEM
- MANUFACTURERS NOT SUFFICIENTLY PREPARED

SOLUTION
- COMPLETE SELF-AUDITS

PROBLEM
- LINE CERTIFICATIONS DO NOT RESULT IN QUAL PRODUCTS

SOLUTION
- MILESTONE SCHEDULES — COMMITMENT

MIL-M-38510
SPECIFICATION REQUIREMENTS PROBLEMS

- DESC DRAWINGS
- DETAILED ATTENTION NEEDED TO DRAFTS
- IMPLEMENTATION OF REQUIREMENT LAG
- NEED BETTER PLANNING AND COMMITMENT

MIL-M-38510
LENGTHY QUALIFICATION CYCLE

	BEST	AVERAGE
MANUFACTURER REQUEST FOR ATT	2 DAYS	44 DAYS
ATT APPROVAL TO PART I REPORT	21 DAYS	11.3 MONTHS
QUALIFICATION REPORT INITIAL REVIEW	2 DAYS	16.5 DAYS
COMPLETION OF PART I QUAL	0 DAYS	1.8 MONTHS

QUALIFICATION
PROBLEMS

ATT CANCELLED (1982)	-	191
ATT OVER 6 MONTHS OLD	-	317 (77%)
ATT OVER 12 MONTHS OLD	-	227 (55%)
ATT ISSUED (JAN 83)	-	412

MIL-M-38510
AUDIT PROBLEMS

- INCOMPLETE & INACCURATE RECORDS
- FAILURE TO KEEP LINE PROCEDURES UP TO DATE
- ALTERATIONS OF RECORDS
  - OBLITERATION
  - WHITE-OUTS

MIL-M-38510
OTHER ISSUES

- QUALIFICATIONS LAGGING — 54%
- DMS

MIL SPEC	GENERIC UP	CERT	ATT	QPL II	QPL I	REMARKS
48001-03	280	YES	YES	YES		QPL-I IN PROCESS
48101-02						
48201-02	NO INTEREST					
48301-02	EXPRESSED BY					
48401-02	MANUFACTURER					
49001-02	8048, 8015					
52001-04	28000	YES	YES	YES(2)		QPL-I FOR 02/04 IN PROCESS
53001	8000	YES	YES	YES		QPL-I PENDING (JUN 83)
TOTAL	UP 16			TOTAL PERIPHERALS		20
	QPL II 10			QPL II		0
	QPL I 1 (6 IN PROCESS)			QPL I		0

RECOMMENDATIONS

CONTINUE TO COVER MICROPROCESSORS WITH MILITARY SPECIFICATION AND ACTIVELY PURSUE QUALIFICATION.

MICROPROCESSING PERIPHERAL:

NO MIL-M-38510 SPECIFICATION WILL BE ISSUED ONLY DESC DRAWINGS. THE DESC DRAWINGS ELIGIBILITY WILL BE QUALIFICATION OF MICROPROCESSORS.

MIL-M-38510 SPECIFICATION ISSUED WILL BE SOME TYPE OF FAMILY QUALIFICATION APPROVAL.

FUTURE INITIATIVES

- STREAMLINE QPL PROCESS
- REDUCE AUDIT BURDEN
- DCAS TRAINING
- HYBRID CERTIFICATION
- REAL TIME PARTS CONTROL
- TESTING

SUMMARY
I NEED YOUR HELP

- COMMITMENT
- SELF-AUDIT
- INDUSTRY/GOVERNMENT PARTNERSHIP
- QUALITY
- MICROPROCESSORS AND PERIPHERALS

"Issues/Answers: VLSI Design, Reliability, Quality, Qualification, Logistics Supportability"

by

Edmund J. Westcott

Technical Director

Reliability & Compatibility Division

Rome Air Development Center

Griffiss Air Force Base, N. Y.

The Speaker will deal with issues and provide answers on how the Air Force means to deal with the control of VLSI device design to control the reliability and quality of new technology microelectronic devices. He will discuss the techniques being proposed by the Air Force for the Qualification of these small scale geometry devices. He will also highlight the dilemma posed by the emergence of custom design and its impact on Logistics Supportability of Military Systems. A summary of the discussion follows:

The Shrinking Geometry of Microelectronic Devices is providing a continual challenge to designers, manufacturers and the using community. The advent of VLSI is having a significant impact on the design of Systems/Equipments (Vugraphs 1 and 2) as well as the approach to the design of the microelectronic devices (Vugraph 3). The amount of logic that can be optimally packed into a chip necessitates the use of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) techniques. Each CAD/CAM approach to the design/manufacture of microcircuits has unique desing rules which must be followed by the designer to ensure adequacy of the design. The electrical characterization of VLSI devices has become so time consuming that it has become impractical to continue to develop test routines using manual and semi-automated techniques (Vugraph 4).

The reduction in the geometry in on-chip device feature size and aluminum line spacing dictates the use of highly complex processes and controls to ensure registration and separation between adjacent lines (Vugraph 5). Assembly operations are being automated to remove the man from the loop to ensure repeatability of process and mechanical-visual inspections are no longer feasible since the degree of magnification and inspection time are inordinately large. Testing requires the use of highly complex and very costly test equipment and there now exists a dilemma due to the increasing speeds and input-output pin interface compatibility with current test equipment (Vugraph 6). One method of dealing with this dilemma is the use of on-chip testability (Vugraph 7). One of the many techniques for achieving reduction of test time while accessing many of the internal device nodes is the use of the "Set-Scan" testability technique (Vugraph 8). This technique provides for software directed interconnection of sequential logic into combinatorial patterns.

The advent of VLSI has provided the opportunity for a "free-lunch" in potential for significant reliability improvement at the chip level (Vugraph 9). As can be seen (Vugraph 10) there is an improvement in realiability that is realized as a reduction in the relative failure rate per function. However, the packaging and interfacing of a large number of input-output pins as well as the need to transfer large power demands and carry away heat is provided a great challenge to both device designers and equipment designers and the potential gain in system reliability might not be fully realized in poorly conceived device and system designs (Vugraph 11). The reduction in feature size and line separation when coupled with the reduced operating logic levels has raised considerable concern over device susceptatility to Electromagnetic Interference (Vugraph 12). The D.C. and A.C. noise levels of microelectronic has been poorly characterized (Vugraph 13) in the past and now requires immediate attention to ensure the reliable operation of VLSI devices. Another area receiving considerable attention is the Propensity for Electromigration fine line geometry devices (Vugraph 14). The characteristics of internal device conductors have been heretofore controlled by Military Standards (Vugraph 15). However recent observations of electromigration failures have led us to believe that the past criteria is not adequate for complex VLSI devices and ndw criteria has been developed (Vugraph 16). RADC is already planning to sponsor a research and development program to develop a Qualification Test to replace the analytical method prescribed in the Military Standard.

VLSI design has created several Quality Issues which must be addressed (Vugraph 17).

One of the most significant impacts of VLSI is that of device Qualification (Vegraph 18). Current device qualification techniques are simply not able to deal with the qualification process in a cost effective manner. New techniques are being developed and will be soom implemented (Vugraph 19). The objectives of the new qualification procedures are described (Vugraph 20). The specific changes being considered for application to VLSI technology devices (Vugraph 21).

The economic Logistic Supportability of Military Systems is of paramount importance and is one of the most important drivers in the need for device standardization (Vugraph 22). Some of the tools available which provide guidance to designers in the proper selection of device technology is the MRAP and Mil-Std 454 (RQMT XX). The device technology progression is shown (Vugraph 23) and the trend of Microelectronic device technology obsolenscence is shown (Vugraph 24). The antethisis of standardization is the current development and proliferation of custom design devices and the manufacture of these devices in so-called Silicon Foundries. The reliability and quality of these devices are rarely demonstrated and therefore lead to serious question of there cost-effectiveness when used in military systems (Vugraph 25). This is further compounded since many of these devices lack formal ownership by the equipment designer and the user may be confronted with the unavailability of these devices during the usefull life of the system. RADC is currently evaluating a number of high technology VLSI devices for consideration for future military applications (Vugraph 26).

MISSION ASSURANCE

ISSUES AND ANSWERS: VLSI DESIGN, RELIABILITY, QUALITY, QUALIFICATION AND LOGISTICS SUPPORTABILITY

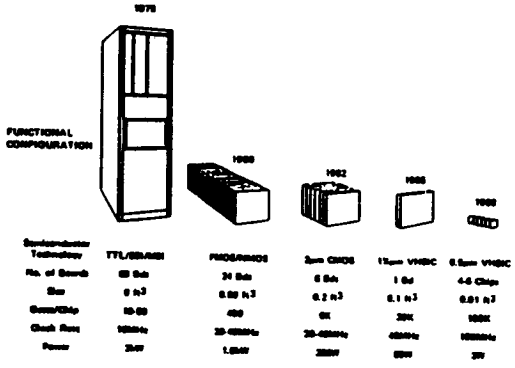
BY

EDMUND J. WESTCOTT

SHRINKING GEOMETRY CHALLENGE

SYSTEM/EQUIPMENT IMPACT

- TECHNOLOGY
- SIZE
- SPEED
- POWER



SHRINKING GEOMETRY CHALLENGE

CAD/CAM/CAT

- DESIGN RULES
- CHARACTERIZATION
- TECHNIQUES

MICROCIRCUIT DEVICE CHARACTERIZATION TECHNIQUES

ELECTRICAL CHARACTERIZATION
- TEST VECTOR GENERATION
  - SEMIAUTOMATIC
  - TIME INTENSIVE
  - MANPOWER INTENSIVE
- SUPPLIER FURNISHED DATA
  - PAST
  - PRESENT
  - REASONS FOR CHANGE
  - IMPACT ON RADC
  - RADC TECHNOLOGY
    - CAD/CAM/CAT
    - LIST OF MNEMONICS

HIGH SPEED TESTING OF DEVICES

VLSI/VHSIC TEST DILEMMA
- I/O PINS
- SPEED
- COMPLETENESS

INCENTIVES FOR ATE IMPROVEMENT

ALTERNATIVES
- ATE IMPROVEMENT
- ON-CHIP TESTABILITY

TEST

ON CHIP TESTABILITY

- REAL ESTATE
  - COVERAGE
  - PENALTY
- IMPLEMENTATION
  - SET-SCAN
  - BENEFITS

SHRINKING GEOMETRY CHALLENGE

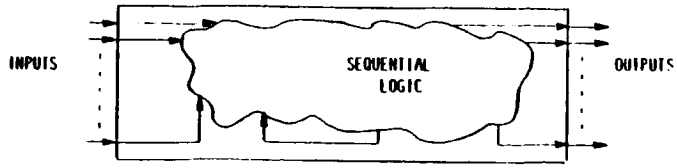
PROCESSES/CONTROLS

ASSEMBLY/INSPECTION

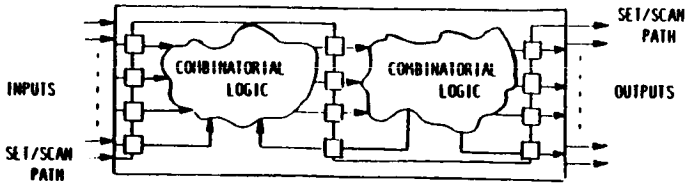
TEST

SET-SCAN TESTABILITY

WITHOUT IT



WITH IT



RELIABILITY ISSUES/ANSWERS

FAILURE RATE

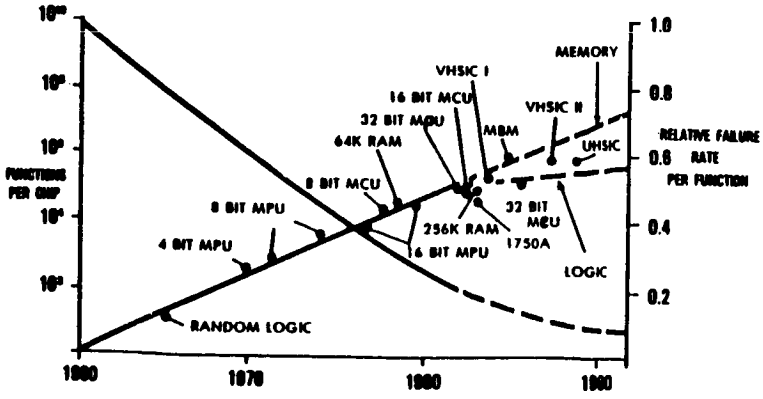
EQUIVALENT GATE

PACKAGING

PINS/INTERCONNECTS

TEMPERATURE/POWER

MICROCIRCUIT COMPLEXITY/RELIABILITY PROJECTION



MPU - MICROPROCESSOR UNIT
MCU - MICROCOMPUTER UNIT
VHSIC - VERY HIGH SPEED INTEGRATED CIRCUITS
MBM - MAGNETIC BUBBLE MEMORY
UHSIC - ULTRA HIGH SPEED INTEGRATED CIRCUITS

RELIABILITY ISSUES/ANSWERS

PACKAGING

PINS/INTERCONNECTS

TEMPERATURE/POWER

MICROELECTRONIC SUSCEPTIBILITY TO EMI

DC NOISE
- ANY NOISE PULSE (W>P.D.)

AC NOISE IMMUNITY REGION
- ILL DEFINED BY MANUFACTURER
  - DEVICE SPEED
  - INPUT CAPACITANCE

ANTICIPATED PROBLEM AREAS
- DENSE CONFIGURATION
  - INTEGRATION OF MACROCELLS
  - FROM STANDARD CELLS

RADC TECHNOLOGY PROGRAM
- EVALUATE S.O.A. DEVICES
  - AC/DC NOISE SUSCEPTIBILITY
  - CHARACTERIZE EMI POTENTIAL

PROPENSITY FOR ELECTROMIGRATION

PAST DESIGN PRACTICE
- LARGE GRAIN SIZE
- WIPE STRIPES

IMPACT OF TECHNOLOGY
- LARGE GRAIN SIZE
- NARROW STRIPES
- CRITICAL RATIO
- OTHER CONSIDERATIONS
  - JUNCTION SHORTING

CONDUCTOR MATERIAL	MAXIMUM ALLOWABLE CURRENT DENSITY
ALUMINUM (99.99% PURE OR DOPED) WITHOUT GLASSIVATION	2×10^5 A/CM^2
ALUMINUM (99.99% PURE OR DOPED)	5×10^5 A/CM^2
GOLD	6×10^5 A/CM^2
ALL OTHER (UNLESS SPECIFIED)	2×10^5 A/CM^2

INTERNAL CONDUCTORS

PROPENSITY FOR ELECTROMIGRATION

- PAST DESIGN PRACTICE
  - LARGE GRAIN SIZE
  - WIPE STRIPES
- IMPACT OF TECHNOLOGY
  - LARGE GRAIN SIZE
  - NARROW STRIPES
  - CRITICAL RATIO
  - OTHER CONSIDERATIONS
    - JUNCTION SHORTING

PROPENSITY FOR ELECTROMIGRATION

- TYPICAL PROBLEM
  - CURRENT DENSITY
  - TEMPERATURE
- PRESENT CRITERIA
  - SHORTCOMINGS
- PROPOSED CRITERIA
  - ADDITIONAL DEVICE PARAMETERS
  - CONDUCTOR DIMENSIONS
  - CONDUCTOR PROCESSING
  - TESTING
- QUALIFICATION PREREQUISITES
  - PROFILE OF CONDUCTOR MATERIALS
  - SUPPORTING DATA
- CONDITIONS FOR ELECTROMIGRATION
  - FLUX DIVERGENCE
  - FORMATION OF VOID

ELECTROMIGRATION QUALIFICATION TEST PROCEDURE

TEST CHARACTERISTIC	REQUIREMENT
STRIPE WIDTH	EQUAL TO MINIMUM VALUE ON DEVICE BEING QUALIFIED
STRIPE LENGTH	GREATER THAN 500 μm
STRIPE THICKNESS (1)	MEASURED WITH SURFACE PROLIFOMETER ON FLAT SURFACE AND SEM (METHOD 2018.1) FOR OXIDE STEPS
STRIPE PROCESSING (2)	IDENTICAL IN ALL RESPECTS TO DEVICE
TEST J	$\leq 1 \times 10^6$ A/CM^2
TEST T	SHALL NOT EXCEED 215°C (125°C to 215°C)

QUALITY ISSUES/ANSWERS

- VISUAL INSPECTION ISSUES
  - PRESENT PRACTICE
    - LIMITATIONS
  - FUTURE NEEDS
    - NEW TECHNIQUES

VLSI DEVICE QUALIFICATION

- CURRENT TECHNIQUES
  - 883 METHODS 5004/5005
- SHORTCOMINGS
  - EXISTING METHODS DEVELOPED FOR SSI/MSI
    - SIMPLE DEVICES
    - HIGH YIELD
    - STRAIGHT-FORWARD TESTING
    - SMALL PACKAGES
    - INEXPENSIVE
  - LSI MADE PROCEDURES MORE DIFFICULT
    - COMPREHENSIVE TESTING
    - VISUAL INSPECTION
  - VLSI IMPACT
    - HIGHLY COMPLEX DEVICES
    - VERY LOW INITIAL YIELD
    - DIFFICULTY IN FUNCTIONAL TESTING
    - VERY LARGE PACKAGES
    - RELATIVELY HIGH COST
- NEW TECHNIQUES
  - VLSI MORE COMPLICATED
    - REQUIRES CONSIDERATION OF:
      - TEST STRUCTURES
      - ACCELERATED TESTING
        - DEFECT DENSITY
        - YIELD
      - SIMILARITY
        - MATRIX
        - CHIPS
        - PACKAGE
      - TESTABILITY
      - BUILT-IN-TEST (BIT)
      - ADDITIONAL TESTING
        - EME
        - RAD-HARD
        - ELECTROMIGRATION

VLSI DEVICE QUALIFICATION

- OBJECTIVES OF NEW PROCEDURES
  - USE STANDARD DEVICE DESCRIPTION
    - HDL
    - SIMULATION
    - CAD/CAM DERIVED CAT
  - SEPARATE DIE AND PACKAGE RELATED TESTS
  - EXPLOIT DEVICE TESTABILITY FEATURES
  - MINIMIZE DEMAND FOR USE OF FULLY FUNCTIONAL DIE
  - REDUCE OVERALL COST OF QUALIFICATION
  - IMPROVE TIME FROM DESIGN TO QUALIFICATION
  - MAINTAIN LEVEL OF RELIABILITY ASSURANCE

CHANGES BEING CONSIDERED FOR VLSI

MORE IN-PROCESS - LESS END OF PROCESS

BUILT-IN-TEST

TEST ELEMENT ACCELERATED STRESSING

PACKAGE QUALIFICATION WITHOUT DIE

GUIDELINES NOT REQUIREMENTS

AUDIT EMPHASIS ON ASSEMBLY AND TEST

LOGISTICS SUPPORTABILITY

VLSI DESIGN IMPACT

NEAR/FAR TERM IMPACT.

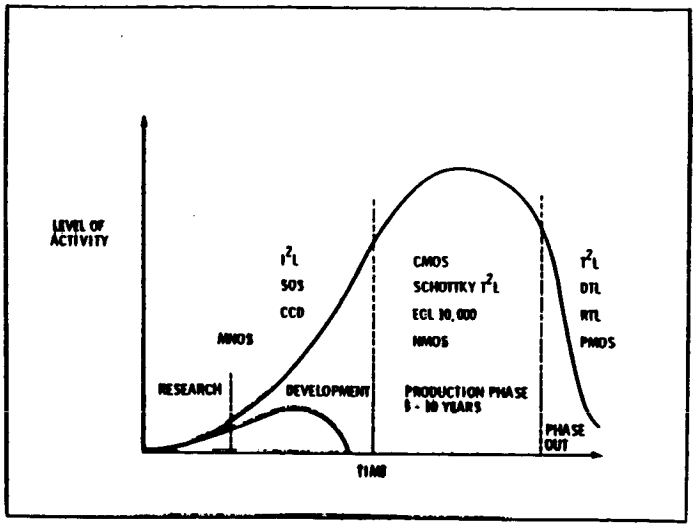
RELIABILITY

MAINTAINABILITY

AVAILABILITY

QUO VADIS

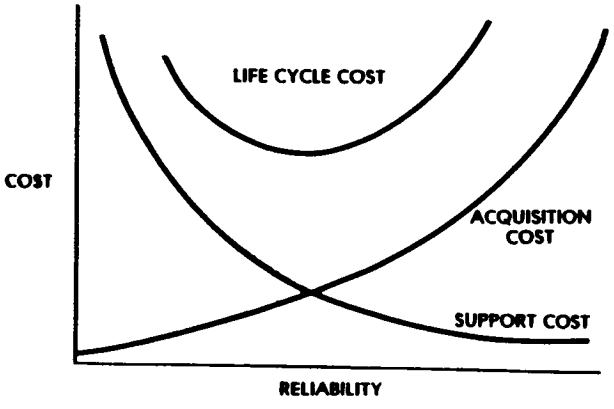
MICROELECTRONIC TECHNOLOGY EVOLUTION



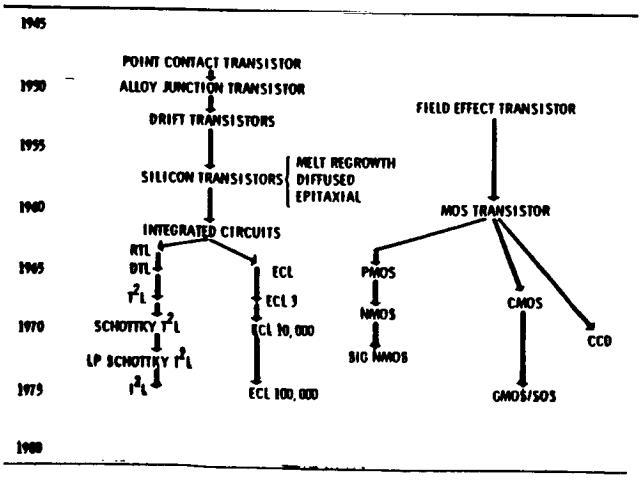
LOGISTIC SUPPORTABILITY OF MILITARY SYSTEMS

STANDARDIZATION
- REDUCES DEVICE TYPES
- REDUCES PRODUCTION COSTS
- BENEFITS/IMPACTORS
- AVAILABLE OVER USEFUL DESIGN LIFE
- SUPPLIER MOTIVATION
  - PROFIT
- RAPID CHANGES IN TECHNOLOGY
  - LIFE EXPECTANCY
  - DEMANDS (PRESENT/NEAR TERM)
- TOOLS AVAILABLE
  - MRAP
  - MIL-STD 454 (ROMT XX)
- SILICON FOUNDRY

THE RELIABILITY IMPACT ON LIFE CYCLE COST



TECHNOLOGICAL PROGRESSION



LOGISTICS SUPPORTABILITY

VLSI DESIGN IMPACT

SHRINKING GEOMETRY/INCREASING COMPLEXITY

NEAR/FAR TERM IMPACT

RELIABILITY

CHIP LEVEL

PACKAGING

I/O PINS

PIN SPACING

INTERFACE/INTERCONNECTION

MODULE

EQUIPMENT

LOGISTIC SUPPORTABILITY

DEVICE DESIGN PROFILE

DEVICE SPEED (MHz)	PACKAGE I/O PINS	PIN SPACING	INTERFACE (MOUNTING)
25	32	.050	LCC (SURFACE MOUNT)
40	42	.025	FLAT PACK (SURFACE MOUNT)
25	84	.050	LCC (SURFACE MOUNT)
25	132	.025	CHIP CARRIER (BRAZEN LEADS)
80-100	148	.025	FLAT PACK (LEADED)
25-40	164	.050	LCC (OPEN VIA)
		.050	CHIP CARRIER (OPEN VIA)
33	180	.100	PIN ARRAY
25	200	.025	CHIP CARRIER (BRAZEN LEADS)
25-40	224	.025	CHIP CARRIER (LEADLESS)
		.0125	FLAT PACK (LEADED)
25-33	240	.100	PIN ARRAY
		.050	PIN ARRAY

LOGISTICS SUPPORTABILITY

NEAR/FAR TERM IMPACT

QUO VADIS

COMPLEXITY

SHRINKING

INCREASED COST

CAPITAL INVESTMENT

LOWER YIELDS

DECREASING PRODUCTION QUANTITIES

INCREASING TECHNICAL RISKS

CONTAMINATION

ELECTROMIGRATION

EME

LOGISTICS SUPPORTABILITY

NEAR/FAR TERM IMPACT

MAINTAINABILITY

SYSTEM TESTABILITY/FAULT ISOLATION

FALSE ALARMS

NTF'S (RTOK)

DEVICE TEST

ATE NEEDS/LIMITATIONS

"ON-CHIP" TESTABILITY

DEVICE R/R

DEVICE OPERATIONAL VERIFICATION

LOGISTICS SUPPORTABILITY

NEAR/FAR TERM IMPACT

AVAILABILITY

DESIGN/TECHNOLOGY

MIL-STD QPL

MIL "LOOK ALIKES"

CUSTOM DESIGN

COMMERCIAL

MICROPROCESSORS & VLSI DEVICES

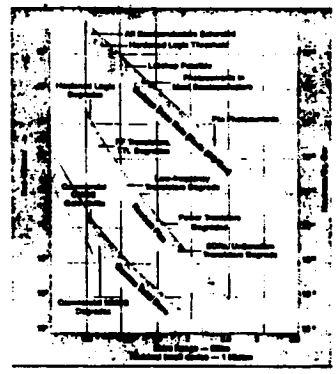
AVAILABILITY FOR SPACE USE

BY

LEON HAMITER

pti

COMPARISON OF EFFECTS OF NEUTRON FLUX AND GAMMA RADIATION ON VARIOUS SEMICONDUCTOR DEVICES



pti

THE DILEMMA IN MICROPROCESSORS AND VLSI FOR SPACE USE

- INADEQUATE PERFORMANCE FOR SPACE NEEDS
- UNAVAILABILITY TO SPECIFIED SPACE QUALITY REQUIREMENTS
- LONG LEAD TIMES
- HIGH COSTS, LOW VOLUME
- ACCEPTABLE UPGRADING PROCEDURES AND LABS

pti

RADIATION HARDNESS LEVELS OF VARIOUS TECHNOLOGIES

	TOTAL DOSE RADS (SI)	TRANSIENT UPSET RADS (SI)/SEC	NEUTRON HARDNESS NEUTRONS/CM²
CMOS (SOFT)	10^3 - 10^4	3×10^7	1×10^{15}
CMOS (HARDENED)	10^3 - 10^6	5×10^8	1×10^{16} ?
CMOS/SOS (SOFT)	10^3 - 10^4	5×10^8	1×10^{15}
CMOS/SOS (HARDENED)	> 10^6	5×10^9	1×10^{19} ?
ECL	10^7	3×10^8	1×10^{15}
IIL	4×10^6	2×10^8	1×10^{14}
LINEAR IC'S	> 10^3	1×10^6	1×10^{12}
NMOS	10^3 - 10^6	1×10^6	1×10^{12}
HMOS	7×10^2	3×10^6	1×10^{15}
PMOS	4×10^3	3×10^6	1×10^{15}
TTL/STTL	> 10^6	1×10^7	1×10^{14}
DI	10^8	1×10^{10}	1×10^{14}

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SPACE REQUIREMENTS

- RADIATION HARD
  - NUCLEAR — $>10^{15}$ NEUTRONS/CM^2
  - TOTAL DOSE — $>10^5$ RADS (SI)
  - TRANSIENT UPSET — $>10^7$ RADS (SI)/SEC
  - SINGLE EVENT
- LOW POWER
- HIGH SPEED
- SPACE QUALITY PARTS
- INTERESTED SUPPLIERS - MOST AREN'T INTERESTED IN S LEVEL
- LOW VOLUME BUSINESS
- LOTS OF INSPECTIONS, TESTS, DOCUMENTATION, ADMINISTRATIVE PROCEDURES, ETC.

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FAILURE RATES -- DATA VERSUS PREDICTION

ALL DATA & PREDICTIONS FOR T_A = 55°C

DEVICE TYPE	DEVICE HRS	DATA - PT. EST @ 60%	PREDICTION	TTq
2901A**	10^6	1100* (350)	62	1
6800	10^7	380	246	3
68000	10^6	680	1242	6.5
8080A	10^7	89	172	2
8002	10^7	110	140	1
8086	10^6	640	175	1
9900**	10^7	5.4	302	1
1802**	10^7	120	884	6.5
MEMORIES				
2115A	10^7	160	1261	6.5
4116	10^6	370	422	1
7643	10^8	38	43	1
6611	10^7	65	605	6.5

* MOST FAILURES WERE IN ONE LOT, REMOVE THIS DATA & FR IS 350 FITS.
** CANDIDATES FOR SPACE USE

pti

PROBLEMS

- NO TRUE STANDARDIZATION OF:
  - PARTS (BY MIL SPEC PART NO.) - OEM P/N's
  - QUALITY
    - TESTS
    - SCREENS
    - SURVEILLANCE
    - DOCUMENTATION

PROBLEMS, CONTINUED

- MIL-M-38510 JAN CLASS S
  - NOT ENOUGH "VISIBLE" BUSINESS TO INTEREST SUPPLIERS
    - HUGE INVESTMENT IN CERTIFICATION, PROCESS CONTROL (PROOF ON A COMMERCIAL LINE), TESTING
    - LONG LEAD TIME BEFORE FIRST ORDER
    - EXPENSIVE TO MAINTAIN QUALIFICATION & PERFORM FULL QCI

    USERS (OEM) RELUCTANT TO ORDER
    - NO QPL
    - WAIVERS & DEVIATIONS NOT ALLOWED
    - MANUFACTURERS DON'T WANT TO ALLOW PURCHASER INPROCESS INSPECTION
    - USERS DON'T TRUST GSI
    - MANUFACTURERS GET A BETTER RETURN ON INVESTMENT FROM OTHER BUSINESS
    - TAKES TOO LONG TO ACCOMPLISH CERTIFICATION & QUALIFICATION
    - MOST ASSEMBLY IN FAR EAST AND CANNOT BE QUALIFIED

PROBLEMS ,CONTINUED

- IF STANDARD VLSI PARTS AREN'T AVAILABLE AS JAN CLASS S .....

  HOW CAN SEMI CUSTOM GATE ARRAYS, CUSTOM VLSI & VHSIC BECOME AVAILABLE TO CLASS S ?

-- N O W A Y --

PROBLEMS FACING THE MILITARY SPECIFICATION AND QUALIFICATION SYSTEM, CONTINUED

- MANY SUPPLIERS DO NOT WANT TO QUALIFY UNLESS FORCED TO BY COMPETITION.
- MANY SUPPLIERS PREFER TO SELL A PART THAT IS CALLED EQUIVALENT TO CLASS B. IT DOES NOT HAVE TO PASS PROCESS CONTROL REQUIREMENTS, GOOD QUALITY ASSURANCE PROGRAM AND THE QUALIFICATION TESTS OF 38510 AND 883.
- AS VLSI DEVICES BECOME MORE CUSTOM AND LESS STANDARD, HOW CAN THEY BE SUPPORTED BY 38510?
- CAN THE VHSIC PARTS BE BROUGHT INTO 38510 SYSTEM?
- TRADITIONALLY, THE 38510 SPECIFICATIONS AND PROCEDURES WERE FOR THE MERCHANT SUPPLIERS AND DO NOT FIT THE OEM AND SILICON FOUNDRIES.

PROBLEMS FACING THE MILITARY SPECIFICATION AND QUALIFICATION SYSTEM

- PARTS CONSTANTLY FACE THE "CHICKEN" OR THE "EGG" DECISION ..... I.E., DESIGN IT IN FIRST OR QUALIFY IT FIRST.
- MANUFACTURERS NEVER HAVE A MARKET PROJECTION FOR THE JAN QUALIFIED PART.
- REQUIRES U.S. FABRICATION, ASSEMBLY AND TEST. NOT ECONOMICAL UNLESS EACH MANUFACTURER HAS ENOUGH VOLUME FOR U.S. BUILT PARTS TO JUSTIFY FACILITY AND OPERATIONAL COSTS.
- SPECIFICATION AND QUALIFICATION CYCLE TOO LONG. THE PART II LISTING HAS SHORTENED THE PROCESS, BUT NOT NEAR ENOUGH.
- VERY COSTLY PROCESS

PART I	20K - 60K
PART II	5K - $10K

- QCI (LOT TESTING) COSTS VERY EXPENSIVE FOR SMALL ORDERS WHEN THE SUPPLIER DOES NOT MAINTAIN A STOCKING PROGRAM.

POSSIBLE SOLUTIONS FOR THE TWO MAJOR PROBLEMS

- RADIATION HARDNESS
  - PROVIDE ADEQUATE POWER TO USE BIPOLAR
  - GOVERNMENT PROVIDE DEVELOPMENT FUNDS TO HARDEN BULK CMOS
  - ESTABLISH PROGRAM FOR COMMERCIAL ORGANIZATION TO PROCURE AND STOCK RAD HARD PARTS WITH ACCEPTABLE QUALITY
    - BIPOLAR ---------- 2901,9989
    - RH-BULK CMOS ------- SANDIA/RCA 1802 AND MEMORIES
    - CMOS/SOS ---------- RCA GPU & MEMORIES

POSSIBLE SOLUTIONS FOR THE TWO MAJOR PROBLEMS, CONTINUED

- SPACE QUALITY
  - FACTORS TO BE RECONSIDERED
    - o TODAYS CLASS B IS BETTER THAN YESTERDAYS CLASS A/S
    - o IS THE PRESENT CLASS S NECESSARY OR WILL A B PLUS --- ACHIEVED THROUGH SELECTION AND UPGRADING---BE ADEQUATE.
  - SINGLE PROCUREMENT AND STOCKING BY PARTS CONTRACTOR FOR ALL NATIONWIDE (OR FREE WORLD) USAGE
    - o GENERATE ADEQUATE VOLUME FOR ANNUAL OR BIANNUAL PRODUCTION OF A FEW STANDARD PARTS
    - o AGGRESSIVE TECHNICAL MANAGEMENT & QUALITY SURVEILLANCE
    - o ALLOWS SCREENING & LOT TESTING TO ADDRESS THE TECHNOLOGY AND NOT EVERY IDEA THAT HAS BEEN DREAMED UP
    - o LARGE COST SAVINGS FOR QCI TESTING, INCOMING TESTS AND QUALITY SURVEILLANCE

RADIATION TEST DATA, CONTINUED

DEVICE TYPE	TOTAL DOSE RADS (Si)	DOSE RATE (TRANSIENT UPSET) RADS (Si)/SEC	NEUTRON FLUENCE N/CM²	COSMIC PARTICLES ERROR/DAY/BIT OR CHIP
MEMORIES - RAMS				
1821 CMOS/SOS RCA	$< 4 \times 10^3$	2.3×10^6 TO 2.6×10^6	1×10^{15}	
		0.83×10^{10} TO 1×10^{10}		
1822 CMOS/SOS	$< 1.1 \times 10^4$	2.5×10^{10} TO 3×10^{10}	1×10^{15}	
2102 NMOS INTEL	3×10^3			
2107B NMOS INTEL	850			
2116 NMOS INTEL	900			
2147 NMOS INTEL	$> 1 \times 10^3$	1.3×10^4		

RADIATION TEST DATA

DEVICE TYPE	TOTAL DOSE RADS (Si)	DOSE RATE (TRANSIENT UPSET) RADS (Si)/SEC	NEUTRON FLUENCE N/CM²	COSMIC PARTICLES ERROR/DAY/BIT OR CHIP
MICROPROCESSORS				
1802 CMOS RCA AND HUGHES	2.5×10^4 TO 4×10^4	1×10^9	1×10^{15}	
1852 CMOS 8-BIT I/O RCA & SANDIA	$> 3 \times 10^4$			
1852 CMOS 8-BIT I/O HUGHES	$< 1.6 \times 10^4$ TO 2×10^5			
6800 NMOS MOT & NAT	$< 1 \times 10^3$			
8080 NMOS	700 TO 7×10^3	$< 1.8 \times 10^9$		
8085 NMOS INTEL	4.2×10^3			
8086 NMOS	$> 1 \times 10^4$			

RADIATION TEST DATA, CONTINUED

DEVICE TYPE	TOTAL DOSE RADS (Si)	DOSE RATE (TRANSIENT UPSET) RADS (Si)/SEC	NEUTRON FLUENCE N/CM²	COSMIC PARTICLES ERROR/DAY/BIT OR CHIP
MEMORIES - RAMS				
8155 NMOS INTEL	5×10^3 TO 1×10^4			
54C920 CMOS NAT	1×10^3 TO 3×10^3			
6504 CMOS RAD HARD HARRIS	2×10^4			
6504 CMOS HARRIS	1×10^4			1×10^{-6}
6514 CMOS HARRIS	1×10^4			1×10^{-6}
6516 CMOS HARRIS	1×10^4			1×10^{-6}
6551 CMOS HARRIS	1×10^4			1×10^{-6}

RADIATION TEST DATA, CONTINUED

DEVICE TYPE	TOTAL DOSE RADS (Si)	DOSE RATE (TRANSIENT UPSET) RADS (Si)/SEC	NEUTRON FLUENCE N/CM²	COSMIC PARTICLES ERROR/DAY/BIT OR CHIP
2901 STTL AMD	$> 2 \times 10^7$	$< 1.1 \times 10^{10}$		
2901A STTL AMD	$> 9 \times 10^6$	3.5×10^{10}	1×10^{14} TO 4×10^{14}	
9900 I^2L TI	6×10^5 TO 7.5×10^5	1×10^9	3×10^{13}	$< 1.2 \times 10^{-5}$ (MTBF > 230 YEARS)
9989 I^2L TI	4×10^5 TO 4.5×10^5	1×10^9	2×10^{13}	$\sim 6.7 \times 10^{-4}$ (MTBF $\simeq$ 4.1 YEARS

RADIATION TEST DATA, CONTINUED

DEVICE TYPE	TOTAL DOSE RADS (Si)	DOSE RATE (TRANSIENT UPSET) RADS (Si)/SEC	NEUTRON FLUENCE N/CM²	COSMIC PARTICLES ERROR/DAY/BIT OR CHIP
ROMS/PROMS/EPROMS				
1832 CMOS ROM RCA	3×10^3 TO 3×10^4			
1833 CMOS ROM RCA	$5 \times 5 \times 10^3$			
3624 STTL PROM INTEL	1×10^7	2.3×10^7		
6340 STTL PROM MMI	$> 1 \times 10^6$	$< 9.2 \times 10^7$	1.5×10^{14}	
6641 CMOS PROM HARRIS	1×10^4			
2732 NMOS EPROM	$< 1 \times 10^3$			
3400 NMOS EAROM GEN	2×10^4 TO 4×10^4	1.1×10^8		
7040 NMOS EAROM	1.7×10^4	2×10^7		

MICROPROCESSORS AND PERIPHERALS

DEVICE/TYPE	TECHNOLOGY	MFG.	MIL SPEC	QUAL STATUS	COMMENTS
2910 MPU	4-BIT x 8 BIPOLAR	AMD, RAY, NAT, FSC, NEC	/44001	NONE	PART II UNTIL 9/82
2906 TRANSCEIVER	LP SCHOTTKY TTL		/44101	NONE	
2906			/44102		
2907			/44103		
2915			/44104		
2916			/44105		
2917			/44106		
2918 QUAD D REGISTER			/44201		
2910 MICROPROGRAM CONTR.			/44501		SPEC RELEASED 3RD QTR 83.
2902 SEQUENCER			/43301		PROPOSED SPEC
1802 MPU	8-BIT CMOS	RCA/HARRIS	/47001	NONE	BOTH STATE THEY HAVE NO PLANS TO QUALIFY THESE PARTS. MOST ASSEMBLY IS OFF-SHORE
1821 1024 x 1 RAM	CMOS/SOS		/47101		
1822 256 x 4 RAM	CMOS/SOS		/47102		
1832 512 x 8 ROM	CMOS		/47201		
1852 BYTE I/O			/47301		
1853 8-BIT DECODER			/47401		
1856 BUS BUFFER (MEMORY)			/47601		
1857 BUS BUFFER (I/O)			/47602		

1802 THIS MICROPROCESSOR AND ITS SUPPORTING DEVICES NEVER HAVE BEEN MILITARY QPL. THE DETAIL SPECIFICATIONS FOR THIS FAMILY HAVE DELETED THE HIGH MAGNIFICATION PRECAP ON THE INTERIOR OF THE CHIP, INSIDE THE MAJOR CONDUCTORS AND BONDING PADS ONLY ON THOSE PORTIONS OF THE DIE WHICH CARRY CURRENTS OF 10 MICROAMPS OR MORE. ALSO, IT IS ALLOWED A PRE-CONDITIONING BURN-IN AT THE MANUFACTURER'S OPTION AND GROUP A, SUBGROUPS 5 AND 6 (DYNAMIC TESTS AT HIGH AND LOW TEMP) ARE OMITTED AS WELL AS OTHER TESTS. HUGHES HAS SHOWN SOME INTEREST IN PURSUING CLASS B QUALIFICATION. THEY FOUND NO EXCEPTIONS ON THE TESTING AND ELECTRICAL REQUIREMENTS OF THE MILITARY DETAIL SPECIFICATION, BUT HAVE TO RESOLVE SOME QUESTIONS ON THE DOCUMENTATION AND TEST PROCEDURES.

MICROPROCESSORS AND PERIPHERALS, continued

DEVICE/TYPE	TECHNOLOGY	MFG.	MIL SPEC	QUAL STATUS	COMMENTS
8040 MPU	8-BIT NMOS	INTEL, AMD, SIEMENS, NEC, NAT, SIG, TOSHIBA	/42001	INTEL PART I CLASS B	
8212 8-BIT I/O PORT	SCHOTTKY TTL		/42101	NONE	
8224 CLOCK GEN.			/42201		
8228 SYST. CONTR. & BUS DRIVER			/42301		
6800 MPU	8-BIT NMOS	MOT, AMD, FSC, HITACHI, SESCOSEM	/40001	NONE	PART II EXPIRED 4/80.
6810 128 x 8 RAM	NMOS		/40201	NONE	
6821 PIA			/40101		
6831 2048 x 8 ROM			/40301		
8001 MPU	16-BIT NMOS	ZILOG, AMD, SGS	/52001	NONE	
8010 MMU	NMOS		52x01		PROPOSED SPEC BY RADC
68000 MPU	16-BIT NMOS	MOT, ROCKWELL, HITACHI, MOSTEK, SIG/PHIL, THOMPSON-CSF	/54001 (3-6 MHz) /54002 (3-8 MHz) /54003 (3-10 MHz)	NONE	SPEC RELEASE EXPECTED 1ST QTR 83

8040 AND 8086 CONT'D THE 8040 IS NOW A MATURE PRODUCT AND IS ENTERING THE DOWNWARD SIDE OF ITS LIFE-CYCLE; HOWEVER, INTEL SAYS IT PLANS TO ALWAYS HAVE 8080 PARTS AVAILABLE AT A COMPATIBLE PRICE. HARRIS IS ADVERTISING A CMOS VERSION OF THE 8086.

8040 AND 8086 PRESENTLY, INTEL IS CLASS B, PART II, QUALIFIED FOR THE 8086. NO INTEREST HAS BEEN EXPRESSED BY OTHER SOURCES. INTEL HAS COMPLETED THE TESTING FOR CLASS B, PART I, QPL, AND THE REPORT HAS BEEN SUBMITTED TO DESC FOR APPROVAL. QUALIFICATION IS EXPECTED 1ST QTR 1983.

8001 ZILOG HAS OBTAINED CLASS B, PART II, QPL APPROVAL FOR THE Z8000 40-PIN (8002 AND 8004) AND IS EXPECTED TO ACHIEVE PART I LISTING IN THE 2ND QUARTER 1983. THE 8001 and 8003 (48-PIN) ARE ESTIMATED TO ACHIEVE CLASS B, PAT II, LISTING BY THE 4TH QUARTER 1983. AND HAS REQUESTED DESC TO CANCEL THE AUSTIN, TX, MICROPROCESSOR FABRICATION LINE CERTIFICATION. NO REASON SPECIFIED.

6800 AND 68000 MOTOROLA LET THE QPL FOR THE 6800 EXPIRE IN APRIL 1980 BECAUSE IT WAS TOO EXPENSIVE TO OBTAIN THE PART I LISTING. AS IT NOW STANDS, THE MOTOROLA PRODUCTS GROUP MADE THE DECISION NOT TO PURSUE THE 6800 AND 68000 MILITARY QPL LISTINGS BECAUSE THERE WAS NOT ENOUGH DEMAND, BUT THEY WILL SUPPORT MANUFACTURER'S, CLASS B, SCREENING. THIS DECISION IS ALSO UNANIMOUS WITH ALL THE SECOND SOURCES.

MICROPROCESSORS AND PERIPHERALS, continued

DEVICE/TYPE	TECHNOLOGY	MFG.	MIL SPEC	QUAL STATUS	COMMENTS
8086 MPU	16-BIT NMOS	INTEL, MITSUBISHI, AMD, NEC, FUJITSU, SIEMENS, HARRIS (CMOS)	/53001	INTEL PART II CLASS B	
8282 OCTAL LATCH	BIPOLAR		/53x01	NONE	SPES BY RADC
8283 OCTAL LATCH			/53x02		
8284 CLOCK GEN.			/53x01		
8286 OCTAL BUS TRANSCEIVER			/53x01		
8287 OCTAL BUS TRANSCEIVER			/53x02		
8288 BUS CONTR.			/53x01		
9900 MPU	16-BIT I^2L	TI, AMI, INTERMETALL (ITT-EUROPE)	/46001	NONE	TI ALLOWED THEIR PART II TO EXPIRE 6/82.
9989 MICROPROCESSOR	16-BIT I^2L	TI	/46501	NONE	PART II EXPECTED 3/83.

9900 AND 9989 TEXAS INSTRUMENTS LET THE QPL FOR THE 9900 EXPIRE IN JUNE 1982 TO PURSUE THE 9989 QUALIFICATION. HOWEVER, THEY WILL SUPPLY 883 CLASS B SCREENED PARTS. CLASS B, PART II, QPL DOCUMENTATION AND TEST REPORTS ARE BEING SENT TO DESC FOR THE 9989. TEXAS INSTRUMENTS ESTIMATES THAT THE 9989 WILL BE QUALIFIED DATE IN THE 1ST QUARTER 1983.

EXPANDED COMMENTS

2901 AMD, UNTIL SEPTEMBER 1982, WAS THE ONLY MILITARY QPL PART II, CLASS B, QUALIFIED. IN SEPTEMBER 1982, ALL AMD MILITARY QPL MICROCIRCUITS HAVE BEEN REMOVED BECAUSE DURING THE MIL-M-38510 RECERTIFICATION AUDIT, THE TEST AREA TRAVELERS SHOWED UNACCEPTABLE RETESTING OR CHANGING OF DATA WITHOUT ANY NOTED JUSTIFICATION. THESE CHANGES WERE NOT BEING REFLECTED ON THE EXTENDED PROCESS SPECIFICATION (EPS). AMD IS TAKING THE NECESSARY CORRECTIVE ACTIONS TO BE REINSTATED IN THE MILITARY QPL. (ALERT: VV-A-82-02, DATED OCTOBER 1982). NO SECOND SOURCES OR SUPPORTING DEVICES HAVE BEEN MIL QPL, SINCE THE MILITARY MARKETING DOES NOT JUSTIFY THE EXPENSE.

TO OFFSET GROWING COMPETITION FROM NEW 16/32-BIT NMOS MICROPROCESSORS (WHICH THREATEN TO APPROACH BIPOLAR SPEEDS AT LOWER COSTS), THE LEADING 2900-FAMILY SUPPLIERS ARE TURNING TO ECL INTERNAL CIRCUITRY AND ADVANCED DEVICE PROCESSING, CLAIMING THEY WILL CONTINUE TO BOOST SPEED 30% EVERY 2 YEARS.

MISSION ASSURANCE

SPACE QUALITY OF NEW PART

TECHNOLOGIES WORKSHOP

DICK LAMBERT
8 JUNE, 1983

- WORKSHOP FOCUS
  - QUALITY; CONFORMANCE TO SPECIFICATIONS
  - ADEQUACY OF CURRENT MIL SPECIFICATIONS
  - IC PROCESSING, PRESENT AND FUTURE
  - RADIATION DESIGN CONSIDERATIONS

- PANEL
  - DICK LAMBERT, CHAIRMAN — SIGNETICS CORPORATION, MANAGER OF QUALITY AND RELIABILITY ASSURANCE, MILITARY PRODUCTS DIVISION, SACRAMENTO, CA. (916) 924-6024
  - DICK SCOTT, CO-CHAIRMAN — JPL, SUPERVISOR OF TECHNICAL GROUP, ELECTRONICS PARTS ENGINEERING, PASADENA, CA. (213) 354-5750
  - DR. DAVE MEYER, — IBM - FSD, MANAGER OF TECHNICAL OPERATIONS AND FUNCTIONAL CHARACTERIZATION, MANASSAS, VA. (703) 367-4215
  - JIM JORGENSEN, — SANDIA LABS, SUPERVISOR OF IC DESIGN, MICROPROCESSORS AND MEMORY, ALBUQUERQUE, NM (505) 844-1997

- POSSIBLE AREAS OF INTEREST
  - DESIGN
    - RADIATION HARDERING
    - CURRENT DENSITIES/MIGRATION
    - HIGH DENSITY INTERCONNECTS
    - TEST PATTERNS
    - SELF TEST
    - POWER HANDLING
    - RELIABILITY
  - WAFER FABRICATION
    - LITHOGRAPHY
    - PROCESS MONITORS
    - REWORK
    - TEST PATTERNS
    - SEM
    - PROCESS CONTROLS
  - ASSEMBLY
    - LSI DIE ATTACH
    - HIGH DENSITY LEAD BONDING
    - MBBP
    - PROCESS CONTROLS
    - PACKAGING
    - PRE-SEAL VISUAL
    - MOISTURE CONTROLS

- PANEL (CONT.)
  - GENE WOLFE, — TEXAS INSTRUMENTS, MANAGER OF DEVELOPMENT PROGRAMS, MILITARY PRODUCTS DEPARTMENT, DALLAS, TX. (214) 995-4242
  - KIRK LEMON, — NATIONAL SEMICONDUCTOR, GROUP MANAGER, SPACE BUSINESS UNIT, MILITARY/AEROSPACE DIVISION, SANTA CLARA, CA. (408) 721-5999
  - ED WESTCOTT, — ROME AIR DEVELOPMENT CENTER, TECHNICAL DIRECTOR, RELIABILITY AND COMPATIBILITY DIVISION, GRIFFISS AFB, NY. (315) 330-3064

- POSSIBLE AREAS OF INTEREST (CONT.)
  - TESTING
    - EQUIPMENT CAPABILITIES
    - SOFTWARE GENERATION
    - TEST VECTORS
    - CONTROL OF JUNCTION TEMPERATURE
  - SCREENING
    - BURN-IN
    - RADIOGRAPHY
    - PIND
  - QUALIFICATION/QCI
  - STANDARDIZATION

- AGENDA

1:00	INTRODUCTION	DICK LAMBERT
1:10	EVOLVING TECHNOLOGIES	DR. DAVE MEYER
1:30	RADIATION CONSIDERATIONS	JIM JORGENSON
1:50	ADVANCED BIPOLAR PRODUCTS	GENE WOLFE
2:10	MANUFACTURER VIEWPOINT	KIRK LEMON
2:30	HIGH TECH QUALITY, RELIABILITY, QUALIFICATION	ED WESTCOTT
3:00	BREAK	
3:15	PANEL DISCUSSION ON QUALITY APPROACHES	
5:00	ADJOURN	

ADVANCED NMOS PROCESS CHARACTERIZATION AND CONTROL

Dr. David Meyer
IBM - Federal Systems Division
Manassas, Virginia

In trying to establish and maintain the quality and yield of VLSI chips currently in fabrication, several basic problems have arisen. These problems will be addressed using a 1μm NMOS process as an example. The characterization strategy which is used to maintain the quality of the wafer processing and yield is described to show the required detail to be able to obtain statistically meaningful data. The physical devices which are used to determine the data are in-process monitor wafers, kerf structures, defect monitor test sites, and line monitor test sites.

BASIC CONSTRAINTS

In any 1μm feature size VLSI circuit of 10K to 100K random logic gates, several basic characterization constraints occur. First, the 1μm feature sizes are difficult to optically inspect, especially to see the sidewall contours. Scanning electron microscopes (SEM) can be used as a periodic check but are slow and can image only the top layer which is limiting when investigating multi-level metal chips with several dielectric passivation layers. Similarly, internal electrical probing of the chip wiring using mechanical probes is very difficult and unreliable. Large gate count random logic chips also significantly complicate diagnostic testing which limits electrical fault location. The combination of reduced horizontal and vertical dimensions limits the usefulness of material diagnostic techniques like SIMS, EDAX, AUGER, etc. because of beam size and material resolution. Finally, the process quality detractors are masked by circuit complexity and associated lower yields which makes detractor identification difficult. Improved electrical characterization have been developed which assist in some of these problems.

1μm NMOS PROCESS DESCRIPTION

A basic 1μm NMOS process was developed by IBM Research (1) in the 1970's. The basic attributes of this process are:

(1) 500nm recessed field oxide
(2) Enhancement and depletion FET's
(3) Totally ion implanted process
(4) Single polysilicide (WSi_2) layer
(5) Contact barrier metallurgy (Pd_2Si)
(6) 25nm gate oxide
(7) 0.35μm drain/source diffusion depth

The basic lithography groundrules are:

Groundrule	Minimum Linewidth
N^t region	1.75μm
Polysilicide	1.5μm
Contact	1.0μm
Metal	1.25μm
Channel Length	1.3±0.3μm

Several concerns were highlighted at that time. Gate oxide breakdown decrease, increased contact resistance, advent of hot electrons, varying threshold voltage control with channel length, and in general, overall dimensional control are problems to be dealt with and eliminated or controlled.

CHARACTERIZATION STRATEGY

In order to be able to investigate the above mentioned problems and others, a characterization strategy is being utilized which has been developed by IBM in the 1970's. There are four main types of wafers and test sites used to monitor the process and to assure its quality and the quality of its product chips. The monitors are:

(1) In-process Monitor Wafers
(2) Kerf Device Structure
(3) Defect Monitor Test Site
(4) Line Monitor Test Site

With these monitors, it is possible to obtain statistically meaningful data about a wide range of parameters from basic device parameters, random defects, physical process parameters, etc. which are used routinely to maintain the process in its desired state and to quickly identify any deviations from the process specifications.

In-Process Monitor Wafers

The wafers start with the product lot wafers and experience the same hot process steps as the product wafers. However, the monitor wafers do not experience the lithography steps so the hot process films and operations are uniform across the wafer. These wafers individually check the various process steps or a series of process steps for process accuracy. Typical measurements on these wafers are:

(1) Capacitance - Voltage
(2) Film Thicknesses
(3) Junction Depths
(4) Layer Resistivities

If any of the measurements indicate a deviation, the product lot is investigated, and a determination is made as to whether the lot should proceed in processing. In addition to these measurements, a series of stress tests are performed on the in-process monitor wafers which gives a good indication of the quality of

the process and the expected reliability of the product chips. Thus, the in-process monitor wafers provide an immediate indicator of product lot problems and through sufficient number of monitor wafers can accurately pinpoint the process which is out of specification.

Kerf Structure

The kerf structure is a "L" shaped area on each product and test site chip on each wafer. This structure is designed to be eliminated during the chip dicing operation and thus minimizes lost chip area. The kerf devices can be probed at both first and second level metallizations. Typical devices on a kerf structure are:

(1) Enhancement and depletion FET's
(2) Capacitors of various dielectric levels
(3) Resistivity monitors
(4) Contact chains
(5) Alignment marks and tolerance

The kerf structure provides parametric data about key devices and structures which is statistically meaningful. This data can be analyzed by wafer, lot, series of lots, etc. to determine parameter trends and possible problem areas. However, the critical areas and number of devices are insufficient to predict yield or defect status.

Defect Monitor Test Site

The defect monitor test site contains structures which have large critical areas such as first level metal running over various topographies. The structures can be electrically measured to obtain statistically meaningful defect data. From this data, visual inspection and delayering techniques, the actual yield and quality detractors can be identified and eliminated by process improvements. The defect monitor critical areas of the various structures are compared to the product chip critical areas to determine the necessary defect monitor level yield to be able to obtain a specific product chip yield. Typical problems which are detectable on the monitor are:

(1) Metal and polysilicon opens and shorts
(2) Missing and extra field oxide
(3) Missing and enlarged contacts and vias
(4) Dielectric defects
(5) Junction leakage

These test sites are stepped into product chip and line monitor mask sets.

Line Monitor Test Site

The line monitor test site is a large array circuit like a RAM or ROM which has large critical areas. A RAM or ROM is used for its extreme density, simple testing and fault location capabilities. The line monitor test site is a stand alone mask set which is periodically processed in the line in order to obtain a routine measure of the line performance from a circuit standpoint. The RAM/ROM is electrically tested to determine its faults. The

test data is manipulated via computer to get bit fail maps which locates the failing bits physically on each chip and gives an indication of the type of defect. Each chip is visually inspected at each failing site to determine the actual physical defect. Often, delayering techniques are necessary in order to be able to identify the faults which are buried beneath dielectric and metal layers, such as at gate oxidation. Summary of the defects found by this technique gives the total photo limited yield (PLY) which can be compared to the process line PLY measurements. As with the defect monitor test site, the critical areas can be calculated for the RAM/ROM and compared to product chip critical areas. Thus, to be able to obtain a desired product chip yield, the line monitor lots must achieve specific calculated yields.

SUMMARY

As VLSI circuits become more complex, and dimensions are reduced, the electrical characterization strategy can be quickly located and identify the fault and determine the magnitude of the problem. Then through visual and/or SEM evaluation, the actual physical problem can be isolated. Thus using this information plus the parametric data, the quality of the wafer lot can be assessed.

Reference

1. 1μm MOS FET VLSI Technology: Part I to VIII, IEEE Transactions on Electron Devices, Vol. ED-26, No. 4, April 1979, pages 318-378.

ADVANCED NMOS PROCESS

CHARACTERIZATION AND CONTROL

DAVID MEYER

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MANASSAS, VIRGINIA

GENERAL TECHNOLOGY PROBLEMS

- 1 MICROMETER DIMENSIONS ARE AT LIMITS OF OPTICAL INSPECTION
- 10K TO 100K GATES PER RANDOM LOGIC CHIPS SIGNIFICANTLY COMPLICATE DIAGNOSTIC TESTING
- 1 MICROMETER METAL LINEWIDTHS STRONGLY LIMITS INTERNAL CHIP PROBING
- COMBINATION OF SCALED HORIZONTAL AND VERTICAL DIMENSIONS LIMITS MATERIAL DIAGNOSTIC TECHNIQUES (SIMS, EDAX, AUGER, ETC)
- PROCESS QUALITY IS MASKED BY CIRCUIT COMPLEXITY AND LOWER YIELDS.
- NEED CHARACTERIZATION STRATEGY TO ISOLATE PROBLEMS ELECTRICALLY

BASIC 1 MICROMETER NMOS PROCESS DESCRIPTION

- 500nm RECESSED FIELD OXIDE
- ENHANCEMENT/DEPLETION DEVICES
- TOTALLY ION IMPLANTED (ARSENIC, BORON)
- SINGLE POLYSILICIDE LAYER (WSi_2)
- TWO LEVEL ALUMINUM METALLIZATIONS
- CONTACT BARRIER (Pd_2Si)
- 1.1 TO 2.5ns DELAY/STAGE
- 25nm GATE OXIDE THICKNESS
- 0.35um DRAIN/SOURCE DIFFUSION DEPTH
- 5Ω-cm P-TYPE SUBSTRATE

MINIMUM LINEWIDTHS

- N+ - REGION	1.75um
- POLYSILICIDE	1.5um
- CONTACT HOLE	1.0um
- METAL (FIRST LEVEL)	1.25um
- CHANNEL LENGTH	1.3 ± 0.3um (0.8 ± 0.2um)

PROCESS CONSTRAINTS

- GATE OXIDE BREAKDOWN
- CONTACT RESISTANCE
- HOT ELECTRONS
- THRESHOLD VOLTAGE CONTROL
- DIMENSIONAL CONTROL
- METALLIZATIONS

CHARACTERIZATION STRATEGY

- IN-PROCESS MONITOR WAFERS
- KERF STRUCTURE ON EACH CHIP
- DEFECT MONITOR TEST SITE
- LINE MONITOR TEST SITE

IN-PROCESS MONITOR WAFERS

- UNMASKED WAFERS START WITH EACH LOT
- CHECK PROCESS STEPS OR SERIES OF PROCESS STEPS FOR ACCURACY. MEASUREMENTS INCLUDE:
  1. C-V FOR V_{TEDM}, V_{TDEP}, FLATBAND, R_s, Nss, ETC.
  2. FILM THICKNESSES
  3. X_j
  4. RESISTIVITIES OF DIFFUSION, POLYSILICON, AND POLYSILICIDE
- FAST INDICATOR OF LOT PROBLEMS AND PROCESS PROBLEMS. SUFFICIENT NUMBER OF WAFERS TO PIN POINT WHICH PROCESS STEP IS OUT OF SPEC.
- STRESS TESTING OF WAFERS IS RELIABILITY INDICATOR.

KERF

- "L" SHAPED STRUCTURE ON EDGE OF EACH CHIP
- LOCATED IN SAW AREA SO IS ELIMINATED AT DICING
- CONTAINS:
  1. VARIOUS SIZE ENHANCEMENT AND DEPLETION FETS
  2. THICK OXIDE FETS
  3. CAPACITORS FOR VARIOUS DIELECTRIC LEVELS
  4. RESISTIVITY MONITORS
  5. CONTACT CHAINS
  6. ALIGNMENT MARKS
- CAN BE PROBED AT FIRST METAL AND SECOND METAL
- GIVES DEVICE PARAMETER STATISTICS BY WAFER AND LOT
- INSUFFICIENT CRITICAL AREAS OR DEVICES TO DETERMINE YIELD OR DEFECT STATUS

DEFECT MONITOR TEST SITE

- PLACED IN PRODUCT AND LINE MONITOR MASK SETS
- CONTAINS LARGE ARRAYS OF CRITICAL LEVELS TO GET LARGE CRITICAL AREAS TO OBTAIN STATISTICALLY MEANINGFUL DEFECT DATA.
- CRITICAL AREAS ARE COMPARED TO PRODUCT CRITICAL AREAS TO DETERMINE THE NECESSARY DEFECT MONITOR LEVEL YIELD TO BE ABLE TO OBTAIN A SPECIFIC PRODUCT YIELD.
- CAN BE TESTED AT BOTH FIRST AND SECOND METAL LEVELS
- SIGNIFICANT PROCESS PROBLEMS AND DEFECTS CAN BE QUICKLY IDENTIFIED, AND THE MAGNITUDE AND ACTUAL CAUSE OF THE PROBLEM CAN BE DETERMINED.
- USED TO IDENTIFIED MAJOR YIELD DETRACTORS AND DETERMINE THE QUALITY OF THE PROCESS AND DESIGN GROUNDRULES.
- TYPICAL PROBLEMS DETECTABLE ARE:

  1. METAL AND POLY OPENS AND SHORTS
  2. MISSING OR EXTRA FIELD OXIDE
  3. MISSING CONTACTS AND VIAS
  4. DIELECTRIC DEFECTS - PIN HOLES, ETC.
  5. JUNCTION LEAKAGE

LINE MONITOR TEST SITE

- STAND ALONE MASK SET WHICH IS PERIODICITY PROCESSED THROUGH THE LINE.
- IS A LARGE ARRAY CIRCUIT LIKE A DRAM, SRAM, OR ROM WHICH HAVE LARGE CRITICAL AREAS.
- USES COMPUTER MANIPULATION OF THE TEST DATA TO GET BIT FAIL MAPS WHICH LOCATES THE FAILING BITS PHYSICALLY AND GIVES AN INDICATION OF THE TYPE OF DEFECT.
- VISUAL INSPECTION AND DELAYERING TECHNIQUES ARE EMPLOYED TO IDENTIFIED THE ACTUAL DEFECT.
- GIVES TOTAL PHOTO LIMITED YIELD (PLY) WHICH CAN BE COMPARED TO IN-LINE PLY.

YIELDS

- PARAMETRIC
- CIRCUIT LIMITED
- TEST
- MASK
- DEFECT - RANDOM AND NON-RANDOM

MANUFACTURING CONSIDERATIONS

E. R. Wolfe

Texas Instruments

ADVANCED BIPOLAR
PRELIMINARY PRODUCT FLOW

FLOW	SUCCESS KEYS/LIMITATIONS
O PROCESSED WAFERS	DEFECT DENSITY · SPEED · POWER PARAMETER
T SAMPLE PROBE	AUTOMATIC PROCESS CONTROL DATA FEEDBACK
T MULTIPROBE	UTILIZING BUILD-IN, SELF-TEST FEATURES WHERE AVAILABLE
M QC MONITOR	
O GEB INVENTORY	
O SAW	
O BREAK	

CONTINUED ON PAGE 2

O = OPERATION T = TEST Q = QC INSPECTION
I = INSPECTION M = QC MONITOR C = CSI INSPECTION
S = SCREEN

TEXAS INSTRUMENTS

ADVANCED BIPOLAR
PRELIMINARY PRODUCT FLOW - PAGE 2

FLOW	SUCCESS KEYS/LIMITATIONS
O SORT	
O CLEAN	
O LOAD INTO CARRIERS	
I INSPECT	REDUCE TO GROSS DEFECT CRITERIA ONLY
Q QC INSPECT	REDUCE TO GROSS DEFECT CRITERIA ONLY
O SEM AS REQUIRED	SEM HAS REDUCED VALUE AS INSPECTION TOOL WITH THREE LEVEL METAL
O INVENTORY	

CONTINUED ON PAGE 3

O = OPERATION T = TEST Q = QC INSPECTION
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S = SCREEN

TEXAS INSTRUMENTS

ADVANCED BIPOLAR
PRELIMINARY PRODUCT FLOW - PAGE 3

FLOW	SUCCESS KEYS/LIMITATIONS
O PACKAGE, PREFORM CLEAN	
O DIE ATTACH	
M QC MONITOR	
O WIRE BOND	MAY HAVE BOTH GOLD AND ALUMINUM BONDING
M QC MONITOR	
O 100% NON DESTRUCTIVE BOND PULL (CLASS S ONLY)	MAY DAMAGE WIRES ON HIGH PIN COUNT DEVICES
O PRE-SEAL CLEAN	
O PRE-SEAL INSPECT	INSPECT FOR ASSEMBLY RELATED DEFECTS ONLY. ADD CRITERIA FOR DOWN-BONDS, UP-BONDS

CONTINUED ON PAGE 4

O = OPERATION T = TEST Q = QC INSPECTION
I = INSPECTION M = QC MONITOR C = CSI INSPECTION
S = SCREEN

TEXAS INSTRUMENTS

ADVANCED BIPOLAR
PRELIMINARY PRODUCT FLOW - PAGE 4

FLOW	SUCCESS KEYS/LIMITATIONS
Q QC INSPECT	ASSEMBLY RELATED DEFECTS ONLY; ADD CRITERIA FOR DOWN-BONDS, UP-BONDS
C CSI INSPECT AS REQUIRED	ASSEMBLY RELATED DEFECTS ONLY; ADD CRITERIA FOR DOWN-BONDS, UP-BONDS
O LID CLEAN	
O SEAL	
M QC MONITOR	
O SYMBOLIZE	
O SYMBOLIZATION BAKE	

CONTINUED ON PAGE 5

O = OPERATION T = TEST Q = QC INSPECTION
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S = SCREEN

TEXAS INSTRUMENTS

ADVANCED BIPOLAR
PRELIMINARY PRODUCT FLOW - PAGE 5

FLOW	SUCCESS KEYS/LIMITATIONS
M QC SYMBOLIZE MONITOR	
S STABILIZATION BAKE	
S TEMP CYCLE	
S CONSTANT ACCELERATION	
S PIND (CLASS S ONLY)	
O LOAD INTO IC PACKAGE CARRIERS	

CONTINUED ON PAGE 6

O = OPERATION T = TEST Q = QC INSPECTION
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S = SCREEN

TEXAS INSTRUMENTS

ADVANCED BIPOLAR
PRELIMINARY PRODUCT FLOW - 6

FLOW	SUCCESS KEYS/LIMITATIONS
Q QC DOCUMENTATION CHECK	
O SERIALIZATION/SEM MARK (AS APPLICABLE)	
O SERIALIZATION BAKE	
M QC SERIALIZATION MONITOR	

CONTINUED ON PAGE 7

O = OPERATION T = TEST Q = QC INSPECTION
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S = SCREEN

TEXAS INSTRUMENTS

ADVANCED BIPOLAR

PRELIMINARY PRODUCT FLOW - PAGE 7

	FLOW	SUCCESS KEYS/LIMITATIONS
T	FINE BURN-IN TEST	FIXTURING FOR JUNCTION TEMP CONTROL, UTILIZING BUILT-IN, SELF-TEST FEATURES (WHERE AVAILABLE)
S	BURN-IN	FIXTURING FOR JUNCTION TEMP CONTROL
T	POST BURN-IN TEST	FIXTURING FOR JUNCTION TEMP CONTROL, UTILIZING BUILT-IN, SELF-TEST FEATURES (WHERE AVAILABLE)
O	BURN-IN PDA (AS APPLICABLE)	
O	FINE LEAK (CLASS S ONLY)	
O	GROSS LEAK (CLASS S ONLY)	

CONTINUED ON PAGE 8

O = OPERATION T = TEST Q = QC INSPECTION
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S = SCREEN

TEXAS INSTRUMENTS

WAFER PROCESSING

OBJECTIVE. TO GENERATE AS MANY GOOD ELECTRICAL CHIPS PER WAFER AS POSSIBLE WHICH WILL OPERATE RELIABLY IN THE INTENDED APPLICATION.

AREAS OF CONCENTRATION

- DEFECT DENSITY
  - QUALITY AND CLEANLINESS OF TOOLING
  - CLEANLINESS OF EQUIPMENT AND FACILITIES
  - CARE AND ATTENTION BY PERSONNEL
  - DEFECTIVES FAIL TO PASS FUNCTIONAL TEST AT MULTIPROBE
- PROCESS REPEATABILITY
  - EQUIPMENT MAINTENANCE
  - CONSISTENCY OF OPERATORS
  - PRIMARY CONTROL IS IN-LINE TESTS AND INSPECTIONS
  - SECONDARY CONTROL IS AT SAMPLE PROBE (FEEDBACK LOOP)
  - DEFECTIVES GENERALLY FAIL TO PASS DC AND AC PARAMETERS

TEXAS INSTRUMENTS

ADVANCED BIPOLAR

PRELIMINARY PRODUCT FLOW - PAGE 8

	FLOW	SUCCESS KEYS/LIMITATIONS
T	+175°C (JUNCTION) ELECTRICAL	FIXTURING FOR JUNCTION TEMP CONTROL, UTILIZING BUILT-IN, SELF-TEST FEATURES (WHERE AVAILABLE)
T	-55°C (JUNCTION) ELECTRICAL	FIXTURING FOR JUNCTION TEMP CONTROL, UTILIZING BUILT-IN, SELF-TEST FEATURES (WHERE AVAILABLE)
S	X-RAY	
O	CULL X-RAY REJECTS	
O	EXTERNAL VISUAL	
Q	QC VISUAL AND MECHANICAL INSPECTION AND DATA REVIEW	

O = OPERATION T = TEST Q = QC INSPECTION
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S = SCREEN

TEXAS INSTRUMENTS

WAFER PROBE

OBJECTIVE. (1) SELECT BY TEST THE GOOD ELECTRICAL CHIPS ON EACH WAFER. (2) COLLECT PROCESS RELATED DATA WHICH WILL RESULT IN IMPROVEMENTS IN YIELD AND QUALITY OF FUTURE WAFERS PROCESSED.

- SAMPLE PROBE

  TEST STRIPS SURROUND EACH CHIP ON EACH WAFER. STRIPS CONTAIN.
  - PHOTORESIST SIZING VERNIERS FOR EACH LEVEL
  - WAFER STEPPING TARGET FOR AUTO ALIGNMENT OF INTERLEVEL PHOTORESIST STEP
    - GLOBAL TARGETS FOR CROSS ALIGNMENT
    - STEP ADJUST TARGETS FOR FINE ADJUST
  - TEST STRUCTURES FOR MEASURING ELECTRICAL PROCESS COMPONENT PLAN
    - RESISTOR SHEETS
    - DUP SHEETS
    - RING OSCILLATORS
    - HFE TRANSISTORS
    - BREAKDOWN VOLTAGES
    - LEAKAGES
    - VIA RESISTANCE
    - THRESHOLDS

DATA IS COLLECTED, COLLATED, REDUCED FOR FEEDBACK LOOP CONTROL OF PROCESSES

- MULTIPROBE
  - PLAN TO USE SELF-TEST FEATURE OF EACH CHIP FOR HIGH CONFIDENCE FUNCTIONAL MODE EXERCISING (HFE - TPS)
  - WILL ENABLE PROBING WITH VERY FEW PINS (10 OR LESS)
  - WILL SAMPLE DC CHARACTERISTICS (1 OR 4 PINS)
  - WILL TEST AT SPEED IF POSSIBLE (SPECIAL PROBE CARDS)
  - MOST OF DC AND AC SCREENING AFTER ASSEMBLY
  - ULTIMATELY PLAN TO CORRELATE MULTIPROBE YIELD WITH SAMPLE PROBE DATA

TEXAS INSTRUMENTS

WAFER PROCESSING (CONTINUED)

- PRIMARY CONCERN IS IN CONTROLLING THE SPEED . POWER RELATED PARAMETERS
- STTL/STL
  1. HIGH SHEET RESISTORS - 1st ORDER - MEASURE RESISTORS
  2. SCHOTTKY DIODE LEAKAGE - 1st ORDER - MEASURE DIODE V_R, V_F
  3. COLLECTOR SUBSTRATE CAPACITANCE - 2nd ORDER - BV COLL-SUBSTRATE
  4. MILLER CAPACITANCE - 2nd ORDER - BV COLL-BASE
  5. BASE-EMITTER CAPACITANCE - 3rd ORDER - EMITTER SHEET
  6. HFE - 3rd ORDER - MEASURE TRANSISTORS

TEXAS INSTRUMENTS

WAFER PREP

OBJECTIVE TO SEPARATE AND SORT CHIPS FOR FURTHER PROCESSING

- WAFER PREP IS STRAIGHTFORWARD IN THE SEPARATION AND SORTING OF ELECTRICAL PRE-SELECTIONS FROM MULTIPROBE.
- THE FEATURE SIZE, COMPONENT COMPLEXITY, AND COMPLEX LAYERING OF THE ADVANCED BIPOLAR DEVICES REQUIRE DRASTIC CHANGES IN THE VISUAL INSPECTION.
- THE INSPECTOR WILL SEE THE FOLLOWING WHEN LOOKING AT AN ADVANCED BIPOLAR CHIP:
  - A NITRIDE PASSIVATION COVERING THE THIRD (POWER-GROUND) LAYER OF METAL.
  - THE THIRD LEVEL OF METAL WILL APPEAR TO COVER VIRTUALLY THE ENTIRE CHIP.
  - THERE WILL BE ONLY THE OUTLINE OF OTHER LAYERS OF METAL AND OXIDE, UNDER THE POWER BUSES.
- AT BEST WE WILL BE ABLE TO VISUALLY SCREEN
  - DIRT OR SURFACE CONTAMINATION FOR RECLEAN OR SCRAP.
  - CRACKS, CHIPS, SCRATCHES OR OTHER ANOMOLOUS DISCONTINUITIES IN THE PASSIVATION.
  - CRACKS OR CHIPS RESULTING FROM SCRIBE (SAW) WHICH EXTEND INTO THE ACTIVE REGION OF THE CHIP.

TEXAS INSTRUMENTS

PACKAGE ASSEMBLY

OBJECTIVE: TO PACKAGE THE CHIP FOR IT'S INTENDED APPLICATION SO THAT RELIABLE FUNCTION CAN BE EXPECTED.

- THE MANUFACTURING FLOW (INCLUDING 100% PROCESSING) IS STRAIGHTFORWARD WITH NO PROBLEMS ANTICIPATED EXCEPT WITH PRE-SEAL INSPECTION.

- VISUAL INSPECTION FOR ASSEMBLY RELATED DEFECTS SHOULD BE STRAIGHTFORWARD WITH THE EXCEPTION OF BOND-DOWNS AND BOND-UPS.
  - A BOND-DOWN IS A BOND WHICH ATTACHES A PAD FROM THE CHIP TO THE SUBSTRATE OF THE PACKAGE.
  - A BOND-UP IS A BOND WHICH ATTACHES THE PACKAGE SUBSTRATE TO A PACKAGE PIN.

BECAUSE OF THE SHARP BEND REQUIRED TO BOND DOWN OR UP, IT IS ANTICIPATED THAT GOLD THERMOCOMPRESSION BONDING WILL BE USED FOR THESE PINS. THIS MAY RESULT IN DEVICES WITH BOTH ALUMINUM AND GOLD BONDING PROCEDURES.

- A CHIP RELATED INSPECTION WILL BE NO MORE ACHIEVABLE AT PRE-SEAL THAN AT WAFER PREP.

TEXAS INSTRUMENTS

TEST -- PROGRAMMING FOR TESTING

- EACH PROGRAM WILL CONTAIN THE FOLLOWING TEST SEGMENTS:
  - CONTINUITY
  - FUNCTIONAL
  - DC PARAMETRICS
  - AC PARAMETRICS

- AC TESTING WILL BE LABORIOUS FOR:
  - PROP DELAYS
  - SET-UP TIMES
  - HOLD TIMES
  - CLOCK DUTY CYCLE
  - 100's, EVEN 1,000's OF TESTS REQUIRED FOR COMPLETE AC
  - PROGRAMMING CAPABILITY IS 1-2 TESTS/DAY/DEVICE
  - PLAN TO DO CRITICAL PATH ANALYSIS IN CONJUNCTION WITH EMULATORS
  - PERFORM AC TESTS ON CRITICAL PATHS ONLY

TEXAS INSTRUMENTS

TEST

OBJECTIVE: TO ASSURE THAT THE IC MEETS ALL ELECTRICAL SPECIFICATIONS. TO ASSURE THAT THE IC WILL FUNCTION RELIABLY IN IT'S INTENDED APPLICATION.

- AREAS OF CONCERN
  - SPECIFYING THE ICs IN A WAY WHICH WILL FORCE USERS TO APPLY THE DEVICES RESPONSIBLY.
    - 2W-3W POWER - CHIP CARRIER PACKAGES ARE SMALL
    - SPECIFY MAX JUNCTION TEMPERATURE -- OR,
    - SPECIFY MAX CASE TEMPERATURE
  - CONTROLLING JUNCTION TEMPERATURE OF ICs UNDER TEST
    - +125°C +/- 3°C JUNCTION
    - +85°C +/- 5°C JUNCTION
    - -55°C +/- 5°C JUNCTION
  - CONTROLLING THE JUNCTION TEMPERATURE DURING BURN-IN
  - ACHIEVING AN ACCEPTABLE LEVEL OF AC TEST WITH REASONABLE LEVEL OF TEST PROGRAM GENERATION EFFORT

TEXAS INSTRUMENTS

PACK AND SHIP

OBJECTIVE: TO ASSURE THAT THE PRODUCT IS READY FOR SHIPMENT AND TO PACK THE ICs FOR SHIPMENT.

THIS PORTION OF THE FLOW IS STRAIGHTFORWARD AND NO PROBLEM IS ANTICIPATED IN THIS AREA INCLUDING FINAL EXTERNAL VISUAL.

TEXAS INSTRUMENTS

TEST -- THERMAL IMPEDANCE

- INNOVATIVE METHODOLOGY MUST BE DEVISED TO PROVIDE CONTROL OF JUNCTION TEMPERATURE DURING ELECTRICAL TESTING AND BURN-IN. LARGE HEATSINK ON PACKAGE BOTTOM OR LIQUID IMMERSION WILL BE REQUIRED.

- RELIABILITY VERIFICATION IS TOTALLY DEPENDENT UPON METHODOLOGY USED FOR OPERATING LIFE.

TEXAS INSTRUMENTS

ADVANCED BIPOLAR PRODUCT
GENERAL FLOW -- IC PRODUCTION

MANUFACTURING OPERATION	TESTING TO BE PERFORMED
WAFER PROCESSING	✓ IN-LINE PROCESSING CONTROL
WAFER PROBE	✓ SAMPLE PROBE ✓ MULTIPROBE
WAFER PREP	= VISUAL INSPECTION = SEM
PACKAGE ASSEMBLY AND 100% PROCESSING	= VISUAL INSPECTION = 100% NON-DESTRUCTIVE BOND PULL
IC TEST	= STRESS TESTING = ELECTRICAL TESTING ✓ X-RAY
PACK AND SHIP	✓ VISUAL INSPECTION

TEXAS INSTRUMENTS

SUMMARY

- OF 32 PROCESS STEPS, ONLY 14 APPEAR TO HAVE UNIQUE ADVANCED BIPOLAR PRODUCT INTEREST
- ONLY 9 COMMENTS HAVE BEEN MADE (25 REPETITIONS)
  - KEYS TO SUCCESSFUL PROCESSING
    - CONTROLLING DEFECT DENSITY (1)
    - CONTROLLING SPEED POWER PARAMETERS (1)
    - SETTING UP AN AUTOMATIC FEEDBACK OF PROCESS DATA FROM SAMPLE PROBE (1)
    - CONTROLLING (AND SPECIFYING) JUNCTION TEMPERATURE AT TEST, BURN-IN (5)
    - MAKING GOOD USE OF BUILT-IN SELF-TEST FEATURES (WHERE AVAILABLE) TO PROVIDE QUALITY TESTING (6)
  - LIMITATIONS OF ADVANCED BIPOLAR PRODUCT WITH RESPECT TO CURRENT HI-REL PROCESSING SPECS
    - 100K WAFER INSPECT, 100K PRECAP; 50K AT WAFER INSPECT (6)
    - 100% NON-DESTRUCTIVE BOND PULL MAY DAMAGE WIRES (1)
  - COMMENTARY ONLY
    - X-RAY NEEDS TO BE TIED TO CHIP POWER/PACKAGE THERMAL CAPABILITY. SHOULD BE REQUIREMENT FOR CERTAIN ICs AT ALL MIL-S/JAN LEVELS (1)
    - PROBABLY SHOULD ADD BOND-UP, BOND-DOWN CRITERIA TO PRE-SEAL INSPECT (3)

(1) REPETITIONS OF COMMENTS FROM PROCESS FLOW

TECHNOLOGY INSERTION FOR SPACE APPLICATIONS

Kirk D. Lemon Jr.
Group Manager - Space Business Unit
National Semiconductor Corporation

The quality of new technologies and the ability to insert them into space applications is going to be directly related to how effectively the current standardized qualification system is adapted to VLSI characteristics. We are emerging from a time when the military was a large portion of the semiconductor market, where time and money did not adversely affect the rigorous qualification of microelectronic component. This is not true today and will not be true for the "silicon systems" of tomorrow.

The areas of concern can be related to the current methods of MIL-STD-883 and the requirements of MIL-M-38510 and MIL-STD-976. Especially sensitive areas are that of visual inspection, testability, test equipment, radiation testing, and the new high density packages needed to accomodate these technologies. In space programs where reliability is the key measure of success and where simulation testing is so time consuming, it requires that complete control of the processes involved be established.

The methods by which to change the existing system to accomodate these new products are still undefined but it warrants investigation into several areas. Some consideration should be given to establish accepted safety factors, study correlation in detail, develop better test hardware, provide access to radiation test facilities, use as much past experiences as possible, and combine the expertise of all companies to help define the best possible solutions. All of this effort should be focused on the main objective of dramatically improving our space systems.

Mission Assurance 1983

TECHNOLOGY INSERTION

FOR

SPACE APPLICATIONS

KIRK LEMON
JUNE 8, 1983

National Semiconductor

Mission Assurance 1983

SPACE PART EVOLUTION

1ST - COMMERCIAL
2ND - MILITARY TEMPERATURE
3RD - 883B
4TH - 38510B
5TH - CLASS "S"

National Semiconductor

Mission Assurance 1983

HISTORY OF SPACE PARTS

- GROWTH
- LIFE CYCLE
- EVOLUTION
- TESTING

National Semiconductor

Mission Assurance 1983

TESTING CHANGES

PRODUCT	TESTER COST	PROGRAM COST
DISCRETE	<$10,000	-
GATES	$75,000	$2,500
8-BIT CPU	$500,000	$50,000
16-BIT CPU	$1,000,000+	$125,000+
VHSIC	?	?

National Semiconductor

Mission Assurance 1983

MARKET GROWTH COMPARISON

	1980	1990
COMMERCIAL	$21.4B	$89.2B
MILITARY	$ .7B	$ 2.0B
SPACE	$ .3B	$ 1.2B

Mission Assurance 1983

WHAT WE ARE LOOKING AT FOR TOMORROW

"SYSTEMS ON SILICON"

National Semiconductor

Mission Assurance 1983

TECHNOLOGY LIFE CYCLE

1955 - DISCRETES > 30 YEARS
1965 - GATES/FLOPS 20 YEARS
1975 - MICROPROCESSORS 10 YEARS
1985 - COMPLEX VLSI ?

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AREAS OF CONCERN

- INSPECTION
- TESTABILITY
- EQUIPMENT
- RADIATION
- PACKAGING

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Mission Assurance 1983

VISUAL INSPECTION

- WAFER GATING
- SECOND OPTICAL
- THIRD OPTICAL
- CUSTOMER PRE-SEAL

IMPROVE SEM CAPABILITY AND TECHNIQUES

National Semiconductor

Mission Assurance 1983

PACKAGING

- LEADLESS CHIP CARRIER
- PIN GRID
- LEADED FLAT PACKAGE
- HERMETIC TAPE PAK

DEFINE STANDARD TYPES FOR APPLICATIONS

National Semiconductor

Mission Assurance 1983

TESTIBILITY

- FUNCTIONALITY, AC, READ AND RECORD
- PARTITIONING
- BUILT IN TEST
- TEST CHIPS OR WAFERS

ESTABLISH CORRELATION - CAN'T TEST EVERYTHING

National Semiconductor

Mission Assurance 1983

AREAS FOR CONSIDERATION

- ESTABLISH SAFETY FACTORS
- STUDY CORRELATION
- DEVELOP TEST HARDWARE
- PROVIDE RADIATION TEST FACILITIES
- BUILD ON PAST EXPERIENCE
- COMBINE EXPERTISE ACROSS COMPANIES

National Semiconductor

Mission Assurance 1983

TEST EQUIPMENT

- ELECTRICAL TESTERS
- BURN-IN EQUIPMENT
- TEST HANDLERS
- MAINTENANCE AND CALIBRATION

DEVELOP VOLUME PRODUCTION CAPABILITY

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Mission Assurance 1983

OVERALL OBJECTIVE IS TO:

IMPROVE RELIABILITY WHILE ADDING CAPABILITY TO SPACE SYSTEMS

National Semiconductor

Mission Assurance 1983

RADIATION TESTING

- TOTAL DOSE
- UPSET - PERMANENT/TRANSCIENT
- NEUTRON
- SINGLE PARTICLE

PROVIDE BIASED, IN-SITE TESTING

National Semiconductor

SUMMARY OF ISSUES AND RECOMMENDATIONS

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Space Requirements

Issue

Lack of standardization of government space requirements. Ineffective implementation of standardized requirements.

Recommendations

Establish commonality between Air Force and NASA. Enforce current standardization policy.

a) Customers (e.g., NASA and AF) have not standardized parts management and technical requirements for Space System. This has resulted in a proliferation of requirements on primes and subs and nonstandardization of part requirements. Space parts requirements should be standardized.

b) Variation in standardization requirements, i.e., screening requirements inhibit advance testing and stocking of devices for multiple space programs. It is recommended that requirements across programs be standardized and tailoring of detail requirements for each program user be disallowed.

c) The monitored line is nonstandard and not compatible with JAN Class S parts. The differences between the monitored line and JAN Class S parts should be resolved.

Suggested OPR

Air Force/NASA

2. Multiple Specifications for Identical Parts

Issue

There are multiple specifications [e.g., Specification Control Drawings (SCDs)] for identical part types for space applications.

Recommendations

Identify an agent and establish procedures. Commonize approach to a single parts system.

a) The continued use of a variety of SCDs by the various space projects to procure space quality parts adds significantly to the overall cost to the Government. A means to afford standardization of such SCDs to some central requirement is needed. Agencies should adopt the policy requiring SCDs be prepared as DESC selected item drawings, for example, and coordinated through a central review to preclude specification duplication or reduction of space quality requirements without waiver. Space quality SCDs and central review activity functions should be developed.

b) Avoid specification duplication in the specifying and procurement of upgraded JAN Class B or JAN Class B or JAN Class S equivalent parts. Have a specification format which must be used when JAN Class S cannot be obtained. This could be an appendix to MIL-STD-1547 and would force each user to have the same specification initially.

c) There is a need for Qualified Products List (QPL) JAN Class S electromechanical and passive parts. JAN Class S parts program should be expanded to include electromechanical and passive parts.

Suggested OPR

DESC RADC Space Division NASA

3. Lead Times

Issue

Lead times on space quality parts are usually not compatible with program schedules. Identify those measures that can be implemented to make lead time congruent with program schedule with no impact on product quality.

Recommendations

JAN Class S and "S equivalent" delivery times are such that they hinder use on many programs. Also, the cost differential between JAN S and B classes is such that many programs such as Avionics are discouraged from using JAN Class S, thus hindering efficiencies attainable through greater volume.

Determine alternatives to reduce the cost and delivery times of JAN Class S while retaining most important quality aspects of JAN Class S. For example:

a) Revise Wafer Lot Acceptance Criteria.

b) Revise Quality Conformance Inspections (QCI) to be similar to JAN Class B instead of required on every lot.

4. Anticipated Use Requirements

Issue

Parts manufacturers are not provided adequate insight into anticipated usage requirements of space quality parts. Manufacturers complain they do not see anticipated market, i.e., what parts and quantities will be ordered in the near future. Parts suppliers do not have sufficient visibility of JAN Class S market to risk costs to get on the Qualified Products List (QPL).

Recommendations

Establish and implement space part usage forecasts and provide to part manufacturers.

a) A parts industry association undertake the task of obtaining appropriate data and providing forecasts to parts manufacturers.

b) Air Force and NASA should have a standard usage list. Contractors should provide manufacturers lists of what types and quantity will be used on near term buys.

c) Government consolidate gross estimate data (e.g., new starts and program dollar estimate).

d) Reduce cost risks to get on QPL.

5. Small Quantity Purchases

Issue

Industry and Government practices are not responsive to small quantity purchases of space quality parts.

Recommendations

Develop practices to accommodate small purchase requirements, e.g., establish a stocking bank and consolidate purchases. AF/NASA provide funds for a contractor/agent/depot to procure, stock, and sell JAN Class S parts to contractors with small quantity needs.

Some uses of JAN Class S parts have shown them to be more cost effective than "S equivalent parts" but several circumstances still make procurement difficult, e.g., low volume, required high performance and quality, long delivery lead times, high front-end costs, proliferation of cheap "S look-alike" parts and conflicts concerning source inspection.

a) Reassess first buy and lot-related front-end costs.

b) Minimize substitution of JAN Class S look-alike parts.

c) Encourage large project joint procurements with the transfer of residual to a central supply.

d) Space programs should be authorized adequate lead time and funding to procure JAN Class S parts.

e) Consolidate cost data for distribution to programs/project managers.

6. Cost Effective Part Qualification Requirements

Issue

Current part qualification requirements are not cost effective for low usage complex devices. Present JAN Class S Quality Conformance Inspection (QCI) requirements may cause 10 week delay in delivery and cost $3K to $6K per lot. JAN Class S wafer lot acceptance causes up to 14 weeks delay in delivery.

Recommendations

Consider limited usage qualification program where appropriate.

a) Modify present QCI requirements to reduce to JAN Class B requirements. Reason - reduce manufacturers deliveries by 10 weeks and effect a cost savings of approximately $3K per lot.

b) Revise wafer lot acceptance for limited usage JAN Class S to a scanning electron microscope (SEM) inspection only. Reason-reduce manufacturers deliveries by up to 14 weeks.

7. Prompt Resolution of Space Quality Requirements

Issue

Advances in high technology parts require prompt resolution of space quality requirements. Current concerns include packaging, testability, inspectability, and radiation hardness. Current qualification requirements are too stringent and costly for low usage complex devices. High density designs promote package proliferation. No standards exist for high density wafer fabrication process monitors (KERF) or test chips (defect monitors). Available test equipment for complex devices is limited. Junction temperature control is critical in high density design. Radiation effects on various technologies are not understood by manufacturers, nor are imposed as design requirements. High power (100x) die visual (883/2010) is ineffective for Large Scale Qualification Integration (LSI) densities. Current MIL-SPEC screening may be inappropriate for high density designs.

a) Consider limited usage qualification requirements.

b) Create standardization system for packaging prior to use in space applications.

c) Define fundamental requirements and uniformity criteria, and evaluate as a possible qualification technique.

d) Define testability requirements for complex devices which are compatible with existing equipment.

e) Establish power density/thermal package characteristic requirements to ensure proper control. Develop burn-in and test hardware to control case temperatures, or consider reduced application operating temperature.

f) Publish known radiation effects by technology, with recommended design derating criteria/precautions such that designers can consider these criteria and simple solutions at initial design.

g) Establish in-process control standards in wafer fabrication, and rely more heavily on electrical testing.

h) Reevaluate cost effectiveness, reliability, and risk tradeoff factors on test factors such as wafer lot acceptance, nondestruct bond pull, Quality Conformance Inspection (QCI), and critical path AC tests. Incorporate in 38510/883.

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