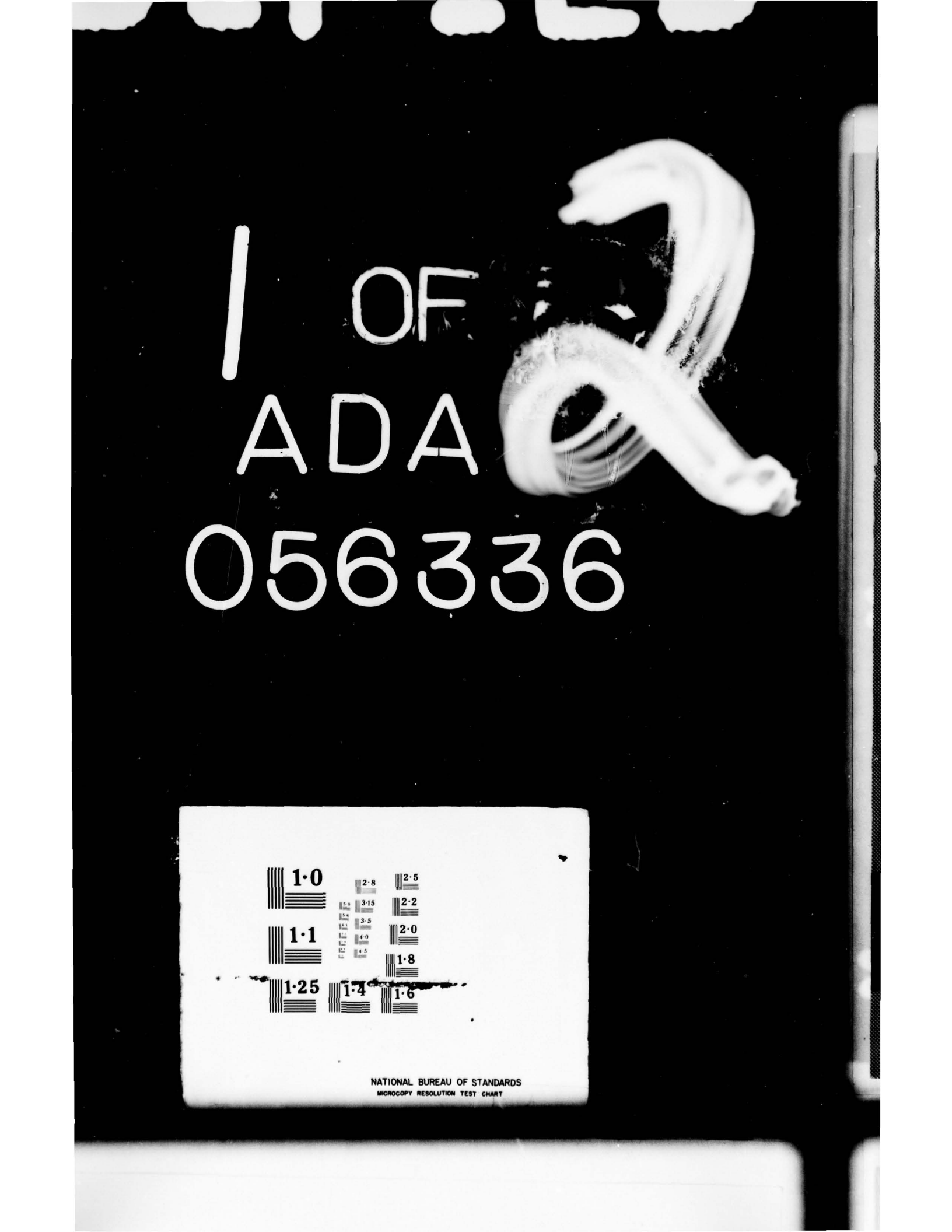
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March 1978

Human Factors Laboratory
Naval Training Equipment Center
Orlando, Florida 32813

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Technical Report: NAVTRAEQUIPCEN IH-301

ATE: BANE OR BLESSING FOR THE TECHNICIAN?

William J. King, Ph.D. and
James S. Duva
Human Factors Laboratory

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Approved:

JAMES S. DUVA
Head, Human Factors Laboratory

DR. J. F. HARVEY
Director
Research and Technology Department

NAVAL TRAINING EQUIPMENT CENTER
ORLANDO, FLORIDA
32813

LEVEL II

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FOREWORD

Operator and technician training for ATE (Automatic Test Equipment) is emerging as a rather critical and sensitive tri-service problem area. A conference on such technical issues has quite far-ranging implications, and, therefore, requires prodigious amounts of cooperation and assistance from many types of professional people to make it all happen.

It is, indeed, a pleasure to take this opportunity to thank all who made this conference possible--CDR Paul Chatelier, Naval Air Systems Command (AIR-340F), who sponsored it; the professional personnel from the four services who actively participated; and Nancy Frazier and Jim Cowart of Telcom Systems, Inc., who did so much of the hard work associated with the overall effort.

The Editors

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Continuing its leadership of maintenance training R&D, the Human Factors Laboratory of the Naval Training Equipment Center, on 3-5 May 1977, convened the Second Biennial Conference on Maintenance Training and Aiding with the title: "ATE: Bane or Blessing for the Technician?" Automatic Test Equipment (ATE) has been put forward as an aid to the technician, and it was the purpose of this conference to determine the extent to which this objective has been achieved.

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Because the design and development of cost-effective training systems requires the laboratory to keep abreast of critical training problem areas in the Fleet, the Naval Air Systems Command (AIR 340F, CDR Paul Chaterlier) directed in 1976 that a Technical Advisory Group (TAG) for maintenance training be established with objectives to:

- Establish a formal medium for the exchange of technical information through a series of biennial conferences and semiannual meetings to provide a broad interchange of maintenance research ideas.

- Plan and coordinate the two key areas of Maintenance Simulation and Training Devices, and Human Maintenance and Troubleshooting Behavior.

It was under the TAG charter that the present conference on Automatic Test Equipment was called. Representation was fully tri-service both in terms of participants and attendees. As with the First Biennial Conference, the present invited participants had the advantage of having read all the papers prior to the meeting. Because of this familiarity with the technical content, a real exchange of technical data and knowledge was possible. Each participant had been asked to include some coverage of the following three elements of general interest.

- What is the author's involvement with ATE?

- What are the potential payoffs and penalties of ATE?

- How does the technician use and interact with ATE?

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ATE: BANE OR BLESSING FOR THE TECHNICIAN?

AN OVERVIEW

THE FIRST BIENNIAL CONFERENCE

In April 1975, the Human Factors Laboratory of the Naval Training Equipment Center convened a workshop entitled, "New Concepts in Maintenance Training Research". The purposes of this workshop were to gather together Tri-Service and Industry Technical Training representatives to exchange information and ideas relating to new developments in maintenance training technology, and to develop guidelines for future research efforts which would lead to more effective maintenance training at less cost. An additional goal was to reduce the amount of research duplication among the Services by continuing this exchange of information on a regular basis.

Over 70 persons attended this workshop, and it was established that maintenance training concepts were undergoing change due to increases in weapon system costs, numbers, complexity, and modification requirements. While DOD was spending one-fourth of its annual budget on maintenance, less than one percent was being spent on maintenance training research. Training costs had to be reduced, and the use of Actual Equipment Trainers (AETs) in training environments had to be at least partially replaced with some form of simulation. Discussions centered on two areas of simulation, 2D (computer-graphic or pictorial presentations) and 3D (software-induced hardware response to "hands-on" application). It was determined that the solution to the training problem would involve some combinations of AET, and simulation (2D and 3D).

Papers presented at this workshop generally addressed three areas of interest to maintenance training: technical publications, simulation, and computer-aided-instruction (CAI).

The discussions of technical publications progressed from the use of the tab manual technique for the previous 25 years to newer innovations including Job Performance Aids (JPAs) for preventive maintenance tasks and Functionally Oriented Maintenance Manuals (FOMMs) for corrective maintenance or troubleshooting.

It was determined that the use of simulation in maintenance training would not only provide cost savings but would also allow for a broader range of instruction in a safer manner resulting in a significant reduction in on-the-job training (OJT) requirements. Increasing costs and complexity of emerging systems, especially test equipment, precluded the use of AETs. Savings of up to 90% had been proved to be possible with the use of simulators rather than actual equipment with the advantages of greater fault insertion capability, easily accomplished modification procedures using software, better availability, and ensured safety to both the equipment and the trainee. "Hands-on" application is a must in maintenance training, and a combination of 2D and 3D simulation techniques provides the optimum means to effect this training.

User acceptance was recognized to be a critical element to the full implementation of simulation techniques. It was agreed that the instructors should be included in the design of simulation systems from the outset so that the advantages of cost savings, broader training capability, and effectiveness of instruction would be understood by the instructor communities.

It was generally agreed by all participants that the people involved in technical publications and in training device design should work more closely together to satisfy maintenance training objectives. Further, it was agreed that the exchange of information had been beneficial and should be continued on a regular basis.

In 1976, NAVAIRSYSCOM directed that a Technical Advisory Group (TAG) for maintenance training be established with objectives to:

- Establish a formal medium for the exchange of technical information through a series of biennial conferences and semiannual meetings to provide a broad interchange of maintenance training research ideas.
- Plan and coordinate the two key areas of Maintenance Simulation and Training Devices, and Human Maintenance and Troubleshooting Behavior.

THE SECOND BIENNIAL CONFERENCE

Under the TAG Charter, the Second Biennial Maintenance Training and Aiding Conference was convened with the theme being "ATE: Bane or Blessing for the Technician?"

This Second Biennial Conference was also well received by the 76 attendees from the military services and industry. Captain H. M. Walker from NAVMAT 04T gave an impressive keynote address which is included in this volume.

In the invitation for presentation of papers, three general questions were asked regarding Automatic Test Equipment.

- What is the author's involvement with ATE?
- What are the potential payoffs and penalties of ATE?
- How does the technician use and interact with ATE?

1. ATE in General

When addressing the subject of ATE, it should be realized that there are three means of testing operational weapon systems: man, built-in testing (BIT), and automatic stand-alone test equipment. The use of manual testing alone is no longer effective with modern complex systems. The amount of technical knowledge required, the time involved, and the rate of defective component return all dictate that some form of automatic testing must be utilized to augment manual methods. Automatic testing is accomplished by means of built-in-test capability, and for those systems too complex to accommodate BIT, by separate automatic testing systems.

Automatic test equipment usually functions in manual, semi-automatic, and automatic modes. The technician can often perform the required testing by manually stepping the ATE through the requisite test. In the automatic mode, however, the equipment being investigated is typically tested under fully automatic operation.

The amounts and types of ATE in the DOD inventory are practically innumerable. The Navy inventory is valued at 7 billion dollars with 500 million being expended annually for new acquisitions. Of this total amount of ATE, 50% is on-line BITE, and 50% is stand-alone equipment. Of the total dollars expended, one-half is for software acquisition.

In the Air Force, 700 million is expended annually. There are 470 different types of ATE in inventory; 3800 sets are on hand; and 80 sets are presently under procurement. ATE is now being used by the Air Force for all aircraft types in their inventory including the space shuttle.

The use of ATE in some form dates back to the early 50s for the Air Force and the early 60s for the Navy. Aviation equipment, especially at the intermediate level of maintenance, established the need initially. The original concept for ATE application was to allow a maximum number of units undergoing test (UUTs) to be serviced with a minimum amount of manning. As increasing amounts of test equipment began to be acquired, proliferation became and still is a problem establishing a need for effective management and maintenance of ATE with considerations for accurate inventories and accounting information. In the Navy, NAVAIR was the pioneer in the use of ATE.

Technician training problems began to emerge as ATE became more numerous and complex. Fewer technicians were required with implementation of ATE; however, a much higher skill level was necessary in order to maintain the systems. The complexity of the equipment being introduced had to be stabilized at a level compatible with the skill capability of the technicians. It became necessary to attack the proliferation problem associated with ATE by consolidation into general purpose and family functional areas in order to match the numbers of available technicians at appropriate skill levels. ATE acquisitions will be undergoing radical changes in the next 5 to 10 years to conform to these consolidation requirements.

It is becoming more and more necessary to provide a system to train technicians to maintain ATE without the use of costly operational equipment. Simulators are now being developed to satisfy this technician training problem.

In order to provide the management necessary to control ATE and its associated problems, NAVMAT 04T was established in August 1976 with additional responsibilities in areas of calibration and metrology. Inventories of ATE are being taken; locations of equipment are being determined; consolidations by type will take place; general purpose testing equipment will be utilized and procured where possible; technician training systems will be determined and developed; and Software Centers will be established for modifications in computer programs.

2. Potential Payoffs/Penalties

From the papers presented during the Conference, it is obvious that all services have realized the potential benefits of ATE as well as the problems generated from widespread application of the equipment.

In the Navy, aviation has been utilizing some form of ATE for the past 20 years including the following aircraft systems:

- AN/USM-429 - E2C Radar and F14A SRAs
- AN/USM-403 HATS - S3A SRAs
- ATS - Inertial platforms and electronics analog and digital testing
- DIMOTE - A7E/TA7C avionic units
- AN/USM 449-AA1550Q - P3C avionics units

The most well known system being utilized in aviation is VAST (Versatile Avionic Shop Test System). Studies were initiated on this system in 1960 with the goal of developing a computer-controlled group of general purpose stimulus generators and measurement instruments designed as independent Building Blocks (BBs) to automatically test sophisticated avionics equipment. The different types of BBs form a complex system; however, each one operates independently allowing for BBs to be added, temporarily removed, modified, or replaced without degrading system operation. A contract was awarded in 1968 to build the VAST system which was designated the AN/USM-247(V) and approved for service use in 1976. The A7E aircraft weapon systems were used as test development vehicles.

The system will provide intermediate and depot levels of maintenance and has a certain amount of built-in self test capability. VAST systems are now located at 15 shore bases and aboard 7 carriers for maintaining avionic systems for the F14A, S3A, and E2C aircraft. Benefits resulting from VAST development include:

- Fewer spare components required.
- Calibration capability is provided.
- Space requirements suitable for shipboard installation.
- Rapid and accurate testing is possible.
- Failed unit turnaround times are reduced.

The BBs comprising the VAST system are general purpose and can easily be adapted for future avionic systems. Many of the benefits expected to be achieved with ATE are realized with the introduction of this system including savings in costs, space, and resources. The only problem encountered with VAST implementation is that system maintenance requires significant upgrading of technician training.

Another system presently being developed by the Navy Metrology Engineering Center is the MECCA (Modular Equipped and Configured Calibrators and Analyzers). This system will be utilized to improve the calibration program by minimizing recurring calibration costs of over one million instruments presently in inventory.

The Air Force has also experienced extensive use of ATE including the following systems:

- Mobile Automatic Radiating Testers (MART) - B58, F106 Aircraft
- Versatile Automatic Test Equipment (VATE) - universal guidance and navigational systems of missiles and aircraft
- General Purpose Automatic Test Systems (GPATS) - designed for depot level usage on systems from C5, C141, F111, aircraft and the Titan and Minuteman ballistic missile systems.

Studies are being conducted by the Air Force to provide for all ATE to be logistically supported with common items by establishment of a new military standard. Inventories of existing types of ATE are being compiled to determine ineffective equipment prior to initiating new procurements. A contractor-supported specialized repair activity (SRA) is being investigated by the F111 System Program Office. This SRA has been operating since 1973 at an annual cost of approximately one million dollars.

The major result of the Army's efforts to implement ATE is the EQUATE system (Electronic Quality Assurance Automatic Test Equipment) which is general support in concept. The development of this system began in 1971 and has continued to be perfected until it now has the capability to support:

- Aviation electronic systems
- Microwave data links
- Fire control systems

- Automatic switching systems
- AM/FM field radios.

Maintainability was stressed during the development. Components can be repaired while the system is in operation. The system has self-calibration and automated self-test capabilities. Space requirements were also considered during the design phase. The system can be located in vans or confined shelters.

A study was conducted utilizing EQUATE vs manual testing methods on the electronic components of the Advanced Attack Helicopter. The results indicated that a 31% cost savings could be realized over a 10 year period with an operational effectiveness factor of 99% using ATE. The advantages to be realized by use of EQUATE are essentially comparable to those of the Navy VAST system. The major problem is also comparable in that effective technician training to operate and to maintain the system is a necessity.

The Army is also addressing a new approach aimed at improving technical manuals and the technician training process by integrating their development and use. The system is designated the AN/USM 410-ITDT (Integrated Technical Documentation and Training). In mid-1975 a committee was formed to improve this training and documentation process resulting in a recent draft military specification for preparation of ITDT. The materials will be included in Job Performance Manuals and Guides which will utilize fifth grade vocabulary in the text. Extensive use of graphics will accompany the manuals. The training is designed to be implemented at the unit level rather than at formal school sites. The courses will be designed to be compatible with the Training Extension Course hardware and software already in use throughout the Army.

The Army Air Mobility Research and Development Laboratory has been conducting research utilizing Logic Model test equipment for maintenance and training. The first LOG MOD Test Set was designed and built in 1976 to be used as a responsive diagnostic device. The skills required to operate the system equal that required to operate a hand-held calculator. LOG MODs can be designed for use with applications of electronic, electro-mechanical, and mechanical systems. The system will be utilized primarily for troubleshooting but with modifications could be used as a trainer. Other applications include design evaluations and technical manual storage.

While realizing the many benefits which are possible with the use of ATE, widespread implementation throughout all of the services has revealed many problem areas associated with the use of this equipment. By taking mutual advantage of successful individual efforts to effect solutions to these problems, all services will enjoy the potential benefits available while jointly resolving problem areas.

There is no doubt that ATE can do the job for which it was designed. The concept has been proved, and during the years to come, more extensive applications will be applied. An increasing amount of dollars will be expended on new equipment and extensive modifications will be effected on the ATE already on hand. Overall savings will be realized in maintenance efforts, logistic support requirements, and time. There are a number of areas to be considered to effect the most efficient and economical use of ATE including:

- Proliferation
- Self-test capability
- Design
- Weapon System Procurement Considerations
- Calibration
- Management
- Training.

As the numbers of ATE being utilized have increased, so have the different types of systems. Each type requires its own considerations in areas of logistic support, documentation, training of operators, and maintenance. This proliferation has become a major problem and must be controlled. Effective management is required for efficient utilization of this equipment. All services have initiated this management implementation, and ultimately, tri-service coordination will improve the efficiency of acquisition and operational implementation. All ATE must be inventoried, located, and grouped into functional areas of application. Equipment becoming obsolete or ineffective must be discarded or replaced so as to fit into existing functional ATE groupings or into a general purpose category. When functional groupings are determined, commonality has to be considered in all new acquisitions. As peculiar or special types of ATE become obsolete, maximum use of General Purpose ATE should be implemented. Eventually, testing

complexes should be functioning with a large variety of systems capable of being tested, and maintenance actions, modifications, or modular replacements effected when necessary without derogating the operation of the entire complex. These general purpose complexes would be capable of satisfying the testing requirements of all new weapon systems.

Approximately one half of the total cost of ATE is for software, either in new acquisitions or in modifications to existing systems. Significant savings could be realized by the establishment of Software Centers to service specific areas of responsibility. Effective implementation and operation of these Centers would preclude much of the contractor involvement in software generation and the associated costs. Again, this is a management function which ultimately will enhance efficiency.

Another consideration in optimizing the use of ATE is the effective use of BIT or self-test capabilities. Proper BIT expenditure has been determined to be approximately 10% of hardware acquisition costs. Studies have proved that BIT will save 33% of operations and support costs which are roughly 10 times the acquisition cost over a 20 year life cycle. Therefore, if an additional 10% of acquisition cost is allocated for BIT features at times of procurement, over 300% savings will be realized during life cycle operation. BIT provides for rapid detection, isolation, and replacement of failed components at the organizational level.

An important feature to be considered in ATE procurement is self-calibration. Present calibration turn-around-time is too lengthy. Normally, such procedures involve 30 to 75 days before the equipment is returned. If extensive repairs are required or critical parts needed, the cycle could take six months. Other factors affecting calibration turn-around-time include backlog and priority considerations for both parts and deploying units. Self-calibration features would serve to reduce the frequency of required calibrations and aid in maintaining instrument tolerances.

3. ATE/Technician Interaction

The introduction of ATE has also served to increase technician training requirements. Test equipment must also be tested and maintained. The high cost of ATE essentially precludes the use of actual equipment for training purposes. Factors other than cost which argue against the use of actual equipment for training operators and technicians are:

- Excessive "down" time
- Misuse of equipment by inexperienced personnel
- Limited fault insertion capability
- Low priority of modifications and parts
- Safety of equipment and trainees.
- Extensive OJT requirements.

Simulation has been established as the means to provide this training. The cost of typical simulation training systems approximate one-third that of the actual equipment. Simulators for ATE technician training are excellent vehicles for utilization of combinations of 2D and 3D simulation features as well as CAI with automated "feedback" capability.

The Navy has recently awarded a contract to develop preliminary data for fabricating a VAST simulator for Fleet use. This simulator will be in place for user evaluation and perfection in early 1979. The cost of procurement is approximately one-third that of comparably configured operational equipment. Other than cost, the advantages to be realized with this simulation training system are:

- Extensive malfunction simulation is possible.
- Modifications are easily accomplished by software input.
- Safety is assured for both the equipment and the trainee.
- There are no warmup requirements.
- Automation provides for record keeping, real-time evaluation objective instruction, and performance measurement.
- Operators as well as maintainers can be trained.
- Simplicity and reliability decrease the life cycle cost.
- OJT requirements are reduced.
- Required training manpower is reduced.

All of the effective features of 2D and 3D simulation as well as CAI will be incorporated in this training system.

The Air Force is also in the process of developing simulation training systems for ATE technicians. A prototype system is an automatic test station of the F111D for I-level training, specifically, the 6883 Converter/Flight Control Test Station designed to maintain five line Replaceable Units (LRUs).

The Air Force Human Resources Laboratory was tasked to develop this prototype ATE training system. The reasons for selection of this particular test system were: its representation of a complex, automatic, I-level test system; its continually low operational availability; and, its tasks were primarily procedural and readily adaptive to computer driven/monitored systems. The simulator was scheduled to be delivered to Lowry Air Force Base in late 1977 for evaluation. The simulator is capable of expansion in the same manner as is possible with an actual general purpose ATE complex. Three additional test stations can be added to the system in the future utilizing the existing computer. Update provisions and component replacement capabilities are provided. Maintenance of the simulator is made easier with features such as automated self-test, fault isolation, and daily software status check capabilities.

There is an established agreement that continuation of present trends in ATE procurement will create insurmountable technician problems in areas of training and retention. It is a fact that fewer personnel are required with application of ATE; however, those personnel needed to operate and maintain these systems must have a higher skill level than has ever been required. It has become necessary to alter the present procurement trends and limit the complexity and variety of test equipment by consolidation into related groups and emphasizing general purpose applications.

In this view, the complexity of test equipment should be limited to the abilities of supporting technicians so that the current requirement for contractor and civil service support can be reduced. When establishing training curricula, consideration should be given to the fact that even if "hands-off" test equipment becomes more of a reality, there still exists a 20 year inventory of previous systems which must be maintained and supported during the remainder of their life cycles.

Retention of trained technicians has to be included in future planning. The time consumed during the training process represents an investment for which intended benefits must be achieved. Losses of trained technicians to industry and unrelated fields due to inappropriate personnel assignment policies should be eliminated. Retention incentives should be improved; manning must be maintained at appropriate levels in critical skills; and the flow through the training pipeline has to be maintained at a sufficient level to satisfy present and projected operational needs.

Human actions are necessary to effectively utilize ATE. Man must be included in the loop to augment the functions of the machine, and the machine must be designed to accommodate man's interface. Thus, Human Factors need to be a prime consideration in the design of ATE and in the development of hands-on training required to maintain the fielded product.

For the latter task of maintenance training, the newly developed designs for maintenance trainers and simulators appear to hold considerable promise.

It should be noted that the facts and ideas presented herein reflect a general compilation of all the presentations at this conference. ATE can do the job and will continue to be procured in substantial quantities in future years. There are, however, problem areas to be investigated, especially in operator and technician training which are common to all services. Hopefully, steps will be taken to resolve these difficulties individually and in unison.

Dr. William J. King and
James S. Duva, Editors

KEYNOTE ADDRESS

CAPTAIN H. M. WALKER, USN
(MAT-04T)
DIRECTOR, TEST AND MONITORING SYSTEMS (TAMS) PROGRAM OFFICE
HEADQUARTERS, NAVAL MATERIAL COMMAND

When Bill King asked me to kick-off this conference, I took a quick look at my credentials and asked, "Why me?" Although I am an aeronautical maintenance officer by designation, I certainly can lay no claims to being an expert on training. But, like most naval officers who have tried to make things work on a ship at sea, I have had to do and make do with what I had at the time. This includes both men and machines. Most of the time, as I recall now, the job seemed to get done. I honestly can't take a lot of credit for that. But, I can't remember when it was a machine that bailed me out either. However, I can remember the many times that a group of sailors, working way outside themselves, have turned things around. It is then that you are likely to hear an expression used perhaps too often in the Fleet, unfortunately, but always with some pride, "Well, we did it in spite of the system." I suppose today I would have to say that I'm part of that system. But I would also say that I believe there are many things that can be done about the system to better structure it to help the sailor. Certainly, one of the best places to begin is with better training, particularly in the use and maintenance of the sophisticated machines we give the sailor to do his job--like ATE for instance. And I think that's what Bill King had in mind for us to discuss at this conference today.

But first perhaps we should take a closer look at the system--to find those parts of it that tend to make life harder rather than easier for our sailors--and specifically the maintenance technician who has to keep our complex systems working. We, who are involved with attempting to improve weapon system support with ATE, preach the gospel of design for testability. We have come to recognize the fact that, for the most part, hardware designers are naturally driven by the desire for performance, often at the expense of other engineering disciplines. Through emphasis on design for testability, we hope to get the designer to think about how things fail and why...as well as how things work. This is nothing new, really. It's what systems engineering is all about. Nevertheless, we have found that too much of the hardware we buy has not been subjected to this integrating discipline. For the most part, the designer does his magic and the reliability engineer, the maintainability engineer, the test engineer and the human factors engineer try to do what they can with it, after the fact. The result is usually a maintenance headache. From the automatic testing point of view, we hope that by implementing the concept of design for testability, we will not only get more supportable systems, but will force a new focus on the larger requirement of a true systems engineering approach to design--including the proper consideration of human factors.

I would like to be able to say that this systemic problem is unique to the prime hardware we have to test. Unfortunately, the ATE community does the same thing to the sailor. We give him ATE which is tough to use, hard to maintain, and not very easy to understand--especially when you consider that the training courses we give him are not adequate to give him a good start, and all the time we're telling him what a good deal he's getting...how we've solved his maintenance problems... when what we have actually done is laid another big one on him. This is the very opposite of what automatic testing is all about. And while our track record with ATE is not all that bad, it is clear that we have been too optimistic in our projections of what ATE can do FOR the sailor and what the sailor can do WITH ATE.

I have mentioned just two facets of the system that the sailor sometimes has to work around--complex hardware that is difficult to test and complex testers that are difficult to use. Both are what I call "up front" problems that we are trying to deal with in the TAMS Office by better management of the acquisition process, both for the prime hardware and the ATE. Nevertheless, the problems are with us today and will be for some time. I don't know how many years mark a generation of Navy technicians these days, but I would guess that several generations of them will be asked to deal with this situation. How we prepare them to deal with it is the essence of the training challenge.

As I said at the beginning, I am no expert on training. But just knowing how training is funded, as a line item of ILS, I would guess that the training community is certainly not burdened with dollars that

it can't spend. I'm sure that program training budgets follow the same pattern of decline as budgets for spares, for tech manuals...you know...all those things that the budget experts tell us will be taken care of next year. So it looks like to me that it would be very smart to substitute brainpower for dollar power in finding ways to give the technician a leg up on the system. I think this conference is a good place to start. There have been many interesting papers submitted and so without further comment from me Bill, lets get into your agenda.

BIOGRAPHY OF CAPTAIN HENRY M. WALKER, USN
TEST AND MONITORING SYSTEMS (TAMS) PROGRAM OFFICE (MAT-04T) HEADQUARTERS, NAVAL MATERIAL COMMAND

Captain Henry McDonald Walker, USN, was born in Martin, Tennessee, 3 May 1931. He attended public schools and the University of Tennessee Junior College there until 1950, at which time he transferred to the University of Tennessee at Knoxville, where he subsequently graduated in December 1952 with a BS Degree in Business Administration.

Shortly following graduation, Captain Walker entered the Navy's OCS program at Newport, RI, and after four months of intensive training, he was commissioned an Ensign in July 1953. He then attended Aviation Ground Officer's School in Jacksonville, Florida, followed by Aviation Maintenance Officer's School in Memphis, Tennessee. After graduating in December 1953, he was ordered to Composite Squadron Five (VC-5), NAS, Sanford, Florida, and was assigned to various Aviation Maintenance Officer billets.

Since his ensign days in 1953, Captain Walker has generally followed a career pattern in Aviation Maintenance. He is a designated Aeronautical Maintenance Duty Officer (1520), and during his 23 years Naval service, he has served in various maintenance, avionics and material officer billets, both at the squadron and staff level, ashore and afloat. Captain Walker's operational background in aviation maintenance has included assignments aboard several different aircraft carriers in both the Atlantic and Pacific fleets. He has made numerous training cruises, several Mediterranean deployments, a NATO cruise and an extended Southeast Asia deployment during the Vietnam crisis.

His duty stations have included: Composite Squadron Five (VC-5), Sanford, FL; Fleet Aircraft Service Squadron Fifty-One (FASRON 51) Detachment ALPHA, Norfolk, VA; Naval Air Test Facility (NATF) Lakehurst, NJ; Heavy Attack Squadron Eleven (VAH-11) and Heavy Attack Squadron Nine (VAH-9), Sanford, FL; Commander Fleet Air Jacksonville (COMFAIRJAX), Jacksonville, FL; Naval Weapons Evaluation Facility (NWEF) Albuquerque, NM; Headquarters Alaskan Command Staff, Anchorage, AK; USS CORAL SEA (CVA-43) Aircraft Intermediate Maintenance Department, Alameda, CA; Naval Air Systems Command, Aviation Maintenance Policy (AIR 403) and Aviation Maintenance Engineering and Policy (AIR 411), Washington, DC; and recently a two year tour in the Office of the Chief of Naval Operations as Head, Aviation Maintenance/Material Branch (OP-514). He is currently assigned as Director of the Navy's newly established Test and Monitoring Systems (TAMS) Program Office in Headquarters, Naval Material Command.

Besides attending a variety of Navy fleet schools, Captain Walker was a student at the Naval War College, Newport, RI in 1964/65. In addition to completing the Command and Staff Course, he also obtained a MS degree in International Affairs from the George Washington University. In 1971 he was assigned to the Industrial College of the Armed Forces in Washington, DC as a student, where he graduated in June 1972.

Captain Walker is married to the former Kathleen Hartman of Knoxville, Tennessee. They have two children: "Mac", Jr., 19, a Sophmore NROTC student at the University of Virginia and Douglas, 17, a Senior at Annandale High School. The Walkers presently reside in Annandale, VA.

Captain Walker's awards include: Bronze Star; Joint Service Commendation Medal; Navy Unit Citation; European Occupation Medal; National Defense Medal with bronze star; Vietnam Service Medal with three bronze stars; Armed Forces Expeditionary Medal for Korea and the Vietnam Campaign Medal.

MATCHING THE MAN AND THE MACHINE

George W. Neumann
Test and Monitoring
Systems Program Office
(MAT 04T)
Headquarters, Naval Material Command

The theme of this conference, "ATE: Bane or Blessing for the Technician" really strikes home. It's a well known fact that the Navy has a difficult time building weapon systems that the sailors can operate and maintain. When viewed in perspective, this is somewhat understandable in that the weapon system designers are trying to get their hardware to do more and do it better, thus they get wrapped up in sophistication. However, here we are in the ATE community, and our primary purpose in life should be to make the technician's job easier, but what do we seem to do? We make the same mistakes as our counterparts in weapon system design do. Essentially, we don't do a very good job of matching the man and the machine.

I expect we knew we were in trouble in the early seventies, when some of the more sophisticated ATE was first being introduced into the fleet. But it was not until 1975, when ASN (R&D) asked us to take a look at the problem in automatic testing, and give him a report on the situation, that we started to really focus on these problems. As a result, the Navy's ATE community got together with the Fleet and produced a now familiar document - the "Report on Navy Issues Concerning Automatic Test, Monitoring and Diagnostic Systems and Equipment," or the so-called "MARCY Report."

The man/machine interface problem and causes were addressed in the report to a large extent within training and manpower problems which are quoted below:

"16. TRAINING AND MANPOWER

Problem: Training and manpower dedicated to the operation and maintenance of ATE is inadequate.

Causes: There are many complex and interrelated causes for Fleet problems related to ATE training and manpower. Among these are:

a. Retention of highly-skilled and trained Navy technicians is difficult due to lack of incentives and competition with industry in the labor market.

b. Current Navy training is inadequate to operate and maintain ATE now deployed in the Fleet; this discrepancy is expected to increase as both weapons systems and ATE systems continue to become more complex.

c. Current manning levels at AIMD ATE shops are inadequate.

d. Navy organizational procedures for Navy personnel assignments result in inadequate skill distribution and lack of adequate support at IMA level. The level of technical expertise generally required must reside within the Navy and not continue to be contractor supplied as is often the case.

e. Proliferation of ATE significantly complicates training requirements."

The solution we proposed read like this:

"Required Action: The CNM shall take the appropriate actions to ensure that the following items are addressed by CNET:

a. Revise existing curricula and training programs in order to force them closer to actual ATE training needs. Training should also be provided for new and planned ATE systems, BIT, monitoring systems, and test program preparation.

b. Continue R&D in improved, lower-cost automated teaching methods in order to keep pace with the additional teaching difficulty associated with the support of complex new technologies.

c. Analyze the "Versatile Training System" in terms of its impact on the stated fleet problems of inadequate skill levels in ATE shops and inappropriate distribution and assignments of fleet personnel.

d. Revise current manning levels and requirements and procedures for determining manning and skill levels in Intermediate-level shops.

e. Provide career plans and incentives to improve retention of highly-training technical personnel."

As you can see this portion of the report dealt with improving the skill of the technicians--and this is certainly a worthwhile goal. However, there is another school of thought that says that instead of trying to make technicians do jobs that their intelligence and training do not equip them to do, let's design our machine to match the man. Probably RADM R. G. Freeman III, who now commands the Naval Weapons Center, said it better than I can, and I'll quote him directly.

> "Basically, there are three types of test equipment: BIT; Automatic, Computer-Controlled Test Sets---such as VAST---and, the human being. Of the three, we resort less and less to the human being and more and more to the automated. But, do we really "Automate" our test equipment support base when we design and build depot-size test hardware like the Versatile Avionics Systems Test---VAST---Equipment, or do we still have the human in the loop? The answer of course, is "yes"---but our human input has now been escalated from the diagnostician and module replacer to practically a "PhD candidate," if he or she is to serve the complex equipment now being made available.
>
> Obviously, none of the three basic kinds of test equipment can be ignored. But today, we are not making the proper trade-offs to the degree we should be. We still need diagnostics---and our man in the loop is fairly intelligent---so we should be able to use his talents better. Right now, we are more inclined to look to massive test equipment which, more often than not, we can no longer afford in quantities sufficient to compensate for the reduction in other test capabilities."

How do we propose to bring the man and the complex machine together? Do we train the man to meet the machine or do we design the machine to meet the man? We feel that the problem can be best solved by attacking on both fronts simultaneously.

But before we start perhaps we should ask one more fundamental question. Do we really know the man we are talking about? I suggest that we do not, at least not well enough. In large organizations, and particularly military organizations, it is too easy to classify people, believe in these classifications, and then make personnel management and training decisions accordingly. I feel that to know the man we hope to match with the machine we must see him in action, find out what turns him on and turns him off, get a first hand feeling for what he can and cannot do, and find out from him what can be done to help him. In this way perhaps we can really define a starting point.

In regard to training, it is ironic to see IBM ads on TV showing interactive terminals being used in grade school classrooms, knowing what is being used in Navy classrooms to teach sailors how to operate VAST. And what about the one by Semi-Conductor in which Johnny smiles when the green light shows he got the right answer on his hand held arithmetic "game." There can be little question that the technology necessary to revolutionize our training concepts and methods is available. The question is what should we be prepared to do about it in ways that are practical and affordable. Further in the paper some of the possible answers will be provided.

In designing the machine to meet the man, much, too, can be done. This paper stresses throughout, the importance we place on design for testability and BIT applied to both the prime hardware and ATE. Implementation of these design disciplines promises to simplify maintenance tasks substantially. We expect to improve ATE utilization and thus provide the technician with a more effective maintenance tool. And finally by reducing proliferation we hope to make it possible for him to understand, use, and maintain the ATE he has been given to do his job.

From this point this paper will discuss the three questions Bill King addressed when he charged a dozen of us to submit papers for this conference. His first question dealt with the author's involvement with ATE.

The Navy has a five to ten billion dollar inventory in automatic test equipment (ATE). This ATE is used at all three maintenance levels: organizational, intermediate and depot. About one-half of this is what we call on-line ATE (i.e., built-in-test performance monitoring) and the other is off-line ATE (i.e., shop testers). More than one-half of the total was spent acquiring the software for these testers. The Navy's annual expenditure for ATE falls somewhere close to $500 million.

The problem of controlling proliferation, assuring the proper applicability of ATE and getting a handle on the funds being spent for ATE is massive. Four out of five dollars being spent are submerged in Weapon Systems contracts, with no ATE breakout available.

So the problem becomes one of management. Whether one is concerned with training, ATE

acquisition, or research and development in advanced testing technology, the bringing together of ideas and resources to provide integrated solutions is a management problem. With this in mind, the CNM requested that a distributive management network be formed for both automatic and manual test equipment plus calibration/metrology and associated support functions. The idea here was not to build an empire in OPNAV, NAVMAT, SYSCOMS or field activities, but to distribute the management effort to all appropriate echelons. At the direction of the VCNO, DCNO (Logistics) has assumed the responsibility of mission and resource sponsor for all test and monitoring systems. In August, the CNM established our office MAT-04T, by combining the functions of ATE, manual or general purpose test equipment, calibration and metrology. By his direction and within our charter, MAT-04T has been given the overall ATE management job.

The second question Bill King posed dealt with the potential payoffs and penalties of ATE.

As a rule ATE advocates tend to be overly optimistic in identifying benefits which can be expected to accrue to the weapon system program from implementing support with ATE. Nevertheless, the benefits are logically credible, given the dominant characteristics of speed, comprehensiveness, and consistency usually attributed to automatic as compared with manual testing. These characteristics lead to the general conclusions that when properly applied ATE has the capability to increase weapon system operational readiness while reducing life cycle costs.

On-line ATE, i.e., BIT, affects operational readiness directly through automatic detection of degraded performance and identification of unit(s) which, when replaced, restore the system to a ready condition. The total downtime for maintenance is roughly equivalent to the time to remove and replace the failed unit(s). The more comprehensive the BIT, the less maintenance downtime is required and the higher the system availability. Along with the readiness benefits, BIT minimizes organizational level maintenance manpower, skill levels and training requirements. In some systems with extensive BIT, such as the Trident Fire Control System, operators are trained to perform the simple removal/replace maintenance tasks. For equipments with BIT implementation, Planned Maintenance System (PMS) checks can be eliminated. A recent Fleet Survey of PMS implications for electronics on ships showed that 100% of the ET's time would be needed to fulfill established PMS check requirements manually. Beyond these life cycle cost savings at the organizational level of maintenance, BIT can effect substantial savings in repair pipe-line costs through fault isolation to relatively simple and inexpensive replaceable assemblies. In the ideal case, with fault isolation to replaceable throw-away assemblies, repair pipe-line costs are eliminated.

The price of BIT can be expressed as a per cent of the acquisition costs for the prime hardware in which the BIT is to be implemented. These costs accrue for development and for production, with incremental costs of BIT applied for each of the units to be produced. The total can be impressive when the costs for BIT are calculated in absolute dollars and must be accommodated in tight budgets. In such cases there is a tendency to procure the minimum amount without due consideration of the substantial life cycle cost savings achievable through the expenditure of additional, comparably modest dollars for more BIT. A recent study indicated that most of the benefits ascribed for BIT can be achieved with expenditures of up to 10% of prime hardware acquisition costs. Proper BIT implementation is estimated to save typically 30-35% of operations and support costs, which, in turn are calculated in DOD to be roughly 10 times acquisition costs for systems with a 20 year operational life. This means that for 10% of the acquisition costs spent now, approximately 300% will be saved later. These figures alone make a compelling case for BIT.

The same clear case cannot be made for off-line, multi-purpose ATE applications without some caveats. Granted, the dominant characteristics of speed, comprehensiveness and consistency apply. However, a number of factors not related to ATE performance affect the life-cycle cost-effectiveness of off-line testing. These factors must be understood, evaluated, and controlled as elements of a support system of which the ATE is but a part, certainly not the whole answer. The development of an effective support system implemented with off-line ATE must be a carefully orchestrated evolution involving imposition of design disciplines in the hardware to be tested, optimization of UUT/tester compatibility, maximization of workload and through-put--to name but a few of the pre-conditions necessary to make the off-line ATE a good investment and achieve its theoretical benefits. When these conditions are not met, alternatives to multi-purpose ATE such as special purpose testers, manual testing or factory repair may provide more economic support solutions.

Having said all of this, it is still clear that the thrust of technology is toward increasingly complex repairables which are beyond the capability of manual testing for all practical purposes. In a sense the

existence of off-line ATE permits the design of complex systems to satisfy sophisticated operational requirements. The mission avionics for the S-3A is a case in point. Without the existing hierarchy of testers at the intermediate maintenance level, the S-3A could not be reasonably supported.

The ATE employed in intermediate maintenance shops on carriers and air stations is needed to maintain a pool of avionics assemblies ready for issue (RFI) as replacement for defective assemblies identified at the organizational level and removed from the aircraft. In this direct support role ATE provides reduction in pipe-line costs compared with the alternatives of depot level repair or discard. In fact economic analysis is performed to validate this effect as a means of justifying the employment of ATE in the first place. The predominant factors in the economic analysis in a given repair scenario are the speed of testing and its reduced maintenance task times and man-hour implications over the life cycle of the repairable. This life-cycle cost impact of ATE has been recognized by the ship maintenance community in plans for development of its own intermediate maintenance capability implemented with off-line ATE.

Another factor, less easily quantified, derives from ATE characteristics of comprehensiveness and consistency, as compared with tests performed manually. In an Army experiment the performance of maintenance functions using ATE and manual testing were evaluated under carefully controlled conditions. It was found that individual equipments repaired on the basis of manual testing were returned defective at a rate of about 1 per month over a six month period; for equipments repaired on the basis of automatic testing no returns were experienced during the 75 days of observation and no reports were received on degraded performance for units pronounced RFI. As is suggested by this experiment the total effect of ATE in this context is reduced maintenance workload and improved operational performance.

In summary, the increased readiness and life cycle cost benefit potential of ATE is unquestionable, theoretically. In practice the benefits can be fully realized only by rigorous application of system engineering disciplines to both prime and support systems design and development.

Now let's take a look at the third question posed by Bill King--"How the technician uses and interacts with the ATE?" This description will touch on a number of different topics, which probably deserve a lot more attention than is given in this paper.

1. MAN/MACHINE INTERFACE

With the advent of ATE as a viable maintenance tool in the 1960's came the vision that it could be made a "turnkey" solution to the burgeoning problem of electronic maintenance. The concept of complex general purpose ATE systems evolved with the prediction that such systems would be capable of servicing a maximum number of UUT's with a minimum amount of manning. It was a popular misconception that man's primary role in the man/machine interface aspect of ATE was to "hookup" and "tear down" the units to be tested on the ATE system and perform only rudimentary housekeeping tasks. Training requirements with respect to maintaining elctronic equipment would decrease because of the capability of storing diagnostic intelligence, with which to perform repeated tests, in computers embedded in general purpose ATE systems. Experience has shown us that manpower requirements have indeed gone down with the utilization of ATE. However, the notion that training could be substantially reduced has proven to be wrong. In short, fewer, but better trained technicians are required to make the ATE concept fly.

For example, utilization of ATE can produce contingencies which require the man to get into the "loop" and assist the ATE to perform its mission. Some of these actions entail:

- Performing adjustments, alignments, and remove/replace actions on UUT's.

- Resolving a multiple fault condition in a test program set up (i.e., discerning whether a fault condition is resident in the test system, interconncetion device, system cabling, or the UUT).

- Responding to ATE system interrupt conditions which can only be resolved by a human decision (i.e., power interrupt sensed by the ATE system which requires human action to remove the interrupt condition).

- Resolve and identify "transient" fault conditions which occur in the operational environment and escape the diagnostic procedures resident in the test programs.

- Identifying and documenting unsatisfactory test program and test system performance and submitting unsatisfactory reports so that system readiness may be improved.

In general, the ATE community has not been receptive to the notion that anomalies may occur such as those described above,

which render the ATE without the man virtually useless in an operational sense. Efforts continue to promote the "turnkey" approach to automatic testing and thus eliminate operator subjective participation in the testing process. In short, let the machine do its thing and keep operator participation to a minimum. After all, he's only a high school graduate. Why risk the chance of having him disrupt the testing process? These are the decision-to-machine orders that every ATE hardware and software designer hears from his upper management. The result has been a product not adequately engineered from a human factors point of view. Let us examine a case in point.

The Versatile Avionic Shop Test (VAST) System was the product of the general purpose ATE system concept previously described. A broad range of current and projected requirements forced development of a complex and expensive test system approximately 32 feet long. The form factor of the test station, I-shaped rather than U-shaped, was based on facility accommodation rather than human factor considerations. As a result, the operator control console is separated from the UUT work surface by approximately ten feet. This prevented the operator from communicating with the VAST System while making adjustments/alignments or performing UUT remove and replace operations. Design and integration of mobile auxiliary keyboard and display, capable of being positioned by the operator to satisfy his work situation, has solved this problem. The important point, however, is that human factors requirements with respect to deficiencies in VAST design were identified and implemented only after the fact. Recognition that the machine must be redesigned to be compatible with man and that ATE utilization is not a turnkey operation is the key issue presented here.

In contrast, let us look at the example of MECCA, a program which addressed human factors requirements and man/machine communication from the start. MECCA is an acronym for Modulary Equipped and Configured Calibrators and Analyzers. It is under development by the Navy Metrology Engineering Center to increase the effectiveness of the Navy Metrology and Calibration Program and features portable, microprocessor-based measurement/stimulus (M/S) modules, and a new generation of calibration controllers. A special feature of calibration controller is an interactive plasma display that incorporates a touch panel keyboard. Operator options are displayed on the panel. By touching the correct spot, desired options can be selected. By thus optimizing the man/machine interface as an integral part of the design, MECCA is expected to simplify operator training requirements substantially while minimizing the recurring costs of calibrating over 1 million instruments in the present inventory.

The requirement for interactive capability in future ATE systems is recognized as a means of allowing the operator to deal with the various contingencies which arise in daily ATE system utilization. Specifically, there is a need for high resolution displays with color capability so that maintenance oriented information can be retrieved on-line. Information portrayal of this kind, coupled with "system" troubleshooting expertise, should enable maintenance personnel to resolve ambiguous test situations readily and increase test system through-put. Thus by recognizing the need for the man-in-the-loop and providing the means for effective interaction with the machine, the total system is made more effective. (Grumman Aerospace Inc. recently demonstrated a development model of a technicolor graphic display which shows considerable promise for such an application.)

2. INTERMEDIATE LEVEL ELECTRONICS MAINTENANCE

The place where the Navy man meets ATE most frequently is in the intermediate level avionics shops located on our carriers and air stations. By the nature and duration of the aircraft mission and requirements for rapid turnaround, the direct support role of I-Level maintenance, augmented substantially with ATE, has been well defined for some time. To a large extent the lessons learned about ATE have come from this environment.

Because of a combination of reduced ships' readiness, high pipeline costs and overloaded depots, NAVSEA, through the Ship Support Improvement Program (PMS 306), is now planning to establish an intermediate level electronics maintenance capability for ships at selected shore locations. ATE is expected to be an important part of this capability. Thus, we have here a unique opportunity to apply the lessons learned by the air community in establishing a truly integrated support system. Since the electronics maintenance workload already exists, it can be defined precisely for optimum ATE selection, including consideration of the man/machine interface. We see this program as the first chance to apply the concept of a family of testers, by selecting individual testers which will optimize workload segregated to reflect functional test requirements. Operator and technician training programs will also be required to use and support the ATE selected. All in all this is an exciting program which gives the Navy a chance to do things right with ATE the first time. We intend to monitor this program closely and provide whatever assistance we can to assure its success.

3. TECHNICIAN PROGRAMMING

Whether appropriate or not, a certain mystique has come to be associated with the generation of test programs for use with off-line ATE. This plus some very real configuration management considerations have led to a hands-off policy for the technician. Nonetheless, workload pressures for intermediate level repair of some modules for which no test programs had been prepared led to experimental efforts in test program generation using technicians and on-site ATE. Results were favorable and in response to fleet requests for resources to implement this capability NAVAIR developed a program to evaluate formally the ability of enlisted technicians to do this work.

Personnel assigned to intermediate maintenance activities at three Naval Air Stations were selected to develop and validate 15 test programs for a mix of analog, digital, and hybrid shop replaceable assemblies (SRA's) to be tested on four ATE systems. As a result of this evaluation there is no doubt that sailors can develop useful test software for SRA's of the complexity of the sample, i.e., up to the lower end of moderate complexity SRA's. The test programs were used as production tools to process a total of 211 SRA's during the evaluation period. What remains to be determined is the envelope of the sailor's capability, and the precise way in which this capability can be exploited. This definition of the technician's proper role in test program generation will introduce additional elements for consideration in the man/ATE interface.

4. DESIGN FOR TESTABILITY

One of the main thrusts of our Advanced Testing Technology Plan is Design for Testability. This deals with designing the weapons system and its associated UUTs so that they are indeed capable of being tested (easily). NSWC Dahlgren is working on development of methods for specifying, demonstrating and quantitatively measuring testability. This is a very difficult task, for we have not been effective in the past in including these types of provisions in our contracts.

One way of forcing design for testability is through readiness requirements which impose comprehensive BIT implementation. A good example is the Basic Processor for the Trident Fire Control System which uses BIT exclusively for fault detection and isolation. The stringent mission requirements of the Trident weapon system dictated that the BP must be maintained by Fleet Personnel on long patrols in a submarine environment. Personnel are trained primarily as operators; they are not equipped for laboratory-like diagnostics. Keeping the equipment 100% up is paramount. Long patrols dictate that "permanent" faults cannot be tolerated, that expert help is available infrequently, and that equipment will run almost continuously. The submarine environment results in the logistics supply being finite and predetermined; it also means that environmental characteristics are nominally invariant (power, cooling, etc.).

The objectives which were established to satisfy this mission were as follows:

- Provide continuous fault isolation during normal operation.
- Provide necessary internal visibility to isolate detected faults.
- Retry operations which indicate faults to determine whether or not fault was soft.
- Report soft faults.
- Provide maintenance bootstrap to verify initial operation.
- Provide internal circuitry to test and isolate faults in basic control circuitry of CUP.
- Provide necessary data to operator for module replacement.

The approach to accomplish these objectives was a multifaceted hardware and software implementation supported by contingencies to resolve items not adequately handled by the primary configuration.

The key issue here is that design for testability for the Trident BP took into consideration human factors consideration (i.e., how does one resolve multiple fault conditions? Soft fault conditions?) as a means of satisfying mission support requirements. The fact that man was a critical element in the support structure was recognized. The Trident people attributed much of their success to a good "corporate memory" in the SSBN community which provided them with the lessons learned from two Polaris Programs and the Poseidon Program, lessons related to establishing practical support design to guidelines and in particular, unambiguous fault isolation techniques. But, most importantly, they established and implemented the philosophy that equipment and procedures must be designed to be compatible with man--not vice versa.

5. OPERATIONAL READINESS MONITORING

Operational Readiness Monitoring is more ship command oriented than technician oriented, but certainly is worthy of note at this conference. Essentially what this concept proposes is automatic, real time sensing of the health of the key weapon systems aboard ship and also the environment the weapon systems and ships encounter. The latter can involve such things as damage control monitoring and electromagnetic emission control.

At present the sailor collects most of this type data through tedious, manual means, and logs and reports the data at specified times during the day. Planned maintenance system checks are done similarly. Obviously many of these checks could be done automatically and reported on a real time basis, thus freeing the sailor for more challenging and productive tasks.

What is really missing is a concentrated program aimed at designing our ships for maintenance. If, during ship design, decisions are made on which parameters should be sensed automatically, and provisions made to build-in the appropriate sensing devices and data management structure, the dollar investment could be relatively low. In addition, automation provides a ready means for manipulating this data once it is collected. Possibly a quantitative measure of the ship capability to perform a given mission would be possible. For that matter there is no reason that ship's personnel capability could not be cranked into such a measure.

6. ATE/SELF TEST

The reasons which can be cited for the use of ATE and BIT to support prime systems and to verify operational readiness apply as well to support and operational readiness verification of support systems. It is ironic that, frequently, ATE Systems are deployed without the capability to be operationally self-supporting. The general question of ATE maintainability, addressed in the "Report on Navy Issues Concerning Automatic Test, Monitoring and Diagnostic Equipment," cites several causes for lack of ATE maintainability. One central cause, that underlines all of these, is lack of a systems approach to ATE logistics planning. For example, the VAST System, initially deployed in 1969, is still the subject of Test Program Set development efforts for support of its modules. Many of these modules are not even designated to be supported on VAST, but "off-loaded" to other systems. A situation such as this exists because the primary effort and talent of the ATE manufacturer is applied to meeting functional requirements. Logistics, as usual, takes on a secondary emphasis.

Self-test is not necessarily an included part of an ATE System. It is one of several alternative approaches to ATE system support, each requiring expertise resident at the ATE System. In the case of self-test, this expertise is supposed to be designed into the software supplied. Other possible methods include Built-in-Test within the system elements, direct contractor support, or highly trained user personnel. Typically, a "mix" of all four approaches is evolved in an operational environment.

The idea that less skill or expertise is required to support ATE than is required to support manual test equipment is false. In fact, ATE has all of the complexity of corresponding manual test equipment plus the additional complexity introduced by automation of control, switching, operator interface and displays. The promise of self-test is that the analytic skill required to perform system maintenance is permanently resident in the test system. This resident capability reduces the human resources required, but in practice rarely eliminates them. Initially self-test programs seldom meet their maintenance objectives. As a result, they are frequently by-passed by capable, "can do" personnel. The effect of this is that, under the pressure to keep systems operational, skilled persons resort to short-cut inventive procedures and the self-test maintenance tool is shelved, replaced by the oscilloscope, by the hand-held multimeter, by maintenance manual, and by guess and by gosh.

The problem of retention of capable personnel will be treated in another section of this paper as will the problem of retention and distribution of up-to-date maintenance information. The effect is clear, though. During the initial deployment of a complex system, its problems are solved by individuals, often working outside established procedures (succeeding in spite of the system). The demands of productivity leave little time to test out and improve self-maintenance tools, so these remain largely experimental. As long as highly-skilled individuals are available to maintain the system, no problem is evident, or, if one is, its magnitude is not apparent. The real self-test problem becomes obvious when the individuals who had been "working around" these deficiencies suddenly disappear for whatever reasons. The balance of the project then becomes a series of get-well programs.

These experiences point to one clear requirement--that test systems and self-test become part of a self-sustained capability. This capability must be tested and enforced as a specification requirement from the first stages of weapon system development. The alternative is perpetual dependence upon contractor expertise when the bill has already been paid to achieve Navy organic self-sufficiency.

7. INTEGRATED TROUBLESHOOTING AND MAINTENANCE PROCEDURES

A substantial improvement in utilization of ATE can be achieved by providing technicians with data for troubleshooting and other maintenance procedures on a rapid, accurate basis. Much of the data is required at the UUT/ATE interface where many complex problems arise. Therefore, to accomplish this task efficiently data retrieval methods and devices need to be integrated with the ATE systems as part of the total support strategy.

Generally, the information required by a technician involved in executing a UUT test program will fall into two categories:

1. Data for maintenance actions such as part replacement or alignment.

2. Data for troubleshooting where program logic has failed due to, say, multiple faults in the UUT.

The first requirement involves action, and therefore information which is explicit and follows a well defined sequence. This type of information is best included as part of the test program and called up as dictated by the test results.

Requirements for troubleshooting may range from small to relatively large quantities of data, in various formats, since the nature of the problem is unpredictable. Thus, a source other than the test program is required. The two most widely used retrieval devices (other than the technical manual) are film storage type, and cathode ray display type. Whatever the data source, however, other questions need to be answered before a suitable retrieval system can be decided on. Such questions are:

a. What is the optimum location?

b. Can a reasonable amount of detail be provided in one frame?

c. Can the display be read clearly without undue eye strain?

d. Is printing capability required for all applications?

The question of optimum location is extremely important. Clearly the optimum location will be in close proximity to the operator/technician. A high percentage of the time this location will be the UUT/ATE interface; however, problems occurring on a large ATE system demand some flexibility in location. So do applications involving lengthy procedures such as calibration, which take place off-line. From these considerations it becomes apparent that there is a need for a data retrieval device that is portable and has good resolution for both graphic and alpha-numeric information. The device needs to be interactive. The cathode ray display type with keyboard best suits applications where the requirements of portability, resolution, and speed of retrieval are paramount. The actual data source for such a device could be self-contained in the form of a magnetic cartridge or if connected to the ATE system computer, would be provided from disk storage. Film storage devices in current use frequently do not meet the needs of a technician working on complex UUT/ATE problems and result in time penalties due to slow access, copying methods, and inconvenient location. Nevertheless, such a device could be used effectively for applications where calls for data are less frequent and where the data requirement is minimal, or sequential in nature.

8. PROLIFERATION OF ATE

A major burden is placed upon the configuration management, training, manpower, and financial resources of the Navy by the very existence of a large number of types of ATE's in Navy inventory. Each system requires its own unique support elements, documentation, specialized training and operating techniques.

The first step in controlling test equipment proliferation is to make a serious accounting of available assets. The test equipment inventory in process, records for all major Navy ATE its types, function, use and availability. This effort will determine if certain ATE's are still being manufactured or if they are obsolete. Finally the assessment by the using activities of the adequacy of performance of these systems in actual application is being solicited. This inventory is being done by Navy for Navy use and is designed to be as free as possible from "salesmanship" claims.

Establishment of a family of ATE is planned. A single list of preferred ATE for Navy-wide use will be published to encourage

that future ATE selections be made from this list. It will include ATE types already in inventory (the "inherited" family), and types available. Under this effort, Navy will perform a comprehensive evaluation of selected ATE systems for performance adequacy and ease of use. An important part of this evaluation is assessment of the man/machine interface.

A second longer range phase includes the development of an optimum family. This most likely will be a Tri-Service effort.

We feel that by controlling proliferation of ATE in this way, we can make the ATE operation and maintenance job more simple with reduction in the different types of ATE available and the development and selection of ATE which can be more easily operated and maintained.

9. TECHNICIAN TRAINING TECHNIQUES

The current training methods employed in Navy schools appear to be mainly classical, e.g., lectures, supported by viewgraphs, chalkboard, wall charts, technical manuals, and reinforced by written tests. Hands-on experience with actual hardware is limited by resource availability, but is considered by students and instructors to be very important. One often hears a comment indicating that students feel that they learn more from the practical work, than from the theoretical. Undoubtedly this is partially true because the traditional method of teaching hardware maintenance requires little direct participation by the student.

During VAST system training the one phase of the course that appears to provide the highest degree of interest and motivation is that dealing with the computer.

This is judged to be the result of the high level of interaction between student and machine. Such involvement generates a feeling of creative accomplishment and provides a means of expanding knowledge at a rate determined by individual learning capability. Indeed students are encouraged to use the computer outside of scheduled classes, and do so on their own time.

The characteristics of an interactive teaching module are similar to that of the computer and it can be deduced that suitable presentation using such a technique would result in a significant improvement in student motivation and the rate of acquired knowledge. This should lead to either fewer hours spent in the classroom, or better use of the time spent. Fewer hours would lead to more time for on-the-job training or more through-put with greater time spent in the field.

It should be understood that complex systems sometimes require many months of everyday practical experience before a technician is fully proficient, regardless of how well trained. This fact must be weighed when deciding on the length of a course. It is very difficult to keep student motivation high for extended periods; and learning suffers accordingly. Also, material learned early in the course, if not reinforced, can be easily forgotten.

With regard to the problem of skill level and quantity of technicians it must be realized that a highly trained technician, particularly if computers and associated peripherals are involved, is a marketable commodity. Thus, to some extent the higher levels of training on complex equipment often lead to increased attrition due to the opportunities that open up in civilian employment. To encourage retention, consideration should be given to providing a better professional environment for higher grade technician as recommended in the Marcy Report.

10. TRAINING AIDS

Our Advanced Testing Technology Plan which I mentioned previously contains at least two tasks on training aids. The first deals with simulation and the second deals with plasma panels for portable maintenance trainers. Plans call for development of a VAST simulator as a means for avoiding the cost of tying up a multimillion dollar VAST station for training purposes.

The question of what training aids are most cost-effective in achieving the learning objectives of ATE operator and maintenance technician training is not easy to answer. For instance, the cost-effectiveness implied in the VAST simulator development decision may not hold true for a less complex system such as HATS. Training and requirements are also dependent upon the teaching methods used in the course. The case has already been made for interactive teaching devices using computer aided instruction modules. How would their use effect the need for on-equipment instruction using either special purpose simulators or actual test hardware?

It seems that with respect to training aids, as with other areas of ATE training, we have more questions than answers. This suggests that the whole subject may not have been given the attention, from a total

systems viewpoint, that it obviously needs. Perhaps the results of this conference will provide some direction.

11. ARTIFICIAL INTELLIGENCE/ROBOTICS

The last item to be discussed deals with Artificial Intelligence and Robotics. Such a task is being performed by the Artificial Intelligence Laboratory at MIT and sponsored by Marv Denicoff at ONR. This task looks into the uses of artificial intelligence in ship maintenance. Several possibilities are being explored.

- Making higher-level officers more productive by providing them with Intelligent Support Systems. These systems would help by contributing a variety of services ranging from briefing people on ship conditions and capabilities to autonomous scheduling of maintenance and repair tasks.

- Making lower-level seamen more productive by providing them with Computer-based Supervisors and Coaches that lead them through repair and maintenance jobs they otherwise could not do.

- Replacing some lower-level seamen with flexible Manipulation and Vision Machines that do physical work.

I will not dig any deeper into this subject other than to say, such an investigation opens a whole realm of possibilities that could be practical ten to twenty years from now. It should be stressed that the techniques MIT is proposing do not center around normal computer-controlled work, but rather gives the computer the ability to learn, to make decisions and to perform certain mechanical functions.

THE CHALLENGE

From the prior discussion of problem areas and some of the initiatives underway, to get a better match between man and machine, it becomes apparent that the Navy program has both near-term and long-range elements.

For the long-range solutions we look to the R&D program and focus on the main objective of developing the tools necessary to achieve truly integrated support systems, in which men and ATE can play effective and complimentary roles. By now the term design for testability has become familiar as an integrating discipline to optimize ATE applications for weapon system support. An equivalent term for optimizing the man/machine interface has been called design for manning. In practice it would represent the process by which human factors considerations would be given proper and timely recognition during hardware design. Such emphasis would provide some assurance that in new technology applications the man would not be forgotten.

Even under constraints of reduced budgets much can be done in R&D to lead the way to improve ATE operator and technician training. Let us try to move this important program element out of the stone age as soon as possible.

For the short range, we intend to exploit the opportunities presented in the development of an intermediate maintenance capability for ships--to do it right the first time. This includes the application of the principles we have learned in developing the family of ATE and the role and functions of ATE software centers. Equally important is the chance to see that man and machine are brought together in a way most productive for both and the vital ship support function being performed.

BIOGRAPHICAL SKETCH

GEORGE W. NEUMANN

BSEE	Maryland University	1952
MEA	George Washington University	1959

1971 to Present - Headquarters, Naval Material Command - Responsible for management of Navy Automatic Test Equipment Program

1961 to 1971 - Naval Ship Systems Command - RDT&E Program Manager for Automatic Test Equipment, Electromagnetic Compatibility and System Effectiveness

1951 to 1961 - Naval Weapons Plant Branch Head in charge of the standardization of components, devices, test equipment and engineering practices for BuWeps

THE "VAST" EXPERIENCE

Michael D. Myles
Naval Air Systems Command

INTRODUCTION

The AN/USM-247(V) VAST (Versatile (Avionic Shop Test) System is one of several automatic testers under the cognizance of the Ground Support Equipment Division of the Naval Air Systems Command. It is used as an example in this paper because of its widespread use in the "AIR" maintenance community, its notoriety and the lessons learned during its introduction and implementation.

VAST SYSTEM BACKGROUND

The VAST System is manufactured for the Naval Air Systems command by PRD Electronics, Inc., Syosset, New York. The VAST System provides intermediate and depot maintenance level testing of avionics equipment aboard carriers and at selected Navy shore sites. The VAST System is the result of extensive studies, initiated in December 1960, which produced a feasibility model of VAST that demonstrated that a computer-controlled group of independent, general-purpose, stimulus generators and measurement instruments called BBs (Building Blocks) could automatically test sophisticated avionics equipment. Additional BBs were later developed to increase the testing capability of the feasibility model. In March 1968, PRD was awarded a contract to develop and build a VAST System, designated AN/USM-247(V). The first VAST System was delivered to Grumman Aerospace Corporation in December 1970 to support selected F-14A aircraft avionics systems. VAST was approved for service use in December 1976. Eighty-three systems have been delivered to 2 aircraft primes for TPS (Test Program Set) development and to 15 shore sites and 7 CV's for fleet support of weapon systems.

VAST SYSTEM DESCRIPTION

VAST is a general-purpose, computer-controlled test system to be used by intermediate and depot level maintenance activities to test and fault isolate avionics equipment. Because the BBs are independent and general-purpose instruments, VAST can be adapted to support future avionics systems. Key features of VAST include the ability to test different types of weapon system components; long term savings in cost, space, people, and resources; rapid testing of complex avionics; increased confidence level in testing; flexibility of updating software programming to adapt to new and modified weapon systems; and the capability of updating/adding/deleting BBs without affecting VAST System operation. Figure 1 shows the functional block diagram for the VAST System. A VAST Station consists of a CSS (Computer Subsystem), a DTU (Data Transfer Unit), and an SMS (Stimulus and Measurement Section). A MWS (Mobile Work Surface) is used to support the ID (Interface Device) and UUT (Unit Under Test) during testing. An I/O (Input/Output) Console or a Tape-Reader/Line-Printer (part of the DTU) are also used as maintenance aids. Figure 2 shows a typical 14-rack configured VAST System.

a. Major Assemblies Description

(1) CSS (Computer Subsystem). The CSS consists of a Control Computer and two MTTUs (Magnetic Tape Transport Units). Input AC power is provided to the CSS via internal rack cabling that originates in the DTU rack.

(2) DTU (Data Transfer Unit). The DTU is the man/machine interface and provides all of the functions required for operator control and monitoring of station operation. All instructions to and data from the SMS (Stimulus and Measurement Section) are processed by and displayed at the DTU. It permits the execution of direct control, monitoring of station performance and selection of operation modes. The DTU interfaces, processes, monitors, controls, verifies, displays and synchronizes all digital communications between the computer and the SMS. Input AC power (from ships/shore power distribution source) is provided to the VAST System via internal rack cabling that originates in the DTU rack.

(3) SMS (Stimulus and Measurement Section). The SMS contains the test and

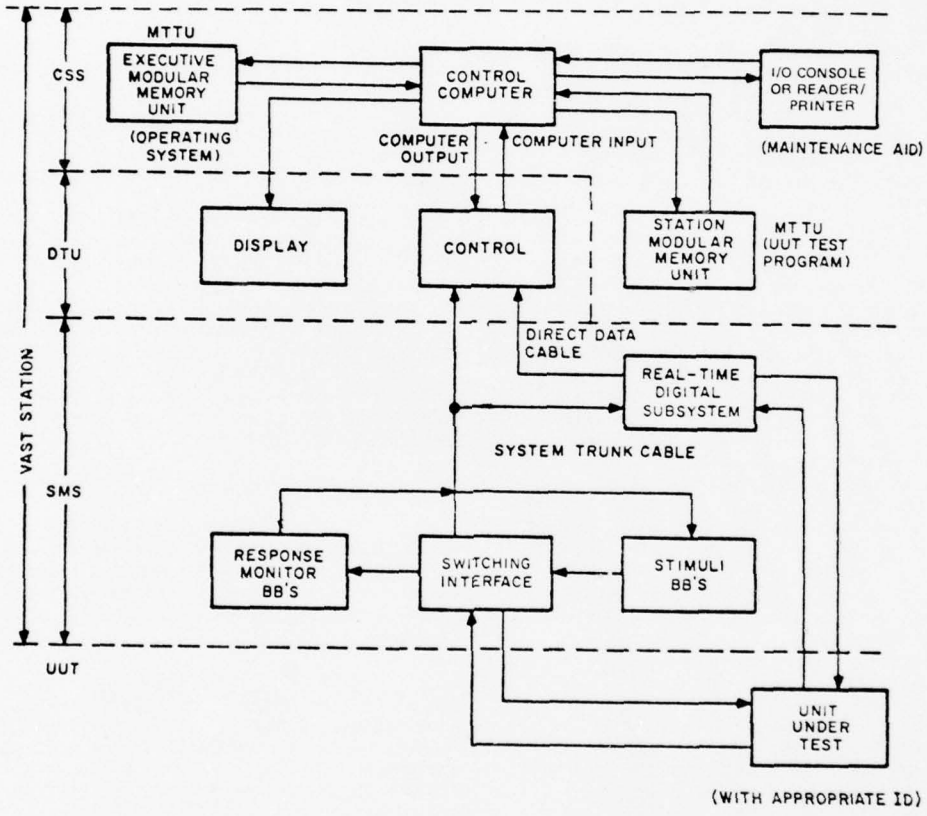


Figure 1. VAST System Functional Block Diagram

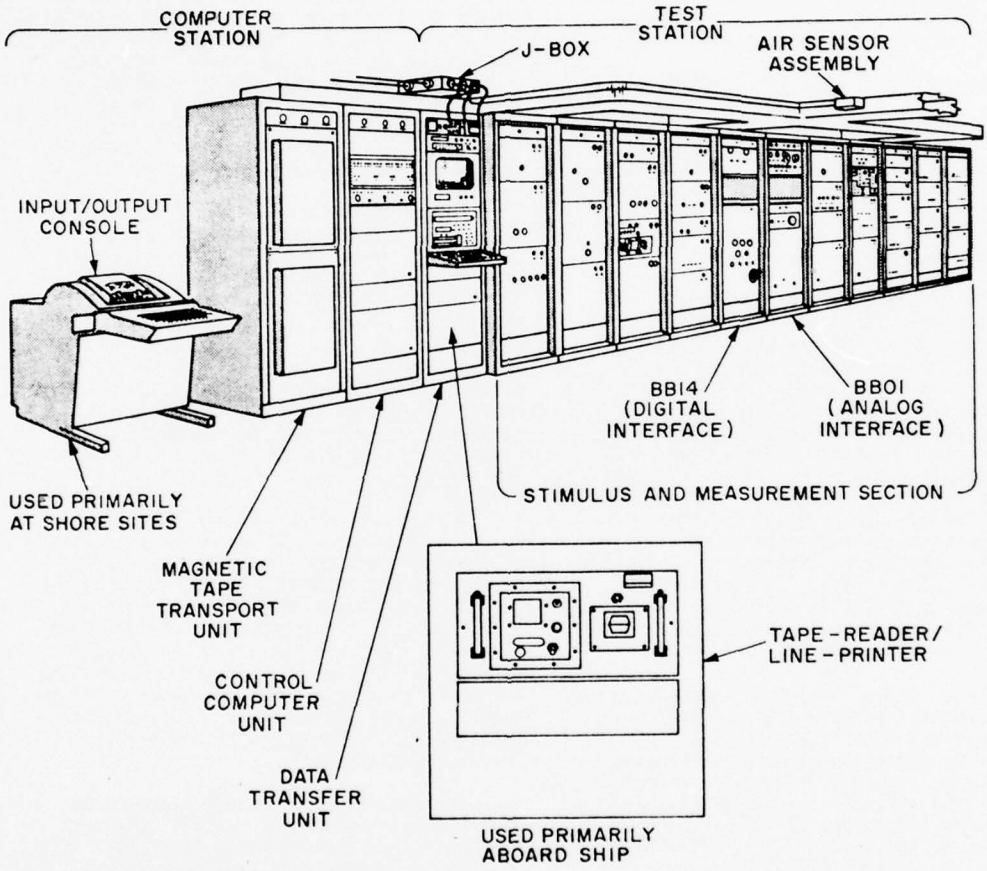


Figure 2. Typical VAST Station 14-Rack Configuration

measurement equipment. It also contains the units which interface, through the ID, with the UUT. The SMS is composed of self-contained, general-purpose, programmable test equipment (Building Blocks); an ICS (Interface and Configuration Switch); and a DSS (Digital Subsystem). The quantity and type of BBs are dictated by the particular workload being supported. The BBs are mounted in standard racks, each mechanically connected to adjacent racks and to the deck. Table 1 lists the functional capabilities of each BB.

b. VAST System Computer Programs

Two types of computer programs are required to operate the VAST Station--the O/S (Operating System) and the object program. Each program is recorded on a separate reel of magnetic tape and played on an MTTU. In addition, an off-line compiler is required to generate the object programs.

(1) O/S (Operating System). The VAST O/S contains the central executive routines for control of the VAST Station computer. During a test of a UUT using the specific object program, the O/S directs analysis of the data portions of the object program, and converts these data into hexadecimal commands. These commands are the output of the station computer. This output controls the operation of the BBs and the DTU. The O/S contains two portions: the resident portion and the nonresident portion. The resident portion is stored in the computer memory throughout a test. The nonresident portion remains on the magnetic tape and is called upon as needed. The O/S is written in Varian assembly language.

(2) Object Program. Object programs contain the information needed for testing specific UUTs. Each unique UUT requires a separate object program, written in a computer language called VITAL (VAST Interface Test Application Language). These object program tapes are called TPTs (Test Program Tapes) and work in conjunction with a TPI (Test Program Instruction) and the ID to permit the VAST operator to perform diagnostic tests on a UUT. Self-check and self-test are object programs written to test VAST UUTs. Self-check (resident on the O/S tape) is initiated by the operator at the DTU keyboard to isolate a fault to a BB, DTU, Computer, MTTU, or I/O Console. Self-test (resident on its own tape) is initiated by the operator at the DTU keyboard to isolate a fault to an SRA.

(3) Compiler. The VITAL compiler is the program which transforms the VITAL source program in card form into an object program on magnetic tape for use with the VAST computer.

VAST BENEFITS

Since the early 1960's NAVAIR has become a very heavy investor in ATE and associated software. This investment has been prompted by ATE's ability to: (a) accelerate testing, (b) improve accuracy and consistency, (c) alleviate testing problems, (d) shorten turnaround times, (e) reduce the drain on spares, and (f) provide the flexibility to respond to rapidly changing support needs imposed by increasingly complex avionics.

The switch over from manual to ATE continues to be increasingly important to NAVAIR because of the: (a) accelerated departure of trained maintenance personnel for jobs in industry, (b) decrease in the level of education attained by the new personnel, (c) a quantum leap in sophistication and complexity of the avionics that must be supported by the new personnel, and (d) shortened life of avionics due to advances in technology and change in missions in response to changing threats and strategies.

NAVAIR estimated that VAST derived space savings would provide both operational improvements and cost benefits. Field experience proved NAVAIR correct on both counts. VAST has reduced CV shop space requirements for supporting the F-14A, S-3A and E-2C avionics. The space reduction provided by VAST was calculated by comparing the space for the present VAST shop with the shop space for the peculiar ground support equipment (PGSE) that would have been required without VAST.

The next-in-line savings expected by NAVAIR was in personnel. If all relevant shop personnel could receive identical training in maintenance and operation--on the identical test equipment--in lieu of training on varying PGSE's, NAVAIR believed that significant savings would result.

In the echelons of maintenance, spare and repair parts occupy critical roles. Aside from eliminating the need to inventory spares for a wide variety of PGSE test equipment, the use of a standard test station (VAST) acts to limit and minimize

TABLE 1

SMS BUILDING BLOCKS AND UNITS

BB	Title
01 (Unit)	Interface-Configuration Switch (ICS)
04	Control Switch
10	Digital Multimeter (DMM)
11	Frequency and Time Interval Meter (FTIM)
13	Delay Generator
14 (Unit)	Digital Subsystem
20	Signal Generator 0.1 - 50 KHz
21	Signal Generator 10 KHz - 40 MHz
22	Signal Generator 20 - 500 MHz
25	Signal Generator 0.4 - 18 GHz
30	Servo Analyzer
31	Synchro/Resolver Standard
33	Phase Sensitive Voltmeter
34	Pressure Generator
36	Arbitrary Function Generator
38	Low Frequency Wave Analyzer
40	Pulse Generator
45	RMS Voltmeter
46	Noise Figure Meter
47	Average Power Meter
48	Programmable Oscilloscope
49	Ratio Transformer
50	DC Power Supply 0.1 - 35 Volts
51	DC Power Supply 22 - 32 Volts
52	DC Power Supply 30 - 500 Volts
53	DC Power Supply 0.5 - 1 Kilovolt
55	AC Power Supply
57	RF Measurement Augmenter
61	Precision Resistive Load
62	High Power Resistive Load

supply problems. The estimated life-cycle cost benefits attributable to VAST to date are based on savings in facilities design and construction, spare repair parts, technical manuals and other logistical areas.

Comparison studies of actual avionic support by VAST and PGSE on identical avionics has shown that VAST reduces maintenance man-hours and elapsed maintenance time. The improved quality of this support demonstrated a substantial increase in flight hours per maintenance-man-hour. In addition, as new aircraft come into the Navy arsenal, such as the projected F-18 fighter, additional savings will accrue to NAVAIR through the use of VAST.

AIRCRAFT AVIONICS SHOP MAINTENANCE FLOW

Aircraft maintenance items, as supported by a VAST Avionics Shop, include weapon system WRAs (Weapon Replaceable Assemblies), SRAs (Shop Replaceable Assemblies), and VAST BBs and SRAs as well.

a. WRA. The WRA is removed from the aircraft as a result of an organizational maintenance action. Supply issues a replacement from available assets and forwards the faulty WRA to the avionics shop for repair. The unit received by the avionics shop is scheduled for testing on VAST. In the process of the VAST test, the WRA is either verified good, aligned and verified good or determined to have a bona fide fault. A WRA verified good is certified RFI (Ready for Issue) and forwarded to Supply for re-issue. Faulty WRAs receive a diagnostic fault isolation test to the next lowest assembly and are sent to repair. The WRA is repaired by removing and replacing the faulty SRA and the WRA is scheduled for re-test on VAST. During this re-test, the WRA is certified RFI or aligned and certified RFI and returned to Supply for re-issue.

b. SRA. A faulty SRA enters the system as a result of an IMA (Intermediate Maintenance Activity) maintenance action; i.e., the faulty WRA is repaired by replacing the faulty SRA or group of SRAs. A group of SRAs is created when the WRA test program is unable to fault-isolate uniquely to the faulty SRA but instead indicates that the fault lies in one of several SRAs. Such a group is called an "ambiguity group" and is generally limited to three (3) or fewer members, as described in the appropriate weapon system specification.

Individual members of an ambiguity group may or may not be faulty. Also, individual members may or may not be designated for fault testing on VAST. SRAs not designated for testing on VAST are disposed of according to their maintenance concept. Conversely, those SRAs testable on VAST (via an SRA test program) are either verified good and returned to Supply as RFI material or verified defective and sent to the appropriate IMA repair activity. If the SRA test program contains fault-isolation routines, then the defective component(s) are indicated. After the SRA is repaired, it is re-tested on VAST, and if verified good, is returned to Supply as RFI material.

VAST AS AN AVIONICS IMA TOOL

The intermediate maintenance support philosophy of a typical VAST avionics shop consists of specific maintenance actions performed in each work area. Such actions are described below in the sequence of events (not in exact detail) of a UUT (Unit Under Test) queued for testing on VAST.

a. Buildup. In the buildup areas, the UUT and required hardware and software are assembled, secured, and placed on the Mobile Work Surface in preparation for testing the UUT on VAST. The "required hardware and software" comprise what is called an OTPS (Operational Test Program Set) which includes the OTPTs (Operational Test Program Tapes), OTPIs (Operational Test Program Instructions), IDs (Interconnection Devices), and ancillary equipment. The OTPI specifies buildup actions for each UUT and identifies required VAST BBs, IDs, and peripheral equipment.

b. VAST Station. Upon receipt of the MWS (with UUT and OTPS) at the VAST Station, Operator 1 installs the OTPT on the MTTU and loads the proper test program into the computer memory. Operator 2 connects the ID to VAST and makes initial set-ups as required on the UUT. During execution of the test, Operator 1 is stationed at the DTU (Data Transfer Unit), observing test results on the CRT and providing manual control as required. Operator 2 remains in the vicinity of the UUT while the test is being performed, to provide operator actions as required on the UUT; e.g., change function switches, connect/disconnect probes, switch RF cables, etc. When required, Operator 2 also reads the OTPI instructions on the microfilm viewer and communicates same to Operator 1. When the test is complete, a tag describing the fault is

attached to the UUT and the Operators accomplish a removal and secure procedure which clears the system and makes VAST available to test another UUT.

c. Teardown. In the teardown area the hardware and software are removed and replaced in the proper storage area after testing has been completed. The teardown actions are essentially the reverse of those performed in buildup, except that the faulty UUT is sent to the designated repair area.

d. Repair. The repair area of the avionics shop is essentially the same as for those utilizing common and/or peculiar GSE (Ground Support Equipment). Repair actions for isolated faults are specified in the maintenance manual.

e. Supply. If the UUT passes all tests and is certified RFI, it is sent to Supply for future use.

VAST MAINTENANCE

The VAST maintenance concept relies on automatic, semi-automatic, and manual maintenance features. Auto-check is fully automatic and requires no operator participation. The semi-automatic features are automatic to the extent that the station computer and computer programs are used to conduct tests, but manual to the extent that some operator intervention is required during a program stop. These semi-automatic features are self-check, self-test, calibration, system performance verification, adjustment/alignment. Calibration and adjustment/alignment may be performed either on-line or off-line depending on the design of the test program and the time required to perform these actions. Manual procedures consist of certain off-line and routine maintenance actions such as cleaning of tape heads, replacing of filters, servicing of mechanical assemblies, etc. The objective of the VAST maintenance concept is to obtain maximum benefit from the automatic capabilities and to minimize the requirement for operator intervention or additional support facilities consistent with the time available for VAST maintenance. BB maintenance consists of fault isolation to the SRA level and either performing adjustment/alignment or a removal/replacement action. SRA maintenance consists of fault isolation to one or two sub-SRAs or to a small group of discrete components and/or adjustment/alignment.

PERSONNEL, TRAINING, AND TRAINING EQUIPMENT

a. Personnel.

(1) VAST maintenance personnel are drawn from the AT (Aviation Electronics Technician), AQ (Aviation Fire Control Technician), and AX (Aviation Anti-Submarine Warfare Technician) ratings. These technicians shall have graduated from an avionics "B" school with previous aircraft/avionics intermediate level maintenance experience.

(2) VAST Operators, basic and advanced, are drawn from the AT, AQ, AX, and AE (Aviation Electricians Mate) ratings. These operators shall have graduated from an avionics "A" school with previous aircraft/avionics intermediate level maintenance experience.

(3) VAST maintenance technicians calibrate VAST Building Blocks requiring periodic calibration or calibration after a repair has been effected. A calibration tape and any other approved test equipment will be available at each site.

b. Training.

(1) Training for weapon system (e.g., F-14A, E-2C, S-3A) personnel includes instructions in basic operation of VAST and utilization of weapon system peculiar Test Program Sets to diagnose faults in weapon system avionics. Operator training, Basic Operator Course, and the Advanced Operator/Station Maintenance Course are available at NAMTDs (Naval Air Maintenance Training Detachments) at NAS Miramar, North Island, Norfolk and Oceana.

(2) Details of the training plans for VAST maintenance technicians are as follows:

(a) Fleet Training. Instruction in intermediate level maintenance of the AN/USM-247 VAST is conducted at NAMTD Norfolk.

(b) Depot Training. Training required in support of VAST DOPs (Designated Overhaul Points) at NARF North Island and NARF Norfolk falls into three broad categories:

1. Training in bit and piece repair of VAST BBs.

2. Training for VAST software management responsibilities.

3. Training of TST (Technical Support Teams) for on-site technical assistance.

Training for TST members began as on-site on-the-job training in support of the VAST Stations at Grumman. More formalized training was obtained from the vendors of certain VAST components, such as Varian and Ampex. Other TST personnel received factory training at PRD for I-level maintenance of VAST.

(3) Training courses available are as follows:

(a) Basic Operator Course. Code BVA AN/USM-247(V) Versatile Avionics Shop test, Catalog II C-198-3010. Length, 120 hours.
- Purpose: Provides instruction in semi-automatic operations, including automatic check, self-check, self-test, WRA testing, SRA testing, limited system fault isolation and periodic maintenance by using applicable equipment, documentation and safety procedures.

(b) Advanced Operator/Station Maintenance Course. Code BVC(V) Versatile Avionics Shop Test, Catalog II C-198-3014. NEC 6652 received at end of course. Length, 640 hours.
- Purpose: Provides instruction in operator intervention techniques in the application of fault isolation to VAST, interface devices (ID, software, and UUTs). Students will be instructed in intermediate maintenance of input/output devices, Magnetic Tape Transport Unit, Computer, Data Transfer Unit, BB01 and BB04.

(c) Intermediate Maintenance Course. Code BVB Versatile Avionics Shop Test, Catalog II C-198-3013. NEC 6653 received at completion of course. Length, 760 hours.
- Purpose: Provides instruction in the maintenance of the VAST including logic analysis, trouble-shooting and repair using diagnostic testing, test tapes, test equipment, publication and safety precautions. This course covers orientation, system concept, operating procedures, computer instruction and language characteristics, computer subsystems, peripheral equipment, DTU functional analysis, digital subsystem and SMS functional analysis.

c. Training Equipment. Equipment required in support of VAST I-level maintenance includes:

(1) One VAST Station with complete inventory of support equipment listed by the approved CGSEL (Consolidated Ground Support Equipment List).

(2) One complete inventory of VAST Test Program Sets.

(3) One set of VAST MAMs (Maintenance Assist Modules).

(4) One complete set of PGSE (Peculiar Ground Support Equipment) as defined in the TOL (Tailored Outfitting List) and in excess of the CGSEL, necessitated by requirements for work-around procedures in lieu of "automatic" test programs.

(5) Selected VAST Building Blocks.

(6) Training material: lesson guides and plans, student information sheets, exams, graphic aids, and printed handouts as required.

LESSONS LEARNED

The original concept of VAST envisioned the use of an operator with minimal training. This operator need only be required to know how to operate VAST and follow the instructions provided in the test program. This concept has been shown lacking because it anticipates a situation in which the program will be perfect. The machine will always operate properly and documentation associated with the testing process will always be up-to-date and correct. Experience has shown that all of these factors seldom prevail in spite of the most stringent efforts. Consequently, the operator must have some knowledge of the test system and the test program to allow him to efficiently overcome test inconsistency, ambiguities and anomalies that may be encountered. As a result, during the course of the VAST program two major iterations took place: (a) realigned VAST training courses to include an advanced operator/station maintenance course in addition to the basic operator and intermediate maintenance courses, and (b) acquisition of supplemental data (e.g., diagnostic flow charts, string lists, test diagrams, program listings) to provide the technician with additional trouble-shooting data when the test program does not provide the right answer.

The assumptions originally made concerning the VAST maintenance technician also suffered from the same inaccuracies as with the operator. It became clear early on that this technician required more training and experience to effectively trouble-shoot the complex VAST system. Commencing in August 1977 an 18-week VAST advanced intermediate maintenance course will be given. The objectives of the course will be to provide training in (a) off-line maintenance procedures; (b) calibration procedures; (c) complex self-test procedures; (d) commercial test equipment; and (e) in-depth theory, adjustment, alignment and calibration of complex building blocks. In addition, an examination of the feasibility of developing and utilizing a VAST maintenance simulator/trainer will commence shortly.

OTHER ATE

While VAST has received the most publicity, NAVAIR has successfully deployed many other ATE's. Several of the current testers in or soon to be in use are:

a. AN/USM-429 CAT III D - Primarily a digital tester (10MHz data rate) introduced to test the new E-2C radar system and F-14A SRA's.

b. AN/USM-403 HATS - Third generation technology hybrid tester introduced to test S-3A SRA's.

c. ATS - Analog and digital tester introduced to test CAINS inertial platforms and electronics (WRA's and SRA's).

d. DIMOTE - Simple digital tester introduced to test A-7E/TA-7C PGSE and avionic UUT's.

e. AN/USM-449 AAI5500 - Several variations of the same general purpose tester configured to test P-3C avionics, TACAN, etc.

A LOOK AT VAST SIMULATION

Mason Evans, Jr.
Principal Investigator
Training Equipment Design
Vought Corporation

SUMMARY

Training on the Versatile Avionics Shop Test (VAST) is now accomplished using dedicated VAST stations, thereby tying up costly operational resources. However, these resources are required for training in order to assure that properly trained personnel are available to provide necessary weapons system support in the fleet. A study of the current VAST training curriculum and the application of Vought knowledge/experience of VAST has been performed in order to determine the feasibility of applying simulation technology to VAST training requirements. This paper presents a training and implementation concept for a VAST trainer based on simulation. It is concluded that simulation will cost-effectively meet the VAST operation training requirements. The estimated cost of an operator oriented trainer will be about one-third that of a comparably configured VAST station. It is further concluded that VAST maintenance and software training requirements can be met cost-effectively by simulation, augmented with selected VAST resources for critical areas of maintenance and software training.

VAST OVERVIEW

The Versatile Avionics Shop Test (VAST), AN/USM-247(V) is produced by PRD Electronics for the Navy. VAST was designed to fill the role of general purpose automatic test equipment (ATE) to support Intermediate level maintenance activities aboard aircraft carriers. Currently, VAST is operational and deployed aboard selected aircraft carriers, installed at corresponding shore sites, and installed at five (5) sites for training. Figure 1 provides a photograph of a VAST station.

VAST's Role

The basic purpose of VAST is to help solve real estate and personnel problems aboard aircraft carriers. The introduction of a new weapons system in Navy inventory generally necessitates the introduction of peculiar ground support equipment (PGSE) and, hence, more carrier real estate is required for the new PGSE, as well as specially trained personnel. The Navy's current policy is that new weapons systems will be supported by VAST to the extent possible and, thereby, reducing the PGSE requirements and saving carrier real estate and personnel. Other direct benefits of a general purpose ATE are as follows:

a. Reduction in new support equipment procurement.

b. Logistical elements are simplified such as spares, publications, and maintenance.

c. Centralization of personnel training requirements.

Functional VAST Utilization

VAST is a highly automated set of test equipment. Once set up, the operator's role is to monitor the Data Transfer Unit (DTU) and respond to displayed messages and/or direction as they appear on the DTU display screen. A typical operator scenario is described below in sequential fashion:

a. Apply power to VAST station (assuming it was down initially).

b. Bootstrap load the control computer.

c. Load VAST operating system.

d. Initiate Station for warm-up (a few minutes up to more than one hour may be required for warm-up due to nature of some building blocks of the test equipment).

e. Collect tapes, publications, ID's for unit under test (UUT). This is, perhaps, a weapons replaceable assembly (WRA).

f. Install ID, connect WRA to ID via cabling.

g. Load test program tape and execute program.

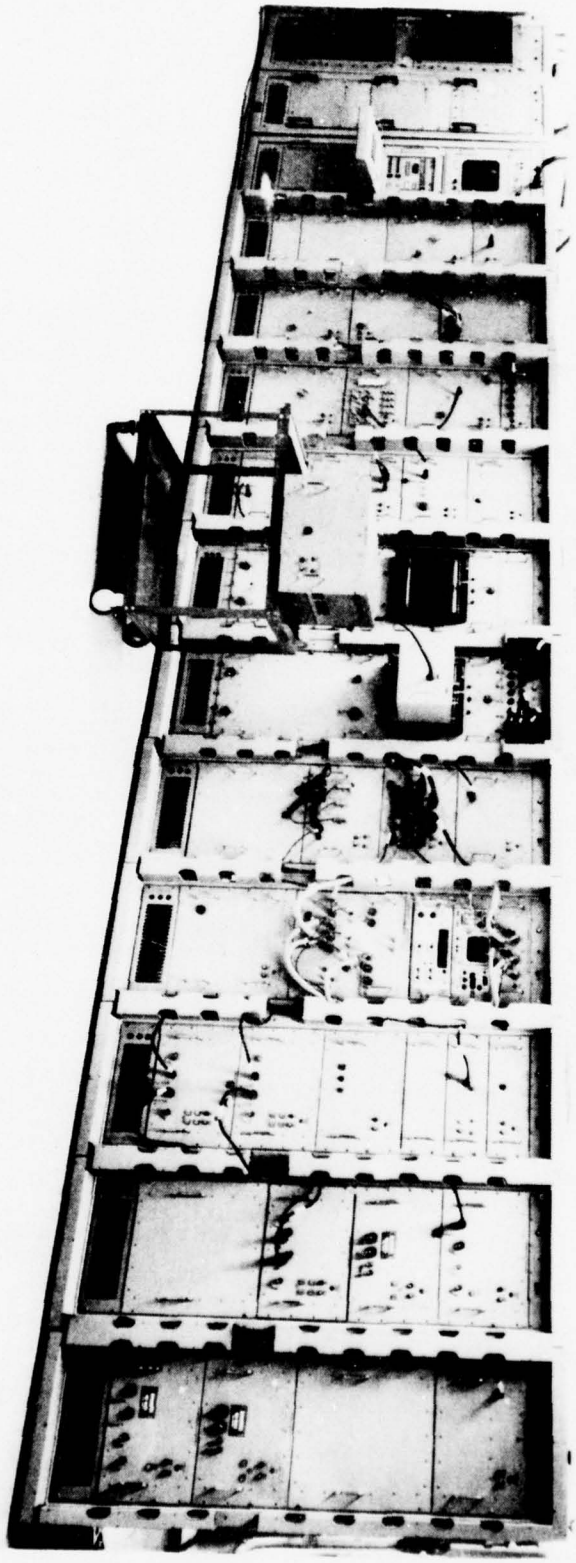


Figure 1. AN/USM-247(V) VAST Station

h. Monitor DTU display. Program activity is displayed on the DTU.

i. In general, the test program continues execution automatically until end of program or until a fault is detected and finally isolated to, say, a shop replaceable assembly (SRA).

j. A message will appear on the DTU display directing appropriate action, such as "Replace 4A3A2A1." The program halts and removes power from the WRA.

k. The operator would remove the WRA from the station, stow ID's et al, remove program tape, and send WRA to Replace/Repair area where the WRA is opened and the SRA replaced from spares.

l. Retest of the UUT is required before the WRA is certified as ready for issue.

m. Ultimately, depending on workload and/or difficulty in opening WRA or obtaining spare SRA, the operator may choose to immediately replace SRA and retest.

Many variations in the use of VAST are possible; this scenario is provided as an example to show some insight into VAST related maintenance activities. Operator intervention capability is provided as well as manual action. The features are required since some UUT's cannot be fully tested automatically. VAST maintenance is performed much in the same way as is the maintenance of WRA's and SRA's. VAST autocheck programs are run continuously using internal VAST system logic coupled with operator observation. VAST self-check is run when a suspected fault is present to determine the faulty Building Block (BB). Self-test is run using ID's and cables for testing the BB's in the VAST itself.

Vought's Experience

The Vought produced A-7E aircraft weapons system was used for the VAST Test and Evaluation program aboard the USS Kittyhawk during 1971. Vought produced a total of 68 test program sets for A-7E weapons replaceable assemblies (WRA) and shop replaceable assemblies (SRA). A test program set is composed of the VAST test software, the interface device (ID), and associated publications. Two VAST stations were resident at Vought for a period of four years. Vought's effort also included support to the Navy and PRD in the development of the VAST programming language (VITAL and MINIVITAL) and the compiler. The VAST is also used for depot support of the A-7E Head-Up Display (HUD) set: Vought developed these test program sets. Vought is currently under contract to produce test program sets for selected elements of the TA-7C aircraft. A VAST station will be in-place at Vought in May 1977 for this program.

The experience gained by Vought during the T&E program and the HUD/Depot program was applied to the development of VAST training courses for the Navy. These courses were provided primarily in support of the HUD/Depot programs. The objective for the HUD/Depot training program was to provide NARF JAX (Naval Air Rework Facility, Jacksonville, Florida) with an organic capability in VAST Test Program Set Design. This course was 800 instructional hours in length. The subject matter taught included the following major topics:

a. VAST station orientation.

b. VAST station operation.

c. VAST station elements and documentation.

d. Design and preparation of Test Program Sets.

VAST TRAINING

Five (5) sites are presently dedicated to VAST operation and maintenance training. These sites are located at the following NAMTD's: North Island, CA; Miramar, CA; Norfolk, VA; Alameda, CA; and Oceana, VA. One VAST station is located at each site. The VAST training includes work with representative Test Program Sets (TPS) developed for the E-2C, F-14, and S-3A.

VAST Training Courses

Two courses are taught on VAST operation and maintenance. These courses are:

a. C-198-3013, AN/USM-247(V), Versatile Avionics Shop Test Intermediate Maintenance Course.

b. C-198-3014, AN/USM-247(V), Versatile Avionics Shop Test (VAST) - Advanced Operator/Station Maintenance Course.

The length of these courses are 200 and 640 instructional hours, respectively.

Table I presents a general outline of the course material provided by both courses. Course C-198-3013 is generally devoted to VAST station operation and course C-198-3014

is generally devoted to greater depth in station operation, station maintenance, and maintenance of WRA/SRA from the E-2C, F-14, and S-3A weapons systems. The total time student spends on the VAST station is about 60 hours during course C-198-3013 and about 120 hours during course C-198-3014.

TABLE I

VAST TRAINING COURSE MATERIAL

A. INTERMEDIATE MAINTENANCE COURSE: C-198-3013

1. VAST Station Operation
2. Perform Self-Check/Self-Test
3. Troubleshoot Station
4. VAST Operational/Working Procedures

B. ADVANCED OPERATOR/STATION MAINTENANCE COURSE: C-198-3014

1. Operator Intervention
2. Fault Isolation
   - VAST
   - ID
   - UUT
   - Software
3. Selected I-Level Maintenance

Vought's Observations

Vought's experience and review of the VAST training programs leads Vought to believe that there is a definite potential to improve the training and to reduce the costs associated with training on VAST. This approach involves the application of simulation technology in terms of developing a VAST station simulation complex that is suited for self-paced instruction and suited for use as a "stand-up" training aid for the instructor.

VAST OPERATOR/MAINTENANCE TRAINING ANALYSIS

A study using subject matter experts has been performed on the material contained in C-198-3013 and C-198-3014 to determine requirements for the training equipment. Preliminary training equipment requirements were determined along with areas which require further study in order to fully define the training equipment requirements. Additional insight was gained through discussions with VAST instructors from selected NAMTRADETS and NAMTRAGRU.

Curriculum Study

Experience with the VAST and study of curriculum shows that the VAST station can be broken down into basically four functional sections: the magnetic tape transport unit (MTTU), the computer rack, the data transfer unit (DTU), and primary interface points--building blocks (BB) 01 and 14. The BB's that form the stimulus and measurement section (SMS) have no readout information except for BB48 (scope) and, in general, scope measurements are automatic. From an operation point of view, the action is primarily at the DTU after the tape is loaded and the UUT setup on the VAST. Self-check and self-test are run in a manner similar to weapon system WRA/SRA and, hence, most of the action is still at the DTU during on-line maintenance activities. All BB's are maintained on station at the SRA level.

C-198-3013. The primary thrust of this course is VAST operation and Station maintenance using the autocheck, self-check, and self-test programs. Maintenance of the 35ASR TTY and MTTU is also taught.

C-198-3014. This course is designed for greater depth of learning in VAST Operation and Maintenance. Further, the student is taught VAST software, ID/cable repair, and execution of representative TPS from the F-14, E-2C, and S-3A weapons systems.

Training Equipment Requirements

A number of clear training equipment requirements fall out of the study described above. The following requirements are identified:

a. MTTU operation.

b. Computer operation to extent required for bootstrap.

c. DTU operation including the maintenance panel.

d. BB01 and BB14 operation.

e. Execution of self-test and self-check programs.

f. Execution of WRA/SRA TPS with ID/cable and WRA/SRA installed.

g. Fault insertion capability.

Fulfillment of the above requirements will satisfy about 90% of the C-198-3013 course requirements and about 60% of the C-198-3014

course requirements. Detailed trade-off analyses are required in order to define the best way to meet the training equipment requirements relative to VAST station SRA maintenance, VAST software generation, program dumps, operator intervention, and BB maintenance off-line. These requirements can be accommodated. The question becomes what type of equipment, i.e., real or simulated?

VAST SIMULATOR CONCEPT

A concept for a VAST simulation device has been developed. The concept embraces self-paced instructional capability and the capability to serve as a standup training aid for the instructor. This concept has evolved from the experience and data base obtained during three years of applied research in operator/maintenance training simulation trainers.

Training Concept

The concept is centered about the approach of distributing each of the critical tasks for initial training and finally intergrating these learned tasks into a functional capability consistent with the course requirements.

This approach addresses a problem common to both "hardware" type trainers as well as simulation type trainers, that is, access to the training equipment by more than one or two students at a time. Duplication (multiple sets) of the trainer in part solves the problem, but in my judgment this approach may be "overkill" and, hence, not cost-effective for many applications of simulation technology. Another important aspect of the use of simulation device is the instructional program used in conjunction with self-paced learning. Self-paced learning is effective and desirable for these devices. Problem--the instructional program may very well become a crutch for the student and his performance be dependent upon its availability. The concept does rely on instructional programs, record keeping, and the like, but the instructor is provided the capability to withdraw these "crutches" as the student shows progress in learning the task. Monitoring provisions are available to the instructor at all times. Furthermore, the instructional program would be built around objectivity, leaving subjectivity for the instructor to handle. Any part of the device would also serve as a standup training aid for the instructor. Figure 2 provides a sketch of the concept described above showing the VAST basic simulators and two satellite carrels.

Implementation Concept

The VAST simulation device would be implemented as a distributed system composed of an abbreviated VAST station simulator and a number of satellite training devices representing those areas for which critical tasks are learned. The satellite devices will include simulation devices and selected VAST equipment; for example, preliminary study shows it will be cost-effective to use a 35ASR TTY rather than a simulation device for it. An instructor station would be provided to allow monitoring of each training area.

VAST Station Simulator

The VAST station simulator would be composed of the following simulated elements: MTTU, Varian Computer, DTU, the BB01/BB14 interfaces, and selected WRA/SRA/ID. Each element would be functional from an operator's point of view with an appropriate instructional program to provide student assistance upon request or at the instructor's discretion. A student carrel would also be provided for enrichment on VAST operation. Figure 3 is a photograph of a VAST simulator mockup.

a. MTTU. The MTTU would be simulated to the extent that the tapes could be positioned and spooled through the tape drive mechanism. A simulated program load capability would be provided.

b. Varian Computer. Simulation of the Varian would be to the extent required to bootstrap the station up from a cold start and allow the operator to run diagnostics from the front panel.

c. DTU. This would be a high fidelity simulation of the DTU including correct display information, maintenance panel indications, keyboard operation, and operator intervention.

d. BB01/BB14 Interfaces. Interface to the VAST station would be simulated to the extent that installation of an ID/Cable set and WRA/SRA are sensed by the simulator and it is possible to provide simulated TPS execution including fault insertion, fault isolation/replacement.

e. WRA/SRA/ID. Selected WRA/SRA/ID combinations would be simulated to the extent described in d., above. The devices would be facsimiles of selected weapons system WRA/SRA/ID and VAST station equivalents for maintenance of the VAST station.

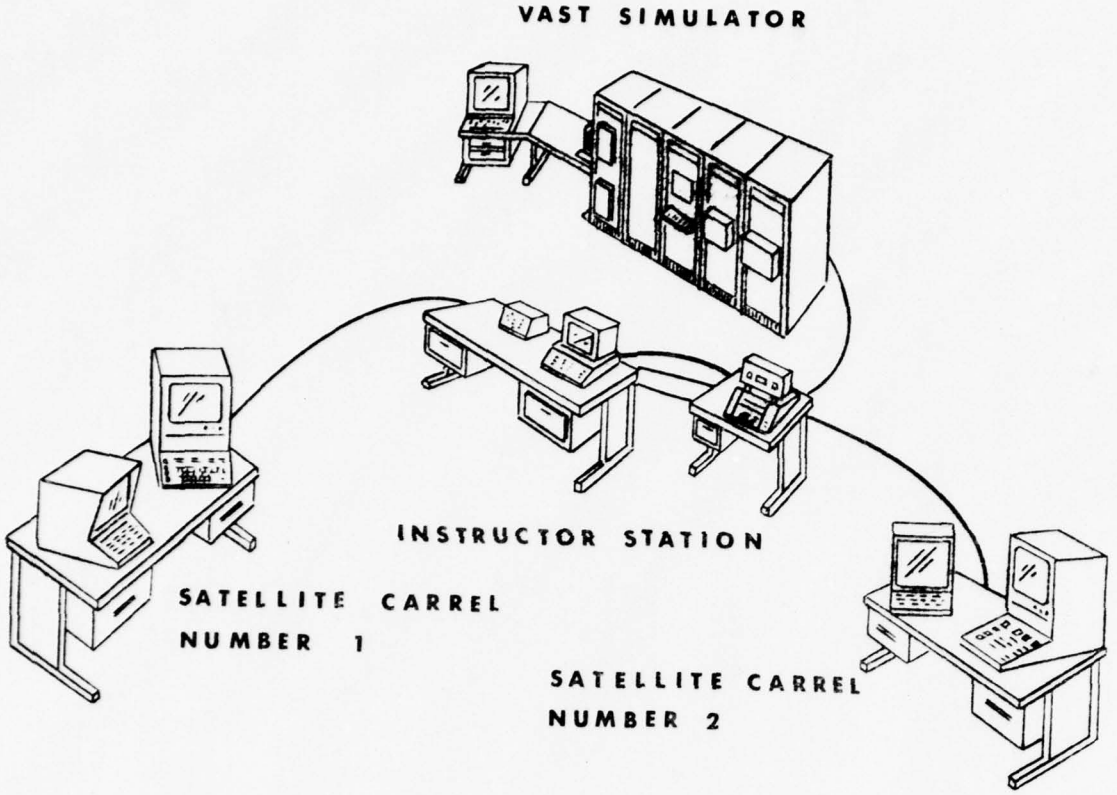


Figure 2. VAST Simulation Concept

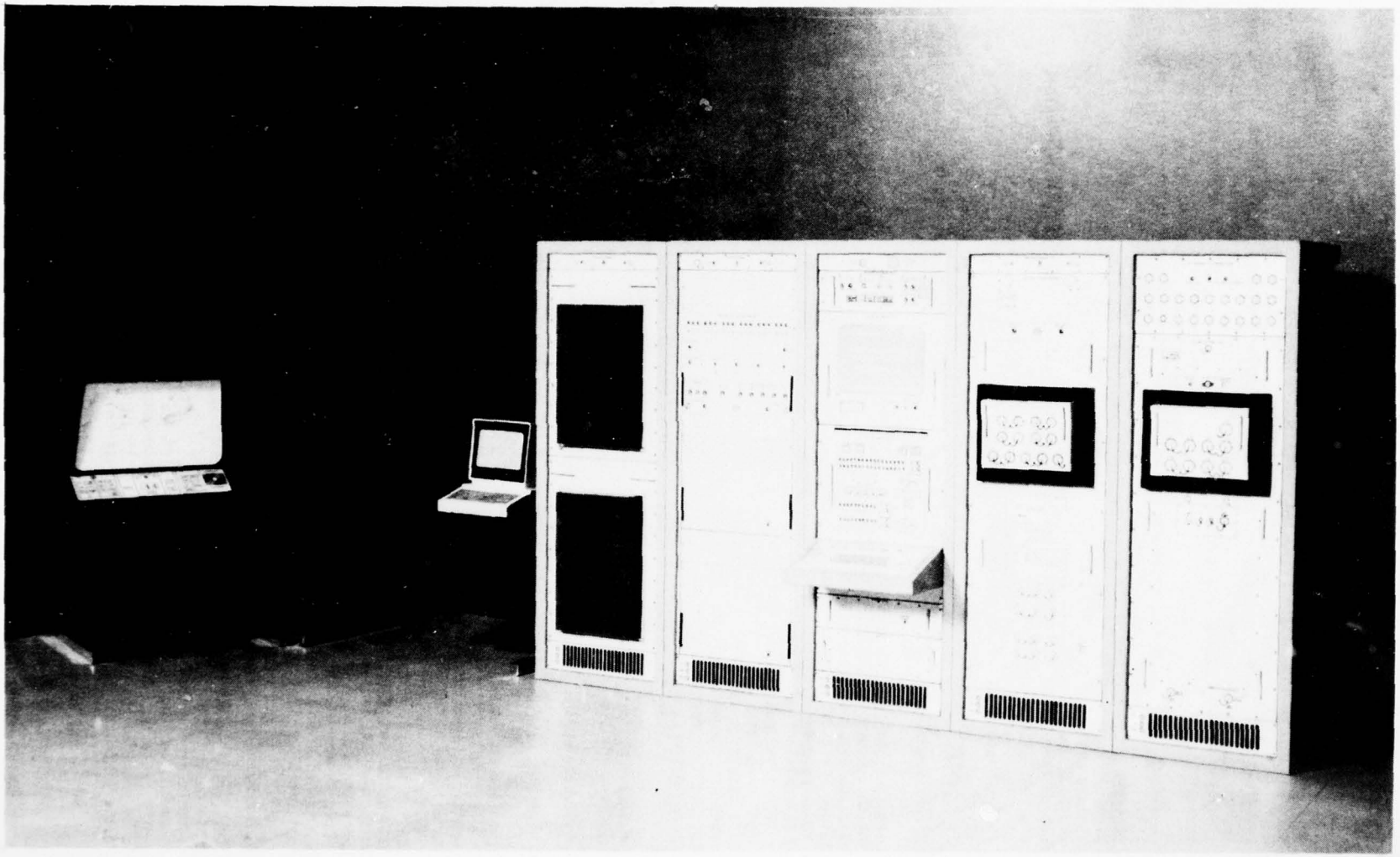


Figure 3. VAST Simulator Mockup

f. Building Blocks Simulation. Selected Building Blocks (BB) simulated implementation would be to the extent that the BB could be extended and SRA fault isolation and replacement could be accomplished.

g. Student Carrel. A student carrel is provided at the VAST simulator which includes a CRT monitor of the DTU display, a projection system, and student control modes. The carrel would be used by a student to correlate the DFC and the DTU displays and monitor the action at the VAST station. Instructor/student communication would occur on the carrel or at the station on the DTU.

Satellite Training Devices

Satellite training devices would be provided for the student to achieve proficiency in critical tasks prior to working at the VAST simulator. Critical operator tasks presently identified for simulation are DTU operation, ID/cable set mounting at BB01/BB14, MTTU tape loading, and Varian operation including bootstrap. Detailed analysis will determine any other critical operator tasks and the technique for implementing the satellite carrel. Critical maintenance and software tasks identified are as follows:

a. Maintenance Tasks - MTTU, 35ASR TTY, Varian, and DTU.

b. Software Tasks - Varian bootstrap, Varian software, and VAST software analysis.

Satellite configurations would include a simulated DTU, a commercial version of the Varian computer, a 35ASR TTY, and a simulated MTTU. The number of satellite carrels will be determined by the number of students as well as the finally determined set of critical tasks. Each carrel would be connected to the instructor station and capabilities provided for the exchange of data. Instructional programs would be provided at each student carrel in a manner similar to that described in paragraph entitled "Training Concept."

Instructor's Station

The instructor's station would be configured to control the VAST simulator and each satellite carrel including malfunction insertion, record keeping, and monitoring each student's activity. A communication link would be provided between each student carrel and the instructor station.

TRAINING BENEFITS

The major training benefit to be realized is the student can work at achieving the critical tasks proficiency one at a time without concerning himself with other aspects of the overall job. After the student has become proficient in performing the critical tasks the work on the VAST station is more meaningful and the next level of training can be undertaken; i.e., TPS execution. Other significant training benefits are:

a. Extensive malfunction simulation.

b. Device designed specifically for training and not subject to mishandling.

c. Recycle times programmable, not dependent on warm-up periods.

d. Record keeping.

e. Frees instructor of relatively trivial tasks such as check cable hookup, DTU commands, and the like.

f. Self-paced instructional capability allows student to advance at his own pace.

PROJECTED COST BENEFITS

The projected cost of a VAST simulator with four satellite carrels is about one-third that of a comparably configured VAST station. This device would be capable of meeting 100% of the operator training requirements and about 60% of the maintenance and VAST software training requirements. The remaining portion of the maintenance and VAST software training requirements can be met cost-effectively at about the same cost ratios through use of selected VAST resources and additional simulation devices located in satellite carrels. Life cycle costs are inherently lower for the simulation device due to simplicity and reliability of the training equipment. The MTBF, for example, is estimated to be 5 to 10 times that of VAST due to the relative complexity, thus providing more training time and reducing maintenance costs. Malfunctions detection/isolation is possible with no hazard to the equipment therefore reducing unscheduled maintenance costs.

CONCLUSIONS

The tasks associated with the operation of VAST can be met with the VAST simulation concept discussed herein. These tasks include tape loading, Varian bootstrap, DTU operation/observation, ID/cable/WRA

Testing/fault isolation/repair and the execution of VAST autocheck, self-check, and self-test. Maintenance tasks readily accomplished by pure simulation are fault detection/isolation through DTU operation, BB isolation with self-check, and BB fault detection/SRA replacement with self-test program execution. Maintenance training on VAST elements such as the 35ASR TTY and Varian may be more cost-effectively achieved through use of the VAST elemental resource itself. Refined trade-off analyses are required to determine the best mix of simulation vs. VAST resource utilization. VAST software training tasks require high fidelity achievable most readily through use of the Varian computer. The satellite approach is judged cost-effective for operator training, maintenance training, and VAST software training.

BIOGRAPHICAL SKETCH

MR. MASON EVANS, JR. received a Bachelor of Science degree in 1955. He entered the Navy and served for two (2) years as an Avionics Electronics Technician. After completing service, he joined McDonnell (St. Louis) and worked for eleven (11) years in the field of simulation including two years in the design/development of flight simulators for commercial aircraft. Mr. Evans joined the Vought Corporation in 1968 where his duties have been split between automatic test equipment design/development including VAST/A-7E test program design and the design/development of simulation based training equipment. Mr. Evans current assignment is Principal Investigator for simulation maintenance training equipment applied research.

APPROACH TO TOTAL SYSTEMS TESTING

James Alan Cauffman
Head, Systems Support Branch
Electronic Technology Division
Research and Technology Directorate
Naval Electronic Systems Command

From a systems viewpoint, the Naval Electronic Systems Command is responsible for development and support of Command, Control and Communications systems, Electronic Warfare Systems and Navigation Aids. NAVELEX interests are multiplatform in nature spanning Airborne, Shipboard and Ground Base needs but mainly ship and shore.

Many of these systems are unique in that they are comprised of components made for commercial markets, thus constraining the maintenance options available.

Another unique characteristic of NAVELEX acquisitions is long service life. Ships, in general, have long life cycles, approximately 25 years, and some of the electronic systems remain in service for nearly as long as the platform. This imposes another constraint on ship maintenance in that the various subsystems will represent many different technological eras (i.e., tubes, transistors, integrated circuits) and hence many different maintenance philosophies.

Constraints or not, the Navy, as the other services, is quite interested in reducing life cycle cost, through the reduction of personnel required to operate and maintain systems and minimizing training and reduced personnel effectiveness caused by high turnover rates.

Science and Technology Objectives for Command Control and Communications (STO-CC) and Support Logistics and Underway Replenishment (STO-SL) specifically call out the requirement to "monitor-at-will or continuously the condition of those platform equipments and systems whose failure would impair combat effectiveness". STO-SL also states requirements for manning reduction of 25-75%, standardization of components/equipments/systems, reduction of shipboard maintenance requirements without impairing effectiveness, and the ability to diagnose essential electro-mechanical equipment with simple standardized test equipment, thus ending proliferation of special test equipments. Priorities for these requirements range from critical to priority (routine).

The functions necessary to satisfy Navy needs are:

1. Operational Readiness Monitoring or the ability to verify availability of resources.

2. Diagnostics or ability to do preventive maintenance and fault isolation.

3. Repair and verification.

In order to establish a baseline, NAVELEX, with the aid of the Naval Ocean Systems Center and Naval Research Laboratory, conducted a survey of Ship's crews during FY 1974. Meetings were held on both the East and West Coasts to develop inputs from all types of fleet operators and maintenance personnel at various levels including ship and shore officers, enlisted men and civilian engineers and technicians. Visits were made to various activities to observe and witness maintenance, repair, calibration and operation functions, both at shore and afloat facilities.

As might be expected the conferences, field visits, and related technical data gathered to date have revealed a wide variety of diversified, sometimes parochial, and sometimes conflicting viewpoints. It is possible, however, to present some consensus and recommendations. One of the first conclusions is that there are a tremendous number of General Purpose Test Equipments (GPTE) in existence in the Fleet today. A major cause of this is the fact that there exist so many different nomenclatured prime equipments on board present ships, each with its own list of required test equipments. It should be noted, however, that several of these differently nomenclatured prime equipments perform the same basic functions, e.g., HF receiving, HF transmitting, etc. Thus it should be possible to reduce the total number of different types of test equipment required in the Fleet by functional grouping. Although this is a prime objective of the SCAT Code, the problem as currently viewed from the working Fleet level is still very real.

The important aspect of this problem is the fact that there exists generally a direct relationship between the magnitude of problems associated with test equipment and the number of different types or models of test equipment in the Fleet. Thus any attempts to reduce this diversity will yield broadly based payoffs in areas such as spare parts support, calibration requirements and the effectiveness of the Fleet technician.

Other problems found with test equipment in the Fleet today can be grouped into three general areas: 1. Problems with the equipment proper; 2. Problems which are primarily a result of user inadequacy (i.e., cockpit problems); and 3. Support problems. Of course the problems found in the Fleet do not neatly fall into the above grouping; most are actually a combination of all three. But the above differentiation will be effective in providing a better insight into existing problem relationships.

1. Problems with the Equipment Proper: The most common gripe in this area was the bulk, i.e., size and weight of some test equipments, most notable being signal generators and spectrum analyzers. Aboard ships this portable test equipment must be frequently moved to various levels. The resultant banging of the test equipment against ladders and bulkheads consequently renders the equipment in a questionable condition for usage, and places additional stress upon spare parts and calibration support activities. Equipments such as these should be replaced with smaller equipments capable of being easily transported around the ship.

Another problem noted was the mechanical construction of most test equipment. The majority of the test equipment in the Fleet today is equipment designed primarily for laboratory usage, not Navy usage.

Closely related to this problem is the complexity of the test equipment which the technician must use. Again this test equipment is not designed for use by Fleet technicians. Consequently, the level of expertise required for proper operation of the test equipment usually exceeds that available in the Fleet.

2. Problems Which Are Primarily a Result of User Inadequacy (i.e., Cockpit Problems): The basic problem in this category is that the Fleet technician does not know how to use his test equipment. This problem has two causes: (1) The technician has never really been schooled in the proper usage of the test equipment and (2) the test equipment is so complex that even if the technician received proper training it would still be beyond his capability.

The typical Fleet technician is an "A" school graduate. In "A" school the technician is taught the theory of operation of prime equipment, and is also given some hands-on experience on a few pieces of test using the test equipment with prime equipment, but merely a brief indoctrination to such items as oscilloscopes, voltmeters, etc. The large number of different pieces of test equipment further precludes introducing the technician to every type of test equipment he may run into in the Fleet.

Consequently the typical Fleet technician comes aboard a ship to test equipment which he has never seen before. And he must learn how to operate and use his test equipment. Basically, then, the problem is one of training. Service groups such as DATC, MOTU, etc., serve to help in this area but the problem is still far from solved. A common comment from Fleet technicians concerning training is that the people who are sent to shore based training schools are the people who can be spared, not the real workers since they are needed to keep the gear operating.

3. Support Problems: (Equipment support of various types, including calibration, repair and spare parts availability). The major gripe in this category is the long turn around time required to complete calibration. This includes repair of the equipment approximately 50% of the time. Typical turn around times reported were 30 to 75 days for calibration and 3 to 6 months if repairs were also necessary. The calibration facilities were questioned regarding figures and asked for comment. Their records showed the time of the average technician required to calibrate an item of test equipment to be 2 3/4 hours. And an average time required to repair an item of test equipment was stated to be 6 hours. The calibration representatives pointed out that from their viewpoint the causes of the long turn around for calibration are the long wait for spare parts and the large amount of test equipment already "inline" to be calibrated. On top of this there is a priority system wherein highest priority for test equipment

calibration is given to deploying ships on the basis of departing date. Thus ships with future deployment dates not only have their test equipment in a long waiting line, but also may be preempted by ships with higher priorities because of imminent departure dates.

Some of these hardware problems are being addressed both by industry and the three services. For example, the "Fluke" Committee (a DOD Committee chaired by Mr. John Fluke and chartered to address the General Purpose Test Equipment procurement policies of the three services) has managed to get an agreement between a major segment of the GPTE industry and DOD which will allow procurement of commercial "off-the-shelf" instrumentation to meet most military needs from an environmental standpoint (Ruggedness). This change in policy can go a long way in supplying lightweight up-to-date GPTE to the Fleet. Another significant trend is the use of microprocessors in GPTE making these standard items excellent building blocks for computer controlled test systems, but even beyond that it allows for instrument design compatible with modestly trained technicians. Over the next few years instruments as complicated as the spectrum analyzer will be operated by turning one knob while a microprocessor makes all the subtle adjustments to obtain correct measurements.

But these trends alone will not answer the Navy's needs. Most test equipment in the field today is designed for diagnostic testing (troubleshooting) yet a large percentage of a ship's GPTE allowance is required for Planned Maintenance (PMS) testing and none of the test equipment can perform operational readiness or systems end-to-end testing. The reason is quite simple, testing the black boxes that comprise a system does not guarantee the system will work because there can be an error build-up or poor interconnections. Furthermore, black box testing is very time consuming and often detrimental in that the system under test is made inoperative by the technician's probing.

Therefore, in the present situation almost no systems testing and very little planned maintenance is done at sea even though a requirement exists.

The RDT&E program that evolved from these studies is striving for a distributed automated test system for electronics that ultimately will rely on built-in test concepts and provide rapid systems status information as well as identify faults to the lowest replaceable unit. At the same time the philosophy of extending the technician's capability in lieu of automating him out of the decision-making role will be maintained since one of the lessons learned is that the Navy technician, while not as well trained as desired, does show initiative on many occasions and is innovative when necessary. This is the long-range objective, however, and since it will take many years to achieve this utopia (as mentioned previously C3 and NAVAID are not normally replaced as frequently as weapons systems) we have to deal with addressing Navy requirements with a program that will evolve into the final objective.

The efforts proposed are directed toward three general areas of investigation and development. First, advanced automated support system concepts will be explored to provide improved support capability for existing and future electronic equipments. These concepts will focus on organizational and intermediate maintenance levels, as a stand-alone capability, but will be compatible with the evolution of a modular readiness, test and checkout system. Compatibility will be achieved through adherence to interface standards such as:

a. RS 232/IEEE488 (8 bit bus interface)

b. MIL STD 1553 (serial data multiplex)

c. SDMS (parallel data multiplex)

d. ATLAS (test specification language)

The second group of tasks will investigate new approaches to testing so as to develop initial or faster, more efficient techniques for testing in the several technology areas, i.e., digital, analog, fiber optics, etc.

Finally, a broad range of tasks are directed toward expanding the technology base for design of electronic systems so as to make them testable. This effort is perceived as the one having the greatest long-term payoffs for increased readiness, simplified maintenance and reduced support costs.

Like most programs this NAVELEX ATE program is long on planning and short on budget so we have to prioritize our work. This resulted in a small program to develop system test concepts for Electronic Warfare and Communications Systems which I will discuss. These two areas were selected not only for their significance to the NAVELEX product line but also because they present a severe problem to the Fleet. Much of the EW/communication function is passive in nature and covers a broad frequency range; therefore, it requires an extraordinary amount of time to do a Readiness/PMS check-out using available test hardware and

methods. Therefore, since the 1974 survey three tasks have been pursued:

1. UHF Communications Test Set (UHF CTS)

2. HF Communications Test Set (HF CTS)

3. EW Calibration Beacon (CBS)

The UHF CTS (developed by the Naval Ocean Systems Center (NOSC) in FY 1975) is a small, lightweight (less than 10 lbs) portable test unit which is used to evaluate performance of the AN/SRC-20 and AN/SRC-21 Radio Sets. It was designed to answer a specific need because the next generation Radio will have a built-in test capability. However, with an inventory of 5000 units in the field the SRC 20-21 series will be in use for many years. Only four connections need to be made to the system under test, all accessible at the Radio.

A photograph showing the CTS and the manner in which it is connected to the communication unit is shown in Figure 1. This test set is designed to test four key system parameters for readiness determination. These include:

a. Receiver Sensitivity

b. Transmitter Power Output

c. Antenna/Multicoupler Efficiency (VSWR)

d. Modulation Percentage

To measure receiver sensitivity, a Stimulus Generator supplies amplitude modulated RF signals simultaneously at all frequencies to which the receiver may tune. This known constant level stimulus is injected into the antenna input of the receiver under test. The audio output from the receiver is fed to circuitry which measures the signal to noise ratio. This signal to noise ratio is directly related to receiver sensitivity. A look-up table is provided to allow direct conversion from the meter readout to receiver sensitivity. Indicator light readout is: green indication for sensitivity better than 17μv; yellow indication for sensitivity between 7μv and 17μv; and red indication for sensitivity poorer than 17μv.

All Transmitter and Modulator Tests are based on forward and reflected power samples obtained from a directional coupler introduced into the antenna line. The output signal from the directional coupler is a composite signal with a time varying component representing the amplitude of the modulating signal and a dc offset representing the amplitude of the carrier.

Transmitter Power Output is determined by measuring the average dc value of the forward power sample obtained from the directional coupler. A low pass filter is used to isolate the dc component of the directional coupler output. The resulting signal is then amplified and routed to the readout section of the CTS.

Antenna/Multicoupler Efficiency is a measure of how well the RF energy generated by the transmitter is coupled into the antenna/multicoupler. Techniques employed in the CTS provide this measurement in terms of reflection coefficient (p) which is the ratio of incident and reflected power samples from the directional coupler. Reflection coefficient (p) is related to VSWR by the formula:

$$VSWR = \frac{1+p}{1-p}$$

No stimulus is required for this measurement, however, the transmitter must be keyed.

In the modulation percentage test, a standard modulating stimulus signal is provided to the transmitter by the Transmitter Stimulus Generator through the front panel microphone input. The degree to which this standard signal modulates the transmitted RF is an indication of the operational condition of the modulator. The Test Set is calibrated to provide a 60% modulating signal to a properly operating transmitter.

The front panel of the Test Set is provided with controls and readouts for go no-go type operation and also to allow quantitative measurements for more comprehensive testing. The readout section consists of a panel meter and a series of colored lights. The panel meter is used in conjunction with look-up tables to provide quantitative results for each of the four system tests. Colored indicator lamps provide rapid go no-go indications. Three colors are used for this indication; go (green), pass (yellow), and fail (red). Indication of invalid operating conditions is provided by a set of orange lamps. For example, if a receive test is requested with the unit under test (UUT) in the transmit mode, the indicator associated with the proper message alerts the operator of this fact. In addition, the readout section is deactivated. Tests are selected by the operator by means of a rotary Function Select switch. Tests are activated, and the self-test function is initiated by means of a

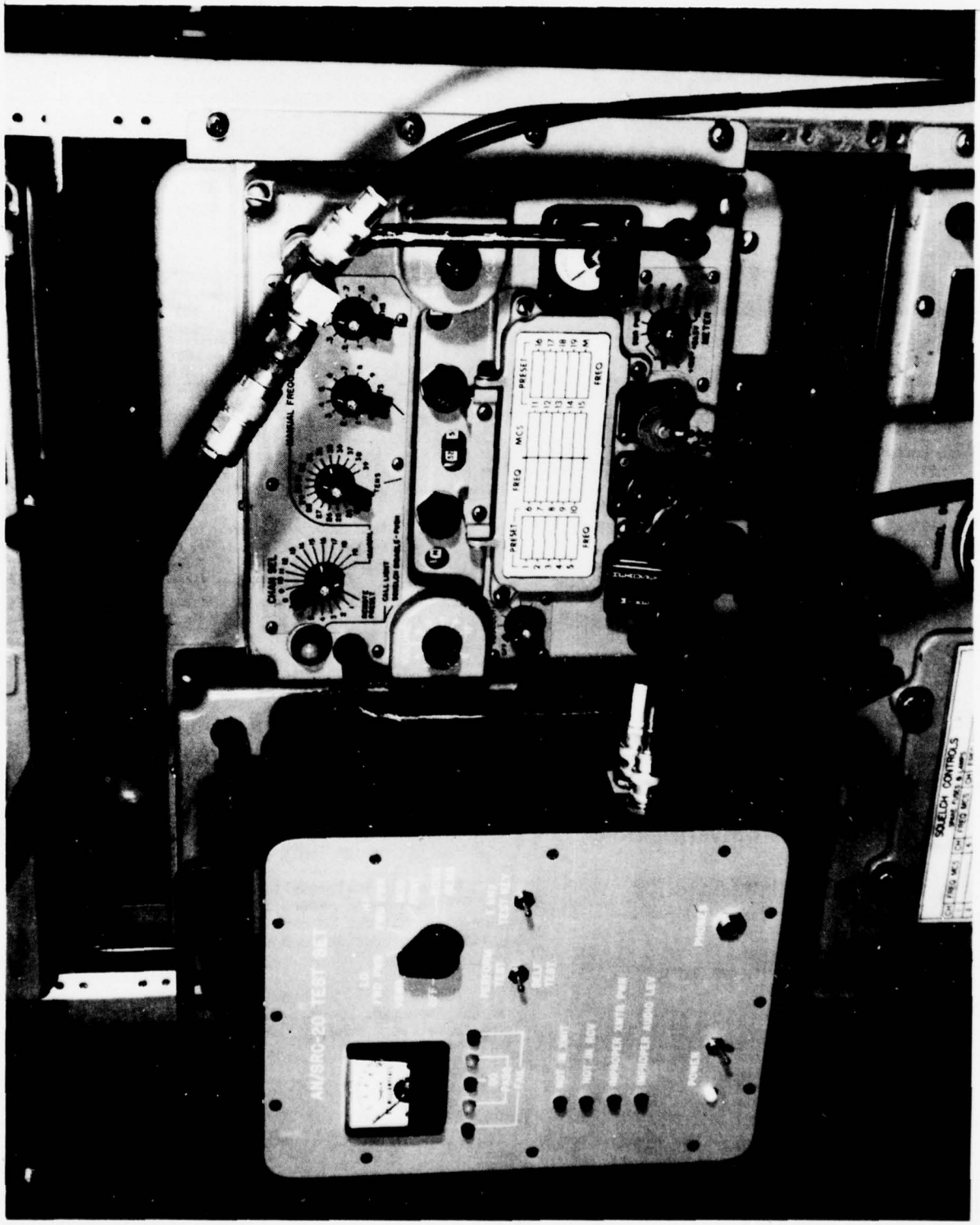


Figure 1. CTS/Communication Unit Hookup

Perform Test/Self-Test switch. A Test Key switch is used to inject the modulating signal for the Modulation Test and to key the transmitter for all transmitter tests. A complete Radio checkout can be completed in about one minute by either the operator or the technician. Using present fleet methods, the same set of tests will require two technicians, four to five pieces of test equipment and about 1-2 hours (not including set-up time).

Twenty prototype units have been built for evaluation by both avionics and ship maintenance organizations. The acceptance has been quite good and the CTS will probably be bought initially to support NAVELEX responsibilities under the Total Ship Test Program or TSTP (a formalized program managed by NAVSEA with the objective of providing on-board system test capabilities by early FY 1980).

A second development by NOSC is the HF Communications Test Set also known as the Receive System Exerciser. It differs from the UHF CTS in several respects. It tests only the passive function because the High Frequency Multi-Channel Fleet Broadcast Receive System is passive. The Exerciser uses simulation to test the system and also uses the system's man-machine interface (teletype or TTy) as the test system output display.

Since the system under test can have four or five different HF receivers (different performance specs) and two or more varieties of cryptographic equipment some decision making is made by the technician who is expected to know, for example, at what distortion level receiver "A" should cease to operate effectively. To accommodate changes in cryptographic equipment a card change is required in the Exerciser. However, the exerciser can accommodate two different types of crypto-gear simultaneously which is the normal ship's configuration.

The following types of distortion are simulated:

1. RF - Weak Signal
2. AF

   Atmospheric Noise
   Signal Fade (Depth and Rate)

3. DC - Bias

   Mark
   Space
   Switched
   Mark End } TTy only
   Space End }

Figure 2 shows the dimensions and front panel of the final exerciser. While quite small, the use of microprocessors and other new techniques make the instrument quite sophisticated. The operator can control all stimulus signals and generate the printout text from the front panel. Further, the microprocessor circuits provide all control panel display information and execute self-test functions.

The RF stimulus is provided by a signal covering the frequency range of interest (2-32 MHz) provided by a comb generator with 100 KHz separation. Signal level is digitally controlled and automatically stepped during a test.

For the AF stimulus 16 channels of tone modulation, selected as required by the particular receive system, are provided. Tone Data (mark/space), audio fading (depth and rate) are digitally controlled. Additive random noise for selectable signal to noise (S/N) ratios are also digitally controlled.

DC stimulus is provided by a digitally controlled message (Quick Brown Fox ...) and heading text with one of five different distortions, at selectable percentages up to 50%, superimposed. Both encrypted and plain messages are used to enable fault isolation to the crypto unit.

Although the operator can select the routine he wishes to run, for a general readiness test or PMS check a total system check would be the first. This would consist of running a message through the system with all distortions at levels which the system should accept (i.e., TTy prints error free text). These levels are then varied in a controlled manner until the error rate is unacceptable. Ideally this failure level would be the design limit for the system.

Since the test results are printed by the TTy, a written record is automatically generated that can be used to determine the onset of degradation down to a major system component.

NOSC is still working on the breadboard of the Exerciser so that some of the details are tentative. However, we hope to have

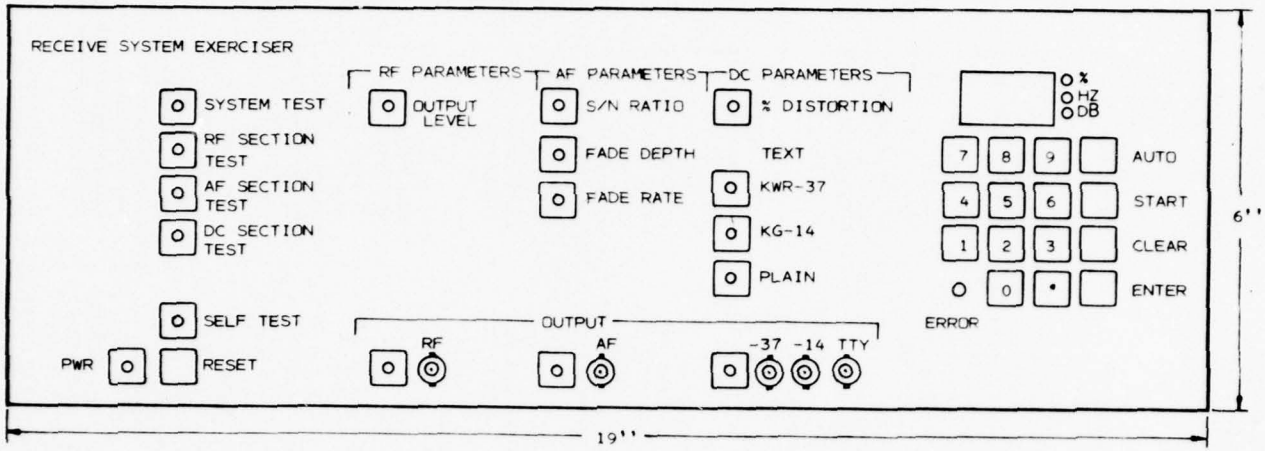


Figure 2. Operator's Control Panel, Receive System Exerciser

prototypes for fleet evaluation in FY 78.

While simulator methods as described above are quite beneficial, providing such testers for all types of systems might be difficult. At the Naval Research Laboratory we have been pursuing an approach using formatted stimuli.

A formatted stimulus is a signal in which all physical aspects (rise time - fall time, pulse width, height, etc.) are controlled and known so that any transformation caused by the system under test can be identified. The philosophy of formatting is to generate stimuli that extend beyond the response capability of the system under test so that the operating limits of the system can be quantitatively measured. A further assumption is that acceptable system performance measured via formatting will directly imply satisfactory operational performance. If this assumption is true then we hope to greatly reduce the number of different tests that will have to be performed to make decisions. Our present guess is approximately 25 tests will suffice. Possibly 10 tests will suffice to define system performance, the balance will be diagnostic in nature. However, we have not yet proved this thesis. For comparison, the TSTP program has determined that it presently requires 2437 tests to complete the communications system PMS on a FF 1053 Class Ship.

Another feature of formatting that is attractive is the potential of testing generic classes of systems simultaneously such as Electronic Warfare, Communications or Navigation. Also, formatted signals are not classified since they bear no information of intelligence value, which is a serious drawback for simulators that use threat signals. Figure 3 illustrates the first formatted signal demonstrated by NRL in 1976. The signal generated was a series of sine waves spaced 1 MHz apart from 1 MHz to 2 GHz (limit of existing signal generators). At intervals of 10 MHz the routine stopped for 1 second to allow a calibration check. The entire series of tests started at amplitudes well above the limits of the receiver; the amplitude was reduced by 3 db, after the series of frequency tests were completed, until the test signal was below the minimum discernable signal of the system under test. The tests were run on a wide band countermeasures system widely deployed in the fleet (AN/WLR-1). The breadboard test system was constructed of Calculator Controlled Commercial Test equipment using an IEEE-488 bus.

With an operator (AN/WLR-1 in a manually scanned system) tracking the formatted signal we were able to check total receiver performance from 1 MHz to 2 GHz in about 2 minutes. At approximately 2000 points across its front end the receiver was checked for its S/N ratio and any unusual attenuations. Also, the system was calibrated at 200 points. With today's test methods this would be an impossible task.

Our ultimate goal is to radiate the formatted signals so that the antenna is included in the test. The long-range approach would be to utilize built-in transducers. However, in the near-term we plan to use a centralized transmitter and commercial test equipment. Presently we have a van mounted set-up (useful for shore tests) plus another laboratory breadboard to experiment with various formats. The initial concentrated effort is on Electronic Warfare Systems.

Other advantages we see for the radiated format approach are that the test system does not become obsolete rapidly and can accommodate new prime system hardware with little or no modification. Also, the concept provides a unique option for "Low" mix ships which is the Navy's definition of a small ship with little or no on-board maintenance. With a "Low" mix ship concept, it might be possible to perform system diagnostics remotely from the Tender before the "Low" mix ship comes alongside for repairs. Remote diagnostics would permit a much faster turnaround time for the "Low" mix ship.

While it is feasible to provide orders of magnitude improvements in technician time required to service systems, it should be remembered that the present requirements are so great that 5 to 1 improvements would probably not allow the elimination of any technician billets, but would allow the fleet to perform properly all the maintenance and calibration services presently required. Also, the potential payoffs for increasing the frequency of total system checkouts (Operational Readiness) in system effectiveness will probably cause the fleet to utilize new automation capability to enhance systems effectiveness rather than to reduce personnel requirements. However, it is possible to develop data to indicate the return on investment of some of these tools.

Going back to the UHF CTS for a moment, we learned from our 1974 studies that it takes up to 5 hours to check out the AN/SRC-20 using conventional methods when set-up time is included. One of the AN/SRC-20

- USING MICROPROCESSOR CONTROLED VCO, GENERATE A CONTROLLED LEVEL SIGNAL AT INITIAL FREQUENCY
- DWELL AT INITIAL FREQUENCY FOR TIME SUFFICIENT TO ALLOW CALIBRATION
  - TYPICALLY ONE SECOND FOR MANUALLY TUNED RECEIVER SUCH AS AN/WLR-1
- RAPIDLY STEP SIGNAL (AT SAME LEVEL) TO NEXT DWELL FREQUENCY
  - DWELL AT INTERMEDIATE STEPS: 5MS
- REPEAT UNTIL ENTIRE BAND IS COVERED
- EXAMPLE: TIME TO CALIBRATE IGHz BAND IN 10 MHz MAJOR AND 1MHz INTERMEDIATE STEPS WITH 1 SEC DWELL IS LESS THAN 2 MINUTES (LIMITED BY SYSTEM UNDER TEST)

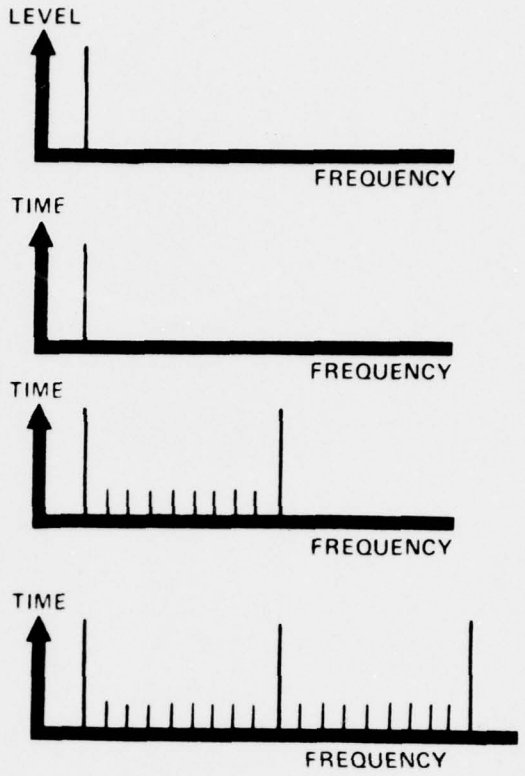


Figure 3. Example of Use of Formatted Signal: Frequency Calibration

functions is to monitor certain UHF frequencies for incoming messages. It was not unusual for the operator to monitor a faulty receiver without being aware of a malfunction. Based on assumptions that only 3000 units are in the field, the CTS costs $2000, and the tester saves 3 hours each time it is used and a technician costs $12.00/hr you can arrive at a savings in time of about 100,000 man hours/yr or 1.2 million dollars/year. The R&D investment is less than $500,000 so that when procurement costs are added the break-even point would occur in two years.

As mentioned earlier, analysis of the PMS procedures on the FF 1053 (USS Roark) shows that it presently requires 842 man hours/yr for the communications system. Present TSTP methods can reduce this time to 355 man hours/yr and with the automation that will be possible another order of magnitude reduction appears possible.

It therefore is apparent that system test concepts are not only cost-effective, but they will provide additional capabilities to the fleet. The Commander will have a more definitive determination of his assets, the operator will have a positive indication of the status of his system and therefore have a higher confidence, and the technician will be able to more quickly isolate equipment faults. Older systems can be accommodated while built-in techniques for new systems can be used where feasible, and over time an Operational Readiness Test System can evolve.

The final point I would like to discuss is the impact on the technicians, i.e., how will he use or interact with the system testers we are developing. The answer is somewhat different for each. However, there are several aspects that are common. First, all three units will be available to the system operator as well as the technicians so that he can perform readiness checks while he is using the prime system. Secondly, all allow the technician to isolate faults to system components rapidly and to achieve this capability with a minimum of hardware through use of the technician's knowledge of the system under test. With respect to the UHF CTS it requires very little skill to use; however, as previously mentioned, it can be used to provide significant amounts of quantitative information if the technician desires or needs it. The unit is intended to be semi-portable in the sense that we hope it will be in the radio room where the UHF radios are installed but will be quite easy to move from one unit to the next (the average ship has 4 UHF radios). Little or no training would appear necessary to fully utilize the UHF CTS.

Training requirements for the Exerciser would be about the same level as required for the UHF CTS for an Operator, and more extensive for the technician because he has to interact more in the decision making process. Furthermore, the HF receive system is more distributed throughout the radio room and connections to the system will not be as convenient. However, none of the skills required should be beyond "A" school level training.

With the Calibration Beacon, the level of training for the Operator would be minimal since it would essentially be a push-button operation similiar to the previous testers. For the technician however, it would be beneficial if he were familiar with the concept of formatting and how it is applied. Further, the Calibration Beacon can be calculator controlled (although we envision microprocessor control for shipboard applications), which would allow the technician some flexibility in programming and control.

In general, the efficiency and effectiveness with which the CBS can be utilized will be a function of the knowledge of the Technician using it, since it is to be an extension of his abilities. At this time we have not addressed training.

One last thought I would like to present is the possible use of formatting to enhance operator training. Much of the training done on simulators teaches an operator to recognize specific classes of signals, usually known threats. It is possible that a variety of formatting could be used to train such that one would be able to measure the limits of the operator's abilities from both an academic and physical aspect. Furthermore, since there is commonality among the various signals operators are trained to recognize, formatted training may have broad use similiar to generic systems testing mentioned earlier.

BIOGRAPHICAL SKETCH

JAMES ALAN CAUFFMAN

Title: Head, Systems Support Branch
Electronic Technology Division
Research and Technology Directorate
NAVAL ELECTRONIC SYSTEMS COMMAND

Primary Responsibility: Present responsibility includes management of basic research, exploratory and advanced development programs in the areas of Electromagnetic Compatibility and Vulnerability, Nuclear Weapons Effects on Tactical Electronics, Nuclear Radiation Monitoring and Automatic

Test Equipment and Techniques.

Summary of Past Experience:

1971 - Present - Head, Systems Support Branch

1966 - 1971 - Program Manager for Electronic Materials and Devices, Naval Electronic Systems Command. Responsible for all exploratory development, principally for solid-state devices.

1969 - 1966 - Engineer with Bureau of Ships responsible for development of microelectronic devices and technology.

1957 - 1960 - U. S. Air Force Security Service assigned to NSA and Electronic Engineer involved in developing computer techniques for analyzing solid-state devices and circuits.

Education: BSEE (1956) The George Washington University
Graduate studies in Engineering Administration.

INDIGESTION FROM WHAT WE ATE

MERLIN K. MALEHORN
Deputy Director, Education and Training
Programs Division (OP-991)
Office of the Chief of Naval Operations

I find myself intrigued by the acronym ATE. In fact, as is obvious from the title, I had to play with it a little in order to make an adept juxtaposition of the acronym with a title which conveys the thought I wish to leave with those who read this paper.

I have no intent to recount a history of ATE per se; there are many who are more versed than I. However, I do recall a four-year association with the AN/DSM-54/55 Missile Test Sets on TERRIER and TARTAR missiles in the late '50s and early '60s, and with similar gear on the TALOS missile. We had one of those typical problems which doesn't seem to have gone away. The operational hardware (i.e., the missile) was complex but maintenance actions were not excessively difficult. The test set tested the missile and told us whether it needed to be fixed, and if so, what to fix. Further, the test set had an internal test to tell us whether the test set was working properly. All very simple. Right? Not necessarily! Things don't seem to go better with Coke (although a good stiff drink helped some people survive).

I can recall also trying to teach technicians to align the AN/DSM-55. Time to complete alignment procedures seemed to work out at about four hours, if I remember correctly. A good share of the time was spent leafing around in the tech manual and referring back and forth between the gear and the manual. (Selection criteria for technicians ought to include flexible neck muscles and quick-focusing eyeballs.) We never could afford the time in school, with the limited amount of gear we had, to give every man a chance to make even a single complete alignment. Heaven only knows how they did it afloat--probably the factory tech reps did it. We finally got the whole process committed to an audiovisual job performance aid (JPA) consisting of slides and audio tape in a machine with stop-action. Then the alignment only took two and one half hours. But we had a terrible and expensive time keeping the audiovisual package current with changes in the gear, and didn't put it into the fleet.

You probably could all recount similar events, some perhaps more successful, in other programs. The state-of-the-art in what is now called ATE has advanced in the past 15 years. Now we are touting applications in increasing variety and circumstance and "designing up a storm." I would suggest that "designing up a storm" will eventually "reap the whirlwind," the way it appears to us in the training and personnel business.

I guess it's obvious that there is some kind of an interface with military training and military personnel in the Navy, as well as in the civilian contractor field and in the Naval Material Command development offices. I will elaborate on that to some extent with reference to the military technician and his problems, in a moment. However, it seems that there has been an implicit assumption that prime equipments are becoming so complex and of such functional enormity that it is necessary to shift the testing load to ATE in lieu of leaving it up to the technician to run around with his "portable" special and general purpose test equipment, probes, etc. Unfortunately, it also seems there has been a very inadequate recognition that shifting the load to ATE simply increases the burden on the technician, as it stands at the present time. Now, instead of having to test 26 racks of tube and transistor electronics, he has to test three or four racks of ATE which perform more electronic functions than the previous 26 racks did and so far do them less reliably. I could almost get into a song and dance about the fleas that have lesser fleas and so on ad infinitum. But you've heard that song before in the form of such statements as "where's the test equipment to test the test equipment?".

I have been recently advised that for the B-1 bomber, tech data people are estimating that even with ATE, the tech manual will encompass approximately one million pages. I suppose it would be two million pages if there weren't any ATE. But what's the difference between one million and two million pages, when the technicians are trying to find data? One million pages of the technical manual is about linear 330 feet of books. I'll admit that not all technicians use all data (and some don't use any), and that the data can be indexed and packaged for utility. The argument about ATE is that it will save manpower. I'm in favor of motherhood and in favor of saving manpower, and I can perceive the implicit promise that ATE will in fact save manpower. I suppose that in a sense it would take a thousand technicians to maintain the

B-1 bomber (even if they were able to handle the large scale integration and microelectronics and all the other good things that are coming out of industry) and with ATE it won't take nearly that many. So we have saved manpower. Correct? But has anyone looked at the capability of the services to attract enough people of the caliber required just to handle the ATE? Yesterday's complex equipment gave us trouble. Now we make equipments an order of magnitude (or several orders of magnitude) more complex, strap on ATEs of a complexity greater than that of last generations's complex prime equipment, and seem to think that it won't be much problem. Who said so? Has anybody taken a hard, systematic, objective look--made any kind of detailed analysis--of the real impact of the trends in ATE in terms of what will be demanded of Navy enlisted personnel in the future and whether it is going to be possible for the services to find those kinds of people?

Current Status

Let's quickly summarize the situation.

In 1971, in the Proceedings of an NSIA/AIA meeting on the Navy's ATE program, Neumann commented that the Navy had invested about two billion dollars in about 300 different types of ATE. He quoted an estimate by Frost and Sullivan in the Electronic News that the government ATE market approximated five hundred million dollars per year, the Navy share of that was one hundred million, the growth rate was 5%, and this did not include certain hidden dollars such as built-in test equipment (BITE) and software which he estimated would double the figure.

In a memorandum of 17 February 1977, the Director, Personnel and Training Analysis Office, Naval Sea Systems Command, provided some data which indicated something over 50 systems applications within the Naval Sea Systems Command, sometimes with both ATE and BITE, as well as back-up special test equipment. On the PHM (Patrol Hydrofoil Missile) alone, it looks as though there are at least eight major systems with ATE and/or BITE.

I've been advised by the expert in NAVAIR that naval aviation is about 10 to 15 years ahead of the surface Navy in ATE applications. Hence, one must assume an enormity confounded.

The 13 February 1976 report to the Assistant Secretary of the Navy (R&D) by the ATE Ad Hoc Working Group on Navy Issues concerning this area makes an interesting comment in this regard:

> "A dramatic example of the ATE problem facing the Navy is the position now faced in support of F14, S3A, E2C and certain Government Furnished Equipment (GFE) avionics systems using VAST. VAST was also expected to support the testing and calibration of its own components. Due to lack of workload handling capacity and the cost and time required for generating test software, many test requirements were offloaded from VAST to other equipments that were already available or being procured. Some of these other support equipments were manual systems and therefore less efficient. To support current requirements, VAST has been augmented by use of factory test equipment for the F14 (CADC, EMTC, HATS, CAT IID (and CAT IIID), MIDGET II, etc.). In addition, VAST components are being supported by additional testers such as the AAI5500 at NARF North Island and manual test fixtures at the NARF and Intermediate Maintenance Activities (IMAs). Many SRAs of the avionics and test sets do not yet have a support vehicle firmly identified or assigned. Use of manual test fixtures with their need for supporting, manual test equipment, eliminates many of the benefits derived from use of ATE."

Aside from proliferation of applications in electronics, there's the dimension of applications in other areas. The literature is becoming rife with illustrations. It's fairly common now, I suppose, to see the mechanic (technician?) in the garage hang some sort of "diagnostic" system on your automobile. Cox reported to the April 1976 ATE conference and workshop in San Diego on the Maritime Administration's computerized steam propulsion plant monitoring and failure prediction system, VIDEC. Wechsler and Peterson reported to the same conference on a feasibility study for a diesel engine condition monitoring system for the LST-1179 Class. Kapler and Doyle, in a recent Grumman study for the Naval Air Systems Command, looked at the requirements and criteria for BIT capability for non-avionics systems in future aircraft. They looked at all sorts of things--hydraulic, pneumatic, electrical applications--and enumerated 19 current BIT applications in these areas.

Problems Created

So, one might ask, what does that do to us? Does it make any significance to the personnel and training communities of the Navy?

Joseph, in reporting to the ATE conference and workshop in San Diego, raised the issue whether and when we will get to the final "hands-off" ATE. The implication here, of course, is that at the present time and apparently for the foreseeable future, ATE is "hands-on"--somebody has to play with it, massage it, pamper it. Further, one might ask about what happens to all the interim suites in the Navy for the next 10 or 20 years after we finally do get to the "hands-off" ATE? We all know that gear installed in the Navy has a lige of its own. Even though we tend to concentrate on the current state of the art, there's a 20 to 30 year tail of older hardware back there that technicians have to maintain and operators have to operate and tacticians have to utilize. So what happens to all of that older ATE that has to be supported until it dies?

Wechsler and Peterson, previously cited, in discussing their feasibility study for a diesel engine condition monitoring system, noted that the system will require more expertise in the engineroom. The detail of that requirement was not provided. Cox, previously cited, noted that the VIDEC system "did not present the friendliest of interfaces to ships' operating personnel." Shupe, in a paper on lasers presented at the San Diego conference on ATE, noted that lasers present special maintenance problems and require high skill levels. Martin, in a paper at the same conference, discussing the role of micro-processors in built-in tests, noted that there is a problem because there is a decreasing pool of high skill level personnel available.

Those comments appear to give early recognition to the possibility that we may have a problem in this area.

On the other hand, has anybody really seriously looked at it? Let us see. In the Proceedings of the ATE conference and workshop in April 1976, there was a section on education and training. The papers presented dealt with the following (any misinterpretation is mine rather than of the authors of the papers):

a. A paper on training Navy managers who acquire ATE as to standardization, the availability of ATE and so forth.

b. The training of program (project) managers with regard to the capabilities and availability of ATE.

c. Training of personnel in the development and acquisition process with regard to ATE software capabilities, languages, program generation, etc.

d. The impact of ATE on the maintenance concept. This paper noted that training for operational and maintenance personnel should center on the idea of the cost effectiveness of the maintenance concept as being a function of alternatives for test equipment, facilities, personnel skills, and operating rules. (This is getting close to the point, but hasn't quite made it--it doesn't seem to recognize yet that there is a certain limit of some kind on the availability of personnel at all, but it definitely suggests or hints at the trade-off analyses.)

e. Training tools and hardware such as audiovisual capabilities, instructional television, computer-assisted instruction.

f. The training of engineers in simulation techniques to be used to generate test programs for ATE.

The above comments on needs for education and training are by all means valid. However, they do not go far enough in recognizing the Navy's problems. Where's the discussion on the training problem for technicians who must maintain the gear, or operate it to find faults in the prime hardware? How many people does it take? What is the nature of training? These questions are not yet answered.

Perhaps, we can come at it in some other way. Let's look at some additional papers. Stroud, in his paper, comments on maintenance center problems. He indicates that there has been inadequate training for maintenance center personnel, and that the answer is to have more system level training on WRAs, inter-connection device/adaptor, ATE system detailed operation, test philosophy, and support documentation. He also indicates that there is need for this training to be provided for shop personnel and for personnel managers. DeTally, in a paper on user interface considerations in the Proceedings of the San Diego ATE conference and workshop, commented that design must consider human responses/coordination, retention capability, man/machine relationships, the fixed nature of machine communications, machine design augmentation, and differing attention levels.

The ATE Ad Hoc Working Group reporting on Navy Issues concerning Automatic Test Monitoring and Diagnostic Systems Equipment for the Assistant Secretary of the Navy (R&D) in February 1976, indicated that there is a problem because training and manpower are inadequate. There is poor retention of personnel, poor training, poor manning, poor personnel distribution, and the requirements are complicated due to proliferation of ATE.

In capsule form, that begins to recognize the problem. However, the answer created was that the Chief of Naval Material should tell the Chief of Naval Education and Training to revise curricula, find better training media, analyze VAST in terms of personnel distribution, revise manning levels, and improve retention. Those are all motherhood statements. I note that the last three of those items don't even belong to the Chief of Naval Education and Training; they belong to the Chief of Naval Personnel. It would seem that there is very little knowledge about the manpower, personnel and training business in the Navy. Certainly, the Chief of Naval Education and Training is going to maintain curricula current. Have you provided the information so he can do it? Are you giving him the financial support he needs? Certainly, he will look for better training media. We are spending about eight million dollars in R&D looking for better training technology. The difficulty is that you can't simply direct that he do it and expect miracles. The Chief of Naval Education and Training might just as well turn around and direct you tomorrow to stop proliferating ATE or quickly to find some way to standardize it--that's a good motherhood statement, too. Can you do it? The Chief of Naval Personnel might suggest to you that manning levels don't get revised just because you tell them to. Somebody has to analyze workload on-board ship, distribute all of the work that needs doing among the personnel that the personnel system can make available, compute pay grade impacts and manning under various conditions, and other such things. If there's only a certain number of ET's in the Navy, there's no way you can stretch them overnight into more ET's. Furthermore, if there aren't any more bunks on ship and no room for any more bunks, and you keep putting more gear on board, there's no way that we are going to be able to put more people on those ships just because you put more gear on. What I'm trying to say to you is that the paper reporting on Navy issues hasn't begun to attack the problem.

Perhaps, in the longer run, there's some research and development going on related to the education and training of personnel on ATE. Looking at the ATE related R&D program of October 1976 as reported in the Advanced Testing Technology RDT&E Program by the Test and Monitoring System Program Office in the Naval Material Command, the following summarizes:

In the area of education and training management, there are five categories. They are: readiness goals and measurement, future aircraft system test requirements, self-contained test vs. off-line, cost estimation, procurement and warranty strategies, and pre-acceptance test and demonstration of readiness and support ability.

Further, there are the following more specific types of programs:

> A VAST training simulator supported by NAVAIR at the Engineering Development level for 2.1 million dollars spread over a three-year time frame.
>
> A plasma panel for a portable maintenance trainer, at the Exploratory Development and Advanced Development levels, supported by NAVAIR, funded at 2.3 million, spread over six years. (This is the NAVTRAEQUIPCEN "MITIPAC" project which is, in my view, primarily a job aid.)
>
> Advanced training technology for support systems at the Exploratory Development level, supported by NAVSEA, four hundred thousand, spread over four years. It's intended to look at the use of computer aiding, information retrieval, holographic capabilities, and the use of the ATE itself as a trainer.
>
> ATE human factors, supported by NAVAIR, in Exploratory Development, over a period of six years, for 1.3 million. It is analyzing work centers regarding the best use of first tour technicians.

That last item is getting a little closer but is not yet quite looking at the basic problem.

Another item of interest recently developed and illustrative of activity in the area is the General Electric GETS, which is, according to GE, "ideally suited for training operators in correct button pushing and fault locating procedures." I also note that Rakow and Chalupa, in a paper prepared for the First International Learning Technology Congress, discussed the use of the computer as the base for a training system.

It appears that we are nibbling at the periphery of an issue which needs deliberate, analytic, positive, and aggressive action.

Problem Statement

The problem is--Have we <u>really</u> faced up to the personnel problem?

What is ATE doing to the technicians' community? There seems to be a tendency on the part of ATE designers, characteristic in general on the material side of the Navy, to assume a free labor pool, infinite in quantity and quality.

Let's talk a moment about the quantity problem. If you add up all ATE manning requirements, what are they? Is the absolute requirement (sheer numbers) growing? How much, how fast? In what ratings? At what pay grades? It is problematic in some minds whether we can get all the personnel we need for the future Navy, particularly under the All Volunteer Force concept. What are you assuming about this when you design ATE? Have you quantified your assumption and made sure that it's a valid assumption? (Remember my previous comment about the 20 to 30 year backlog of gear in the fleet that has to be maintained--that doesn't go away when you put new gear on board.) Are you assuming less technicians will be necessary in sheer numbers--let's see the study that proves this to be a good assumption for the Navy, as a whole, not just your particular piece of gear. Making the number lower on your gear doesn't help you get people for your system when other ATEs are adding requirements and the total demand is too great.

Let's talk about the quality problem. If the equipment requires fewer men in sheer numbers, what does it do to the skill levels we are looking for? What are the changes in skills that are necessary? How many are different from now? How different are they? Micromin repair is an illustration of a skill that had to be introduced--what others are we talking about? What ratings are you concentrating upon? One of the ratings that has to do with computers, the DS community, is growing so fast, and proliferation of equipments is continuing at such a rate, that the situation is critical and will continue to be so for some time. Are you assuming that you are going to be able to get DS's? Have you checked that assumption to find out if that's a good one--I suspect it isn't. Where are we going beyond electronics applications? What are you doing to other ratings--for example, the MM rating? What's going to be involved in training them, since they really aren't familiar with these kinds of skills at all? Is it cost effective to assume that these ratings can handle automatic test equipment? If it is not a good assumption, what rating is going to do it? Are you assuming the training will cost less? Let's see the study. Let's see it for the totality of ATE--not just for your microcosm.

Let's talk about the selection problem. Are we talking about an additional large group of people who are going to have to be data processors--who are going to have to understand fully the software in the system even though they may not program it or reprogram it --in other words, will have to know what it is doing and understand why it does it that way, in order to be able to use the ATE? Is there any chance of getting that many people with those kinds of intellectual skills--are we looking for people who think analytically and do we know we can find them in the number that are going to be necessary? How do you find them? Have you studied that problem? Let's see the study.

Let's talk about the fleet manning problem. How do you anticipate we are going to combine jobs on various ATE's so that we have a full-time billet for a man whom we can afford to provide (train, retain, etc.) in a good pay grade structure for personnel management? Is the concept of the first term ATE technician being a button pusher, the second term ATE technician fixing the prime hardware, and the third term ATE technician being the maintainer of the ATE, a good distribution of skills? It may be from your standpoint as ATE designers, but is it a good distribution from the personnel management standpoint? Is it the optimum use of talent and time, given all the other factors that enter into personnel management equations?

Let's talk about the cost to train and how to train. Is the total training R&D program adequate to support improvements in training as related to ATE? What is the training problem? How do we get to the skills you are looking for? For example, if we perceive that the ATE can itself be used as a training vehicle in how to use itself to do its job, is it really possible to write the training software, considering that we seem to have a lot of trouble merely writing the diagnostics for the test equipment itself. How big is the training pipeline going to have to be, and can it be afforded out of training resources that are available to the Chief of Naval Education and Training, given that he has many other commitments that are growing. Have you analyzed the cost of training to support all of ATE? If so, let's see the study.

Let's talk about the design interface with the man. What is the testing or diagnositc process or routine that works for and with the man? Should the routine be set to run and have him note things that go on, should we have it run and stop, or what? What should be the level of detail for on-line testing vs. testing off-line? How is he going to get calibrations done? Are there too many preventive maintenance requirements to the point that he doesn't have time to do the other work he is supposed to do or in fact is engaging in provocative maintenance instead of keeping up the gear? Can't we drive towards standardization and reduce the variety of skills and knowledges and performances that a man must have? Who's attacking this problem directly and continuously and trying to put a handle on it?

THE BASIC ISSUE IS: WHAT ABOUT THE MAN IN THE SYSTEM? HE SEEMS TO BE JUST AN AFTERTHOUGHT. THE PROBLEM HAS NOT BEEN LOOKED AT. IF ATE IS NOT SHORTLY TAKEN UNDER TOW IN TERMS OF PERSONNEL AND TRAINING IMPACT, THE PEOPLE WILL NOT BE THERE TO DO WHAT HAS TO BE DONE WITH IT AND THE FLEET WILL HAVE A BAD CASE OF UNDIGESTED ATE.

BIOGRAPHICAL SKETCH

MERLIN K. MALEHORN

Mr. Malehorn is the Deputy Director, Education and Training Programs Division (OP-991), Office of the Director, Naval Education and Training, on the staff of the Chief of Naval Operations. The Programs Division is responsible for monitoring, evaluating, and directing modifications as necessary to the on-going military education and training programs within the Navy. In addition, for the Director, Naval Education and Training, Mr. Malehorn is the action officer on research and development in the areas of training and training simulation, as well as related aspects such as human factors, personnel, and manpower. As such, he is responsible for a research and development program of about $20,000,000 annually in training and training devices.

Mr. Malehorn has served as an Education Specialist with the Navy Department for 23 years, in a variety of positions dealing with curriculum development, procurement of training material, program administration, policy formulation, and other management responsibilities generic to the business. He received the Department of the Navy Superior Civilian Service Award in 1967.

As a Captain in the Naval Reserve, he is currently assigned as the Director, Plans and Policy, Naval Reserve Readiness Command REGION SIX, Washington, D. C.

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SIMULATION OF AUTOMATIC TEST EQUIPMENT FOR AIR FORCE TECHNICAL TRAINING

by

Gary G. Miller
Dennis I. Downing, Major, USAF
Air Force Human Resources Laboratory

and

James A. Gardner, PhD
Chriss Clark, PhD
Honeywell Inc.

INTRODUCTION

Amidst controversy concerning the appropriate role of the technician in maintaining today's sophisticated weapon systems, the use of Automatic Test Equipment (ATE) continues to expand. In addition to the ATE purchased for field use, the Air Force currently procures extra copies, at substantial cost, for use in the classroom. Tnis operational equipment is used in Air Force technical training to train students to operate and maintain several types of test stations; these stations are designed to test major aircraft components at the intermediate level (I-level) of maintenance.

ATE in the Training Environment

While the I-level maintenance shops have generally benefited from the increased use of ATE, training personnel to operate and maintain the equipment has posed a new set of problems for the training community. A well documented problem, in both the field and classroom, is the unavailability of fully operational test stations. This problem is a function of the low reliability of this very complex test equipment and the significant "down" time associated with required maintenance. Test station unavailability is especially pronounced in the training environment due to intermittent use of the station, station misuse by the student, less experienced maintenance personnel, and training facilities low priority with respect to receipt of needed replacement parts.

Due to the presence of high voltages associated with ATE, training on the operational equipment is often degraded to avoid risk of injury to the student. This concern for safety combined with test station unavailability severely limits the trainee's "hands-on" practice of general operation and maintenance tasks.

More specifically, the use of ATE as training devices limits the range of equipment faults and emergency conditions to which trainees can be systematically exposed. Consequently, trainees are not permitted sufficient practice trouble-shooting problems they are likely to encounter in the field. Duplication of a controlled set of equipment faults generally requires physical insertion of costly prefaulted hardware components. Permanent damage to the station to effect faulty functioning is simply not an option. In some instances, trainees are merely exposed to a set of randomly occurring actual equipment malfunctions.

As a matter of practical concern, ATE is inflexible in training situations. It requires costly modifications, if not complete replacement, to adapt to evolving training needs.

Simulation as an Alternative

A relatively recent alternative to actual ATE in the maintenance training environment is simulated test equipment. Miller (1974) reviewed the concept of simulation and its uses in technical training to date. In general, simulators address the deficiencies of ATE as training devices in that they are normally less expensive, more reliable, more easily maintained, have a large capability for duplicating malfunction conditions, are quiet, are safe for practicing dangerous and/or expensive test procedure, and afford flexibility. There remain, however, a number of unresolved issues regarding simulation that have limited its acceptance in technical training curricula.

The purpose of the current paper is to discuss an ongoing Air Force research effort to assess the potential for simulation in I-level maintenance training. The program's

immediate focus is the development and evaluation of a simulator-based training system to teach operation and maintenance of a selected automatic test station belonging to the F-111D shop. However, the selected test station serves primarily as a vehicle 1) for demonstrating the feasibility and overall practicality of using simulated complex electronic equipment for training I-level maintenance procedures, and 2) for addressing several of the outstanding issues related to simulation. The current effort is part of a comprehensive program to evaluate the requirements for, and the use of low-cost simulator training devices in Air Force technical training. A later program phase will attempt to develop a methodology for identifying where simulation can be used effectively in technical training applications.

SIMULATOR-BASED TRAINING SYSTEMS

Definitions of simulation and simulators abound; see Miller (1974) for a review. Nonetheless, certain general features characterize nearly all simulator-based training systems.

First, these systems incorporate devices that duplicate, in varying degree, the appearance and the operation of selected actual equipment. The resultant "simulators" range in complexity from simplistic cardboard mockups to the very sophisticated flight simulators used in pilot training. The essential feature is that the simulators provide "sufficient" realism 1) to evoke and permit practice of specified job-related tasks, and 2) to enhance transfer of learned skills/knowledge to real-world job environments. Certain aspects of the actual equipment are deliberately omitted; that is the simulators are characterized by less than 100% engineering fidelity. The simulators become training devices when these omissions are based on careful identifications of how the devices are to be used in the training environment - what persons with what entry-level skills/knowledge are to be trained to perform what set of tasks to what level of proficiency under what conditions?

Secondly, simulator-based training systems may incorporate supporting instructional features-trainer-unique features and capabilities not inherent to the actual equipment. These features could include carefully controlled learning situations, step-by-step monitoring of trainee actions, performance feedback, automated instruction, and well designed student and/or instructor station consoles. Again, however, the requirement for these various adjunct features must be based on a clear specification of intended simultor trainer use.

SIMULATION IN MAINTENANCE TRAINING

Outstanding Issues

Many studies have recognized the potential of simulation in maintenance training (e.g., Lumsdaine, 1960; Parker and Downs, 1961; Baker and Wahnick, 1970). Several unresolved issues, however, have limited its acceptance in technical training.

Fidelity. Chief among these unresolved issues is fidelity. What is or how does one determine the appropriate level of physical/operational realism to ensure effective training? Miller (1953) and Gagne (1954) have both emphasized the distinction between engineering and psychological fidelity. Full engineering fidelity requires that the physical and functional characteristics of actual operational equipment be duplicated within very tight tolerance specifications - whether or not those characteristics provide critical cues or required interfaces for the trainee learning a particular job. Maximum psychological fidelity, on the other hand, requires only that degree of equipment duplication necessary for the trainee to transfer to the job environment (with zero decrement) those responses he learns to perform in the training environment. After reviewing the major studies in maintenance simulation, Miller (1974) concluded that engineering fidelity can be quite low in devices used to train certain procedural tasks without subsequent transfer.

Evaluating Training Effectiveness. The issue of transfer of training while often discussed, is rarely addressed adequately. Numerous studies (Denenberg, 1954; Briggs, Besnard, and Walker, 1955; Cox, Wood, Barne, and Therne, 1965; Rifkin, Peiper, Folhey, and Valverde, 1969; McGuirk, Peiper, and Miller, 1974; Wright and Campbell, 1974) have concluded that simulators train equally as well as operational equipment alternatives. However, most of these studies have suffered from the lack of adequate measures of transfer of training.

Life-Cycle Costs of Training Equipment. The issue of lifecycle costs (LCC) requires that both the acquisition and longterm maintenance costs of training equipment (including associated personnel costs) be addressed. Savings ranging from 20% to 90% of actual ATE life-cycle costs have been attributed to simulator-based training systems. (See King, 1975.) Honeywell, for example, conducted a program under sponsorship of Naval Air Development Center (NADC) to compare the costs of using actual versus simulated test equipment for training maintenance skills related to AN/ALQ 100 electronic warfare

equipment. (See NADC Report, NADC 75177-40). Cost comparisons were made using a Navy cost analysis model. The comparison attributed a potential 53% LCC savings to the use of demonstrated simulator-based training system.

User Acceptance. No doubt the widest use of simulation to date has been for pilot training. Flight simulators have significantly reduced the number of required training hours in actual aircraft, with consequent reductions in required aircraft and fuel consumption. In some cases of retraining qualified pilots to operate new aircraft, the actual aircraft is used only for final checkout.

Traditionally, flight simulators have been characterized by extremely high engineering fidelity to the point that they could be considered aircraft without wings and the cost of associated training systems sometimes exceed that of the aircraft themselves. This can be attributed to two major factors:

1) limited data concerning what features of the aircraft system are required to train the mission, and

2) the demands of users for a training device that "feels like" the real thing.

The conviction was held that the actual equipment was the best training environment; simulators somehow represented a degraded training environment, but were "accepted" initially because they became the only reasonable alternative in light of government edicts to conserve fuel.

The problem of overcoming the user community's resistance to simulator-based training is a major concern for the maintenance training area, where actual equipment is currently the norm, and must be considered in trainer design.

I-Level Maintenance Training

King (1975) noted that the area of I-level maintenance training, which currently relies on actual ATE, had been considered by many to be impervious to an effective use of simulation. Resistance was based on the established requirement of "hands-on" training and a general distrust of the two-dimensional approaches to maintenance simulation that had been developed previously. Consequently, due to the complexities of I-level jobs and equipment (ATE), the sheer volume of "different" maintenance tasks, and the somewhat complex job of the test station repairman, simulation was initially dismissed as technically infeasible.

In 1973, this situation began to turn around with the NTEC-sponsored feasibility demonstration of a simulated ALQ-100 test station, designed and built by Honeywell. The coupling of the above demonstration with an Inspector General's report that was critical of I-level resident training for the F-111D, prompted the Air Training Command (ATC) to issue a formal request to the Air Force Human Resources Laboratory (AFHRL) to investigate the potential of simulation technology for I-level training. Specifically, ATC requested that AFHRL design, fabricate, test and evaluate the potential for simulation of an I-level maintenance test station for the F-111D aircraft.

The particular test station selected was the 6883 Converter/Flight Controls Test Station designed to maintain five Line Replaceable Units (LRUs) from the F-111D. It was chosen because: 1) it is representative of complex, automatic, electronic test stations found in I-level maintenance shops; 2) it suffers from extremely low availability, particularly in the classroom; and 3) the tasks required to operate and maintain the 6883 are largely procedural and thereby readily adaptable to a computer-driven/monitored training system.

6883 PROTOTYPE DEVELOPMENT

Project Objectives

The immediate objectives of the 6883 Project are to design, develop, and implement realistic, cost-effective programs that provide hands-on training of Level-3 Apprentices to maintain the 6883 Test Station and associated LRUs. These programs will incorporate a simulated 6883 Test Station, simulations of four associated adapters, and three simulated LRUs that have been designed and will be fabricated, integrated, tested, modified, delivered, and installed by Honeywell. In conjunction with these immediate project objectives are the related goals: 1) to develop unique simulation techniques, as required, and 2) to identify other training/simulation technology needs. An example of a recognized new technology issue is the appropriate trade-off between hands-on student practice of a maintenance task and conceptual training of the same task using computer-aided instruction (CAI) techniques in a hands-off or modified hands-on mode.

The project also has the broader objective to demonstrate that simulated, complex electronic maintenance equipment is not only a feasible but also a practical alternative to actual test equipment for training purposes; demonstration of that fact

has implications for future training systems procurements. Simulated maintenance equipment becomes a practical alternative when the associated life-cycle costs are less than those of corresponding actual equipment. This reduction can be effected primarily by substantial reductions in both initial procurement costs and the long-term maintenance costs for simulated equipment. In addition, the use of simulated equipment as a training device should at least maintain and preferably improve upon the level of training effectiveness achieved with actual equipment.

The 6883 Simulator system designed by Honeywell addresses the deficiencies of the actual 6883 and LRUs currently used in training through a unique, flexible configuration. To assess the training effectiveness of the simulator-based 6883 training system, a later phase of the overall Air Force program will include a rigorous comparative evaluation of 6883 training conducted using the actual 6883 versus the 6883 simulator.

Functional Specification Development

The crucial first step in the design of any simulator-based training system is the development of a functional specification that defines the training features to be provided. The training system functional specification guides the subsequent simulator design and determines in large part the ultimate training effectiveness of the device. For this reason, considerable attention was given to preparation of the 6883 Maintenance Training System functional specification.

Initial Task Analysis. Formal task analytic procedures were employed to identify the job-related skills and knowledge required to operate/maintain the 6883 Test Station. Miller and Gardner (1975) used a task analysis procedure developed by Miller (1974) to gather these preliminary data. Data were gathered at both the training site and operational base to ensure validity and comprehensiveness of the analysis. These data provided a description of the job environment that the trainee enters following resident training.

Sixty tasks were identified that represented the major functions of the test station operator/maintainer. These tasks were rank-ordered based on composite indices reflecting each tasks' frequency of occurrence, difficulty to learn, and criticality to mission success. The final hierarchial ordering of these task data was used as a guideline for making recommendations regarding functional fidelity of the simulations to be developed. The task analysis data were used to develop a preliminary functional specification for a simulator-based system to train 6883 operators/maintainers. The specification required that the proposed training device allow hands-on performance of each of the identified tasks and simulate 50 representative faults. The proposed system configuration included a student console, instructor console, 6883 and LRU simulations, and associated peripherals. Some of the major instructional features were extensive feedback, reinforcement, knowledge of results, prompting, departures from strict realism, sequencing of subject matter and faults from easy to difficult, time compressed sequences, efficient trainee performance measurement, and the capability to eliminate feedback and prompting gradually.

Emphasis was placed, therefore, on developing the structure of the tasks that mediate successful training of ATE operation and maintenance; the equipment design to be developed would efficiently incorporate that structure. This approach was described by Gagne (1967) in his discussion of the basic principles of training design. Gagne listed these principles as consisting of: a) identifying the component tasks of a final performance; b) insuring that each of these component tasks is fully achieved; and c) arranging the total learning situation in a sequence which will insure optimal mediational effects from one component to another.

Request for Proposal. The preliminary functional specification and data resulting from the task analysis formed the basis for a Request for Proposal (RFP) to develop a simulator-based training system for 6883 operation and maintenance. Bids were received, evaluated by an interdisciplinary team of 13 psychologists, engineers, programmers, and subject matter experts; the program was awarded to Honeywell Inc.

Project Scope and Emphasis. Before Honeywell could begin detailed system design, the project scope and emphasis had to be clearly defined. Accordingly, the target training population was described (e.g., what are the entry-level skills/knowledge of the trainees and to what level of expertise are they to be trained?); current training course content, structure, and deficiencies were identified.

Two training courses related to I-level maintenance of F-111 avionics are taught at

Lowry Technical Training Center (LTTC), Lowry Air Force Base, Denver, Colorado. Individuals in Course 3ABR32631D-002 are trained to operate the various test stations in the F-111D shop, including the 6883, to test, inspect, and trouble-shoot malfunctioning LRU's. Not only are they trained to isolate the source of the malfunction, using automatic and semi-automatic test procedures, but they are also trained to perform the appropriate corrective action. In addition, they are trained to perform some preliminary tests of the station itself to ensure that it is functioning properly.

Individuals in course 3ABR32630B-000/001/002 are trained to maintain the test stations in the F-111D shop. This involves testing, inspecting, trouble-shooting, and repairing any test station that an operator has identified as malfunctioning. The focus of concern is the test station itself rather than the LRUs.

Both courses are ogranized in multiple blocks, taught in a prescribed sequence. Only one or two of the later blocks are concerned specifically with training on the 6883 Test Station and related LRUs. The preceding blocks in both courses include 10-12 weeks of basic electronics, generalized instruction on automatic test equipment and training on specified F-111D avionics test stations other than the 6883.

Deficiencies in current 6883 training courses were identified through review of course records and through interviews with instructors, 6883 operators/maintainers, and recent course graduates. The major inadequacies of current 6883 training are the very limited "hands-on" practice of job-related tasks and, in particular, the severely limited range of equipment faults that trainees witness. Use of a simulator makes it possible to expose all trainees to a series of equipment malfunctions specifically selected for their training value. The data also suggested that emphasis be placed on fault-detection and isolation, though representative repair procedures should be trained as well.

Based on the foregoing observations, Honeywell's 6883 Maintenance Training System has been designed to provide "hands-on" practical application of classroom theory and instruction that trainees receive prior to and during the 6883 blocks of courses 3ABR32631D-002 and 3ABR32620B-000/001/002. The content and format of remaining course blocks are not to be affected. Emphasis has been placed on fault isolation, particularly in those areas of the test station that are common to other test stations in the F-111D shop. Representative repair procedures are to be trained as well.

Detailed Specification Development. Given the established project scope and emphasis, the 6883 Maintenance Training System was designed to improve training effectiveness by providing 1) computer-assisted instruction (CAI) and guidance, 2) efficient performance measurement, 3) specific and immediate feedback, 4) a variety of realistic trouble-shooting tasks, and 5) objective criteria for trainee evaluation. In addition, the system configuration was to reflect the RFP's requirement for an expandable network of test station simulators. Honeywell clarified, confirmed, and expanded the 6883 preliminary specification provided in the RFP. Additional test station and LRU maintenance data were examined to establish a final set of malfunctions to be simulated. Considerations affecting these selections included: the resultant variety of malfunctions (reflecting varied fault sources and requiring varied use of the appropriate Technical Orders); the representativeness of the malfunctions vis-a-vis the real world; and the level of expertise expected of 3-Level Apprentices upon completion of resident training. The malfunction selections were further refined based on inputs from field personnel in the F-111D Shop.

The particular selection of malfunctions impacted the detailed simulation hardware design, as well as related software and instructional material. The tasks that trainees must perform to 1) checkout, 2) trouble-shoot, and 3) repair the test station and LRUs, in light of the selected malfunctions, were systematically identified. These tasks were further described in terms of the required operator/maintainer actions (e.g., place 400 CPS and 60 CPS circuit breakers in ON position; set DATAC MODE switch to NORMAL); the associated man/equipment interfaces; and relevant cues (e.g., displays and indicator lites). These task data were cross-referenced against the panel-by-panel features of the test station and with each LRU's features. This analysis identified an initial set of equipment features and fidelity levels to be reflected in the simulation designs.

A detailed system functional specification was finalized based on a trade-off analysis that addressed program cost, system flexibility, expansion potential, training effectiveness, relevance of simulated procedures to 3-Level Apprentice tasks, and the objective to demonstrate the practicality of a range of simulation and training techniques. This detailed specification

enumerated the specific procedures to be trained, the selected set of test station LRU malfunctions, and the required test station/adapter/LRU simulation features and functions specified. The means for fabricating the simulations so specified were developed at a later time.

Throughout this detailed requirements analysis, careful consideration was given to the evaluation phase scheduled to begin after installation of the system at Lowry AFB. A formal training-effectiveness analysis of the system will be conducted by AFHRL to assess the practicality of I-level maintenance simulation. The relative merits of ATE-based and simulator-based training will be contrasted through a comparison of students trained using the present operational 6883 Test Station and those trained using the simulator. A range of simulation techniques and training procedures has been specified to permit assessment of the relative effectiveness of different approaches. Detailed performance measures were specified which far exceed the instructor's immediate needs. These data will be recorded on cassette tape for later statistical analysis and can provide insight into both the simulator training effectiveness and the student's learning process. Finally, the hardware design incorporated a number of features which facilitate data collection and system modification. Through the inclusion of such additional hardware, software, and courseware features, an effective evaluation of the feasibility and practicality of maintenance simulation will be possible.

System Overview

This section provides a general description of the basic system block diagram, proposed installation facility layout, and an artist's conception of the 6883 simulator-based training system.

Generalized Block Diagram. The 6883 Maintenance Trainer is a multi-computer system which drives simulations of the 6883 Test Station and associated LRU's through appropriate interface hardware. Student actions on the simulated equipment are sensed by the computer through the same interfaces. Appropriate student guidance and feedback is provided by a CRT/keyboard and random access slide projector. Student performance is recorded by the computer system and is output to the instructor's CRT/keyboard in summarized form. These same performance data are output to a cassett tape and high-speed printer for record-keeping. Figure 1 illustrates the training system hardware block diagram.

The 6883 Maintenance Training Simulator is controlled by two Honeywell Information Systems Model 716 computers (hereafter referred to as H716's). The computer system architecture is a multi-processor, distributed system providing expansion capabilities. One H716 computer functions as a classroom controller, operating the instructor station CRT/keyboard, high-speed printer, disk, tape drives, and inter-processor interface. In addition, the classroom controller performs the following functions:

- store program segments on the disk;
- satisfy program loading requests of the 6883 Simulator LRU's and any additional stations via the training system computer, and
- act as a software development device for programming the station controller while the system is not being used for instruction.

Data transfer between the classroom controller and the student station controller is performed using an industry standard RS232 interface. Three (or more) additional RS232 interfaces may be used to connect additional test station simulators to the classroom controller. The 6883 simulator computer architecture is therefore designed to permit low-cost, rapid expansion to a total of four or more simulated test stations. In this manner, a single instructor at his console can simultaneously monitor several different station simulators.

The second H716 functions as the student station controller. The student station controller operates the student CRT/keyboard, random access display unit, interprocessor interface, I/O multiplexer and test station and LRU simulation features. A Trainer Interface Electronics System (TIES) provides an input/output multiplexing capability for sensing student actions and for driving displays and indicators on the simulated equipment. A random access Mast slide projector is computer-controlled through this multiplexer. The student station controller is designed to provide the following functions:

- operate all digital/analog conversion hardware;
- process all student actions at both the CRT/keyboard and the test station/LRU simulation;
- request additional program data segments from the classroom controller;

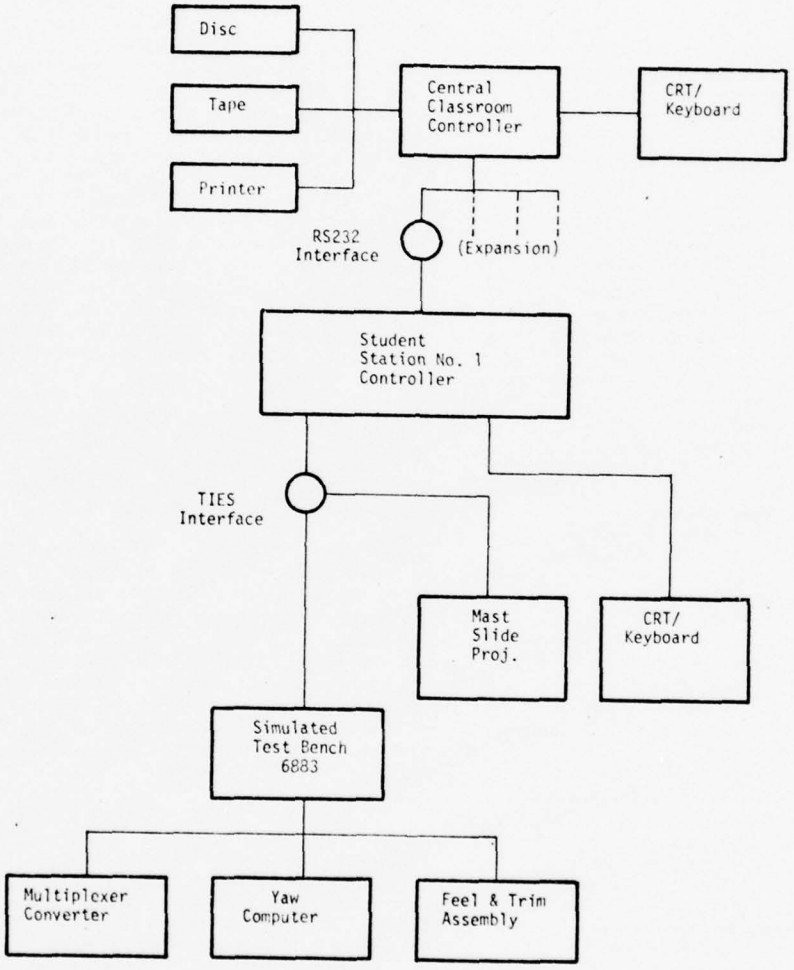


Figure 1. 6883 Maintenance Training System Block Diagram

- drive all student CAI;
- transmit student performance data to the classroom controller for display to the instructor; and
- cooperate with the system controller to perform simulator self-diagnostic procedures.

Generalized Trainer Layout. The 6883 Maintenance Training System installation layout has been designed to provide optimal efficiency and ease of operation. An artist's conceptualization of the proposed system hardware arrangement is shown in Figure 2.

The instructor console, consisting of the instructor CRT/keyboard and high-speed line printer, is located in the right front quadrant of the room. This arrangement affords the instructor an unobstructed line-of-sight to the student console and 6883 Simulator. Easy access to the classroom and student station controllers is possible with this arrangement, thus facilitating disc changes, tape changes, and H716 front-panel entries. Location of the instructor console in close proximity to the computer systems reduces the required cable lengths and probability of electromagnetic interference. A Hewlett Packard 2640B CRT keyboard is included at both the instructor and student consoles and the high-speed line printer is placed at the instructor station.

The student console, consisting of a CRT/keyboard and slide projector is located in the rear left quadrant of the room adjacent to the 6883 Simulator. Most student actions at the student console will take place at the CRT/keyboard while most actions on the 6883 Simulator will involve the DATAC panel in the far left equipment bay. The proposed room layout positions the student CRT/keyboard and DATAC panel in close proximity to simplify trainer operation. The proposed arrangement permits cabling to the student console along the left wall, thus reducing cable lengths and possible electromagnetic interference.

Simulation Requirements

Simulated 6883 Test Station. The extent to which the simulated 6883 Test Station resembles the actual four-bay test station varies from panel to panel. The 6883 Simulator consists of 28 metal photo panels, 3 pull-out drawers, and an unmodified GFE oscilloscope, arranged in the appropriate 4-bay configuration. Selected front panels are represented completely with metal photos. Others are simulated using metal photos plus appropriately positioned functional equipment. Figure 3 depicts the specific panel-by-panel design details.

As noted earlier, tradeoff decisions were then made to optimize the trainer design in terms of design efficiency, costs, and training capabilities. Two examples of this tradeoff analysis are the simulation requirements for the Data Transfer and Control (DATAC) drawer and the power supply drawers. The DATAC was selected for in-depth simulation because it is central to a variety of maintenance procedures. In addition, it requires a range of maintenance tasks and a number of different techniques for effective simulation; it provided a cost-effective way to examine a variety of simulation and training. Although the 6883 has several power supplies, only a single power supply drawer was simulated internally; maintenance procedures, simulation techniques, and the skills and knowledge required for trouble-shooting are common among most power supply circuits in the 6883.

Simulations of the three test station pull-out drawers reflect varying levels of fidelity within each drawer. A more detailed description of the DATAC drawer simulation follows as an example.

DATAC Drawer Simulation. The DATAC panel is the principal technician interface through which automated test requests are initiated, test modes are changed, and test results are displayed. The maintenance technician must use the DATAC for all trouble-shooting procedures, whether manual, semi-automatic or fully automatic. Due to its importance, most simulated procedures involve the DATAC and require the use of all front panel controls and indicators.

A high fidelity simulation of the DATAC is being provided which includes all front panel and interior controls and displays, and representative printed circuit card simulations. A metal photo of the actual 6883 DATAC front panel is mounted on a drawer assembly of appropriate size. The required front panel controls and display windows shall be mounted on that photo. Photos are sensed and driven by the student station controller. The drawer shall extend in the same manner as the operational unit. The upper interior portion of the DATAC drawer shall contain a simulation of the hinged card frame assembly and register bit display indicators and controls. The card frame assembly shall contain 56 simulated printed circuit cards. There shall be 13 different simulated PC card configurations. Four of the 56 cards will be removable and

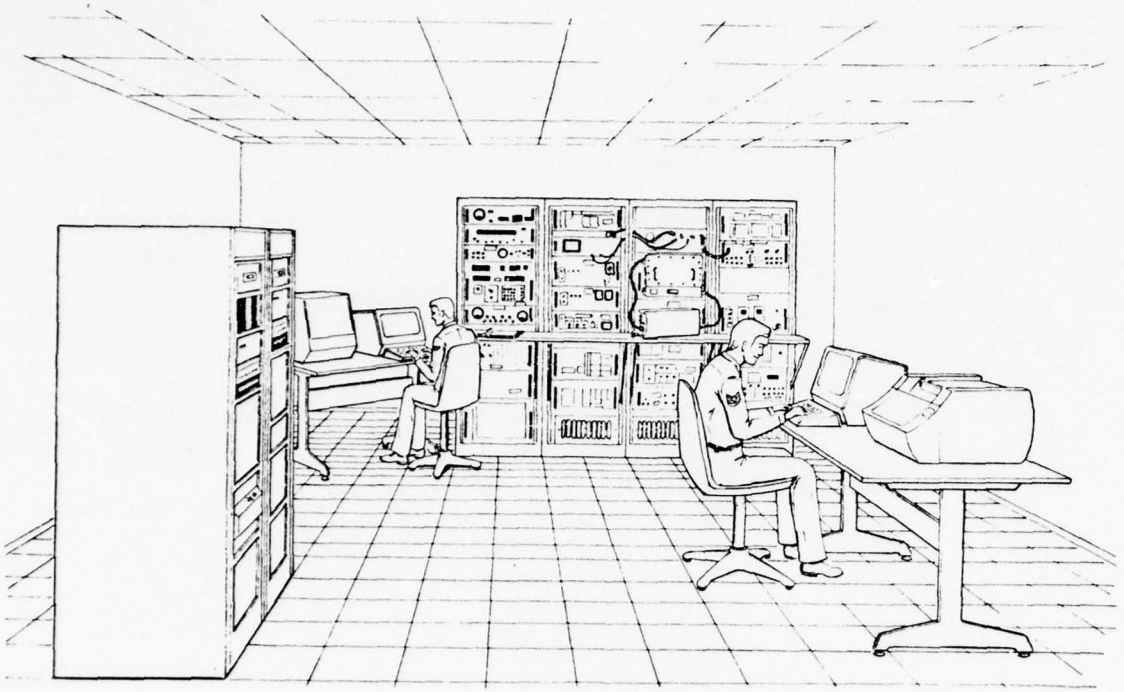


Figure 2. Artist's Conceptualization of Classroom Arrangement of Hardware for 6883 Maintenance Training System

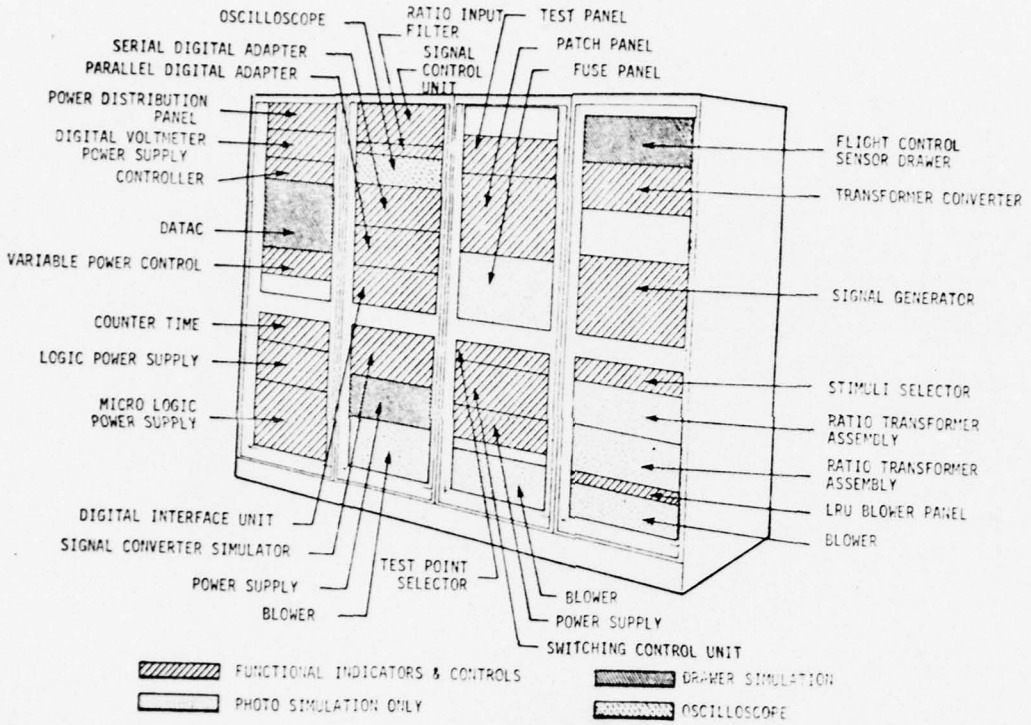


Figure 3. Panel-by-Panel Summary of Simulation Levels Required Across Test Station

will be sensed by the computer.

The hinged card frame assembly containing the PC cards shall hinge to a locked position. Metal photos shall be used to provide visual simulation of internal PC test points on the rear of the upper and lower card frame assemblies. The DATAC simulation shall also include functional simulation of bit display lights, address lights, test sequence lights, subaddress lights, sequence interrupt and manual modify switches. (See Figure 4.)

General LRU Simulation Requirements. In general, the exterior of each of the three LRUs is simulated in appearance. The front panels are represented using metal photos, reflecting identification plates, elapsed time meters, and jack and switch identifiers. The necessary functional features of each unit are mounted at the appropriate positions on the metal photos. Each simulated LRU will be appropriately weighted to resemble the corresponding actual equipment. All simulated LRUs will have handles in the appropriate locations.

A more detailed description of an exemplary LRU simulation follows.

Feel and Trim Assembly. The front panel of the feel and trim assembly is represented by a metal photo, reflecting the unit identification plate, all jack identifiers, and the elapsed-time meter. The six jacks and jack covers on the front panel are three dimensional to permit the trainee to cable the LRU to the appropriate adapter.

The interior of the LRU is simulated through a combination of metal photos and elementary sculpturing. The upper and center relay panels are represented by a single metal photo, positioned within the housing at the level of the two panel boards in the actual equipment. Likewise the right side of the assembly, including adverse yaw network assemblies is represented as an appropriately positioned metal photo. Limited color can be added to this metal photo to facilitate component identification. Signal converters, amplifiers, and the spoiler rectifier assembly are appropriately sized and positioned, three-dimensional sculptures made from aluminum blocks.

Pushbuttons are mounted on selected components in the photos and on selected ones of the sculpted components as well. These buttons are used by the trainee to indicate the location of components that are identified as fault sources during malfunction scenarios. The location of these buttons was determined 1) by noting which components are sources of fault for the selected set of malfunctions and 2) by identifying other components that are likely to be confused with the correct component when the trainee is attempting to locate the fault source within the assembly. This latter consideration is necessary to provide a valid test of the trainee's ability to locate designated components. More complete simulation of the interior is not cost-effective. Emphasis is on the trainee's demonstrating that he can isolate and locate faulty components correctly, not on training disassembly of the unit. (See Figure 5.)

Expandability/Flexibility

A major feature of the 6883 hardware configuration is expandability/flexibility. At least three additional simulator training devices, different from the 6883, can be driven by the Honeywell 716 computer that is acting as a classroom controller. This feature accommodates the long-term need that Air Force technical training has for increasing numbers of simulators to meet their training requirements. Moreover, as the focus of training changes with the evolution of test equipment, the hardware system configuration developed for the 6883 can adapt - requiring only the replacement of obsolete simulation hardware with updated simulations; major system components (e.g., student console, student station controller, interfaces) can be reused with the replacement simulation.

The software and courseware architecture are similarly designed for flexibility. As additional or replacement simulations are incorporated into the system, only the data base specific to the new test equipment must be added to the software. Instructional materials or courseware are written in common English in a specified character-per-line, lines-per-page format to facilitate generation and/or modification of lesson materials by instructor or support personnel. This becomes an especially important feature when reconfiguration of equipment requires changes in the training course content.

Simulator System Maintenance

Any practical alternative to using ATE as training devices must address the problem of ATE unavailability. A replacement training system must be reliable, easily maintained, and thereby consistently available for training.

The 6883 simulator-based training system is designed to be repairable to the component level by 5-Level Air Force Specialists. Prior to delivery of the training system, Honeywell will conduct a maintenance training program that will equip an initial set of specialists to perform periodic, preventive, and

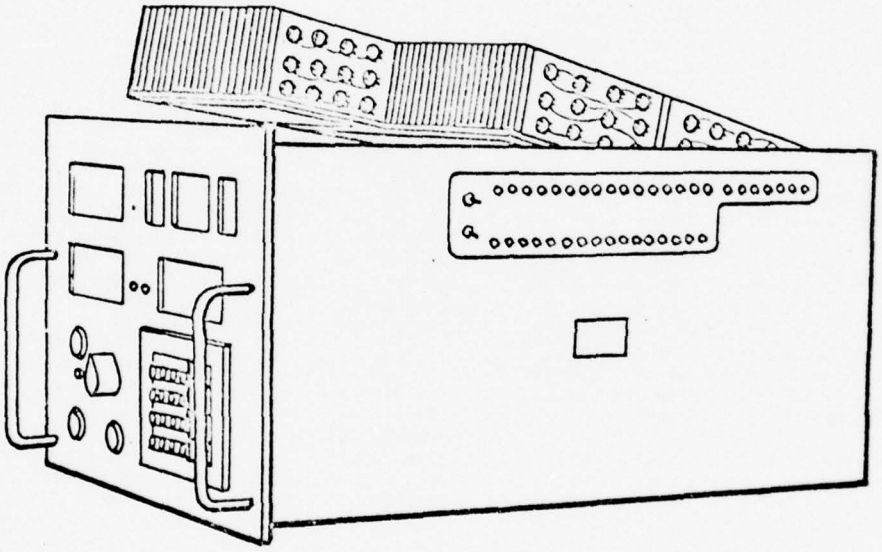


Figure 4. DATAC Drawer, A1A3, Simulator
(side view)

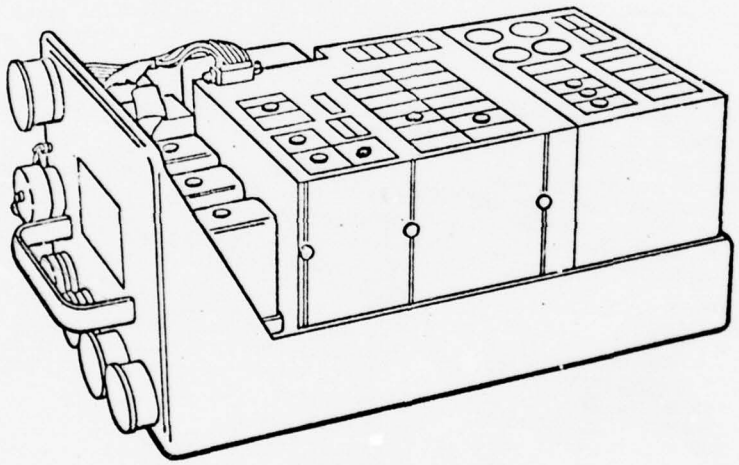


Figure 5. Feel and Trim Assembly Simulation

corrective maintenance on the 6883 Simulator. These same persons will critique the maintenance manuals to be delivered with the system. Final versions of the documentation will reflect their comments.

Major design objectives include, to require no unique maintenance skills of this Specialist and to require the fewest possible preventive maintenance procedures and equipment alignments. Off-the-shelf, locally available system components are used wherever feasible.

Automated self-test and fault-isolation procedures are being developed for the system interfaces and simulation hardware. Software programs shall be developed to permit daily automated status checks of the simulator prior to student instruction.

All computer and peripheral equipment shall be totally supported through a separate contract with Honeywell's Denver Field Office.

Project Status

All hardware design tasks have been completed and were approved by the Air Force at a Critical Design Review held 2 March 1977. That approval constituted a design freeze and accordingly Honeywell has proceeded with full-scale hardware fabrication. Software and courseware designs are proceeding. Delivery of the complete system to Lowery Technical Training Center is scheduled for late 1977.

Program Benefits

The major benefits of the 6883 prototype effort are several. First, the program will provide a vehicle for evaluating the feasibility, practicality, training effectiveness, and acceptability of complex electronic test equipment simulators for use in I-level training environments. Demonstration of the capabilities of a simulator-based training system for I-level maintenance training can impact future training equipment procurements.

Second, the program has produced a functional specification that can serve as a model for specifying future simulator-based training systems. Compliance with some of the older standards for specification preparation appears to be unnecessary, costly, and sometimes inappropriate as training philosophy shifts to replace actual equipment with simulators.

Third, the simulation techniques developed for and used in the fabrication of the 6883 Simulator System are available to incorporate into subsequent simulations, as appropriate, without recurring development costs.

Fourth, following HRL's evaluation of the 6883 simulator-based training system, the complete system will be made available to Lowry Technical Training Center for use in their training curriculum. At that time, LTTC may wish to modify the manner in which the system is used (e.g., by using it to train selected portions of additional course blocks; significant features of the 6883 are common to other test stations in the F-111D shop.) Alternatively, LTTC may wish to modify/add to the malfunction set delivered with the trainer.

RESEARCH ISSUES

Although the efforts now underway in the Navy and Air Force in ATE simulation will provide answers to some questions, much remains to be done to develop the principles and concepts for the training of complex maintenance jobs. Some of the areas that cannot be addressed in their entirety in the current program phase are instructor and student feedback requirements, computer requirements, level of reprogramming, modularization, sequencing of materials, and dimensionality requirements.

To address some of these questions in more rigorous fashion, an extensive formative and summative evaluation is planned to determine the training and cost-effectiveness of the 6883 simulator. Based upon the results of these evaluations, recommendations can be made as to the optimal configuration for a simulator-based 6883 training system. These recommendations have ramifications for other evolving I-level maintenance training systems as well.

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BIOGRAPHICAL SKETCHES

GARY G. MILLER

Mr. Miller received his B.A. degree in Psychology from Dequesne University in 1966 and his M.S. degree from Missouri State University at Warrensburg in 1969. He joined the staff of the Technical Training Division of the Air Force Human Resources Laboratory in 1972 after serving a tour of duty in the Air Force as a Launch Control Officer and Missile Staff Training Officer in the Minuteman system. Mr. Miller is assigned to the Training Techniques and Evaluation section where he is involved in research on the design and evaluation of training simulators, devices, and aids; and the development and application of individualized and automated self-instruction techniques for technical training. Mr. Miller has authored numerous publications in the area of training systems, especially simulation technology as it applies to maintenance training. He received the Department of the Air Force Outstanding Civilian Performance Award in 1976. Mr. Miller is currently involved as a task scientist and program control officer in an advanced development project entitled Simulation for Maintenance Training. Mr. Miller is also working on his PhD in Educational Psychology at the University of Colorado.

MAJOR DENNIS DOWNING

Major Downing received his B.A. degree in 1964 from Western Michigan University with a major in Psychology. Upon graduation he entered the U.S. Air Force and served as a Personnel Officer for 3 1/2 years at Wurtsmith AFB, Michigan. He then received an Air Force Institute of Technology graduate fellowship to study Engineering/Industrial Psychology at Purdue University. While there he received an M.S. Degree in 1969 and Ph.D. in 1971. After leaving Purdue, he was assigned to the Space and Missile Systems Organization at Norton AFB, California where he served as Chief, Human Factors Section, MINUTEMAN System Program Office, until 1975. There he was in charge of all human engineering, personnel requirements determination, and personnel sub-system test and evaluation activities related to several MINUTEMAN modernization programs. Prior to joining the Air Force Human Resources Laboratory in 1976, Major Downing attended the Air Force Command and Staff College at Maxwell AFB, Alabama. Maj. Downing is now Chief, Maintenance Simulation and Training Devices Section, of the Technical Training Division, AFHRL, at Lowry AFB, Colorado. He is currently Program

Manager of an advanced development project entitled, "Simulation for Maintenance Training" which has the objective of improving Air Force Technical Training and reducing the associated training equipment costs through research into applications of advanced simulation technology.

DR. CHRISS CLARK

EDUCATION

AB, Mathematics, University of Illinois, 1969.

MA, Psychology, University of Illinois, 1973.

PhD, Psychology, University of Illinois, 1976.

CURRENT RESPONSIBILITIES

Dr. Clark is a Principal Research Scientist in the Training and Tactics Technology section of the Man-Machine Sciences Group. She is chiefly involved with the design and development of military training systems incorporating simulator training devices. She is currently Principal Investigator responsible for general program management and the training aspects of a research and development effort sponsored by the Air Force Human Resources Laboratory to design, construct, and deliver an F-111 6883 Converter/Flight Control Test Station Maintenance Trainer. Her responsibilities include the definition of procedures which relate training requirements to required operational capabilities of simulator-based training systems, related computer assisted instruction, performance measurement, and feedback provided to the trainee. She has contributed as well to the development of a guide to assist government procurement agencies in the design of simulators to be used as training devices.

EXPERIENCE

Dr. Clark joined Honeywell in the summer of 1976 after completing her Doctorate in Psychology at the University of Illinois, where she majored in social psychology and minored in measurement. As a first year graduate student she held a traineeship in measurement, granted by the United States Public Health Service. Thereafter, she held a research assistant-ship at the Aviation Research Laboratory of the Institute of Aviation where she was actively involved in Human Performance Research. Her primary research interests during that time were experimental design and the application of new designs to studies of visual target detection.

DR. JAMES A. GARDNER

Dr. Gardner is a program Manager in Training Systems at the Training and Control Systems Center (T&CSC) of Honeywell, Inc., in West Covina, California. He is currently Deputy Program Manager of the F-16 Simulated Avionics Maintenance Training (SAMT) project involving the design and development of ten organizational-level maintenance simulators for the United States Air Force and four European participating Group nations. Dr. Gardner was formerely Project Manager for the Training System Program Office at the Systems and Research Center (S&RC) at Honeywell, Inc., in Minneapolis. There, he managed a program sponsored by the Air Force Human Resources Laboratory to design, construct and deliver an automated intermediate-level maintenance trainer for the F-lll 6883 Converter/Flight Control Test Station and directed development programs in simulation and maintenance training technology. Earlier, he was program manager of a project sponsored by the Naval Air Rework Facility to develop and deliver maintenance simulators for the AN/AVG 8F-4N Visual Target Acquisition System (VTAS). He has participated in other studies in the development of maintenance training technology for such systems as the Navy's ALQ-100, ALQ-126, and BE&E Programs. Before joining Honeywell, he was a field engineer for Sarkes Tarzian, Incorporated, where he was responsible for the development of commercial and educational television systems. He holds a B. A. degree in psychology from Indiana University, and an M.S. degree and a Ph.D. in psychology from North Carolina State University.

USAF USE AND TRAINING FOR ATE

Major P. O. Schill
CM Sgt. H. G. Abney
USAF ATC, Randolph AFB, Texas

BACKGROUND

Improvements in electronics technology have resulted in more sophisticated and more complex avionics systems in aircraft weapon systems. As electronics systems have become more advanced, support test equipment has also become more complicated. Most new weapons systems entering the Air Force inventory make extensive use of Automatic Test Equipment (ATE) to isolate or trouble-shoot problem components. Test equipment has always been used to some extent but the use of ATE and built-in-test (BIT) features are a large part of today's new aircraft systems designs.

The Air Force considers ATE to be an element or subset of support equipment. It is defined as electronic devices capable of automatically or semiautomatically generating and independently furnishing programmed stimuli, measuring selected parameters of an electronic, mechanical, electro-mechanical or electro-optical item being tested, and making a comparison to accept or reject the measured values in accordance with predetermined limits. Automatic test equipment may also include independently configured automatic or semiautomatic devices which are capable of detecting, measuring, and evaluating electrical/electronic or electro-mechanical/electro-optical characteristics of systems and equipment. It normally operates by use of previously prepared test software recorded on punched tape, card decks, magnetic tapes, disc pack, cassettes, or other storage media.

Microelectronics and integrated systems have increased the use of ATE. The complexity of the integrated systems makes the use of ATE mandatory in terms of manpower and time. The proliferation of ATE is as great as the number of new avionics systems and the cost of this support equipment is as extensive. The current ATE market has been estimated at $400 to $600 million annually with all new aircraft (F-16, B-1, and Airborne Warning and Control System (AWACS) scheduled for both built-in and automatic test equipment.

The Air Force has been using automatic test equipment to some extent since the 1950's. In many cases, special test equipment was designed for specific weapon systems. Mobile Automatic Radiating Testers (MART) were used for the B-58 and F-106 aircraft weapon systems and the Versatile Automatic Test Equipment (VATE) was developed to test the universal guidance and navigational systems of missiles and aircraft. Also, the General Purpose Automatic Test System (GPATS) was designed for depot maintenance and is currently used to support the C-5 and C-141 aircraft and the Titan and Minuteman ballistic missile systems. A computerized modification to GPATS provided for depot maintenance on the F-111 aircraft.

The F-111 introduced a new era in ATE development. Special purpose test equipment for the various models of the F-111 aircraft number from 11 to 13 of which approximately half may be considered ATE. Greater sophistication and a steadily advancing state-of-the-art has made it possible to support the F-15 in the field with a total of six test stations of which three are ATE. Present planning calls for five of the six B-1 test stations to be automatic while all of the F-16 aircraft weapon system's test stations (a total of four) are scheduled to fall into the category of ATE. Thus, it is quite evident that the Air Force is moving toward greater reliance on the ATE to support its newer weapon systems.

Since integrated systems do not readily adapt to manual testing, more and more ATE enters the inventory each year. According to the Automatic Test Equipment and Life Support System Management Division of San Antonio Air Logistics Center, the Air Force's single manager for ATE, there is a total of 470 different types of ATE currently in the Air Force inventory. The total population of sets is 3711. Additionally, there are a total of 79 new items in acquisition or programmed for future acquisition. Major systems supported by or scheduled to be supported by ATE are listed below:

A-7	F-15	B-1
A-10	F-102	E-4
B-52	F-105	E-3A
C-5	F-106	
C-130	F/FB-111	Space Shuttle
C-135	T-43	ALCM (AGM-68A)
C-141	SRAM	EF-111
F/RF-4	Minuteman	
T-38		

Automatic test equipment supports the three levels of maintenance within the Air Force maintenance structure. These include:

A. Organizational:

Direct maintenance support of aircraft on the flightline includes both scheduled and unscheduled maintenance.

B. Intermediate:

In-shop repair of Line Replaceable Units (LRU's) to include troubleshooting and removal, repair and/or replacement of components and sub-components.

C. Depot:

Maintenance performed at one of the five Air Logistics Centers, the Air Force Guidance and Metrology Center or other locations designated as a Specialized Repair Activity.

The Air Force Air Training Command (ATC) has the responsibility and the capability to train newly recruited airmen and more experienced personnel in the maintenance and operation of organizational and intermediate level automatic test equipment supporting all aircraft in the active Air Force inventory.

PROCUREMENT RATIONALE AND DEMONSTRATED PERFORMANCE

In earlier paragraphs some of the rationale offered for procurement of ATE has been mentioned. Integrated systems do not lend themselves to manual test routines. Integrated systems are too expensive in terms of time and manpower to check out manually. Historically, it appears that weapon system contractor proposed the use of ATE to support newer, integrated systems in an attempt to provide the latest state-of-the-art equipment. In sequence, the contractors built the aircraft and installed sophisticated, integrated systems and then specified the test equipment to be used through submission of the Aerospace Ground Equipment Requirements Data which include ATE. As stated earlier, the Air Force's first real involvement in ATE occurred with the procurement of the F-111. Due in part to the shortcomings of the F-111, ATE Military Standard 1513 (USAF only) entitled, Trade Studies Criteria for Selection of Avionic Test Support Systems, was publicized in 1971. This standard provides that a trade study be performed to prove that ATE is more cost-effective than a manual test alternative prior to procurement of additional avionic Automatic Test Systems.

A proposed military standard entitled, The Acquisition of Automatic Test Systems, is being coordinated in draft at this time. This standard will require that a thorough study of existing ATE be accomplished and that all existing ATE be proved ineffective in supporting a new system prior to procuring a new item of ATE. The standard also will seek to insure that new items of Automatic Test Equipment function effectively and are logistically supportable.

The Air Force has enjoyed some success with Automatic Test Equipment. Specifically the AN/APM-307V( ) Fault Detection Tester, an item of organizational level test equipment for the F-4 series aircraft is, according to the Constant Hit and Corona Ace studies, the most reliable and effective testor for the aircraft fire control system. Similar success has been enjoyed with the AN/APM-54, Fault Detector Tester used with the F-106. Both of these items were developed and procured after the weapon systems were deployed operationally for several years.

On the other hand, the experience with the F-111D ATE has not been so good. In an effort to deploy the aircraft early, the ATE was accepted with degraded performance characteristics. The ATE performance has not to this day been upgraded sufficiently to allow organic support capability of the Mark II avionics system by the host unit. In fact, the F-111 System Program Office (SPO) found it necessary, in 1973, to establish a contractor Supported Specialized Repair Activity (SRA) at Cannon Air Force Base, New Mexico to repair components which Air Force personnel

and equipment could not maintain. The annual cost of this SRA is approximately $900,000. Although the SRA was established as an interim measure, there is no indication that it will be dissolved in the near future.

Some problems have also been encountered with the F-15 Avionics Intermediate Shop equipment. Because of testing the ambiguities and the failure of the automatic stations to meet design specifications. The F-15 SPO proposed, in 1974, to purchase 551 additional pages of contractor technical data and extender modules to facilitate manual tests and certain items of manual test equipment to supplement the automatic test stations. Tactical Air Command concurred that this was a sound idea and necessary to insure field supportability of the F-15. The cost of the F-15 program is therefore increased by the cost of the supplementary manual test equipment and data, the additional manpower required to perform the manual procedures and the additional training required by the maintainers to enable them to perform the manual tests.

Because of the high initial and recurring costs of ATE, one would expect to find literature documenting savings in terms of reduced time and manpower expenditures in support of operational systems. This writer has been unable to find any such documentation. Further, Lt Col Walter L. Gordon, Chief, Maintenance Management Auditing Branch, USAF Audit Agency, Kelly Office, Kelly AFB TX stated that after completing an extensive audit of the USAF ATE program over the past year, no documentation on existing systems was found to support the claim that ATE did reduce manpower or time expenditures.

AIR FORCE CAREER FIELD STRUCTURES AND TRAINING

For the purpose of discussing technician interface with ATE, it is most convenient to subdivide the ATE into two categories: that supporting organizational and intermediate maintenance and, that supporting depot maintenance.

Organizational and intermediate maintenance using ATE is performed exclusively by Air Force enlisted personnel in one of the airman avionic career field specialties. Because of the wide variety of aircraft using ATE and the variation in maintenance concepts employed in supporting these aircraft, confusion can result when trying to describe the technician's interface. Older aircraft, such as the B-52, rely solely on conventional Air Force Specialty Code (AFSC) personnel to operate and maintain ATE. Conventional AFSC's stress vertical specialization, i.e., the specialist is trained to maintain a limited number of avionic systems at the organizational and intermediate level and to maintain his own peculiar test equipment. Thus, on the B-52, AFSC 321X0K, Bomb/Navigation Systems Specialist, is responsible for maintaining the Electro-optical Viewing System to include troubleshooting and repairing the system on the aircraft, repairing the LRU's in the shop using the special ATE and repairing the ATE when it malfunctions.

Other older systems such as the F-4, A-7 and C-5 use modified conventional avionics support structure. Again, personnel holding conventional AFSC's are responsible for organizational and intermediate repair of the avionics systems, to include troubleshooting the aircraft and repairing LRU's with ATE. A new AFSC, 326X0, Avionics Aerospace Ground Equipment (AGE) Specialist, is responsible for repair and calibration of the ATE.

Newer aircraft, such as the F/FB-111, F-15, F-16, and B-1 employ or will employ a totally different maintenance concept. Avionics systems on these aircraft are maintained by personnel in the integrated avionics career field. The integrated avionics career field stresses horizontal specialization in that specialists are responsible for more systems but only at one level of maintenance. For instance, AFSC 326X1D is responsible for repairing LRU's from any avionics system or an aircraft that can be tested and repaired on Automatic Test Equipment. AFSC 326X0B is responsible for repair and calibration of Automatic Test Equipment. A chart showing the integrated avionics career field structure may be found at Figure 1. It may be noted that the Integrated Avionics In-Shop Specialties relate only to type of test equipment used and not to a particular set of equipment or aircraft weapon system.

Prior to August 1976, training in the integrated avionics specialties for newly recruited airmen was accomplished under a "representative" training approach. That is, certain selected test stations and LRUs were used to acquaint the apprentice with the systems he or she would soon be working. Under this approach, some trainers would receive instruction on systems they would not work on during their initial duty assignments, or possibly would never work. Also, trainees would not receive instruction on some system that they would be required to maintain. The major users indicated that this was creating an on-the-job burden they could not support. Since August, however, ATC has been training newly recruited airmen who are classified

AFSC	TITLE	RESPONSIBILITY
326XOA	Avionics AGE Specialist/ Technician (Manual AGE)	Repair/calibration of manual test stations associated with F/FB-111, F-15, F-16, C-5
326XOB	Avionics AGE Specialist/ Technician (Automatic AGE)	Repair/calibration of automatic test stations associated with F/F-111, F-15, F-16, C-5
326XOC	Avionics AGE Specialist/ Technician (F/RF 4 Peculiar AGE)	Repair/calibration of manual and automatic AGE associated with F/RF 4 series aircraft.
326XOD	Avionics AGE Specialist/Technician (A-7D Peculiar AGE)	Repair/calibration of manual and automatic AGE associated with A-7D aircraft
326X1C	Integrated Avionics Component Specialist/Technician (Manual AGE)	Repair Aircraft LRUs using manual test stations associated with F/FB-111, F-15, F-16
326X1D	Integrated Avionics Component Specialist/Technician (Automatic AGE)	Repair aircraft LRUs using automatic test stations associated with F/FB-11, F-15, F-16
326X1E	Integrated Avionics Component Specialist/Technican [Electronic Counter Measures (ECM) Systems]	Repair aircraft ECM LRUs using manual or automatic test stations associated with F/FB-111, F-15, F-16.
326X2A	Integrated Avionics Systems Specialist/Technician (Fire Control/ Bomb-NAV)	Flight line repair of integrated systems on F/FB-111, F-15, F-16
326X2B	Integrated Avionics Systems Specialist/Technician (Instrument/ Automatic Flight Control)	Flight line repair of integrated systems on F/FB-111, F-15, F-16
326X2C	Integrated Avionics Systems Specialist/Technician (Communication/Navigation/Electronic countermeasures)	Flight line repair of integrated systems on F/FB-111, F-15, F-16

FIGURE 1 INTEGRATED AVIONICS CAREER FIELD STRUCTURE

into the integrated avionics specialties in special courses which cover only that equipment associated with the aircraft system against which the airmen will be assigned. There are a total of 28 weapon system-oriented courses supporting the 10 integrated avionics AFSCs. Training in this manner is expected to greatly reduce the amount of on-the-job training required for newly recruited personnel and to make them more productive sooner in their enlistment. A special training evaluation is scheduled to begin this summer to verify the effectiveness of these courses.

Since personnel are now being trained on only those items of equipment on which they will work during their initial duty assignment, a series of special training courses is also being offered when required for personnel transferring from one weapon system to another.

ATC has experienced some sizeable management problems in initiating and administrating the weapon system-oriented training program. Initial reaction from the major users of the trained product, however, indicate a great deal of improvement over previous training techniques.

Present weapon system-oriented courses are quite lengthy and thorough. For example, AFSC 326X0B personnel receive 11 weeks of electronics principles training to include high reliability soldering techniques. The total course length varies from 21 weeks to 48 weeks and is dependent on the number of ATE stations covered in the course and the maintenance repair level authorized for the systems. In all cases, extensive training is provided in system operation, troubleshooting and repair.

Historically, ATC has depended almost entirely upon actual equipment trainers for maintenance training courses, including ATE. The high initial and recurring costs, plus the supportability problems experienced at ATC training centers, led ATC, in association with Air Force Human Resources Laboratory, to initiate a research project in the use of maintenance training simulators. The item chosen for this initial simulation project was the Converter and Flight Controls Test Station (an item of ATE supporting the F/FB-111 aircraft). The hardware/software contract for this training device was let to Honeywell Incorporated in August 1976. System delivery is scheduled for January 1978. It is expected that maintenance training simulators, in addition to reducing training costs, will also increase effectiveness by allowing the simulation of system malfunctions.

Air Force depot level maintenance is performed almost exclusively by civil service civilian employees. The inherent stability within the depot system negates any requirement for ATC to maintain a training capability for depot level ATE systems. Instead, ATC, as the Air Force's single agent for training procurement, buys contractor training for depot maintenance personnel when new systems are procured. The depots are required to maintain their capability to operate and maintain ATE and other systems through an internal on-the-job training program.

It has been recognized for quite some time that the cost of software supporting ATE systems is at least as expensive as the hardware itself. In an attempt to reduce software-related costs, each of the Air Force Air Logistic Centers has begun to establish independent software support centers. These centers will provide the Air Force with an organizational capability to generate software and software changes for new and existing ATE systems. ATC is providing initial training for programmers being assigned to the software support centers.

LOGIC MODEL TEST EQUIPMENT FOR MAINTENANCE AND TRAINING

by

William L. Andre
James T. Wong
Headquarters, U.S. Army Air Mobility
Research & Development Laboratory

INTRODUCTION

In 1973 the Army Air Mobility Laboratory Headquarters at Ames Research Center, Moffett Field, California, initiated special research investigations in the area of diagnostics technology. These investigations have developed Logic Model (LOGMOD) concepts for performing a variety of functions related to design, maintenance, and testing. As a result of research investigations conducted both in-house and under contract, the first LOGIC MODEL TEST SET was designed and built during 1976. The cababilities of the Logic Model test set are the principal topics discussed here. The theoretical and mathematical concepts have been addressed in the referenced papers.

The basis or starting point for the project relates to the notion of maintenance dependency charts. The Navy has for several years used these charts as a graphical aid in fault isolating. The mathematical structure underlying this concept was identified and generalized in an abstract setting. From this the logic model basis was formed and expanded to allow any complex hardware design, whether of a mechanical, electromechanical, or electronic nature to be modeled. As a result, the logic model techniques can be applied to most military systems in the Army, Navy, and Air Force. The degree of application for a particular system is determined by the degree to which access is available to observing and measuring the set of events which exist in a given design.

The original objective of the project was to develop a design evaluation tool which would provide greater capability for evaluating design concepts from engineering drawings and schematics. In particular, those aspects of hardware design that determined the system requirements for troubleshooting, maintenance, and training as evidenced during the operation phase of equipment life cycle, were the overall driving factors. The logic model analysis techniques which were developed have gone a long way in the direction of providing this capability.

It was found that the very same structure that was used as a design evaluation tool could also be used once hardware was built and fielded to perform trouble-shooting and diagnostic functions on the fielded equipment. An attempt was made to design a test set using recent off-the-shelf components that would provide this capability.

The first Logic Model test set was designed and built by December 1976. Since then experience has been gained regarding its use and application. The following observations have been made:

a. The Logic Model test set synthesizes trouble-shooting strategies and provides instructions to the test set operator which equal the knowledge of the hardware designers of the equipment under test.

b. The skill level required to operate the Logic Model test set is roughly equivalent to that needed to operate a hand-held calculator that performs arithmetic operations.

c. The time required to fault-isolate malfunctions is reduced greatly, often by at least two orders of magnitude.

d. The ability to fault-isolate is expanded such that any malfunction or combination of malfunctions within an equipment can be fault isolated within the design constraints of the equipment.

e. The Logic Model test set requires no design change in the test set itself to fault-isolate different equipment, only a software change is required.

f. The Logic Model test set can be used to simulate actual failures and

therefore, provide training experience in fault isolation and trouble-shooting as a training aid.

The following sections address the specific capabilities of the Logic Model test set, establish some comparisons of this test set with automatic test equipment, address cost aspects, the operational requirements, and discuss application areas.

CAPABILITIES

A character of the test set is that it does not require but can admit a physical connection to the equipment under test. For all tests and inspections required by the test set, the man is the link.

A hand-held control keyboard has been designed to allow initial numeric information to be keyed in. Operating in this mode, the Logic Model test set performs in what may be considered a semi-automatic mode. There are advantages and disadvantages associated with this.

Some of the advantages are:

a. The test set becomes a piece of general purpose equipment applicable to many diverse hardware systems.

b. The human link provides the capability of performing multiple complex tests which could not normally be economically performed by fully automatic test equipment.

c. No physical connection between the test set and the equipment under test means the test set, if desired, could be located in a spot remote from the unit under test (i.e., field technicians can use the test set by talking to someone at a fixed base operation over the phone).

Some disadvantages may be:

a. The time to test is dependent on the speed of the technician.

b. The technician sometimes makes mistakes and can make a wrong decision.

The Logic Model test set can also be designed for use in the ATE mode where no human link is required to perform the trouble-shooting sequence. This could be accomplished by appropriate use of test measuring equipment which could translate the measured parameter information into a go-no-go situation. Then the need for the man is eliminated and advantage can be taken of the great reduction in actual test time that can be achieved. No reduction in diagnostic time is achieved since the test set arrives at decisions in a period of time which for all practical purposes is instantaneous. If the Logic Model test set were used in an ATE mode, then some of the advantages may be:

a. The human error probability which can be considered high without the test set and considered low with the test set can be reduced further or effectively eliminated.

b. The overall time to trouble-shoot is reduced to the same magnitude of time as that needed for the test to function (usually fractions of a second).

Some disadvantages may be:

a. The ATE mode brings the test equipment closer to being special purpose equipment with the automatic sensing aspects being peculiar to the equipment under test.

b. The hardware cost of the ATE mode can be greater than the semi-automatic mode.

c. The ATE mode is restricted to relatively simple tests and cannot take advantage of the inherent capability of the human brain to perform complex tasks not economical or feasible for ATE testing.

The economical aspects of using the Logic Model test set in either semi-automatic or fully automatic (ATE) modes show high potential for cost savings.

Within Army aviation one of the highest single causes of maintenance burden is faulty diagnostics. It is not uncommon to find that up to forty percent of returns to depot were unjustified.

The logic model approach will not only effect improvement in the diagnostic batting average, it also will contribute to allowing technicians to perform maintenance and trouble-shooting of very sophisticated equipment. This means many things; some of which translate into a strong impact on the training area and improved maintenance capability. Hardware formerly considered too sophisticated to be put in the hands of the user and maintenance man can now be more readily accommodated.

It would be impossible at this time to compute the actual cost savings that this

class of testing equipment can achieve in the next few years. However, when taken on a system by system basis, it would not be surprising to find the cost avoidance and savings would not simply be measured in the millions of dollars but could be counted at the billion dollar level.

OPERATIONAL REQUIREMENTS FOR DIAGNOSTICS

The Logic Model test set is basically a responsive diagnostic device, which interacts with a person familiar with the simple operational procedures of the Logic Model test set. Conceptually, the test set is a mechanization of the diagnostic concept employing the functional Logic Model of the system under test. The test procedure follows the intrinsic property that a system malfunction can be detected by checking the terminal events of the Logic Model. To do this, no in-depth understanding of the basic Logic Model as well as the testing strategy is required. In fact, the information needed to operate the test set is as follows:

1. Familiarization with the locations of each test point on the system under test.

2. Operation of the appropriate common test equipment, such as an oscilloscope, voltmeter, pressure gauge, etc., required to measure test point parameters.

3. Sufficient training or knowledge to determine whether or not a measured (or observed) quantity is within tolerance.

4. Operation of the Logic Model Test Set.

Here we have tacitly assumed that each test point in the system under test is accessible for testing purposes. With this stipulation in mind, a quick review of the four requirements stated above reveals that the first three items can be easily mastered without lengthy and intensive training. The remaining requirement is equally simple, as is illustrated by the following sequence for operating the test set.

1. Plug the test set power cord into a 110 volt outlet.

2. Turn on the power switch, located on the front panel of the test set.

3. Open the floppy diskette compartment door, located on the front panel, and insert the prepared floppy diskette containing the appropriate functional Logic Model, and then close the door.

4. Push the reset button, located on the front panel of the tester, and the test set will ask, through the display panels, for the desired Logic Model on the magnetic diskette.

5. To input the requested information key in the identified code through the hand-held keyboard and the display will register the code on the panel. The "C" key on the keyboard is provided to clear any undesired entry. The "." or period key on the keyboard is provided as a command to accept and execute.

6. Now the test set will respond and ask for the numeric code relating to the observed malfunction. Only terminal event malfunctions need be considered.

7. Insert the correct code and push the period key.

8. The test set then computes a strategy and determines the specific test required such that the technician can determine from the result of the test if it was "good"---within the specification, or "bad"---out of tolerance.

9. Key in "G" for good, or "B" for bad, then push the "." key.

10. This interface between the operator and the test set continues as outlined in steps 8 and 9 until the malfunction has been determined. At this point, the test set identifies the defective items.

11. Push the reset button and the test set is ready to continue if other malfunctions exist.

12. To turn off the test set, open the compartment door and remove the floppy diskette, and turn the power switch off.

Although the foregoing operational procedure is an elementary exercise, it demonstrates the simplicity of operation associated with the Logic Model test set.

APPLICATIONS

To date, several distinctly different but related areas of application have been found. These areas address the following:

1. DESIGN EVALUATION
2. TROUBLE-SHOOTING/DIAGNOSTICS
3. TRAINING AID
4. MAINTENANCE MANUALS

The design evaluation aspects have already been discussed; however, some specific examples of how the designer can use the logic model are worth mentioning. On a general purpose computer the logic model which identifies all the design functional relationships can be operated upon to compute some very useful statistics. For example, the time to fault-isolate any component in the design can be computed. The utility of each test point or observable can be assessed by identifying the frequency of use of test points. Often many are found redundant and not needed in the design. Characteristics of design very sensitive to the ability to maintain and effect repair can be identified. The requirement for developing Logic Models at the design stage requires the existence of engineering drawings. Technicians or the engineers themselves can formulate the baseline data package from which the Logic Model is generated. Logic Models need not be generated by hand.

The troubleshooting/diagnostics application stems from the product of the design effort. That which was used to develop and evaluate a design becomes exactly the same tool used by the technician to take care of the hardware when it gets to the field. If the design logic is good so will the maintenance logic be good. Classically, the person who designs the hardware is not the one to maintain it. The point to be made is that the design for function and design for maintenance should go hand in hand and the logic model techniques provide a basis for effectively doing this.

As a training aid the test set can provide a means for familiarizing the student with what to do and how to go about it for any combination of faulty components. The repair and fault isolation procedure can be simulated on the test set very rapidly and repeatedly. Any combination of failures can be addressed without having to spend time engaged in trying to follow and understand a fault tree. Since the Logic Model is equivalent nominally to a fault tree of size two raised to the n power where n is the number of components in the system, a fault tree for a design with twenty components would have more than a million paths if it were equivalent to the Logic Model test set diagnostics.

The effect of utilizing the Logic Model test set with respect to maintenance manuals is of interest since the need to develop elaborate fault trees or trouble-shooting procedures can be reduced significantly if not eliminated altogether. The present experience in formulating a maintenance manual around the Logic Model test set has indicated that a conventional manual as presently used and developed can be reduced in size significantly. This can occur because many of the tasks and rationale contained in the manual can be handled within the test set. Also, the level of comprehension required to effect a repair can be greatly reduced, eliminating the need for detailed information and technical statistics.

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PERSONAL BIOGRAPHIES

JAMES T. WONG

Title: Research Mathematician, Advanced Systems Research Office

Organization: Headquarters, US Army Air Mobility Research & Development Laboratory

Responsibility: Perform mathematical research in the areas relevant to the Laboratory airmobile research effort.

Past Experience: Research, teaching.

Educational Background: PhD in Mathematics

WILLIAM L. ANDRE

Title: Research Engineer, Advanced Systems Research Office

Organization: Headquarters, US Army Air Mobility Research & Development Laboratory

Responsibility: Conduct and manage research investigations relating to reliability, maintenance, diagnostics, and aircraft weapons.

Past Experience: Reliability & Maintainability Engineer, US Army Weapons Command, Rock Island Arsenal; Staff Engineer & Program Manager, Headquarters, US Army Air Mobility Research & Development Laboratory, Ames Research Center.

Education: MS Industrial Systems, BS Mechanical Engineering.

THE AN/USM-410

AN ARMY GENERAL SUPPORT AUTOMATIC TEST EQUIPMENT

Robert Chouinard
Nick Karalekas and Jerry Kastning
Department of the Army
DRCPM-ATSS

I. AN/USM-410 SYSTEM CHARACTERISTICS

A. BACKGROUND

1. The AN/USM-410, known also as Electronic Quality Assurance Automatic Test Equipment (EQUATE), was developed under an Army contract beginning in June 1971. The first brassboard system was completed in 1973 and has been used to test the concept of the use of automatic test equipment at Direct Support (DS) and General Support (GS) levels. A second simplified system was developed as a programming station. Systems 3, 4, and 5 were Advanced Development Models and have been used or selected for implementation on such items as aviation electronics, microwave data links, fire control systems, automatic switching systems, and AM/FM field radios.

2. The AN/USM-410 is well documented with a 66-page Specification, a set of Army format Operation and Maintenance Instruction Manuals, a detailed program manual, a system software maintenance manual, a set of training course manuals, a thorough final technical report, and a detailed set of Category E, Form 1 drawings.

B. SYSTEM DESIGN CHARACTERISTICS

1. The AN/USM-410 system consists of computer, control, measurement, stimulus and switching subsystems. The control processor is a conventional minicomputer supplied with a 32K memory to provide the capability of its more intimate involvement in both test generation and execution. Among peripherals, the disc is for permanent storage of the run time system for stimulus control and measurement analysis and the compiler, plus temporary storage of test programs being compiled or executed. The video terminal is the major man/machine interface in the generation and compilation of test programs as well as for routine testing operations. Commands are entered through the terminal keyboard and are displayed, as are their results, on the video screen.

2. A number of I/O device options may be used to input the source test programs. The printer maintains a permanent record of test results, and the control panel provides all control functions for UUT (Unit Under Test) testing and program debugging.

3. The measurement and stimulus subsystems are characterized as third generation in that the power of the computer has been employed to increase the range and versatility of measurements and stimuli, while at the same time decreasing the hardware required. Analog waveforms are derived from frequency and amplitude components generated within the computer; digital stimuli are conceived at the ATE interface to minimize line lengths and signal switching. The measurement subsystem is composed of a low-speed voltage sampling unit, a high-speed voltage sampler, and a frequency sampling unit. The voltage units convert the signal to digital data, which are in turn subjected to any of a number of waveforms analysis programs, including fast Fourier transform, digital filtering, statistical analysis, min/max list sorting and least squares fitting.

4. The various AN/USM-410 subsystems are designed and packaged to permit the creation of a family of configurations capable of satisfying a variety of specific applications.

a. The Digital Test Station is the simplest configuration which can support all digital units to a 1-megabit rate.

b. The Low Frequency Test Station is configured for DC to 3 MHz for low frequency hybrid analog/digital units.

c. The RF Test Stations support communications avionics and navigation units from DC to 500 MHz range.

d. The Microwave Test Station supports communications, avionics, navigation, IFF, ECM and radar units from DC to 18 GHz range.

5. In addition to a Unit Under Test Station, the AN/USM-410 contains a programmable interface unit which permits the majority of the system's analog and all digital stimuli and measurements to be routed to a myriad of universal test points. Under program control, each connector pin may be designated either as a stimulus, measurement, or load point. Test points are directed by universal test points cards. Accordingly, this requires far fewer test adaptors than other ATE. As an example, present analysis indicates that all 78 different types of AN/USM-410 PC Boards, as well as several hundred AN/TSQ-73 and TACFIRE boards, will be testable on one $2,000 adaptor when all of the software is completed.

6. The AN/USM-410 has been designed for maintainability and supportability. Maintenance access is from the front of the racks. All drawers can be pulled forward without breaking power connections allowing chassis and wiring troubleshooting while the equipment is in operation. This is the type of design required for sheltered or van-mounted equipment.

7. The AN/USM-410 is totally self-calibrated through the replaceable calibration standards and calibration software that can be called at any time. Self-calibration of the measurement subsystems and programmable interface unit is performed by software routines using the DC-standard as a reference. The calibration factors are stored and automatically accessed whenever a measurement is made to provide the necessary offset software correction during UUT testing.

8. The maintenance concept makes maximum use of the automated self-test capability, allowing the generator (at organizational level) to detect equipment malfunctions by isolation to the functional level. The capability exists in the self-test program to further isolate a malfunction to the line replaceable unit (LRU), model, printed circuit board, or to a piece part.

II. AN/USM-410 COST BENEFIT ANALYSIS

1. A study performed by the Systems Analysis Office, USAECOM, examined the cost-effectiveness of Automatic Test Equipment (ATE) when used in a field Army Maintenance environment. Cost and operational effectiveness of ATE and manual test equipment (MTE) were compared relative to their support of a major weapon system, the Advanced Attack Helicopter (AAH). The ATE system depicted in this study is the Electronic Quality Assurance Test Equipment (EQUATE).

2. The study shows a projected savings of thirty-one per cent (31%) for EQUATE versus MTE over a ten-year period. Operational effectiveness of the weapon system is determined to be 0.993 when supported by the EQUATE system versus 0.985 for MTE.

3. Data Collection. Data was collected on three main areas: Prime Equipment and the LRU, Maintenance System, and the support equipment. Sources of the analysis data were Avionics Laboratory, ET&D Laboratory, Maintenance Directorate, Procurement and Production Directorate, Material Management Directorate, and Cost Analysis Office of ECOM, PM Advanced Attack Helicopter, Tobyhanna Army Depot, PM, TACFIRE, TRADOC, and RCA. Data collected was consolidated and analyzed before being used in the study.

a. Prime Equipment. This consisted of a work breakdown structure (WBS) of the AAH, which enabled a detailed analysis using the logistic model designed to evaluate requirements in terms of cost, test equipment, personnel, stockage, etc. On this basis, data such as repair times, failure rates, number and types of modules, were collected on the AAH LRU's.

b. Maintenance Systems. This included a determination of the number and types of maintenance units and associated maintenance personnel contained in the force structure. The failed item flow from one shop to the next was also determined from the scenario. Some of this information was obtained from MASSTER tests.

c. Support Equipment. Data was collected on both ATE and M/SPTE because both concepts were considered. The M/SPTE required to maintain each of the LRU's were identified in sufficient detail to permit utilization of the logistics model. Test

equipment downtime parameters and manpower were established so as to determine shop loading and support availability for the cost and effectiveness portions of the study.

The general purpose ATE was configured to support the AAH and the avionics LRU's which include electronic as well as electro-optical and servo-inertial equipments. ATE data collection consisted of information on expected failures, repair times, hardware and software costs, manpower requirements and logistic impact.

4. Logistics Models. The logistic model used for this analysis is the Logistic Cost Analysis Model (LOCAM IV). It was used instead of the GEMM/SETOM model because the larger number of cost input parameters permitted, and because the availability of LRU support equipment parameters. The output of the LOCAM model provided cost for storage, maintenance personnel, test equipment, inventory management and transportation.

5. Cost Analysis. The life cycle cost estimated for each alternative maintenance concept (i.e., ATE and M/SPTE) was determined using the outputs from the computerized Logistic Model. The R&D and Production Cost of the weapon system and test equipment was considered. Cost of application programs for the Line Replaceable Units (LRU's) on the AAH were considered where appropriate for ATE and SPTE. Initial provisioning was not charged on previously deployed GFE.

Sensitivity analysis was performed to determine the effect of increasing operating hours of the weapon system and test equipment operating hours to simulate active wartime and inactive wartime postures.

6. Effectiveness Analysis. The effectiveness of each maintenance concept alternative was evaluated by determining the major weapons systems operational availability and by assessing the intangible benefits of each maintenance alternative.

The logistic model used provided the predicted operational availability of the weapon system under each alternative maintenance concept. Sensitivity runs provided additional operational availability values for wartime, active, and inactive postures.

7. ATE Advantages. The following advantages of ATE were noted during the Cost Analysis study:

a. Reduction in manpower required in combat service support operations.

b. Reductions in the technical skills required to diagnose malfunctions and determine corrective procedures.

c. Reduction in down time for the support equipment.

d. Reduction in line items due to the reduction in the number of types of test equipment in use.

e. Substantially improved material readiness.

f. Reduction of funds required for maintenance training.

g. Reduction in research and development expenditures for test equipment peculiar to new items of electronic equipment.

h. Reduction in supply material required due to more accurate testing and less substitution.

i. Decreased transportation cost due to less supply materials required.

j. Reduced calibration required due to less test equipment required and self-calibration capability.

k. Minimizing repair requirements by reducing the number of faulty equipments returned to the user.

l. Card repair can be performed in the field.

m. Ease of logistic data and reorder data being transmitted to appropriate channels.

n. Increase accuracy in testing and fault isolation.

o. Repeatability of UUT testing.

p. Increased confidence in test and diagnostic results due to accuracy of test equipment.

q. Providing self-test capability down to modules, circuit boards and piece parts.

r. Automatic documentation of test procedures.

8. Conclusions. Fielded Automatic Test Equipment (ATE) is less expensive than Manual/Special Purpose Test Equipment (M/SPTE) in support of the Advanced Attack Helicopter (AAH); over a ten-year period, thirty-one per cent (31%) savings can be realized.

Operational availability of the AAH is higher when ATE is used as the support system as opposed to M/SPTE; i.e., .993 for ATE and .935 for M/SPTE.

ATE does a more thorough and accurate diagnosis of a Unit Under Test (UUT) than M/SPTE, including quality inspection of repaired UUT.

Standardization of initial and repetitive testing is possible with ATE as the support system.

More testing and diagnosis time is available and less quantity of hardware is required with ATE than with M/SPTE.

A single fielded ATE is capable of supporting 218 AAH deployed in the European theater during peacetime and wartime conditions.

The support of other major weapon systems by Automatic Test Equipment is potentially beneficial based on this analysis.

III. PLANNED MAINTENANCE AND TRAINING CONCEPTS

A. BACKGROUND

The AN/USM-410 test station is scheduled for deployment at the Restructured General Support level of maintenance. The AN/USM-410 will become an integrated portion of the TMDE to be used within the corps tactical general support area and as such will augment the manual test equipment being used to support current systems, rather than to replace it in its entirety.

B. MAINTENANCE PLAN

1. The AN/USM-410 will be supported by three levels of maintenance: Organizational, Intermediate, and Depot Level.

a. Organization Level Maintenance will be performed by the operator and consists of system calibration and self-checks and board, module and instrument replacement. All operator organizational checkout and test will be performed using the AN/USM-410 self-test capability. The operator will not be required to use any external TMDE to perform his maintenance. The AN/USM-410 should not require the development of any peculiar off-line test equipment. It shall be able to detect 98% of all equipment malfunctions through an inherent on-line status monitoring capability and be able to isolate 95% of all single occurring faults to the instrument or card level through self-diagnostic capability. Fault isolation to a single card is desired with a maximum ambiguity of 1.5 cards. Fault isolation to the instrument level is permitted only when a commercial type instrument without an inherent self-diagnosis capability is used and it is deemed more cost-effective to replace it and repair it off-line. All replaceable components will be sufficiently accessible to permit an operator with minimum training to replace it. Repair level analysis will be performed to allocate the repairs to be performed at each level of maintenance. Repair of instruments, modules and boards, and isolation and correction of those malfunctions not correctable by the operator will be performed by intermediate maintenance personnel.

b. Intermediate Level Maintenance will be performed by a centralized maintenance activity given the mission of AN/USM-410 repair. It will include in-shop board, module and instrument repair, on-site fault isolation and repair, technical assistance to AN/USM-410 users, and isolate malfunctions not isolated by automatic self-test to include multiple malfunctions and intermittent or ghost malfunctions caused by dependent circuit relationships.

c. Depot Level Maintenance will include rebuild, overhaul, refurbishment and repair of boards, modules and instruments not repaired at general support. Use of contractor furnished technicians (CFT's) or Army Field Maintenance Technicians (FMT's) is considered depot level maintenance. Included under depot level maintenance would be the preparation and updating of the AN/USM-410 component application programs as required, and reprogramming as authorized by programming modification work orders.

2. The maintenance burden for only unscheduled maintenance for each maintenance category would be as follows:

a. Operator organizational maintenance will be limited to the correction of those malfunctions that can be diagnosed to a faulty board, module or instrument and the faulty unit replaced within a total maintenance time of 1-1/2 hours.

b. Intermediate maintenance by maintenance support teams shall not exceed 24 hours for fault isolation and eight hours for repair.

c. Depot level maintenance will be required when the AN/USM-410 cannot be repaired within the timeframe allocated to intermediate maintenance.

3. Float AN/USM-410's will not be authorized within the theater; nowever, float instruments, modules and boards will be stocked. This spare float is required at the unit using the ATSS due to the maintenance concept of removal correction through the replacement of faulty items. Specific quantities to be stocked at each center will be determined by analysis based on density of the AN/USM-410 RAM data, repair turn-around time, etc.

C. SYSTEM SUPPORT PARAMETERS

1. Scheduled Maintenance. Scheduled maintenance includes both abbreviated daily preventive maintenance (PM) checks and weekly confidence checks. Of a total possible 168 hours of operating time per week, not more than 14 hours can be allocated to scheduled maintenance as follows:

a. Daily PM Self-Check - NTE one hour per 24 hours' operation (six hours per week).

b. Weekly PM Confidence Check - NTE six hours per week (replaces daily check).

c. Cleaning, lubrication, adjustments and other PM services - NTE two hours per operating week.

d. Maximum operating time per week is 154 hours.

e. Maximum scheduled maintenance time per operating week is 14 hours.

2. Unscheduled Maintenance. Unscheduled maintenance is performed each time the AN/USM-410 experiences a system failure. A failure is defined as any operating malfunction that prevents the AN/USM-410 from performing its primary mission that is not diagnosed and corrected within the timeframe allocated for scheduled maintenance.

3. RAM Requirements. The AN/USM-410 shall be designed so that all instruments, modules or boards shall be sufficiently accessible to permit removal and replacement in five minutes or less (exclusive of diagnostic time) by the operator. The following parameters apply:

a. Inherent Availability:

Desired: 0.995
Acceptable: 0.990

b. Mean-Time-Between-Failure:

Desired: 500 hours
Acceptable: 250 hours

c. Mean-Time-to-Repair:

Desired: 2.5 hours
Acceptable: 2.5 hours

d. Automatic Fault Detection - 98% of all faults

e. Automatic Fault Isolation - 95% of all single-occurring malfunction

f. Mean-Time for Automatic Fault Isolation - 30 minutes

g. Maximum Ambiguity (boards/modules) - 1.5 hrs.

h. Maximum Ambiguity (boxes, assemblies or instruments) - 1.0 hrs.

i. Maximum time to remove and replace boards/modules or instruments - 5 minutes

D. AN/USM-410 TRAINING CONCEPT

1. For those failures that cannot be isolated using the AN/USM-410 self-test capability, a skilled AN/USM-410 repairman will be required. This individual must be intimately familiar with the peculiarities of the AN/USM-410's being supported and be able to augment its inherent self-test capability to diagnose faults and effect repair. The importance of this distinction is a function of capability gained through specialized training and experience. Assuming that the AN/USM-410 has a MTBF of 250 hours with an inherent availability (A_I) of .99 and operates 24 hours per day (23 hours for

mission, one hour for PM), the system will then be operational 8,672 hours out of a possible 8,760 hours per year and require 32 separate maintenance actions. The above is based on inherent availability and does not include normal logistical downtime (NLDT). If the AN/USM-410 can automatically diagnose 95% of all single-occurring malfunctions to an operator replaceable component (instrument, card, or module) and the ratio between single occurring malfunctions and multiple-occurring malfunctions is 5 to 1, you can break down the 32 maintenance actions per year as follows:

a. single-occurring malfunctions: 24

b. multiple malfunctions: 6

c. manual diagnostic action: 2

Further, with a total MTTR of 2.5 hours for all levels of maintenance, the annual maintenance burden is 80 hours. If the operator performs maintenance actions only when the fault is diagnosed automatically and the operator MTTR is .58 hours (30 min auto fault isolation and 5 min remove and replace), the annual operator maintenance burden is 14 hours for 24 maintenance actions per machine. The remaining eight maintenance actions would require intermediate maintenance and account for 66 annual hours of maintenance per machine. This translates into an average of 5.5 hours of maintenance above operator level per month. Thus, if it were desired that all maintenance be performed by the operator, it appears that the frequency of fault isolation and repair beyond that which is computer directed is so low that he would never become proficient. On the other hand, if a separate skill were established for this maintenance, then the quantity of repairmen authorized would be based on the density of AN/USM-410's supported. His workload would then be such that he could maintain his proficiency and efficiently and effectively maintain the equipment.

2. If the goal of developing a common core family of the AN/USM-410 for the Army is met, then it follows that MOS could be designed to perform intermediate maintenance on this common family. The AN/USM-410 maintenance technician would have a system maintenance responsibility and provide that expertise necessary to isolate and correct those malfunctions not correctable at the operator/organizational level. The skills required would have to include computer maintenance, as without the computer there is no automatic self-test, and extensive knowledge in electronic troubleshooting. In many cases, no matter how effective the BIT procedures are for any equipment, multiple failures can cause ambiguities not isolatable through automatic test. Further, there may be failures in one component that affect other circuits in such a manner due to dependent relationships as to cause a good component to appear bad and resultantly fool the atuomatic self-test. In addition, software maintenance skills will be required at the intermediate level to as a minimum be able to distinguish the difference between software and hardware related faults and submit software investigation reports (SIRS) when anomalies are found.

3. The operator, relieved of the maintenance responsibility, will spend the majority of his time interfacing, testing, and repairing commodity peculiar UUT's using the AN/USM-410. As the skills required to operate the AN/USM-410 are expected to be minimal, his predominate skills will be oriented toward the commodity peculiar adaptors, interface devices and UUT's to be tested. The operator's UUT knowledge should be sufficient to augment automatic diagnostic procedures performed by the AN/USM-410 and to repair unserviceables while affixed to the AN/USM-410 (when it is determined to be advantageous). In addition, if the application program is faulty or the AN/USM-410 fails during a UUT test, the indication could be ambiguous and show a UUT failure. The operator, then, to effectively differentiate between UUT failures and AN/USM-410 failure, must have an intimate knowledge of the UUT. Thus, the operator, in addition to ATE operation, must have a detailed knowledge of the electronic, mechanical, optical, etc., of the commodity UUT's. This evaluation is consistent with other service lessons learned and Army testing of the AN/USM-410.

4. It does not appear to be conceivable that one course or one school could effectively teach an operator to use all possible adaptors, interfaces and test and repair all peculiar UUT's. It does appear feasible, though, to develop one POI for AN/USM-410 peculiar operation. That is, to instruct the operator in the loading and running of programs, use of all I/O devices, and operation of self-test procedures.

5. The duration required for the training must be short (NTE 160 hours). Therefore, little would be gained to provide centralized training for operation and then ship an operator to a commodity-oriented school for the remainder of his training on the commodity peculiar devices. Further, to reduce MOS proliferation, existing commodity-oriented MOS's could include AN/USM-410 operation in their POI. Since the MOS's selected by each commodity would already include training on the maintenance of peculiar UUT's, the inclusion of AN/USM-410 operation should provide little increase in course length. This approach has several distinct advantages. First, the operator MOS would not be peculiar, thus a density of operators would be available in the shop. This insures that sufficient operators will be available in the facility to allow for rotation and prevent the boredom inherent in operating automatic equipment. Second, the individual has commodity skills in addition to AN/USM-410 operation. He can be effectively utilized when the AN/USM-410 is down for maintenance. Third, the total skills required by the operator will be oriented toward the actual task complexity.

6. Intermediate maintenance of AN/USM-410 components should be consolidated into one RGS facility. At this facility, the AN/USM-410 modules/instruments will be treated like any other UUT as part of the scheduled workload. This relieves the other sets from a self-maintenance function and dedicates them to the peculiar systems that they are supporting. It also consolidates the adaptors and programs required for the AN/USM-410 modules and instruments into the one facility that has the best capability to support this equipment. In addition, it limits the amount of AN/USM-410 repair training required to an MOS/MOS's within one commodity only.

E. SUMMARY OF AN/USM-410 TRAINING CONCEPT

1. The AN/USM-410 operator must possess skills commensurate with the system being supported. He must be a skilled operator; however, AN/USM-410 peculiar training would be minimal while system peculiar training would be maximized.

2. Use of AN/USM-410 for an existing system would require inclusion of additional AN/USM-410 operator training into the current MOS producing course being conducted for that system. The system maintenance technician receiving this training would be provided an ASI identifying him as an AN/USM-410 operator.

3. AN/USM-410 peculiar operator training should be limited to those skills necessary to conduct UUT tests and performing AN/USM-410 automatic self-checks.

4. AN/USM-410 operator maintenance skills should be limited to those skills necessary to identify computer-located faults and to remove and replace faulty modules/instruments as directed by the self-test.

5. The predominate training required by the AN/USM-410 operator will be commodity peculiar and strongly UUT-oriented rather than ATE-oriented. This also includes care and maintenance of peculiar adaptors and interface devices. He must be sufficiently knowledgeable about the UUT being tested to be able to understand the UUT test logic and distinguish between UUT failures and ATE failures.

6. One POI for AN/USM-410 operation should be developed and provided to each commodity school as an addendum to the MOS producing course(s) that will include AN/USM-410 operation.

7. A skilled AN/USM-410 maintenance technician will be required. His skills should include the software and hardware maintenance of the common core family of the AN/USM-410.

8. One commodity (signal) should be given the mission of AN/USM-410 support and USACS&S should be tasked to develop an MOS and MOS-producing course to perform this mission (based on the TASA/QQPRI provided by PM, ATSS).

9. The centralized RGS facility should do all AN/USM-410 module and instrument repair and provide on-site maintenance support to the other RGS centers using AN/USM-410. The MOS decisions should be based on the TASA/QQPRI provided by PM, ATSS.

F. INTEGRATED TECHNICAL DOCUMENTATION AND TRAINING (ITDT)

1. Background. Integrated Technical Documentation and Training (ITDT) is a new approach aimed at improving both manuals and the training process by integrating their development and use.

For quite some time, the Army has been concerned with the extremely high cost of owning equipment. It has been estimated that in some cases overall yearly cost of ownership exceeds the initial cost of procurement. At least one third of our DOD personnel are

engaged in some aspect of full time maintenance. This does not include operator personnel who perform maintenance on a part-time basis.

Various studies have shown that: Thirty percent of a sample group of 118 track vehicle mechanics incorrectly diagnosed mechanical malfunctions. Seventy percent of a sample group of 59 automative repairmen incorrectly diagnosed automatic malfunctions. (DA Board of Inquiry on the Army Logistics System-1966.) A review of electrical troubleshooting procedures in the technical manuals for the M113/M113A1 Full-Tracked Armored Personnel Carrier revealed that some procedures were impossible to perform and others were simply incorrect. (Red Team Assessment of M113/M113A1 Carrier Personnel Full-Tracked Armored, April 1976.)

In mid 1975, a DARCOM/TRADOC joint committee was established to seek ways to improve the training and documentation process. In an effort to improve both documentation and training, the working element of the committee has produced, under contract, a draft military specification for the preparation of ITDT (MIL-M-632xx). It has also assumed monitorship of another Mil Spec produced by DARCOM under contract, for overall improvement of literature (MIL-M-633xx).

2. ITDT Program. The whole literature-training system development is keyed to and receives input from a detailed front-end analysis of the weapon system. This consists of performing in-depth equipment and functional analysis from perliminary maintenance allocation charts, parts, reliability data, maintenance, packaging and deployment concepts, operational characteristics, and configuration and environmental consideration as well as other sources which have a bearing on how the item is to be operated and maintained.

Operation and maintenance job tasks are identified by equipment and functional analysis and expanded and detailed in a task analysis as shown in Figure 1. This process results in a determination as to which tasks are selected for training, these are primarily subtasks which are recurring in nature.

Materials to be included in the job performance manuals (JPM) are determined through a detailed behavioral task analysis. The JPM break-out is similar to what we now have in our present system of numbering manuals. The key differences are in the organization of each manual by type. The overall objective behind the development of the manuals is to come up with a product that is readily usable by the man in the field. The JPM tells the man in simple terms what is to be done.

JOB PERFORMANCE MANUALS

VOL I - REFERENCE DATA, INSTALLATION & OPERATION

VOL II - PM, ALIGNMENT, ADJUSTMENT, CALIBRATION

VOL III - TROUBLESHOOTING DATA

VOL IV - REPAIR & REPLACEMENT JOB SEQUENCES

} JPM

VOL V - SAFETY, FIRST AID, TASK SEQUENCES, ACCESS & PREPARATORY TASKS, USE OF TOOLS AND TEST EQUIPMENT - JPG

The Job Performance Guide (JPG), a separate volume, describes common and frequently recurring tasks in detail and is used as a training test with the extension training materials.

Other key requirements are that all superfluous material will be eliminated and only that information required for successful task performance will be included. Manuals are to be prepared at a 5th grade level. This means that in addition to using a 5th grade vocabulary, graphics will be used extensively. The training package will provide the man-machine interface.

In keeping with the Army training philosophy, the training will be designed to be conducted at the unit level where the soldiers spend 90 per cent of their time. The only subjects to be taught in a formal school environment are those that cannot be taught in the field. This would include, but not necessarily be limited to, areas which require high cost simulators and trainers, a high ratio of high quality instructors to students.

In order to be used efficiently at a unit level, the material must be self-paced and wherever possible self-teaching. To meet requirements of the varied backgrounds of the personnel in the units, the training package must have multiple entry and exit points. These are needed so that a soldier can learn only what he needs to know in order to perform specific tasks. This is also a desirable feature for cross-training personnel in allied MOS's.

Since the content of the curriculum will be determined by the front-end analysis, it will be task based and performance oriented.

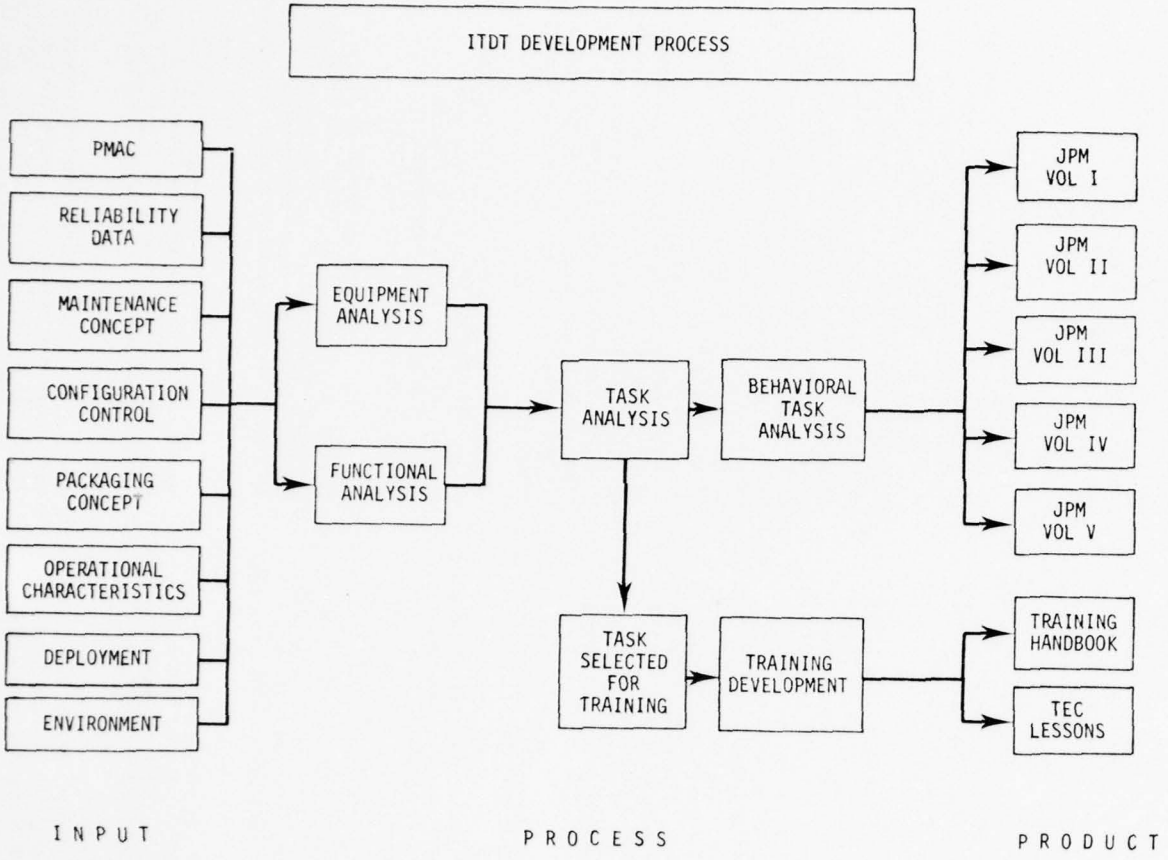

ITDT DEVELOPMENT PROCESS
PMAC
RELIABILITY DATA
MAINTENANCE CONCEPT
CONFIGURATION CONTROL
PACKAGING CONCEPT
OPERATIONAL CHARACTERISTICS
DEPLOYMENT
ENVIRONMENT
EQUIPMENT ANALYSIS
FUNCTIONAL ANALYSIS
TASK ANALYSIS
BEHAVIORAL TASK ANALYSIS
TASK SELECTED FOR TRAINING
TRAINING DEVELOPMENT
JPM VOL I
JPM VOL II
JPM VOL III
JPM VOL IV
JPM VOL V
TRAINING HANDBOOK
TEC LESSONS
INPUT
PROCESS
PRODUCT

Figure 1

The tasks will be determined by the demands of the hardware and not from someone's guess as to what should be taught.

The tasks selected for training determine the content of the JPG. This is the principle training document. It may be written in a programmed instruction format or as a straight text, or it may be written as a series of instructions or directions, but whatever its format, it will be written on a 5th grade level and amply illustrated.

The tasks selected for training also are used to determine the training objectives. In addition, they will form the basis for all criterion tests, pre-tests, post-tests, prognostic/diagnostic.

The extension training materials (ETM) which consists of training extension course (TEC) lessons, visuals, aids, simulation devices and tests is an integral part of ITDT in that it teaches the man in the field how to use the JPG and JPM. A brief training handbook will be provided describing the ETM lesson package. It will be directed at supervisors and will explain how the ETM lessons are to be used in conjunction with the JPM/JPG, the unit training program and OJT. It will list the ETM lessons, and explain how the various ETM modules can be used either independently or as a training sequence.

3. ITDT Implemenetation. During development, ITDT will be validated every step of the way. The developer will hold small group trials of all lessons using 10 to 16 soldiers per trial when the first draft of materials is prepared. Large group trials will be held prior to final acceptance by the government.

This will consist of determining whether the soldier test population can operate and maintain the equipment with no instruction other than that provided by the JPM, JPG, and ETM.

Recognition of the promise which ITDT holds can be seen in a draft AR 1000-2 requiring that all new major equipment systems will be considered for inclusion in the ITDT program.

"Included in the contract will be the requirement to develop and provide for evaluation during development/operational test II, integrated technical documentation and training materials, training simulators, training ammunition, automated test equipment, special tools and other subsystems as appropriate which are required to support the basis system."

"The operational tests will be conducted in a truly tactical environment involving the use of field maintenance, training, manuals, countermeasures, etc. A complete integrated logistics support package and training package must be validated during OT II. Sufficient test hardware will be procured early enough to prepare for and demonstrate during DT/OT II the adequacy of the training and logistic support package."

AR 1000-2 (Draft)

Due to the higher costs involved in implementing ITDT, not all weapon systems or projects will be given ITDT treatment. Several criteria favoring the implementation of ITDT are as follows: combat criticality, high density, large MOS population, high training costs, commonality with other systems, and has foreign military sale potential. Three factors which may weigh against applying ITDT would be the availability of funding to support the program, the advanced stage of life cycle of the system, and the possible impact on the schedule for the development and fielding of the weapon system.

The DARCOM/TRADOC committee is sponsoring three demonstration projects - two on fielded systems, a wheeled vehicle and a tank turret and one on a developmental system, the BCS. ITDT is also being injected into the TACFIRE project while it is still in the development phase.

4. ITDT Summary. The ITDT approach offers the promise of significant gains, many of which are not readily apparent. In addition to improved maintenance, the following payoffs are feasible:

a. Reduced number of Military Occupational Specialties (MOS), simplifying personnel management, MOS mismatch problems and retraining requirements whenever a soldier is reassigned or when unit inventories are changed.

b. Reduced training costs. It was estimated for the tank turret with a reduction in MOS's required that over $2 million would be saved in annual training costs.

c. The greatest payoff, however, will occur with new systems, where the total system can be developed concurrently. This will insure that when a system is fielded, it will be supported by technical documentation that the soldier can understand and an extension training package that teaches. This, in turn, will lead to less waste through

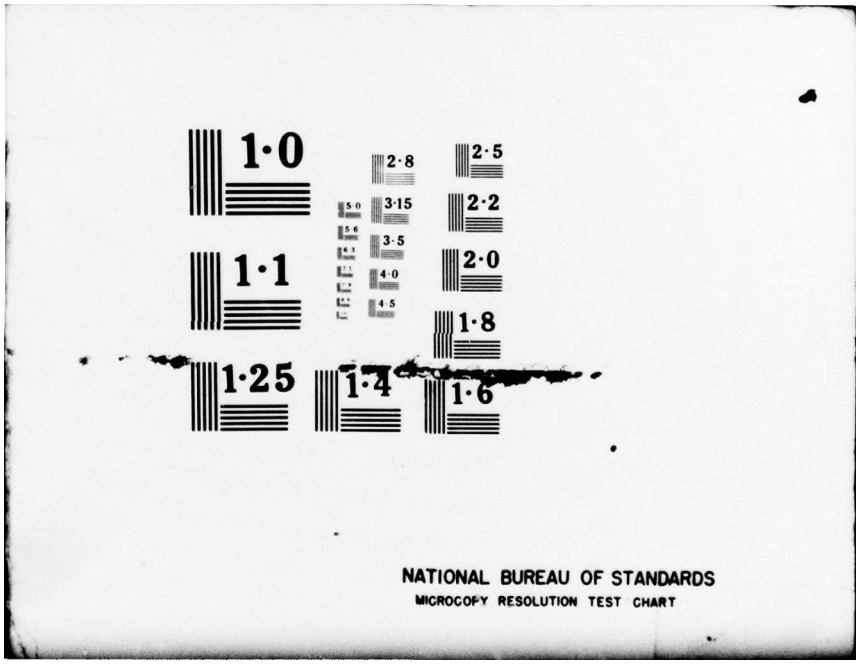
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NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

better maintenance procedures and increased battlefield effectiveness through better maintained equipment.

An abundance of available research data points to the conclusion that the Army has a good concept. What now remains to be done is to institutionalize the program and field a completed project to prove that something can be done to reduce the cost of equipment ownership.

LONG-RANGE TRENDS IN AUTOMATIC TEST EQUIPMENT - IMPACT ON THE TECHNICIAN

Dr. Jan Miller
Mantech of N.J. Corporation
(San Diego Operations)

Paul J. Giordano
Giordano Associates, Inc.

SUMMARY

This paper addresses the long range trends in Automatic Test Equipment as they affect the technician. The authors expect that radical changes in the support system will be made over the next 5-10 years. These changes will have a significant impact on Navy operators and maintenance personnel. With respect to Bane or Blessing, this impact will be favorably received by the operators who will be called upon for interpreting on-line diagnostics of the prime systems under their cognizance. However, in the case of the maintenance technicians, there is some serious question as to their ability to cope with the complex off-line maintenance actions required at intermediate and depot levels. It is expected that in the future Navy technicians working at the second and third echelon of maintenance will require increasing professional civilian support. Some combination of civil service and contractor personnel will probably be required to handle the diverse work load anticipated below organizational level.

To circumvent the growing dichotomy between operation and maintenance personnel, the authors will put forth the thesis for discussion that operators be trained for organizational level maintenance actions and that lower echelons of repair be managed by industrial facilities manned by some hybrid of Navy technicians and civil service personnel with support of contractors as required.

INTRODUCTION

In order to develop this thesis, this paper will detail the current trends in Automatic Test Equipment being promulgated by the Navy in response to CNO requirement #3 aimed at improved fleet readiness at affordable costs.

The development of Automatic Test Equipment technology trends will be evaluated in terms of its impact on WORK LOAD, FACILITIES and TEST FUNCTIONS. The trade-offs between facility, work load, and function represent the parameters which will dictate the future requirements for Automatic Test Equipment in Navy facilities.

When traded-off against the rapid advances that have been made in Automatic Test Equipment technology, it is expected that a "FAMILY OF AUTOMATIC TEST EQUIPMENT" will be generated in an evolutionary manner. To compliment this family of Automatic Test Equipment, "SOFTWARE CENTERS" will be developed to generate the required test program sets and to manage the enormous configuration problem which must be solved.

Both Family of Automatic Test Equipment and Software Centers are conceptual terms which can take on many dimensions depending upon the procurement decisions that are made over the near term. It is intended in a discussion of this paper with the twelve participants that alternative concepts of the Automatic Test Equipment family of the future and, alternative structures for software management be related to their specific impacts on operator and maintenance personnel.

It is hoped that this discussion will clearly indicate the pros and cons of the many alternatives, thereby having an influence on the major decisions that must be made. Since the concept of a family of Automatic Test Equipment and Software Centers are embryonic in nature, discussion of alternatives as they relate to operator and maintenance personnel may have a profound impact on the decisions that are taken in the Navy.

TRENDS IN AUTOMATIC TEST EQUIPMENT (ATE) TECHNOLOGY

Prior to defining the Automatic Test Equipment family concept, let us review the most significant trends in Automatic Test Equipment technology.

DESIGN FOR TESTABILITY

Probably of most importance is the increasing recognition by the highest levels of Navy Management of the need for DESIGN FOR TESTABILITY in our new weapon systems.

There are three levels of Design for Testability of interest to us at this conference. The first is operational testability. In the development of operational requirements for new systems, it is becoming increasingly common to see support parameters specified early in the project. It is during this phase that operational concepts are developed which have a significant impact on the entire maintenance concept to be employed for the system. For example, in deploying its systems, the Navy has certain ships with broad capabilities referred to as hi-mix ships. On the other hand, many smaller ships have entered the fleet with limited but specific mission profiles. These smaller ships are usually referred to as lo-mix. Of significance to us is that lo-mix ships cannot accommodate large numbers of people or excessive test equipment at the organizational level. In addition, to support lo-mix ships, new overhaul and maintenance strategies are being developed which take maximum advantage of intermediate maintenance activities (IMA's) such as Mayport, here in Jacksonville, Florida. In this case, we see that deployment profiles which consider maintenance strategies will have a marked impact on future maintenance concepts.

The second level of Design for Testability will probably have most significant impact on the maintenance technician. It is during this trade-off that the level of BIT is determined and the required OFF-LINE SUPPORT is established.

One of the most promising solutions to support this fleet of the future is built-in test (BIT). Despite our poor track record in the past with implementation of BIT, the technology in electronics has advanced to a point where with the utilization of new LSI circuits, the prior problems of power and space constraints are no longer limiting factors. In addition, the extensive use of digital computers in our weapon systems makes it increasingly feasible to develop operating software systems where one of the significant functions is to self-test the weapon system. Through a judicious use of hardware and software, BIT will ultimately isolate failures at organizational level to the printed circuit board or assembly thereby allowing repair by replacement actions as opposed to diagnostic actions. In-depth repair in those cases where BIT is implemented successfully will be relegated to second and third echelon levels. This level of trade-off produces essentially the work load that will be supported at organizational, intermediate and depot levels by both built-in and off-line Automatic Test Equipment. This work load when accumulated across all weapon systems has a major impact on the type and quantity of Automatic Test Equipment to be implemented.

In making Automatic Test Equipment decisions, a combination of work load considerations, facility considerations and the diverse range of parameters to be tested are the key factors in establishing the Automatic Test Equipment acquisition plans.

It is essentially this diversity and the enormous populations to be worked with at different facilities which has created the concept which we will refer to today as "Family of Automatic Test Equipment." Coupled to this, the enormous task of writing and controlling intelligent test program sets for this broad range of parameters has given rise to the concept we're referring to as software centers.

The third level of Design for Testability is the detailed design trade-offs made at the prime system and equipment level which enhances the overall testability of the product itself. At this level, such considerations as fault tolerant design, redundancy, accessibility and partitioning are given detailed design consideration. Failures at this level give rise to impossible work-around programs after the fact.

We all know too well the results of poor Design for Testability.

In reviewing the above, one can see that the Navy has seriously embarked on a major effort to alert program managers of the significant benefits of early consideration of support in their weapon system designs. As this program gets underway, the net result to the user will be increasing levels of BIT across all types of Navy weapon systems. In the past, BIT was limited to those applications dictated by absolute strategic necessity such as the Trident weapon system with its long deployment cycles and confined space. The success of the Trident program is a key model for future implementation of BIT. As we will discuss later, the major impact of this trend will be felt by the operators, who must be trained to handle the on-line diagnostic function provided by the prime

equipment under their control.

OFF-LINE TECHNOLOGY

Let's now examine the trend in Automatic Test Equipment for the more commonly known types of Automatic Test Equipment, namely off-line test and repair. In the off-line area, the most significant advances in technology have occurred in the following areas:

1. Use of higher order languages
2. Development and use of interactive compilers
3. Development and use of computer aided program generation and Automatic Test Program Generation (ATPG)
4. Development of programmable interface units and universal switching sub-systems
5. Advances in calibration technology leading to self-calibration

These five areas were selected because of their direct impact on the maintenance technician.

The stimuli and measurement portions of the Automatic Test Equipment will not be considered since, if done properly, they will be transparent to the user. The most significant advance in this area has been the development of so-called third generation systems which use computers to generate stimuli and measurement functions. These developments hold great promise for broad range low-cost test systems in the future. Since they are transparent to the user, detailed descriptions will be omitted from this paper and handled during the discussion period if questions arise.

The technology areas which directly impact the user concern the input/output and internal interfaces of an off-line Automatic Test Equipment. In preparation for our discussion, the following brief descriptions of the above key developments are offered:

1. USE OF HIGHER ORDER LANGUAGES

"NAVMAT has generated an instruction on the use of Atlas as Navy standard. DOD has concurred with this approach and is encouraging tri-service convergence of Atlas-Opel (Army) languages by 1980. Atlas is a high level test language, easily readable by man and machine, which expresses the stimulus and measurement requirements of a unit under test (UUT) in terms oriented to the parameters, pins, and physical constants related to the UUT. It is thus independent of the ATE or manual test facility being employed. It is intended primarily for writing test procedures, or test specifications for the UUT in a clear complete and unambiguous form. The language has a history of use in industry and DOD and is being increasingly applied internationally by ATE users and developers, both commercial and military. It is non-proprietary and has evolved through use and application feedback." When used as a standard test language Atlas is expected to become a natural interface with other software supporting elements such as:

- Test Requirements Documents
- Automatic Test Program Generation
- Test Program Compilers
- Automatic Documentation Aids
- ATE Data Banks

"The principal advantages of Atlas are (1) that it exists in usable form and (2) that it is already widely accepted and applied. As a standard, it has the capability to provide a self-documenting means of communication between UUT designers, ATE designers, Test Engineers, Test Programmers, and Maintenance Technicians all of whom perform diverse tasks related to UUT and ATE hardware and software."

2. DEVELOPMENT OF INTERACTIVE COMPILERS

Early versions of ATE used machine language which was very difficult to work with but extremely flexible in computer control. Where compilers were developed to translate a higher order language to machine code, they were usually off-line. This meant that the compilation was done with a separate computer as opposed to the test station control computer. If the program did not work first time through the programmer (Engineer or Technician) had to go back and forth to correct errors.

Interactive compilers involve on-line writing, editing and debugging. They are resident on the test station computer. The power of the interactive compiler is well known to the test program designer. The question for our meeting is the use of this powerful tool by Navy personnel. The enormous cost in front of us for test programs suggests that perhaps technicians can be trained to write and debug as well as use test programs. NAVAIR is evaluating this

potential with pilot programs. Questions arise such as:

Can our technicians handle the problem at today's skill levels?

Do we want Test Systems to be interactive at all?

What impact will this have on configuration management?

3. DEVELOPMENT AND USE OF COMPUTER AIDED PROGRAM GENERATION AND AUTOMATIC TEST PROGRAM GENERATION (ATPG)

"ATPG is the process by which a computer, together with a software system, is used to simulate the circuit network of a unit under test (UUT) for purposes of determining test parameters. UUT design data from schematics and/or logic diagrams is coded and input is sent through the computer. Here it is transformed into a mathematical model of the UUT and placed in computer memory...the UUT model is exercised by the cap algorithm to determine the stimulus and response signals of a fully exercised and properly performing UUT. The programmed fault modes for each component, based on reference to a resident circuit model library, are then inserted in the modeled network. This produces a fault dictionary of failed components related to each combination of input and output signals. Outputs are stimulus/response data which prescribe the end-to-end test of the UUT, with fault data for the desired fault isolation. The principal advantages of ATPG (over manual methods) are substantially increased TPS effectivity and reduced TPS acquisition costs. Logic automated stimulus and response (LASAR), applicable to medium scale digital logic circuit testing, is available through teleprocessing terminal access to a central computer at the Applied Physics Laboratory of Johns Hopkins University. This capability is managed and serviced by the Naval Air Engineering Center, Lakehurst, New Jersey. An improved version of LASAR has been leased from the manufacturer by the Naval Air Systems Command. Advanced digital and analog ATPG applications are in various stages of R&D."

The questions raised for interactive compiler usage by the fleet become even more serious in terms of ATPG where at this time many professionals in private industry are not trained in the use of ATPG.

4. DEVELOPMENT OF PROGRAMMABLE INTERFACE UNITS AND UNIVERSAL SWITCHING SUB-SYSTEMS

Our real hopes are in this area. If the maintenance technician is to succeed with ATE utilization to handle the diverse workload we must simplify the interface device (ID's). On today's systems ID's are becoming more and more of a problem. They are cumberson, take too long to interconnect, include too many active circuits, and fail frequently. It is inconceivable to imagine handling the workload in our depots with the level of interface devices required by today's systems. The future is bright, however. We can create programmable interfaces which limit ID's to mechanical adaptation only. As we combine broad-range computer generated stimuli/measurement devices with programmable adaptors and interface units it becomes feasible to project cost effective use of ATE at 2nd and 3rd echelon or repair.

In Navy generation of tomorrows "family of ATE", we must insist that simplified interfaces be a key design parameter of the internal ATE switching and routing sub-systems.

5. ADVANCES IN CALIBRATION TECHNOLOGY LEADING TO SELF-CALIBRATION

It has been estimated that $50 million per year is spent of calibration. Technology advances in LSI circuitry allow microprocessor functions to be distributed in test system stimuli/measurement devices so as to allow self-calibration. We must stress these types of advances that reduce workload since the amount of testing projected over the next decade is mind-boggling. In addition to LSI usage, techniques for incorporating standards either internal or through an interface exist now. In many cases we do not have this capability in our systems because we forgot to ask for it. Finally, the ATE self-test programs can be tightened and placed on a 2nd tape or disk and used as a partial calibration check thereby reducing the frequency of calibrations.

CONCLUSIONS AND ALTERNATIVES FOR DISCUSSION

TREND

Future weapon systems will utilize more built-in test.

IMPACT

Operators will handle organizational level maintenance through BIT recognition and repair by replacement.

PROBLEMS

Need manuals which recognize operator responsibility for on-line repair.

Supply system must have on-board spares.

Operator training must include BIT recognition.

TREND

Maintenance concepts are changing for Lo-Mix Ships with ideas such as Engineered Overhaul Cycles (EOC).

IMPACT

Workload at 2nd and 3rd echelon will increase and require schedule management.

PROBLEMS

Should IMA repair capability be increased? Pearl, Mayport, Alameda, etc.

Should Depot capability be increased?

Should screening be performed at 2nd echelon or on-board?

TREND

Off-line ATE will be asked to handle more workload, of more diversity (High Frequency to RF, High Speed to 20 MHz, Hi-Power and Hybrid), at more facilities.

IMPACT

A family of ATE must be considered as opposed to universal supertesters.

PROBLEMS

Workload Apportionment

Facility Management

Definition of ATE Family

Software Management (Generation of test program sets and configuration control vs end item revisions and test system compatibility is the largest problem facing the support Navy today!!)

TREND

Family of ATE will be available for future facility and program managers for selection as opposed to redesign for each project.

IMPACT

Sanity vs Proliferation!

PROBLEMS

Which technological advances described in early portion of paper will be utilized in family definition, i.e.,

Interactive systems vs simple push button control panels

Functional systems for limited or multi-purpose applications

Multi-port or multiple systems

Programming stations vs test stations

Distributions systems vs master/slave vs self-contained sub-sets

Degree of self-test

Degree of self-calibration

Commercial or Military grade designs

Common language or translators from A to Z

Single compiler or family of compilers

Programmable switching at interface or limited fixed/workload

Standard interface specification or general functional requirements

Degree of program transparency for family of ATE evolution.

We have presented a broad cross section of the overall problems. Our parochial solutions have been omitted to stimulate discussion. There is no obvious solution but the problem is real. It is hoped that during this coming year the Navy under the guidance of NMC MAT-04T will define the Navy family of ATE concept. NAVAIR has taken the lead in this program. The authors hope that seminars and discussion such as this will have an impact on these very important decisions that will be made.

BIOGRAPHICAL SKETCHES

DR. JANATHIN MILLER is currently Technical Director of Education and Training, ManTech Western Operations. She has over ten years experience in assessing, conceptualizing, implementing and evaluating media training support systems in a variety of military adult education/career education environments. Most recently, she supported the development of visual aid and course materials for the ATE acquisition Management Course, sponsored by the Test and Monitoring System Office (MAT-04T), which was presented in Washington for the first time in March 1977.

Dr. Miller received her PhD in Instructional Technology and Media Management System from Cornell University.

MR. PAUL J. GIORDANO has a total of 25 years experience in System Management and Engineering.

He is President of the consulting firm, Giordano Associates, and had been President of Instrumentation Engineering, Inc., which manufactures commerical and military ATE... was Vice President of Bradford National Corporation and Head of Advanced Development for the System Management Division of Sperry Rand...has written numerous technical papers... lectured at Naval War College and led seminars on System Engineering at Webb Institute of Naval Architecture.

Prior to joining Sperry Rand, Mr. Giordano was head of the Navy System Performance Effectiveness Program. In this capacity he was responsible for the development of many Navy programs in support of the Weapon System Acquisition Process.

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Commander 1
Naval Sea Systems Command
Code 03416 (Mr P. J. Andrews)
Washington, DC 20360

Commander 1
Naval Air Development Center
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Human Factors Engineering Division 1
NAVAIRDEVCEN, Code 7005
ATTN: CDR Charles Theisen
Warminster, PA 18974

Human Factors Engineering 1
Attn: Dale Mahar, Code 1226
Pt Mugu, CA 93042

Chief of Naval Air Training 1
ATTN: Code 3121
NAS
Corpus Christi, TX 78419

US Air Force Human Resources Lab 1
AFHRL-AS
Advance Systems Division
Wright-Patterson AFB, OH 45433

US Air Force Human Resources Lab/DOJZ
Brooks AFB, TX 78235 — 1

AFHRL/FTO
ATTN: Mr. R. E. Coward
Luke AFB, AZ 85309 — 1

Headquarters
US Air Force Systems Command
DLS, Andrews AFB
Washington, DC 20331 — 1

US Air Force Human Resources Lab
AFHRL-FT (COL J. D. Boren)
Flying Training Division
Williams AFB, AZ 85224 — 1

ASD SD24E
ATTN: Mr. Harold Kottmann
Wright-Patterson AFB, OH 45433 — 1

Commander
Navy Air Force, US Pacific Fleet
NAS North Island (Code 316)
San Diego, CA 92135 — 1

Chief
Naval Education & Training Liaison Office
AF Human Resources Laboratory
Flying Training Div
Williams AFB, AZ 85224 — 1

Commander
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Naval Air Systems Command Headquarters
(AIR 340F)
Washington, DC 20361 — 1

Naval Weapons Center
Code 3143
ATTN: Mr. George Healey
China Lake, CA 93555 — 1

Chief of Naval Education and Training Liaison Office
Human Resource Laboratory
Flying Training Div
(ATTN: CAPT W. C. Mercer)
Williams AFB, AZ 85224 — 1

Commandant
US Army Field Artillery School
ATSF-TD-TE (Mr. Inman)
Ft Sill, OK 73503 — 1

Dr. Jesse Orlansky
Institute for Defense Analyses
Science & Technology Div
400 Army-Navy Drive
Arlington, VA 22202 — 1

Director Educational Development
Academic Computing Center
U. S. Naval Academy
Annapolis, MD 71402 — 1

Commander
Naval Air Systems Command
Naval Air Systems Command Headquarters
(AIR 413B)
Washington, DC 20361 — 1