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2nd MICOM Logistics Research and Development Workshop Unclassified

27-28 August 1991

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35898-5000

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BSTRACT (Continue on reverse if necessary and identify by block number)
This document presents the proceedings of the Logistics Research and Development ·kshop held at University Center (Exhibit Hall) Huntsville, Alabama (Registration at ı Bevill Center) 27-28 August 1991. The Workshop objective was to energize the Army ;sile community towards solutions for generic logistic support system deficienies and the luction of logistics related weapon support costs. The workshop program was balanced to :ract the interests of both the system designer and the logistician. The workshop ʝhlighted examples of work already in progress, provided the forum for critical assessment current practics and explored selected contemporary issues such as the impact of ıdevelopment items (NDI) on the development and logistics community. An additional ıective of the workshop was to motivate industry to undertkae more R&D under the lependent Research and Development (IR&D) Program.

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PROCEEDINGS

SECOND MICOM LOGISTICS RESEARCH AND DEVELOPMENT WORKSHOP

27-28 August 1991

MICOM LOGISTICS RESEARCH AND DEVELOPMENT

Workshop Chairman, Mr. Kenneth E. Dulaney

Workshop Co-Chairman, Mr. William C. Pittman

AGENDA

Tuesday, 27 August 1991

0730 Registration, Tom Bevill Center Lobby. Workshop will be held at University Center (Exhibit Hall), behind Tom Bevill Center.

OPENING SESSION

0800 Administrative/Introductory Remarks by Mr. Avery C. Baswell and Mr. Kenneth E. Dulaney Chief, Technology Integration Office/Chief, Industrial Operation Division Research, Development, and Engineering Center

0810 Keynote Speaker Dr. Richard G. Rhoades Assoc. Director for Systems of Research, Development and Engineering Center.

Session I

Chairman Henry M. Fail, Jr. (205) 876-3561

Session II

Chairman John V. Davis (205) 842-7646

1400 "Obsolescence – An Old Age Problem" by *Dr. Richard Lane (205) 876-5073* ......

1430 "Military Standards are Cost Effective" by *Dr. Noel E. Donlin (205) 842-0156* .....

1500 "Designing Accelerated Tests for Accurate Life Cycle Predictive Technology" *by Michael J. Cronin (518) 785-2469* ....

BREAK 15:30 – 16:00

1600 "An Artificially Intelligent Parametric Processor for Realtime Design Supportability Feedback" *by Curtis M. Low (205) 842-0867* ....

1630 "Concurrent Engineering Initiatives at MICOM" by *Patti Martin and Bob Shackelford (205) 895-3479* ....

1700 "Data Collection Issues – Training, Availability, and Repair Time" by *Dr. Jeffrey L. Riggs (205) 895-6817* ....

FINISH FOR DAY 17:30

Resume – Wednesday, 28 August 91

0730 "Shelf Life Concerns for Optical Dispensers" *by Julie I. Locker (205) 842-7648* ....

Session III

Chairman Dr. J.R. Jones (205) 876-5042

0800 "A Low-Cost Micromachined Thermally Isolated Resistance Structure for Dynamic Thermal Scene Simulation Compatible with Standard CMOS IC Fabrication Technology" by *Dr. Mike Gaitan (301) 975-2070* ....

0830 "A Laser Doppler Displacement Meter Vibration Sensor in Mechanical Diagnostics" by *Dr. Charles P. Wang (213) 635-7481* ....

0900 "Evaluation of a Laser Tracking Interferometer for Large Dimensional Metrology" by *Sharon M. Johnson (205) 842-8537* ....

BREAK 9:30 – 10:00

1000 "Calibrator Performance Prognostication" by *Tom Withrow (206) 356-5950* ....

1030 "AGT 1500 Direct Support Diagnostic" by *J. Scott Shurtleff (203) 385-3813* ....

1100 "Built-In Trend Analysis Device" by *J.R. Miller (205) 876-9494* ....

1130 "Army Dynamic Pressure Measurement Technology" *by John Ball (205) 876-9501* ....

LUNCH 12:00 – 13:00

1300 "High Accuracy Digital AC Voltage Measurement Algorithm" *by Ronald L. Swerlein (303) 679-2029* ....

1330 "Research and Measurement of Infrared Sources at the NIST Thermal Imaging Lab" by *Robert T. Bruening (301) 975-2318* ....

Session III (Continued)

1400 **"Fractography of Tensile Fractured Optical Fibers Using Scanning Electron Microscopy" by *George G. Bryant (617) 923-5210*** ....

1430 **"A Front End Processor for Reliability, Maintainability, and Cost" by *Curtis M. Low (205) 842-0867*** ....

1500 **"Shelf Life Issues with Infrared Detector Dewar Assembly" by *Neil D. Supola (703) 664-1861*** ....

Panel Discussion

Start: 15:30 **Finish: 17:30**

Topic of Discussion: **Conflict Between Research, Development and Logistics During a Project Life.**

Panel Members:

Moderator: **J. Delbert Williams – *Deputy Director of System & Engineering and* Production Directorate *(205) 876-4727***

BG Robert W. Pointer, Retired, Director Strategic Progam Mechanical Technology, Inc., Latham, N.Y. *(518) 785-2211*

Robert J. Kuper, USA Armament/Munitions, and Chemical Cmd. Chief, Predictive Technology Branch *(201) 724-3296*

David A. Sparks, Chief Logistical Analysis Division of Missile Logistics Command *(205) 876-9158*

Robert K. DuBois, Director of TMDE Activity *(205) 876-1134*

Ronald E. Chronister, Suprv. Production Engineering Division *(205) 895-3478*

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APPENDICES

INTRODUCTION

This document presents the proceedings of the 2nd MICOM Logistics Research and Development Workshop at the University Center Exhibit Hall, Tom Bevill Center, University of Alabama, Huntsville, 27-28 Aug 91. Mr. Kenneth E. Dulaney, Chief, Industrial Operations Division, System Engineering and Production Directorate, Research, Development, and Engineering Center and Mr. William C. Pittman, Program Manager of Advanced Sensors Directorate were cochairmen of the workshop.

The objective of this workshop was to identify logistics research and development opportunities that will allow more effective support of U.S. Army Missile Command (MICOM) systems over the life cycle of these systems. The first workshop with this objective was held on 18-19 Oct 87. An Army Material Command policy letter, 28 Feb 85, defines logistics research and development (R&D) as: "That portion of the overall research, development, test and evaluation (RDTE) which applies science and technology to solve generic logistic support system deficiencies and reduce logistics related weapon support costs through existing funding and approval channels." Army weapon systems often receive inadequate support over the life of these systems because research and development is viewed as only a discrete phase of the life cycle management process, and not as an activity that must be keyed to the entire process of development, acquisition, maintenance, and replacement of these systems. The theme of the workshop was "Stretching the Logistics Dollar through R&D." The workshop highlighted examples of work already in progress as well as other efforts that are planned, with additional emphasis on the gaps in this area that must be filled. An additional objective of the workshop was to encourage industry to undertake more logistic R&D under the Independent Research and Development (IR&D) program.

The keynote address was given by Dr. Richard G. Rhoades, Associate Director for Systems, Research, Development, and Engineering Center. Dr. Rhoades has previously served as Director for Propulsion and Associate Director for Technology of the Center. He came to Redstone in 1963 as an Army officer and was originally assigned to what is now the Weapon Sciences Directorate. He received his Doctorate in Chemical Engineering from Rensselaer Polytechnic Institute and is a native of Northampton, Massachusetts. Dr. Rhoades is married and has three daughters.

The hosts for the workshop were: the Research, Development, and Engineering Center, the Missile Logistics Center, and the Test, Measurement, and Diagnostics Support Activity. Members of the workshop steering committee from these organizations were: Mr. William Pittman, Chairman, Mr. Russell Altman, Administrator, Mr. Kenneth Dulaney, Mr. Henry Fail, Mr. Timothy Gebhart, Mr. James Miller, Dr. Stephen Smith, and Mr. Otho Thomas.

This document was prepared from papers collected by the workshop administrator, Mr. Russell Altman. All papers from the three sessions are included, in the order presented during the workshop, along with a summary of open forum table discussions. The workshop agenda is included as Appendix A and attendees are listed in Appendix B.

MICOM LOGISTICS R&D INVESTMENT STRATEGY

KEYNOTE ADDRESS
FOR
WORKSHOP ON LOGISTICS R&D
27-28 AUGUST 1991

DR. RICHARD G. RHOADES

JULY 1991

RESEARCH, DEVELOPMENT, AND ENGINEERING CENTER
U.S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

INTRODUCTION

Good morning, ladies and gentlemen. Welcome to the Second U.S. Army Missile Command (MICOM) Workshop on Logistics Research and Development (R&D). The theme of the workshop is "Stretching the Logistics Dollar through R&D." (see viewgraph 1)

LOGISTICS R&D INVESTMENT STRATEGY

- **FOCUS ON GENERIC TECHNOLOGY INVESTIGATIONS IN HIGH PAYOFF AREAS**
  - **SOFTWARE**
  - **PREDICTIVE TECHNIQUES**
- **LEVERAGE INDEPENDENT RESEARCH AND DEVELOPMENT INVESTMENTS**
  - **NEW POLICY IN FORMULATION**
- **FOCUS ON THE FUTURE**
  - **INFRARED FOCAL PLANE ARRAYS**
  - **MILLIMETER AND MICROWAVE MONOLITHIC INTEGRATED CIRCUITS**
  - **UNCOOLED INFRARED DETECTOR ARRAYS**

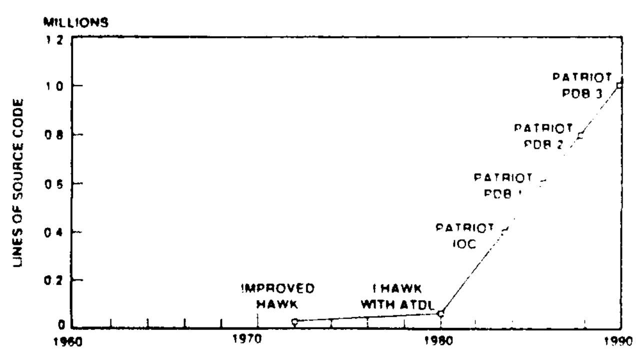
viewgraph 1

Our investment strategy in this area is to: (l) focus on generic technology investigations in high payoff areas, (2) encourage and leverage industry Investment Research and Development (IR&D) investments, and (3) focus on the future. In the next few minutes, I will touch on a few elements of that strategy. Through this strategy, our goal is to: (l) improve weapon producibility, (2) reduce weight, volume, cost, and manpower requirements, (3) control the number of shelf life components, (4) minimize the impact of component obsolescence, and (S) reduce equipment down time. In short, to reduce the cost of material ownership. The workshop will highlight examples of work already in progress as well as other efforts that are pianned with emphasis on the gaps in this area that must be filled. Since I know many of you are deeply involved in materiel R&D and production, let me make one point about the deep self interest our community has in accomplishing effective logistics R&D, especially in a period of reduced defense spending. As I'm sure you know, the Army's share of the defense budget must pay for several major expenses; it must cover the costs for military manpower; it must cover the costs of sustaining and training that military force (keeping it ready); and it must provide for investments in modern equipment for that force - the R&D, procurement, and military construction accounts. Since there is little utility in having a military force that is not ready, there is a strong commitment in the Army's leadership, and, I believe, in the Congress to fund the sustainment and training accounts. Thus, given an Army of a particular size - the current consensus is on an active force of 535,000, and a commitment to keep that force ready, the more it costs to keep that force ready, the less there is available for the investment accounts if the budget top line is fixed - as it currently is, and typically will be, logistics R&D, properly carried out, can significantly reduce the amount we must spend to sustain the force, to keep it ready, permitting the Army to spend more funds in modernization investments -particularly in the procurement accounts that actually result in new or improved items in the field and which have shrunk dramatically in the last two budget years.

With that comment as prelude, let me now say a few words about our investment strategy - the first part of which is to: <u>FOCUS ON GENERIC TECHNOLOGY INVESTIGATIONS IN HIGH PAYOFF AREAS</u>

Software is one of those pervasive technologies that is part of all of our defense systems. An estimate of DOD expenditures on software for FY 90 is $32 billion; over 10 percent of DOD's entire budget. Software usage will continue to grow because of its demand as a supporting technology for our widespread use of advanced technology. The Army has had an order of magnitude increase in weapon system software in the past decade and the arrival of smart weapons and precision guidance has been the major contributor to this trend. (see viewgraph 2)

EXAMPLES OF SOFTWARE GROWTH FOR SOME SYSTEMS IN PDSS

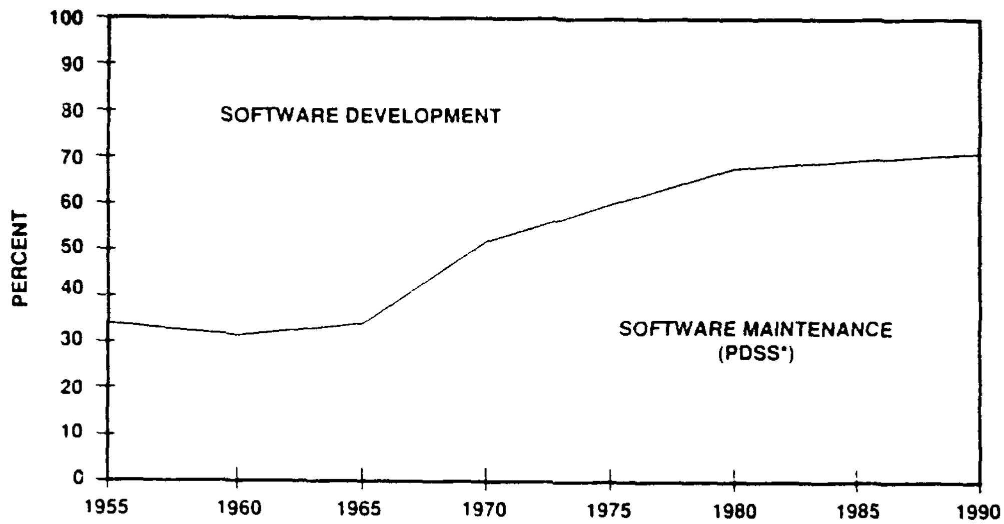


*PDB - POST DEPLOYMENT BUILD

viewgraph 2

Presents a comparison of Improved HAWK and PATRIOT in terms of lines of code to illustrate this dramatic increase. The end to this phenomenal growth in software is not in sight. (see viewgraph 3)

SOFTWARE COST DISTRIBUTION



*PDSS – POST DEPLOYMENT SOFTWARE SUPPORT

viewgraph 3

Seventy percent of the life cycle software cost is now incurred during the operational phase of its life with the initial development cost of software only 30 percent. In 1955, those figures were reversed. (see viewgraph 4)

POST DEPLOYMENT SOFTWARE SUPPORT

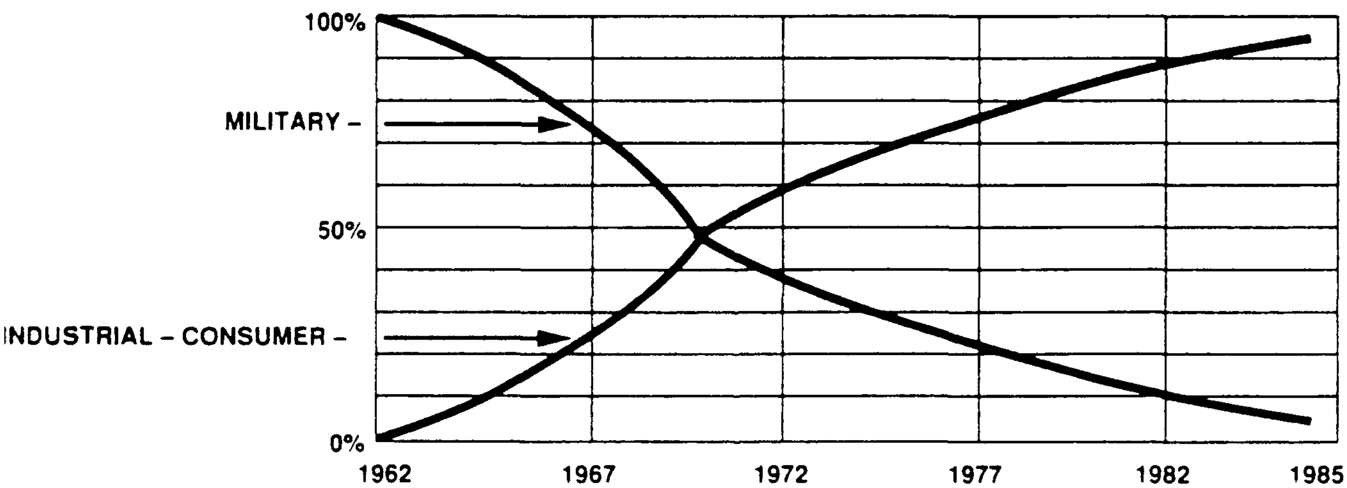
SYSTEMS' PDSS TRANSITION TREND AT MICOM

PATRIOT OTT	(IN-HOUSE NOW)
AN/TSQ-73	(IN-HOUSE NOW)
HAWK II	(IN-HOUSE NOW)
MLRS MT	(IN-HOUSE NOW)
FISTV	(IN-HOUSE NOW)
GROUND TOW	(FY 92)
BRADLEY TOW	(FY 92)
ATACMS	(FY 92)
HELLFIRE OMS	(FY 94)
FAAD C2	(FY 95)
AUAV	(FY 96)
MLRS	(FY 96)
HELLFIRE LONGBOW	(FY 97)
LOSAT	(FY 97)
ASAT	(FY 98)

viewgraph 4

In order to improve our software cost posture, we must take advantage of the investment leverage in doing the right things during software development to improve its quality and supportability. Incidentally, having said how pervasive software is, I don't see that our request for papers resulted in any on the subject of software for the workshop. Clearly, the wider use of Ada is intended to reduce the cost of both software development and ownership. The Research Development and Engineering (RD&E) Center is concentrating on improving its predictive tools in two areas: (l) component obsolescence, and (2) shelf life prediction. (see viewgraph 5)

DECLINE IN DOD MARKET SHARE OF INTEGRATED CIRCUITS



SHIFT IN IC APPLICATIONS

viewgraph 5

Since 1962, the DOD market share of integrated circuits has dropped from nearly 100 percent to about seven percent today, while the commercial-consumer market has grown to over 90 percent in the same period. Since the life of an integrated circuit product is measure in only a few years, while the life of a weapon system in the field is frequently measured in decades, presents the Army with a pervasive problem in obsolescence. Our System Engineering and Production Directorate has developed the tools and methodology for analyzing and predicting obsolescence in MICOM weapon systems, and presenting the several decision alternatives for solving the problems that may include circuit emulation, redesign, component substitution, alternative components, or circuit upgrade. We are not yet to the point where return-on-investment (ROI) projections can be made, but that is a goal. You will hear three papers on this subject in these workshops. (see viewgraph 6)

PRODUCT ASSURANCE DIRECTORATE
STOCKPILE RELIABILITY PROGRAM

SRP COST SAVINGS ANALYSIS VALIDATED RESULTS

SYSTEM	INVEST TO DATE	COST AVOIDANCE	APPROX ROI
SHILLELAGH	18.3 M	641.5 M	34:1
TOW	6.5 M	935.6 M	143:1
DRAGON	6.0 M	275. 1 M	46:1
HAWK	58.4 M	195.6 M	2:1
CHAPARRAL	9.4 M	45.9 M	4:1
REDEYE	152.9 M	2,108.8 M	13:1
SRP TOTALS	251.5 M	4,202.5 M	16:1

viewgraph 6

Another area where investment in the development of predictive techniques is paying good dividends is in shelf or service life projections. While items with shelf lifes shorter than the desired system life present costly logistics problems, we have not found it possible to develop state-of-the-art systems which do not utilize electronic components, films, adhesives, and other items that degrade with time and environmental exposure. Operation DESERT STORM has taught us much about the impact of the environment on modern weapon systems. In early system development, every effort is made to hold shelf life items to a minimum, to perform tests and analyses to project a realistic deterioration factor, and assure that adequate built-in-test equipment is incorporated to identify problems. We must also support already designed and fielded systems in the most cost effective manner possible. Our Production Assurance Directorate committed to ensuring that shelf life test programs on missiles and missile components are effective. It is our primary goal to allow hardware to remain in the field as long as performance and safety requirements can be met. We have found that in most cases, shelf life estimates are conservative and extensions are possible based on a well-thought-out service life program. These extensions have resulted in very substantial reprocurement and replacement cost avoidances as shown. As can be seen, the approximate overall ROI for the systems to date is 16:1. As we find more innovative ways to cut costs of testing, share data, and refine initial shelf life estimates, we expect this ROI to improve. This effort coupled with implementation of the ideas presented in Mr. Ivey's paper presented at the 1987 MICOM Logistics R&D Workshop has the potential for greatly improving the shelf life problem. (see viewgraph 7)

POLICY ORIGINS FOR LOGISTICS R&D IN THE IR&D PROGRAM

- **STATEMENT BY DR. RICHARD DELAUER, UNDER SECRETARY OF DEFENSE, 11 MARCH 1982**
- **DOD INSTRUCTION 3204.1, 1 DECEMBER 1983**
- **ARMY REGULATION 70-74, THE INDEPENDENT RESEARCH AND DEVELOPMENT PROGRAM, 3 DECEMBER 1984**
- **AMC PAMPHLET, AMC-P 700-XX LOGISTICS GUIDE FOR INDEPENDENT RESEARCH AND DEVELOPMENT, EVALUATIONS, 1989**

viewgraph 7

The second element of our investment strategy is to encourage and make use of independent R&D investments. Although the role of logistics in the industrial IR&D program has been officially recognized for almost a decade, the Government can be much more effective in communicating the needs in this area so as to provide industry with the basis for decision-making. Independent Research & Development payments by DOD are oniy made for work which has "a potential relationship to a military function or operation." Industry understandably is not going to undertake work in an area that is defined ambiguously, making it difficult to establish a link to a "military function or operation.." Dr. Richard Delauer, Under Secretary of Defense in a message on 11 Mar 82 recognized the important role of contractors in the support of logistics. He stated:

"Technical innovation is essential in improving the readiness of our next generation's weapons and reducing their logistics and manpower burden — greater effort must be applied to make technology available which can be used to increase reliability, reduce repair facilities, and equally important, reduce the need for highly skilled personnel — Industry must play a major role in achieving our objectives by emphasizing those technologies in their IR&D programs.

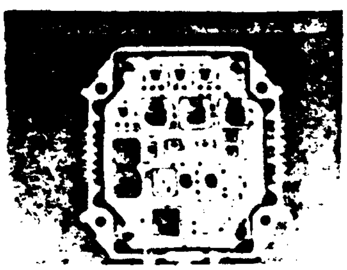
The following year, the role of logistics in the IR&D program was recognized in DOD Instruction 3204.1, 1 Dec 83. His key policy statement was:

"IR&D projects that lead to reduction in acquisition and support costs of defense systems and equipment shall be given the same consideration as is given to exploring the solution of critical performance deficiencies in U.S. Military capability."

In January of this year, we began using the revised IR&D project evaluation worksheet that contains explicit evaluation factors for logistics. In the near future, the RD&E Center will prepare a statement of needs as authorized by AR 70-74, The Independent Research and Development Program, 2 Dec 84, that may be used as a guide in formulating IR&D programs, and this will include needs in Logistics R&D. The AMC-P 700-XX is still in preparation and will provide a guide for conducting evaluations of logistics R&D projects. (see viewgraph 8)

LOGISTICS R&D FOR GENERIC TECHNOLOGIES

MIMIC



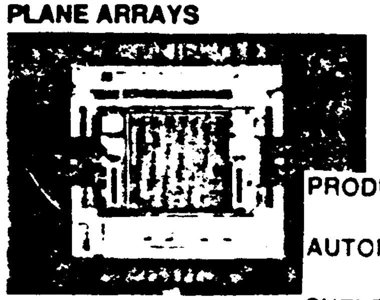
LITHOGRAPHY STANDARDS

MATERIALS STANDARDS

NON-CONTACT CIRCUIT PROBES

PRODUCIBILITY

INFRARED FOCAL PLANE ARRAYS



PRODUCIBILITY

AUTOMATED TESTING

SHELF LIFE INVESTIGATIONS

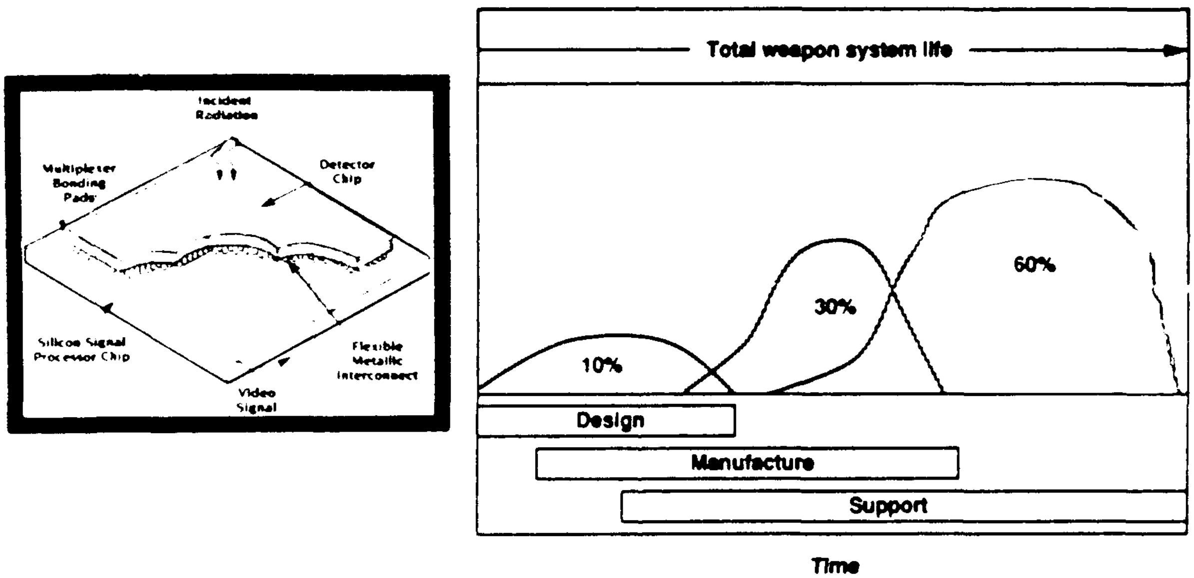
iewgraph 8

The last element of our investment strategy is to focus on the future. The supporting research in measurement standards, test measurement, and diagnostic technology tends to lag the investments in key enabling technologies we need for future weapon systems. For example, the microwave and millimeter-wave industry has more than doubled over the past 20 years, but the budgets in the industry IR&D program and at the National Institute of Standards and Technology for the development of measurement standards, test measurement, and diagnostic technology have not kept pace with the growth of the technologies themselves. The same time lag is found in the field of second generation infrared focal plane arrays. Fortunately, positive changes are taking place in both areas to reduce the lags. DOD policy now requires that any major program on a generic technology contain the logistics R&D as an integral part of the program package.

The DOD Microwave and Millimeter-Wave Monolithic Integrated Circuits Program is a critical enabling technology we need for MICOM systems. The purpose of the MIMIC program is to make microwave and millimeter wave subsystems for use in military weapon systems "front ends" affordable, available, and broadly applicable. The emphasis in the program is on designing, fabricating, and testing monolithic circuits with the objective of increasing the ability of the United States industry to provide high performance and affordable microwave and millimeter-wave products. The program is divided into four parts covering six years with a budget of approximately 570 million dollars. Army requirements provided a primary motivation in formulating the program. The National Institute of Standards and Technology is conducting a supporting program to develop materials standards, lithography standards, and new non-contact MIMIC circuit probes for operation above 60 Ghz. This critical logistics R&D work will allow us to field affordable Army systems with this technology, and is coordinated through the U.S. Army Test, Measurement, and Diagnostic Equipment Support Activity here at Redstone Arsenal.

The DOD (DARPA) Infrared Focal Plane Array initiative is a generic technology program somewhat analogous to MIMIC; it has the goal of making infrared focal plane arrays affordable, broadly available, and applicable for a number of defense applications. A major emphasis in the program is on improving yield and producibility of both scanning and staring focal plane arrays. The first phase of 25 months has been completed, and Phase II, which will last 33 to 36 moths, is just beginning. As in the case of MIMIC, Army requirements provided a major focus for formulating the program. A Memorandum of Agreement between DARPA and MICOM provides for the transfer of the technology from the program into MICOM systems. Automated testing is a critical technology for transitioning focal plane arrays into fielded system in an affordable manner, and fortunately this area is receiving attention both by DARPA and in industry. Potential shelf life problems with dewars for second generation infrared focal plane arrays will receive careful attention in the logistics R&D effort, and you will hear a paper on this subject by Mr. Neal Supola of the Center for Night Vision and Electro-Optics (CNVEO). (see viewgraph 9)

WEAPONS SYSTEM COST VS TIME



viewgraph 9

The design phase of a weapon system represents only 10 percent of the life cycle costs of the system, but locks in 70 to 80 percent of the life cycle cost. The improvement being made in the early design of second generation infrared focal plane arrays provides an excellent example how a favorable impact can be made on the downstream logistics support required to operate and maintain the infrared focal plane array module. Electronic clocks and biases are incorporated on the focal plane readout chip to reduce the number of interfaces to the chip through the dewar. This fewer number of interfaces has a large impact on reducing cost and improving reliability. The infrared focal plane array will be designed to withstand repeated thermal cycling and this has a direct effect on improving the reliability of the chip and extends the useful life of the assembly. Finally, the reduction in the testing time allows for more thorough qualification of infrared focal plane array assemblies without increasing the cost or reducing the reliability.

An example of a new technology that can reduce logistics costs: The High Density Array Development program at the CNVEO which has the goal of developing an uncooled long wave infrared detector, is an example of how an R&D project can significantly reduce the logistics burden while creating new military capabilities. The uncooled detector will allow the use of infrared detectors for man portable weapon sights, surveillance devices, driver's aide for support vehicles, and possibly some sensors for seekers. Among the reasons these military applications were not addressed previously, or in reduced numbers, are high acquisition and life cycle costs. The uncooled technology utilizes a staring focal plane array operating at room temperature. Because it is a staring array, no optical scanner is required. Because it operates at room temperature, no vacuum dewar or cryogenic cooler is required. The absence of the scanner mechanism, vacuum dewar, and cryogenic cooler will increase the MTBF of fielded systems significantly, increase the shelf life of "one-shot" systems such as missiles, and reduce the parts inventory and skills diversity necessary for maintenance The reduced mechanical complexity and lack of cryogenic cooling also reduces the system power requirements tremendously. This translates into much reduced battery costs for weapon sights in manportable systems (anticipated weapon sight power requirement, for example, is four watts) where battery costs may dominate the total life cycle cost.

This completes my remarks. I leave you now to explore many of these topics in more depth during the workshop.

LOGISTICS R&D WORKSHOP
INTRODUCTION TO SESSIONS I
BY HENRY M. FAIL, JR.

The Army and all of DOD is entering into a period that will be marked by large reductions in resources...both money and manpower. More than ever before, weapon systems' operating and supporting costs, which account for the largest part of our life cycle costs, must be attacked and minimized. This is the only way we will be able to develop and deploy new systems and support these already in the field. With reduced manpower, it is mandatory that we find ways to use weapon systems easier and make those weapon systems less manpower intensive to maintain and operate.

We're going to see some ways during sessions I, in which we're driving exactly toward those goals. We'll hear from subject matter experts as they tell us of what's coming the pike to help. These range from Designing to Testability, to Integrated Electronic Technical manuals, to Technology Insertion.

Together, Government and Industry, we can through Logistics R&D hold the line on life cycle cost increases and still maintain the excellence of fielded missile systems that our soldiers have come to expect and rely on.

Christine Fisher

POINT PAPER

INTEGRATED DIAGNOSTICS FOR THE 1990S (PE 0603708D)
(A TECHNOLOGY DEMONSTRATION PROGRAM)

WHAT IS INTEGRATED DIAGNOSTICS? : Integrated Diagnostics is a strategy to design and develop weapon system maintenance capability (e.g., built-in-test, test equipment, technical information, and training) as a "package," built to work together. In contrast, today, pieces of maintenance capability are individually specified and bought, and then fit together in field use. Integrated diagnostics promises to substantially improve the quality of maintenance, and significantly reduce the logistics deployment tail. Commercial implementations of the integrated diagnostics strategy have shown major benefits in the "bottom line" of system cost and availability (power plants, the AT&T phone system, the FAA air traffic control radars, the automotive industry). Limited military prototypes of integrated diagnostics on the Apache, M-1, and A-10 have shown the potential for improved maintenance with lower skill levels.

WHAT THIS PROGRAM ELEMENT DOES: This OSD program element (established in FY91) funds the transition of existing DoD laboratory research (6.2/6.3) with high payoff potential into real products. Weapon program managers sign up to perform a large scale field demonstration, to migrate the products into use once successfully demonstrated, and to make results available for DoD wide application.

FY91/92 PROGRAM:
ARMOURED VEHICLE INTEGRATED DIAGNOSTICS DEMONSTRATION: The target of the first project selected is improving day-to-day organizational level maintenance for Army track vehicles. Using the M1 Abrams tank as the test bed, the goal is to demonstrate the feasibility of substantially more accurate, timely, effective diagnostics while off-loading much of the extensive test equipment (about 1/2 weight and volume) and voluminous technical manuals now required for maintenance. Based on Army 6.2/6.3 (test technology) and Air Force 6.3 (interactive tech manual) research combined with state of the art commercial computer technology, the project is being managed by the PEO-Armoured Systems Modernization with the help of the Army Human Engineering Laboratory. An M1A1 battalion demonstration is planned to begin in FY92.

FORMAL PAPER WAS NOT USED DUE TO BEING CLASSIFIED

U.S. Army

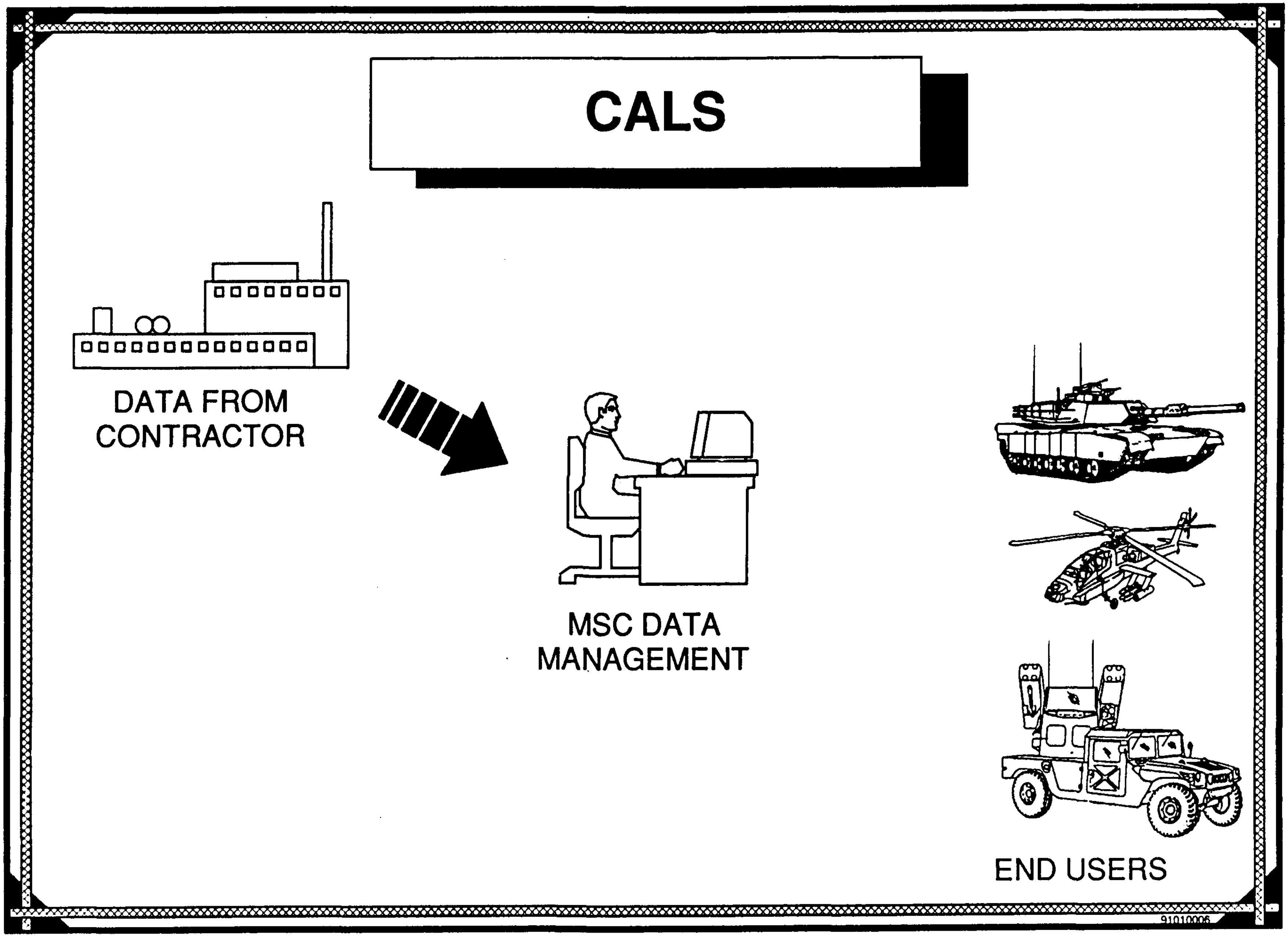
Test, Measurement and Diagnostic Equipment Activity

"Interactive Electronic Technical Manuals (IETM): The Users Interface Into Integrated Diagnostics."

27 Aug 1991

Patrick Stevens

91070007


CALS
DATA FROM CONTRACTOR
MSC DATA MANAGEMENT
END USERS
91010006

IETM

DEFINITION

Interactive Electronic Technical Manual (IETM) is a CALS compatible electronic representation of the instructions for the installation, operation, maintenance, training, and support of weapon systems, weapon systems components, and support equipment. The digital information is stored on magnetic or optical media and used in conjunction with a weapon system processor, a Portable Maintenance Aid (PMA) or an approved computer system. An IETM shall also contain an expert system. The expert system will (at a mini mum) incorporate preventive and diagnostic maintenance capability. When applicable, it will also link to the Built-In-Test (BIT) (via a standard data bus), prognostic routnies and the automated system.

91070008

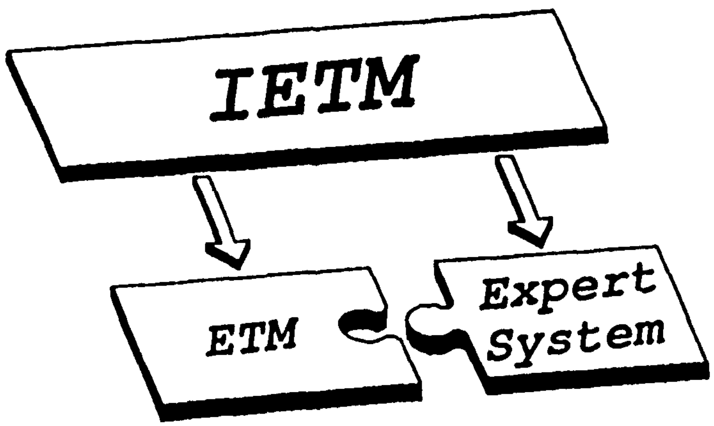
DEFINITIONS

* In accordance with the IETM / ETM Policy

Electronic Technical Manuals (ETM)

CALS compatible electronic representation of the instructions for installation, operation, maintenance, training, and support of weapon systems, weapon system components, and support equipment.

Interactive Electronic Technical Manuals (IETM)



90110008

PMA: CONTACT TEST SET III

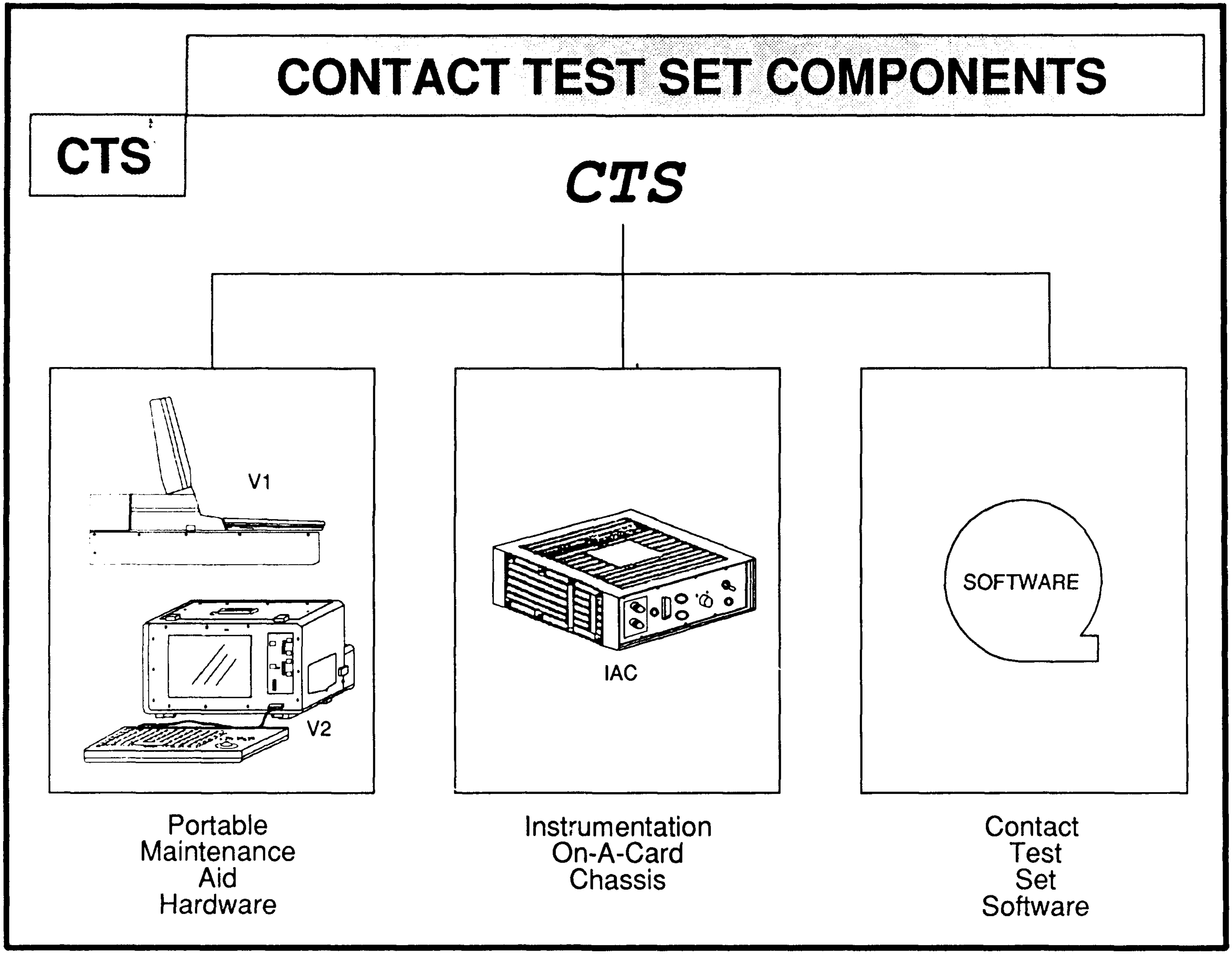
CTS

The Contact Test Set (CTS) is a man-portable piece of test equipment designed to be carried into the field to test and repair weapon systems.

The CTS consists of two pieces:

- Portable Maintenance Aid - A man-portable computer system which hosts the diagnostic software and IETMs.
- Instrumentation Pack - A chassis which contains instrumentation boards (i.e. DMM, Counter/Timer, etc.)

The CTS was originally developed as part of the Integrated Family of Test Equipment, managed by PM, TMDE.

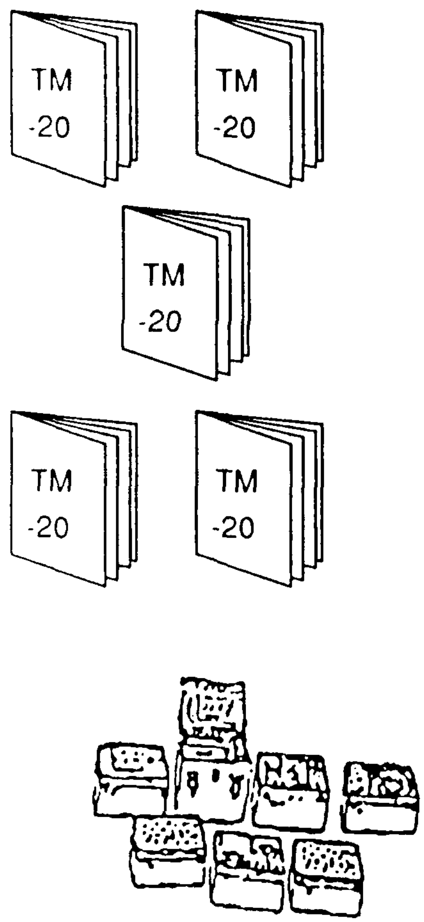

CTS
CONTACT TEST SET COMPONENTS
CTS
V1
V2
Portable Maintenance Aid Hardware
IAC
Instrumentation On-A-Card Chassis
SOFTWARE
Contact Test Set Software

91070010

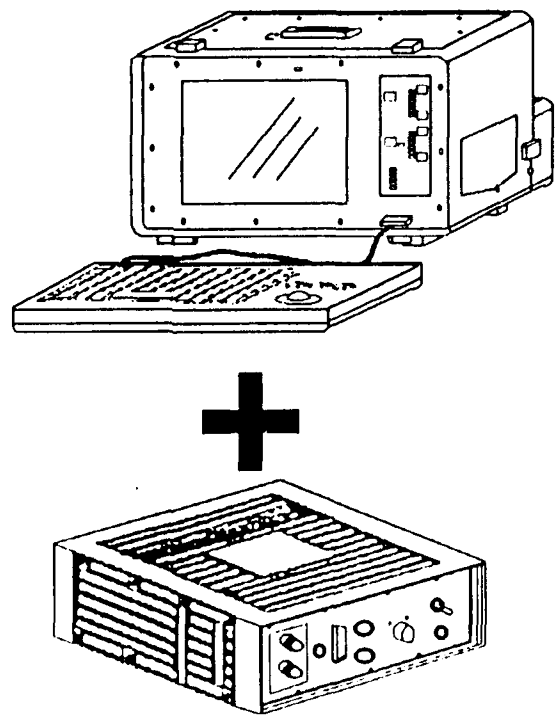
INTERACTIVE ELECTRONIC TECHNICAL MANUALS

TMDE

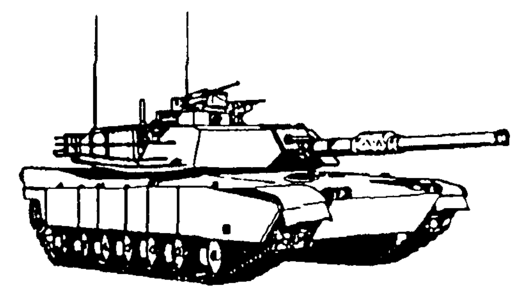
REPLACE THESE



WITH THIS

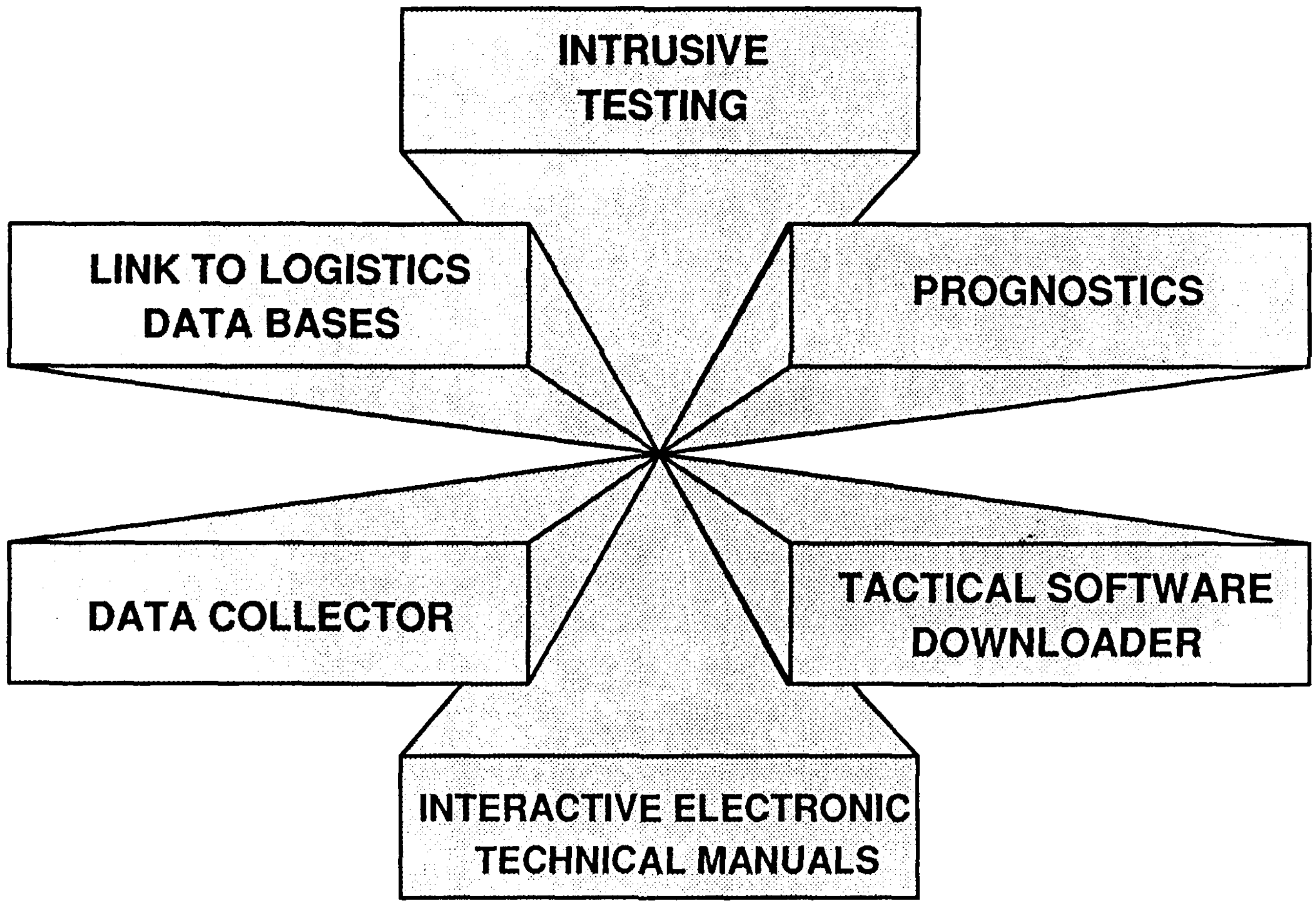


TO FIX/MAINTAIN THIS !



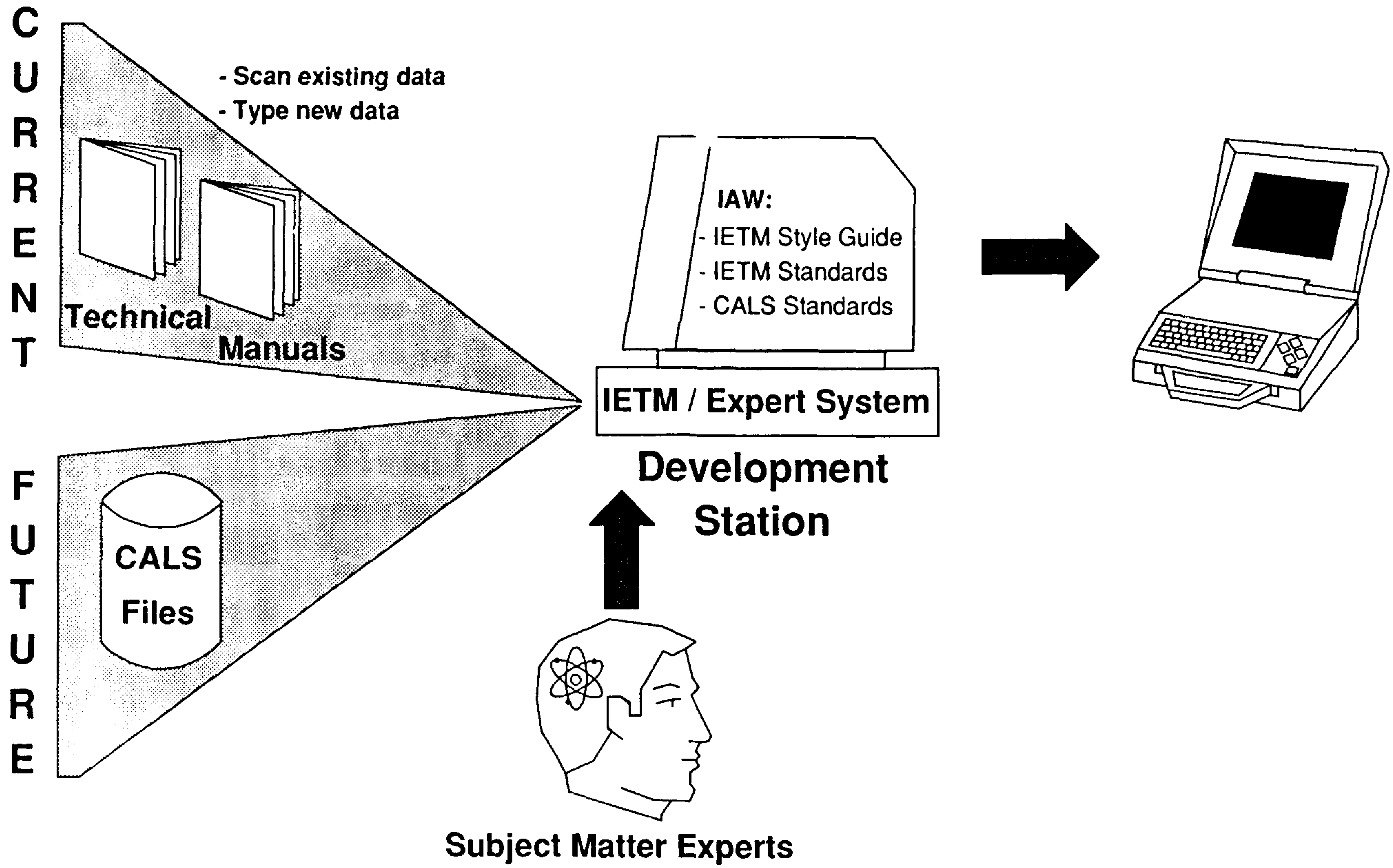
CTS

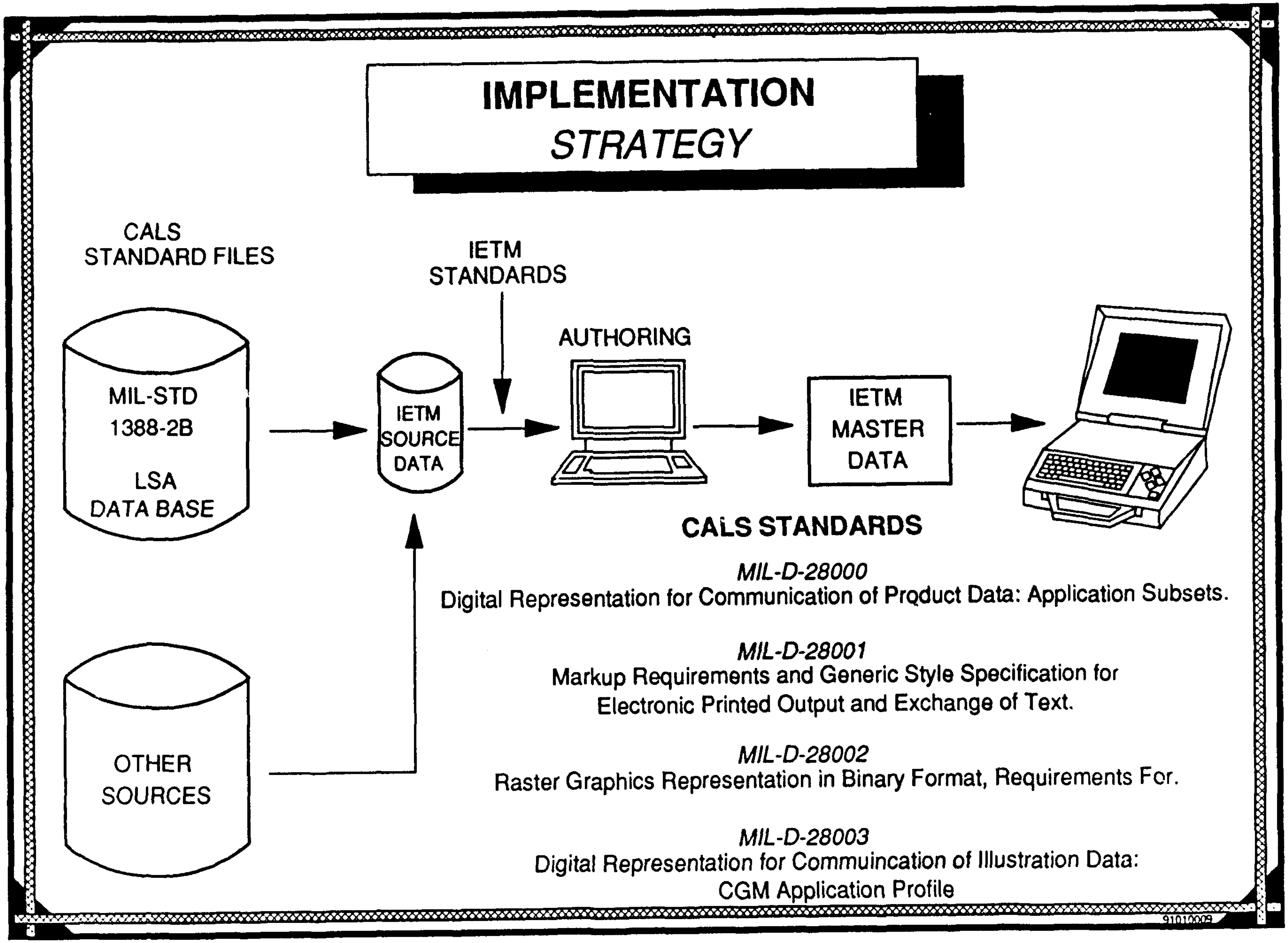
CONTACT TEST SET FUNCTIONS



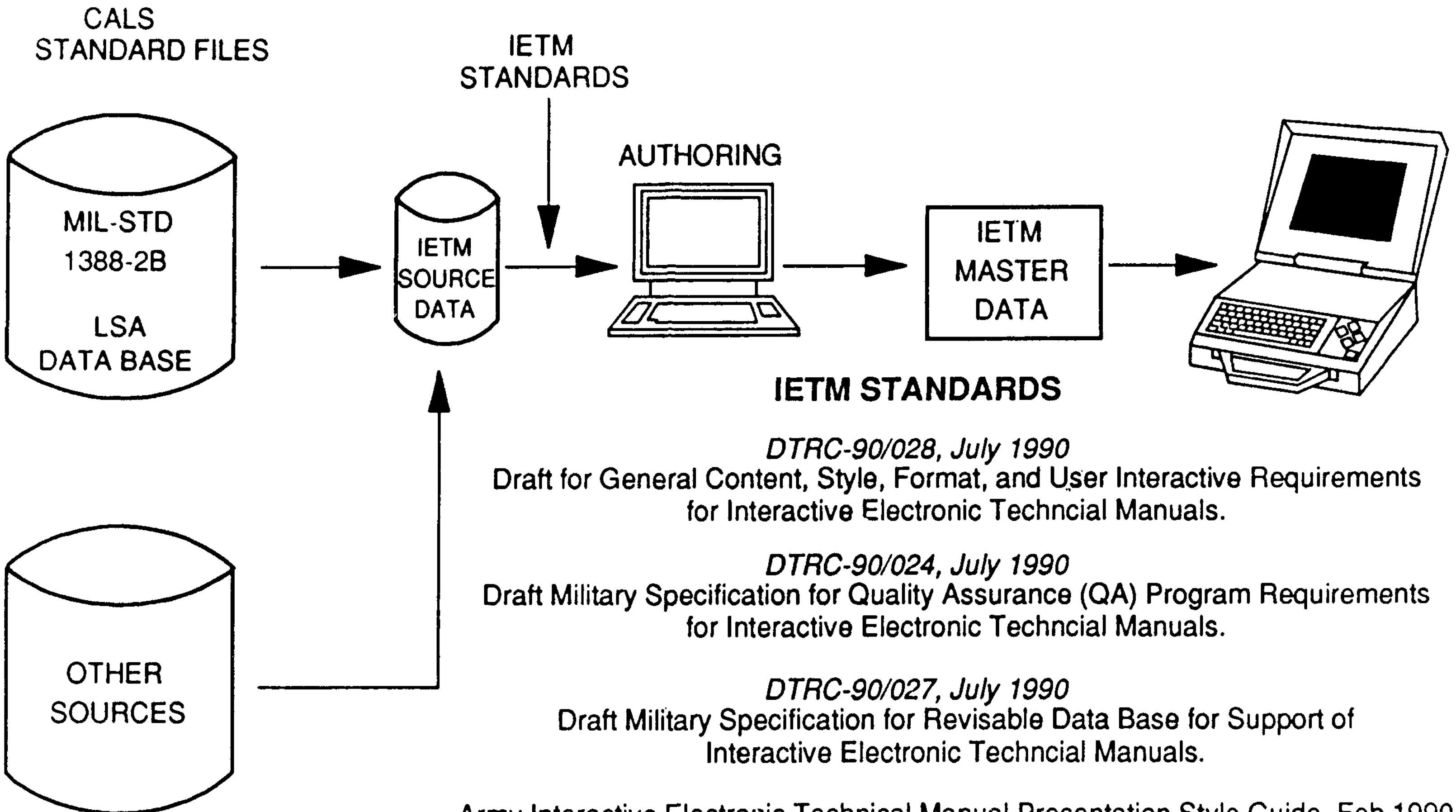
IMPLEMENTATION STRATEGY

IETM




IMPLEMENTATION
STRATEGY
CALS
STANDARD FILES
MIL-STD
1388-2B
LSA
DATA BASE
OTHER
SOURCES
IETM
STANDARDS
IETM
SOURCE
DATA
AUTHORING
IETM
MASTER
DATA
CALS STANDARDS
MIL-D-28000
Digital Representation for Communication of Product Data: Application Subsets.
MIL-D-28001
Markup Requirements and Generic Style Specification for
Electronic Printed Output and Exchange of Text.
MIL-D-28002
Raster Graphics Representation in Binary Format, Requirements For.
MIL-D-28003
Digital Representation for Commuincation of Illustration Data:
CGM Application Profile
91010009

IMPLEMENTATION
STRATEGY



IETM STANDARDS

DTRC-90/028, July 1990
Draft for General Content, Style, Format, and User Interactive Requirements for Interactive Electronic Techncial Manuals.

DTRC-90/024, July 1990
Draft Military Specification for Quality Assurance (QA) Program Requirements for Interactive Electronic Techncial Manuals.

DTRC-90/027, July 1990
Draft Military Specification for Revisable Data Base for Support of Interactive Electronic Techncial Manuals.

Army Interactive Electronic Technical Manual Presentation Style Guide, Feb 1990

91010010

IETM PRESENTATION STYLE GUIDE

IETM

The purpose of the Style Guide is to establish design criteria, principles, and practices to be applied in the development of the User Interface, so as to:

- Foster IETM information and presentation standardization within and among systems.
- Provide guidelines to assure assure all IETM UIs operate in the same manner.
- Achieve the required performance level by the user in the field.
- Minimize the skill, personnel requirements, and training time required to maint ain weapon systems.

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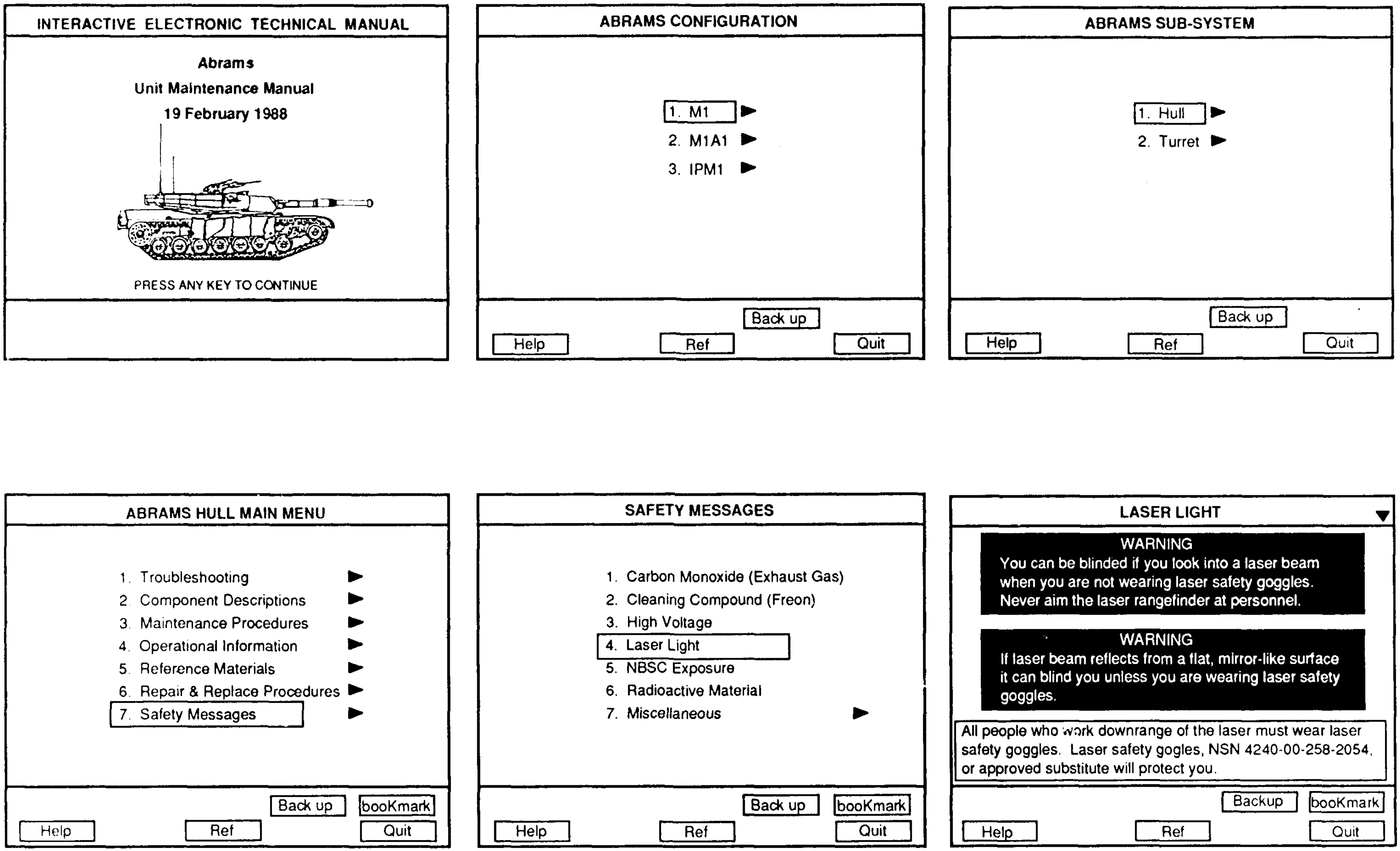

Figure 6: Example Menu Structure

91040006

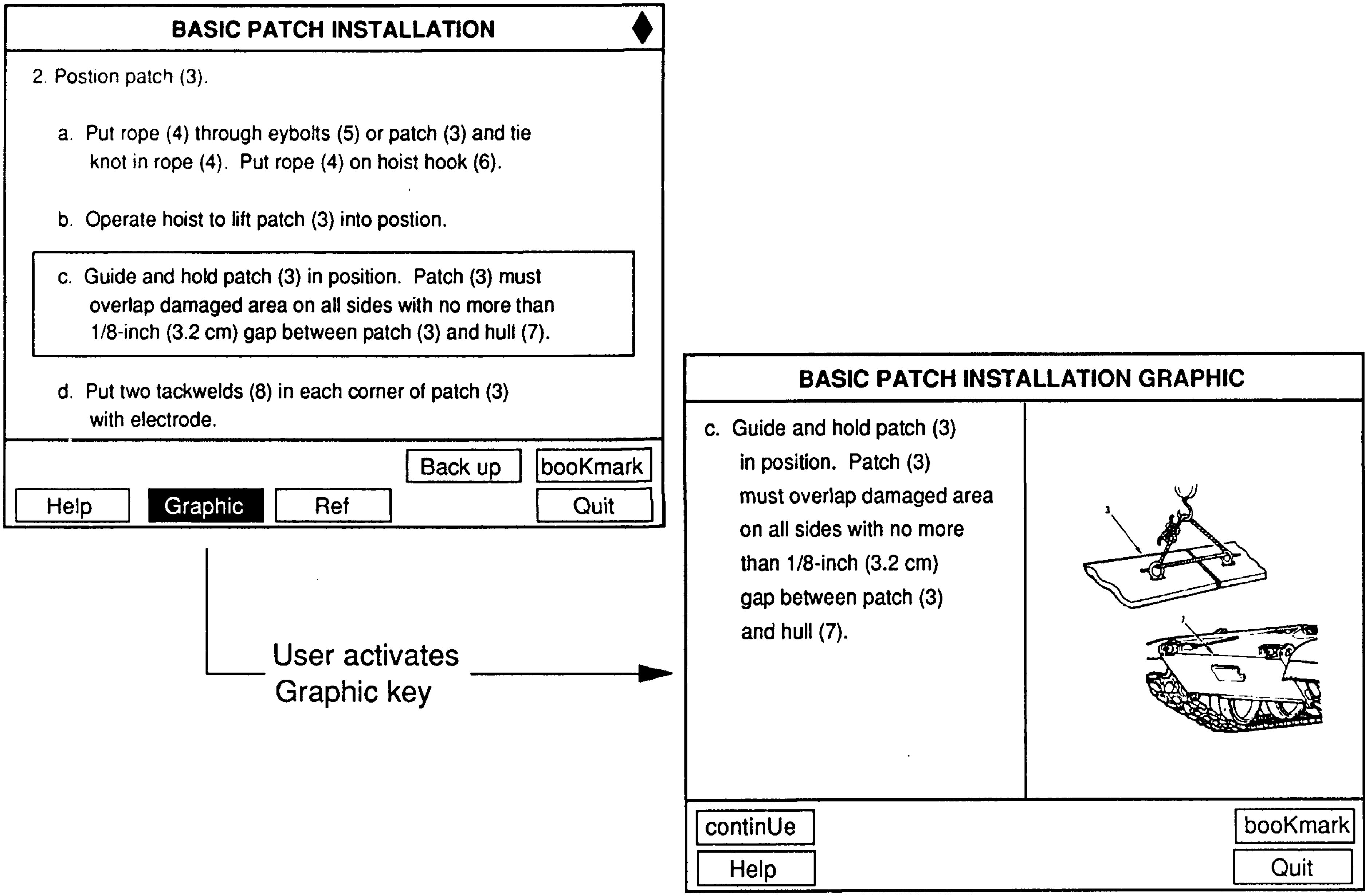

Figure 7: Example Graphic Screen Format

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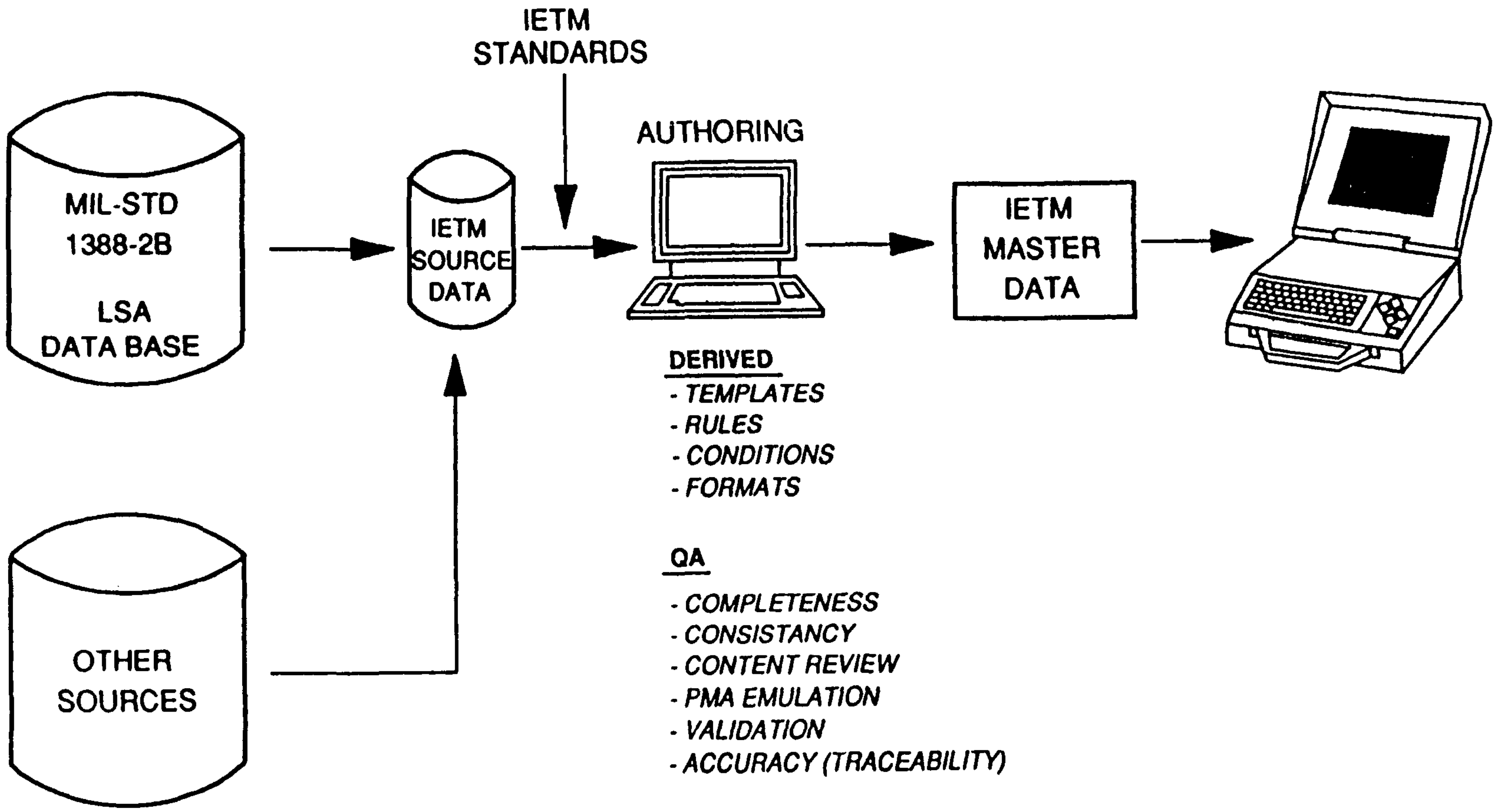
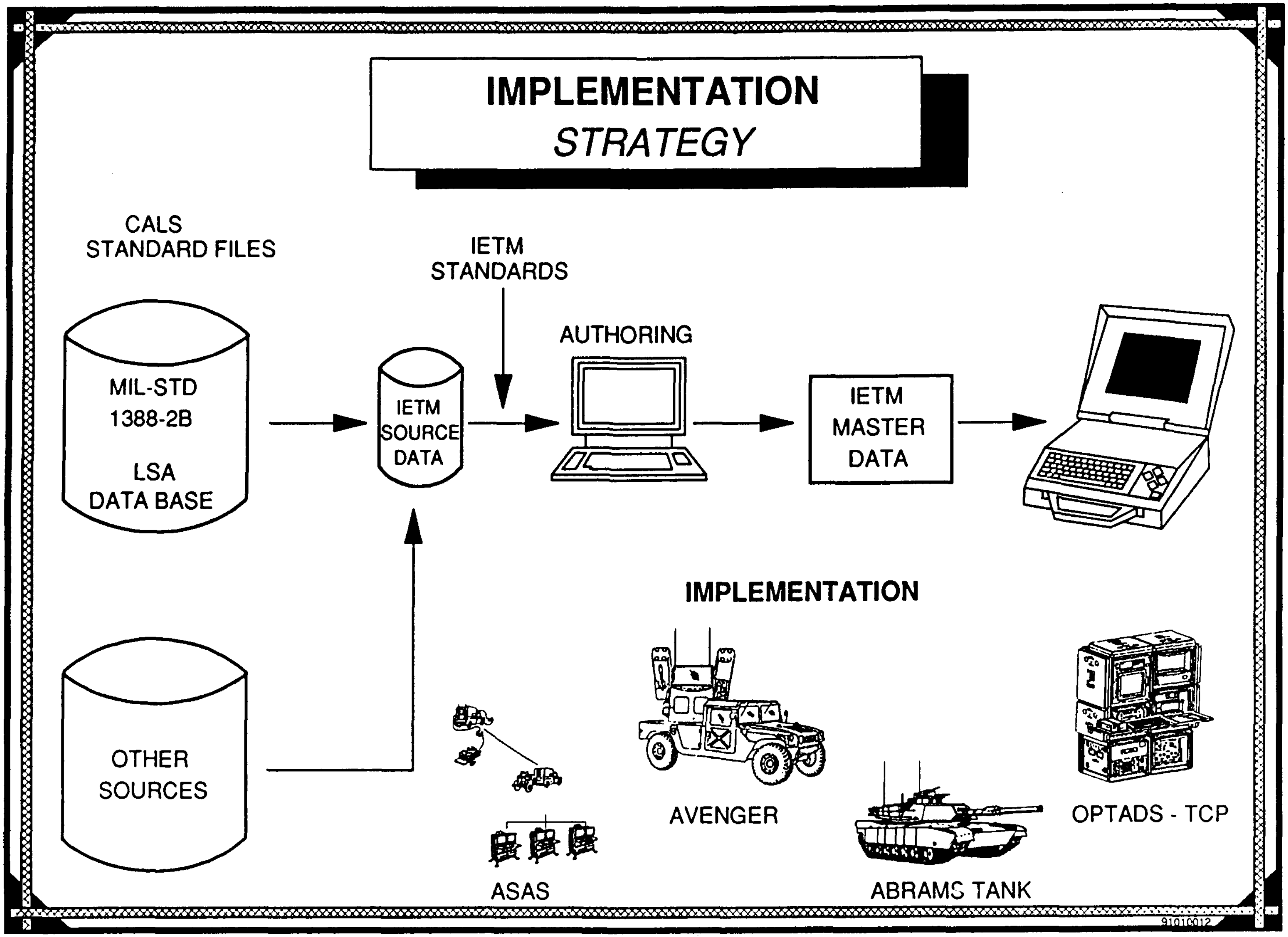
IETM IMPLEMENTATION
STRATEGY




IMPLEMENTATION
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1388-2B
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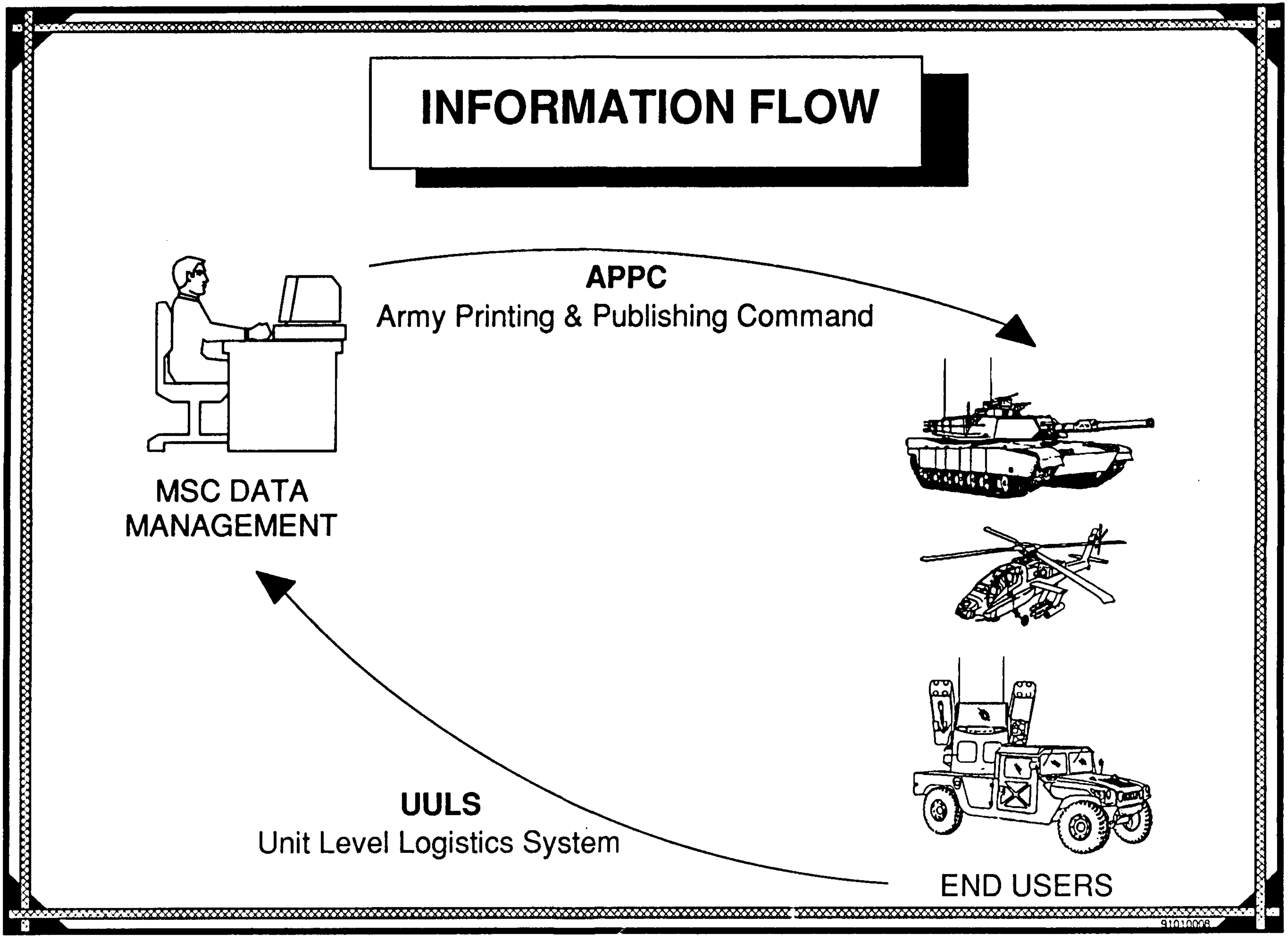
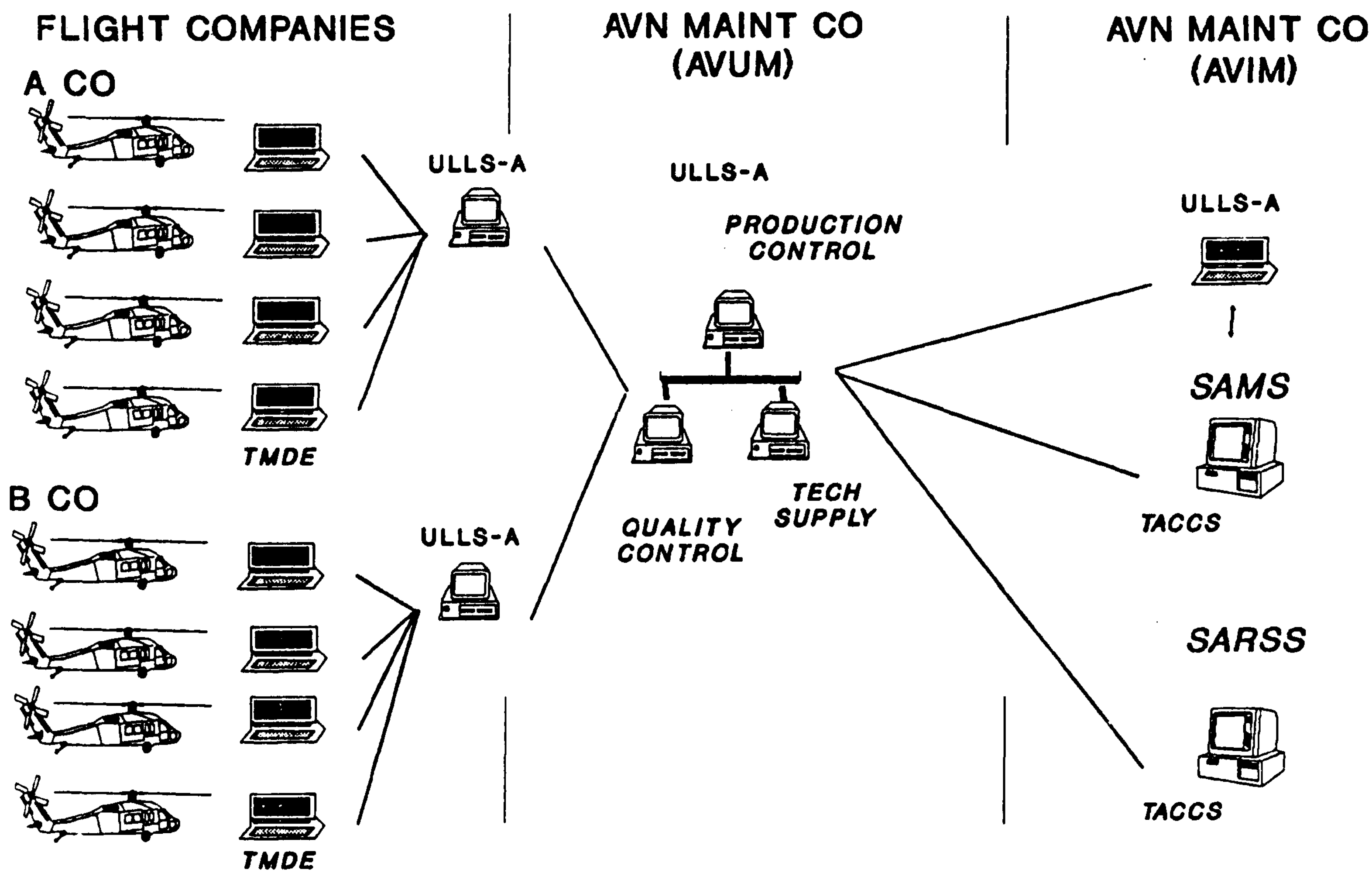
STANDARDS
IETM
SOURCE
DATA
AUTHORING
IETM
MASTER
DATA
IMPLEMENTATION
ASAS
AVENGER
ABRAMS TANK
OPTADS - TCP
91010012

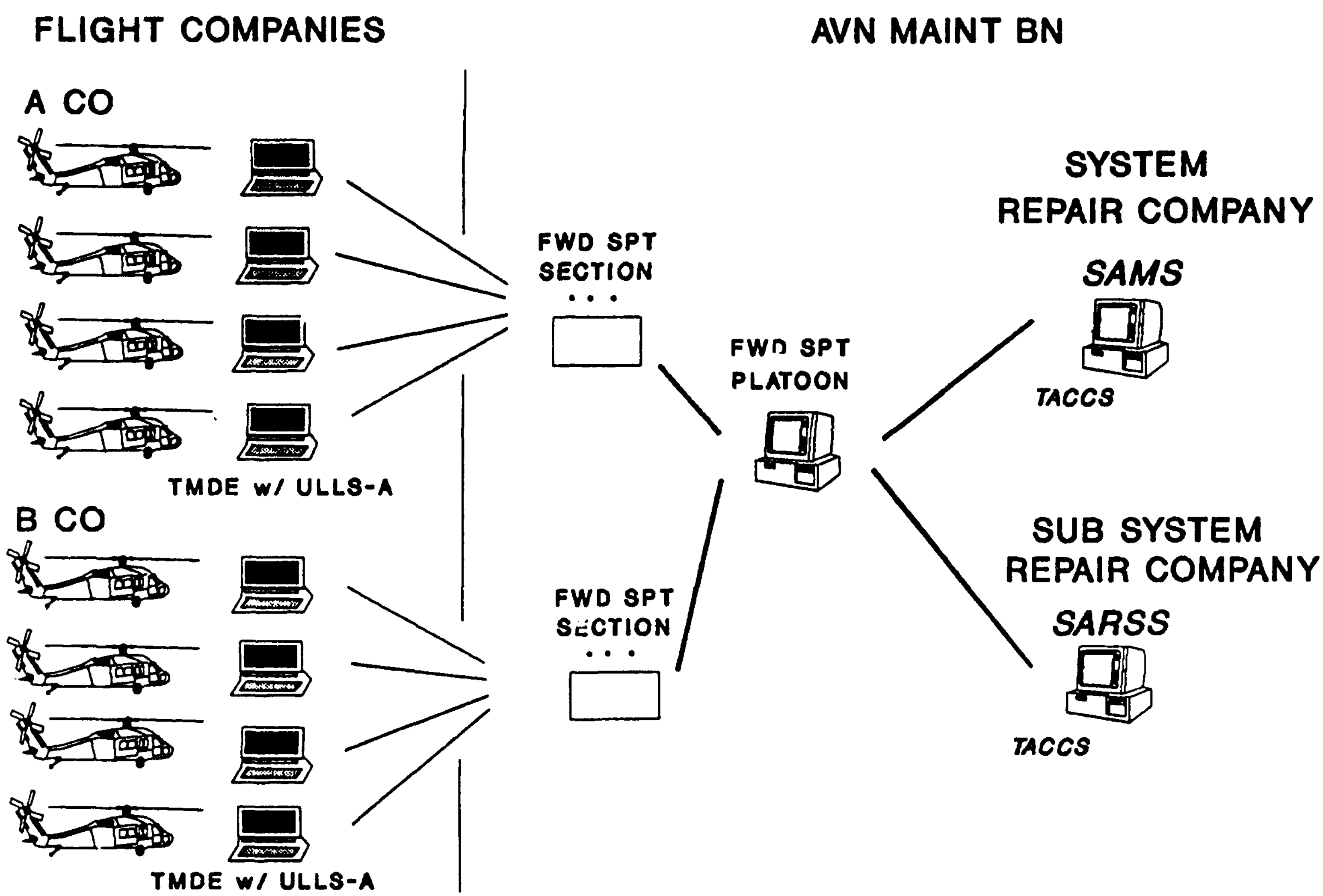

INFORMATION FLOW
APPC
Army Printing & Publishing Command
MSC DATA
MANAGEMENT
UULS
Unit Level Logistics System
END USERS

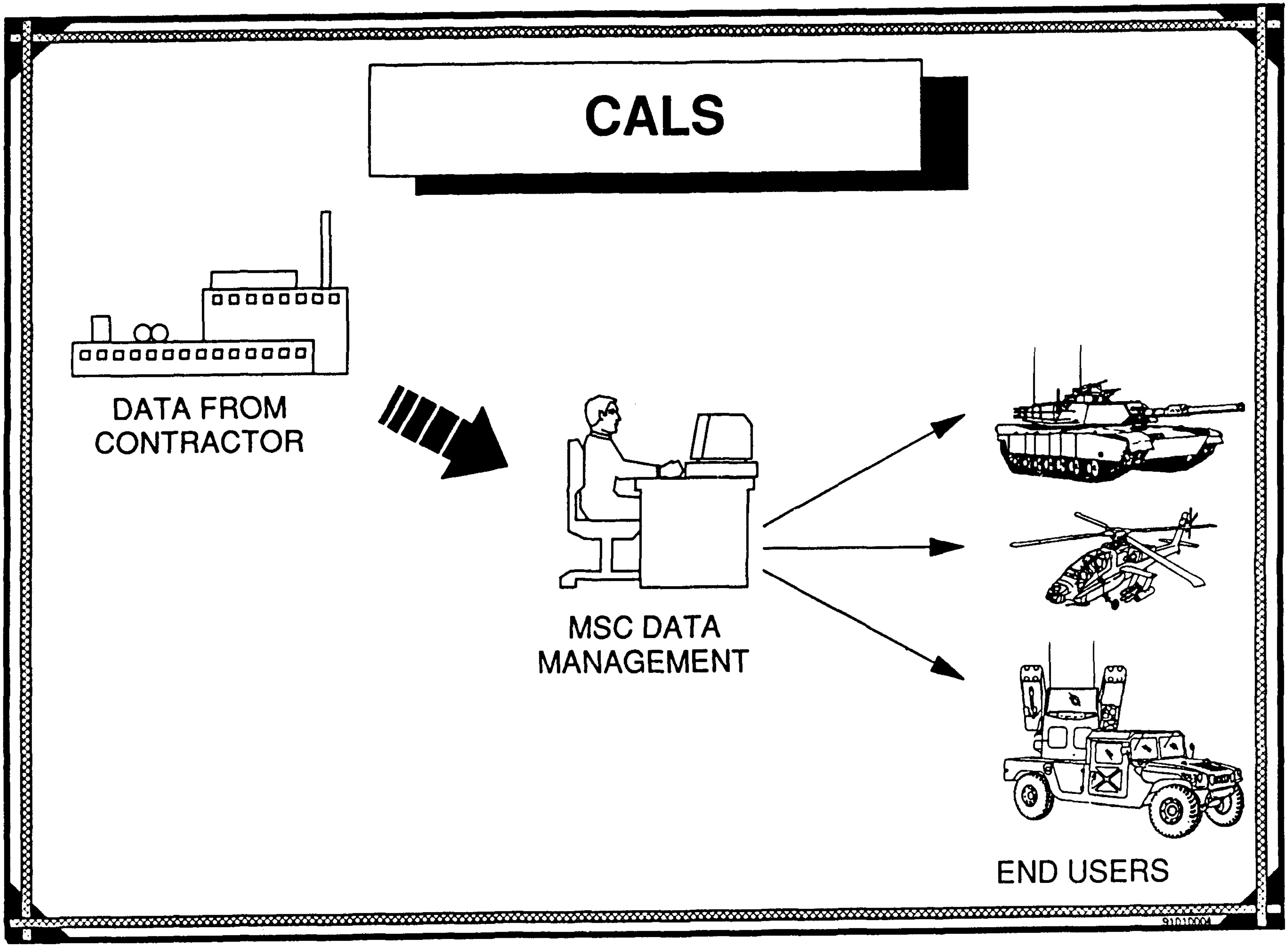
ULLS-A DATA FLOW

CURRENT MAINTENANCE STRUCTURE
WITH TMDE DEVICE & COMPANY COMPUTERS



ULLS-A DATA FLOW
PROPOSED ALB-F STRUCTURE




CALS
DATA FROM
CONTRACTOR
MSC DATA
MANAGEMENT
END USERS
91010004

UTILIZING TECHNOLOGY INSERTION TO

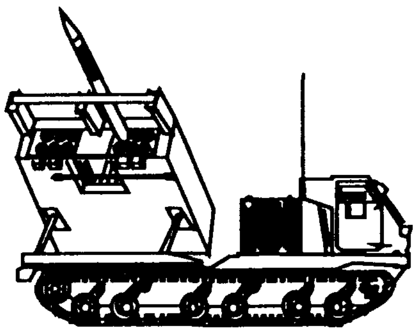
ATTACK THE O & S COST BURDEN

BY

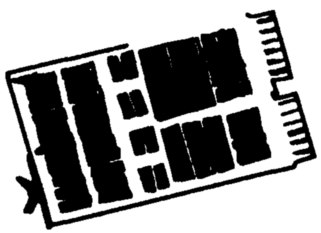
KENNETH E. DULANEY
Chief, Industrial Operations Division
System Engineering and Production Directorate
Research, Development, and Engineering Center
U.S. Army Missile Command

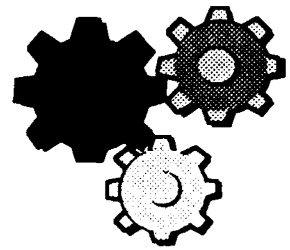
In a shrinking budget and rampaging support cost environment, the Army is rapidly finding itself in a position of being unable to develop, produce, and field critically needed weapon systems. The U.S. Army Materiel Command is extremely concerned about the situation and has taken a full frontal assault on this area. From the Tech Base Program through production modification and spares support, the thought process of reducing O & S costs must be institutionalized within the Army management and decision making structure.

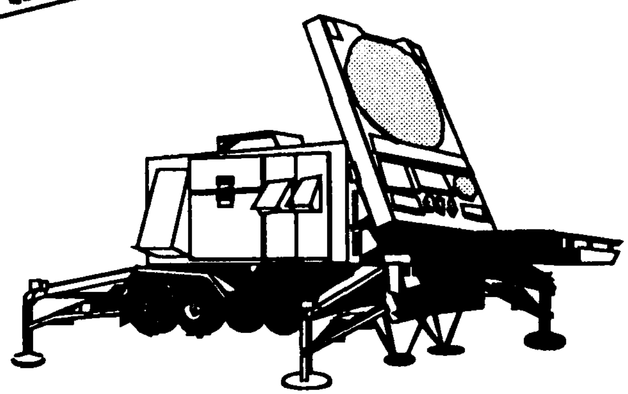
This presentation will describe the efforts ongoing by the U.S. Army Missile Command to implement an effective approach of utilizing technology insertion in the spares program of our fielded weapon systems. Discussed are the barriers and changes in information for decision making which must occur for this effort to efficiently occur.



UTILIZING TECHNOLOGY INSERTION TO ATTACK THE O & S COST BURDEN







Kenneth E. Dulaney
Systems Engr and Production Dir
Research, Development, and
Engr Center
US Army Missile Command

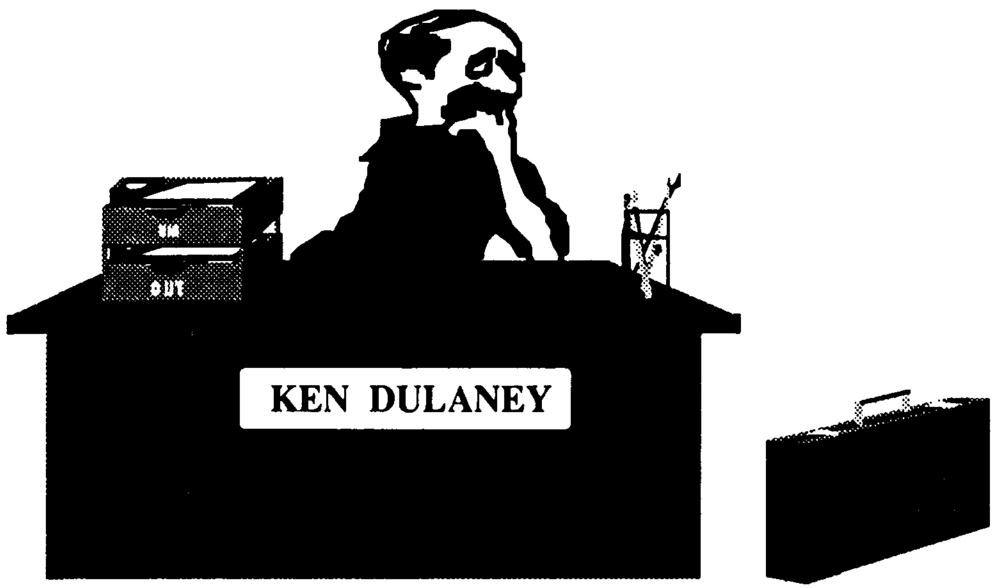
TECHNOLOGY INSERTION

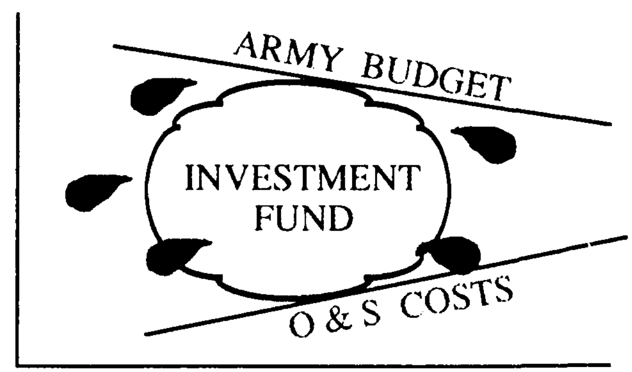
PROBLEM STATEMENT

The O & S Costs Associated with Fielded Weapon Systems is Rapidly:

a. Overburdening the Army Budget

b. Inhibiting the Ability of the Army to Produce and Field New Weapon Systems



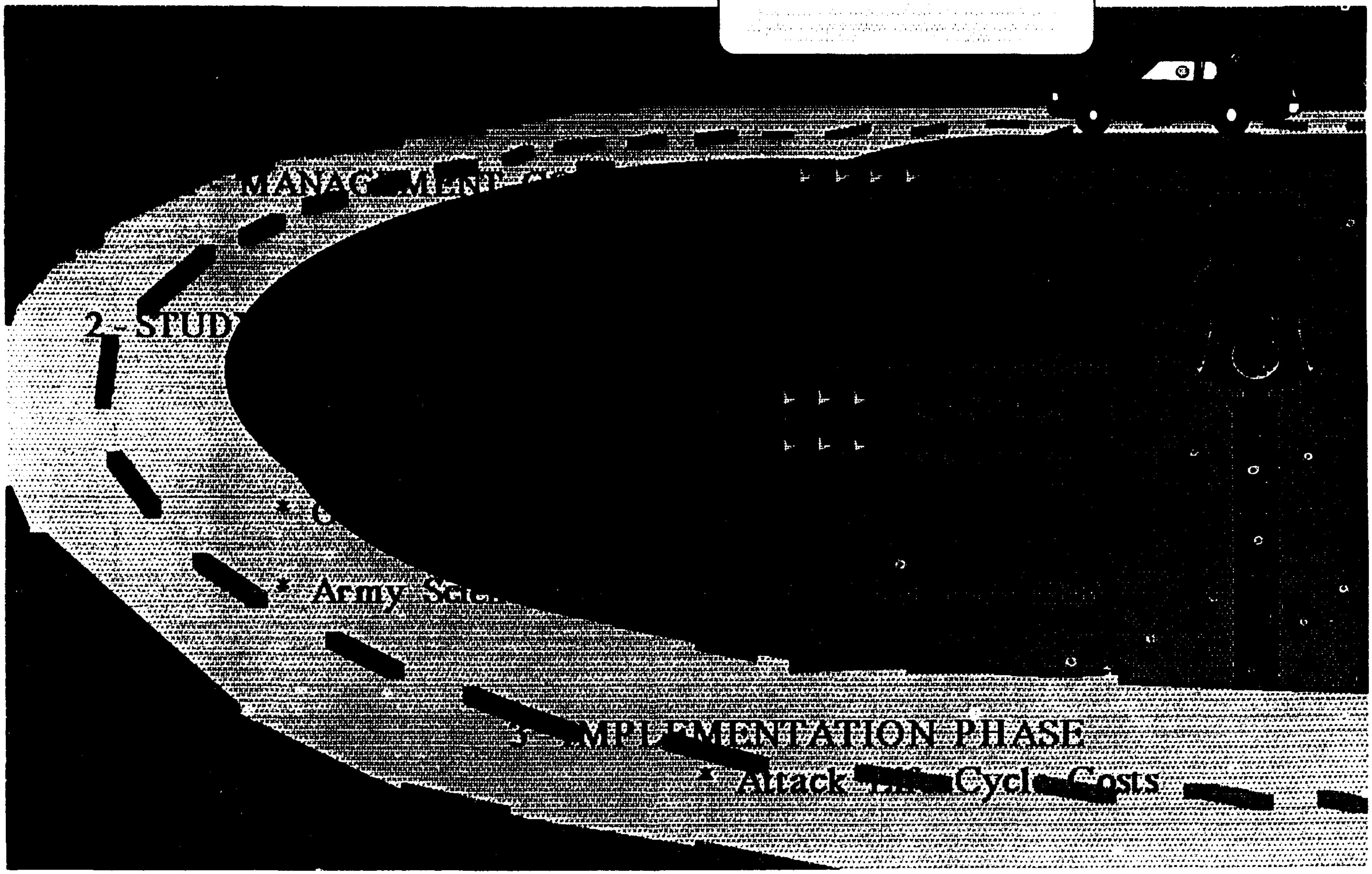


PROBLEM STATEMENT

THE O & S COSTS ASSOCIATED WITH SUPPORTING FIELDED WEAPON SYSTEMS AND THOSE BEING DEPLOYED IS INCREASING. THE ENVIRONMENT TODAY PROJECTS THE DEFENSE BUDGET WILL LOSE GROUND. THE RESULT IS THAT THE AMOUNT OF MONIES TO DEVELOP, PRODUCE, AND DEPLOY NEW WEAPON SYSTEMS ARE SIGNIFICANTLY BEING SQUEEZED. THUS, NOW YOU HEAR MORE ABOUT SHELVING TDPs, DEVELOP BUT DON'T PRODUCE, SCALED DOWN DEPLOYMENT, ETC. THE LONG TERM RESULTS ARE A CONTINUED DECLINE IN THE INDUSTRIAL BASE, LOSS OF TECHNOLOGY ADVANTAGES, LOSS IN THE CAPABILITY OF THE ARMY TO SUSTAIN AND WIN A CONFRONTATION.

TECHNOLOGY INSERTION

BACKGROUND

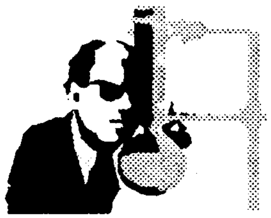


BACKGROUND

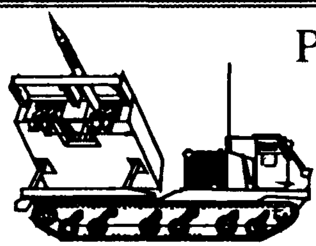
FORTUNATELY, ARMY MANAGEMENT HAS RECOGNIZED THE PROBLEM AND IS TAKING DRAMATIC AND AFFIRMATIVE STEPS TO DO SOMETHING ABOUT THE SITUATION. THE PROBLEM HAS BEEN STUDIED AND CONTINUES TO BE TWEAKED BY A SIX-STAR STEERING COMMITTEE. THE MSCs ARE NOW BEING GIVEN THE GREEN LIGHT TO GO UTILIZING TECHNIQUES OF FOCUS, DYNAMICS, AND CONTINUOUS IMPROVEMENT.

TECHNOLOGY INSERTION

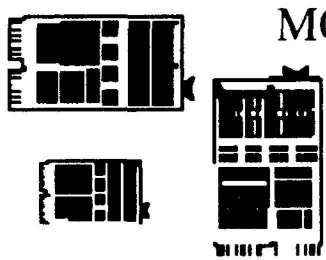
Q : WHERE DO I START OSCR ?
A : EVERYWHERE IN WEAPON SYSTEMS LIFE CYCLE



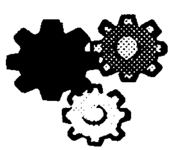
TECH BASE - Apply 4 % Tech Base Money to the Generic O & S Technology Cost Drivers - Tremendous Life Cycle Savings
CATALYST - Focused Tech Base Vision



PROGRAM COST - Apply 1 % of Weapon System Programs to attack O & S costs - Quick investment return potential
CATALYST - Value Engineering



MOD PROGRAMS - 20 % good on minor MODs, strict Materiel change policy to emphasize O & S on major MODs
CATALYST - Increased cost emphasis vs. performance enhancement



SPARE/REPAIR PARTS - Apply 1 % of ASF money to reduce spares costs
CATALYST - Technology Insertion

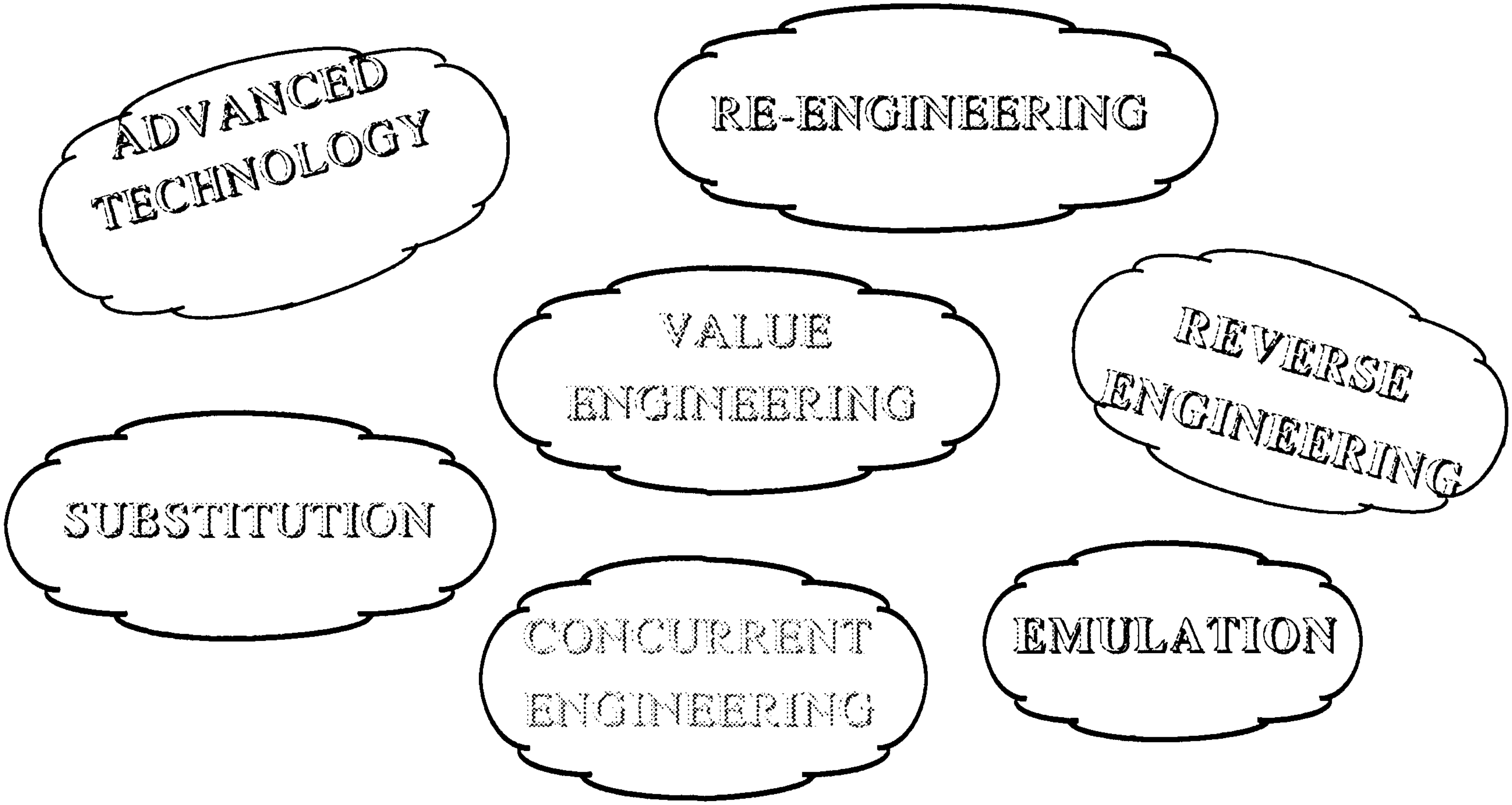
WHERE DO I START OSCR?

MANAGEMENT HAS DEDICATED A BROAD-BASED CONCEPT ON ALL DOLLARS THAT AMC MANAGES TO ATTACK O & S COSTS. THE CATALYSTS HAVE BEEN DEFINED WHICH CAN MAKE IT HAPPEN MOST EFFECTIVELY AND EFFICIENTLY. THIS SESSION WILL FOCUS PREDOMINANTLY ON TECHNOLOGY INSERTION EFFORTS TO ATTACK SPARE/REPAIR PARTS AND WILL ALSO DISCUSS THE TECH BASE APPROACH.

TECHNOLOGY INSERTION

DEFINITION

UTILIZATION OF ENGINEERING METHODOLOGY TOWARD HIGH COST SPARES TO SAVE $



TI DEFINITION

TI HAS MANY TECHNICAL ALLIES THAT GIVE IT THE PROMISE OF SUCCESS. VALUE ENGINEERING, RE-ENGINEERING AND SUBSTITUTION ARE INSTITUTIONALIZED WITHIN OUR SYSTEMS. THE OTHERS ARE ACTIVELY BEING PURSUED. THE VISION OF FOCUSING THESE EFFORTS TOWARD O & S COST REDUCTION ON A LARGE SCALE HAVE BEEN MISSING IN THE PAST. THEY ARE NOW A REALITY AND A MUST FOR SURVIVAL.

TECHNOLOGY INSERTION

<u>IMPLEMENTATION CONCEPT</u>

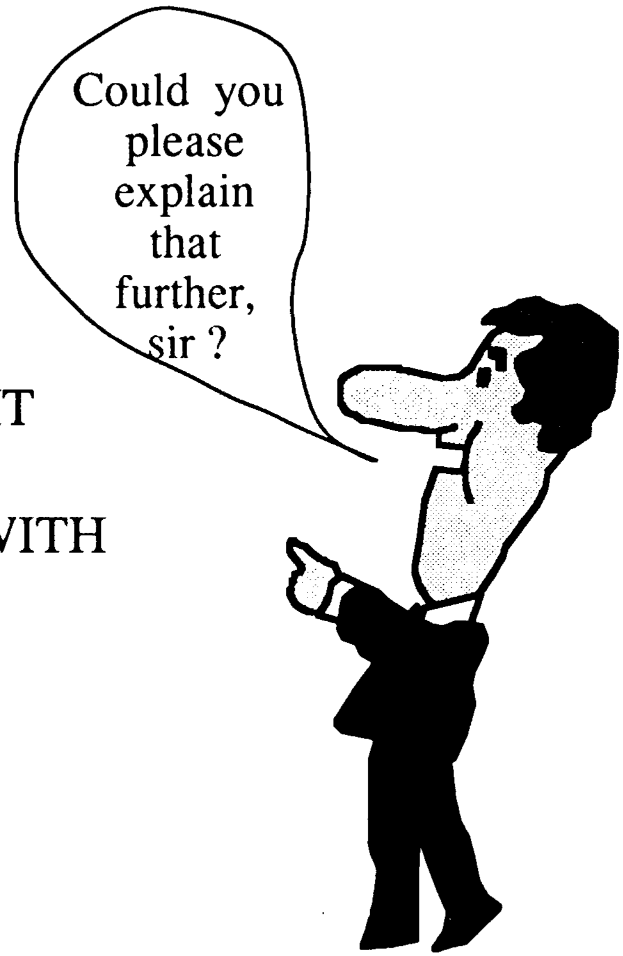
BUY SPARES IN <u>MULTIPLE NSNs</u>

GROUPED ACCORDING TO <u>SIMILAR</u>

<u>MANUFACTURING PROCESSES</u> BOUGHT

TO <u>PERFORMANCE REQUIREMENTS</u> WITH

<u>MULTI-YEAR CONTRACTS</u>



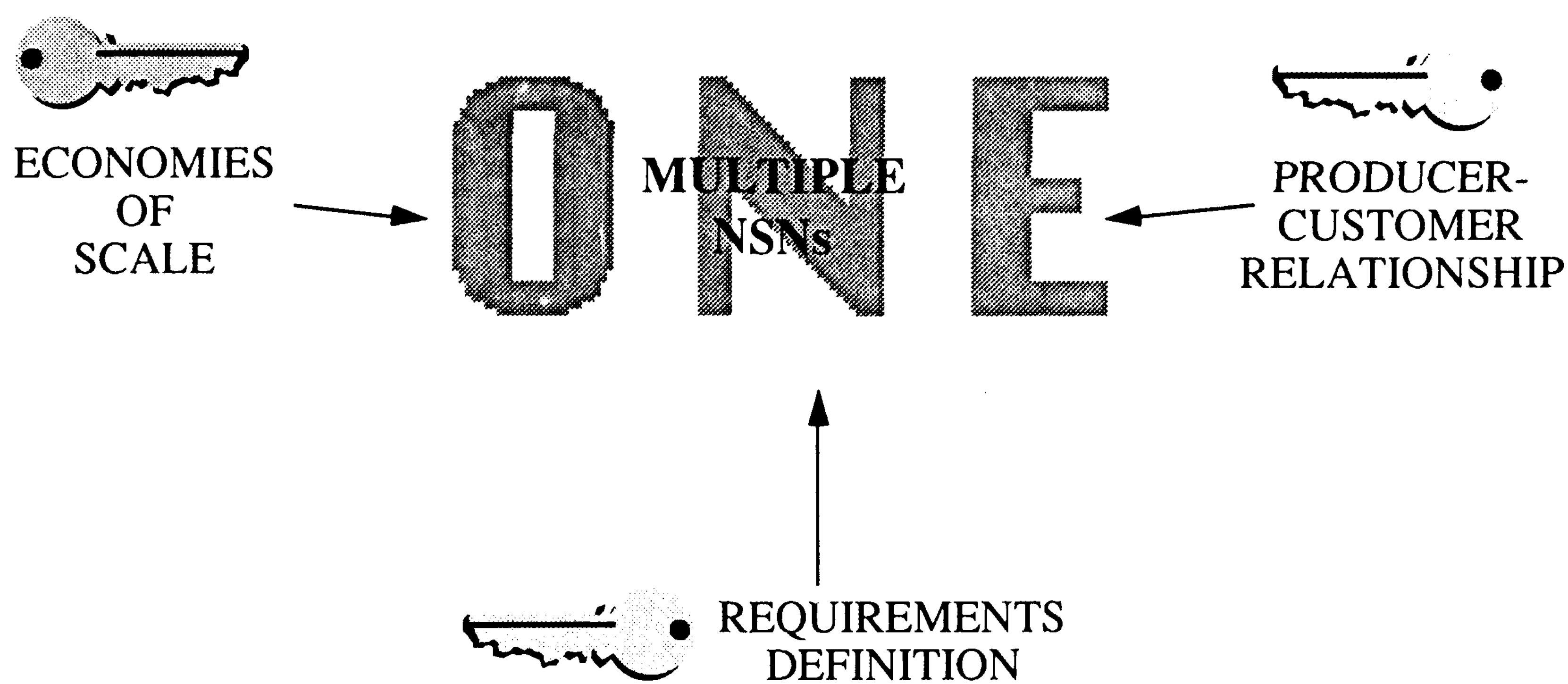
IMPLEMENTATION CONCEPT

THE IMPLEMENTATION CONCEPT APPEARS AWKWARD. FOLLOWING WILL BE A BREAKDOWN OF THE 4 KEY ELEMENTS OF THE CONCEPTS IMPLEMENTATION BARRIERS, AND KEYS TO SUCCESS.

TECHNOLOGY INSERTION

THE BIG - FOUR

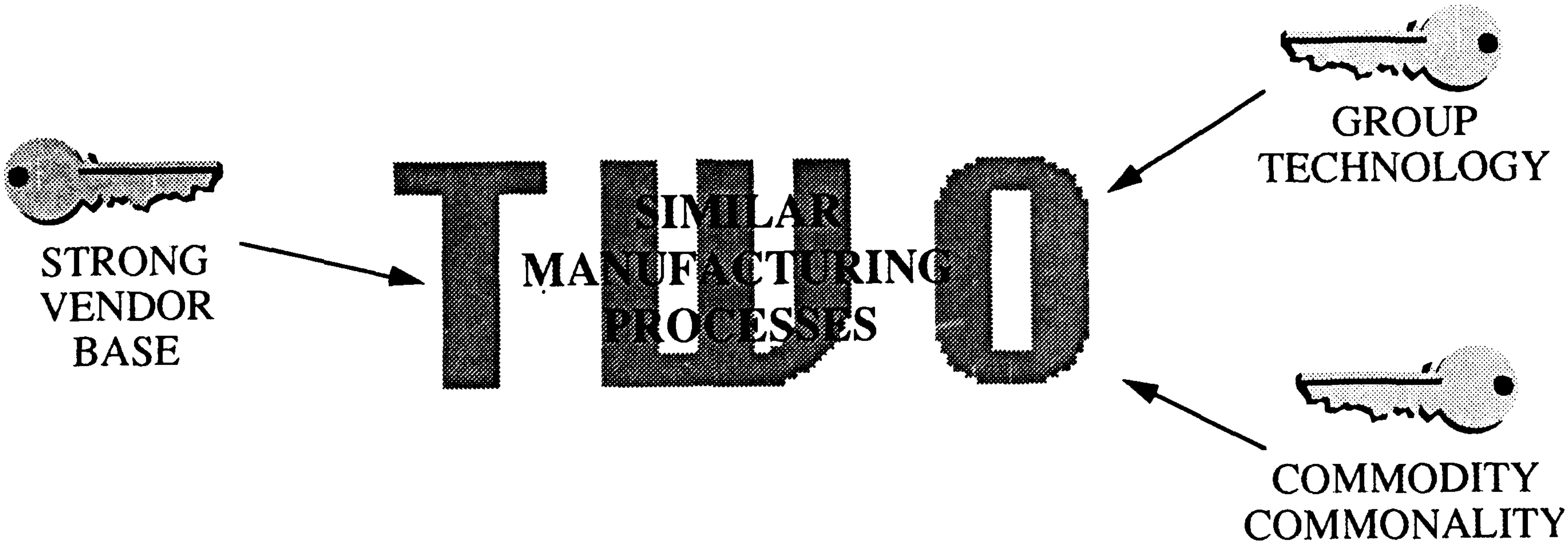
LARGE SCALE SPARES CONTRACTS



TECHNOLOGY INSERTION

THE BIG- FOUR

GROUP PARTS TO REACH ECONOMIES OF SCALE



THE BIG-FOUR

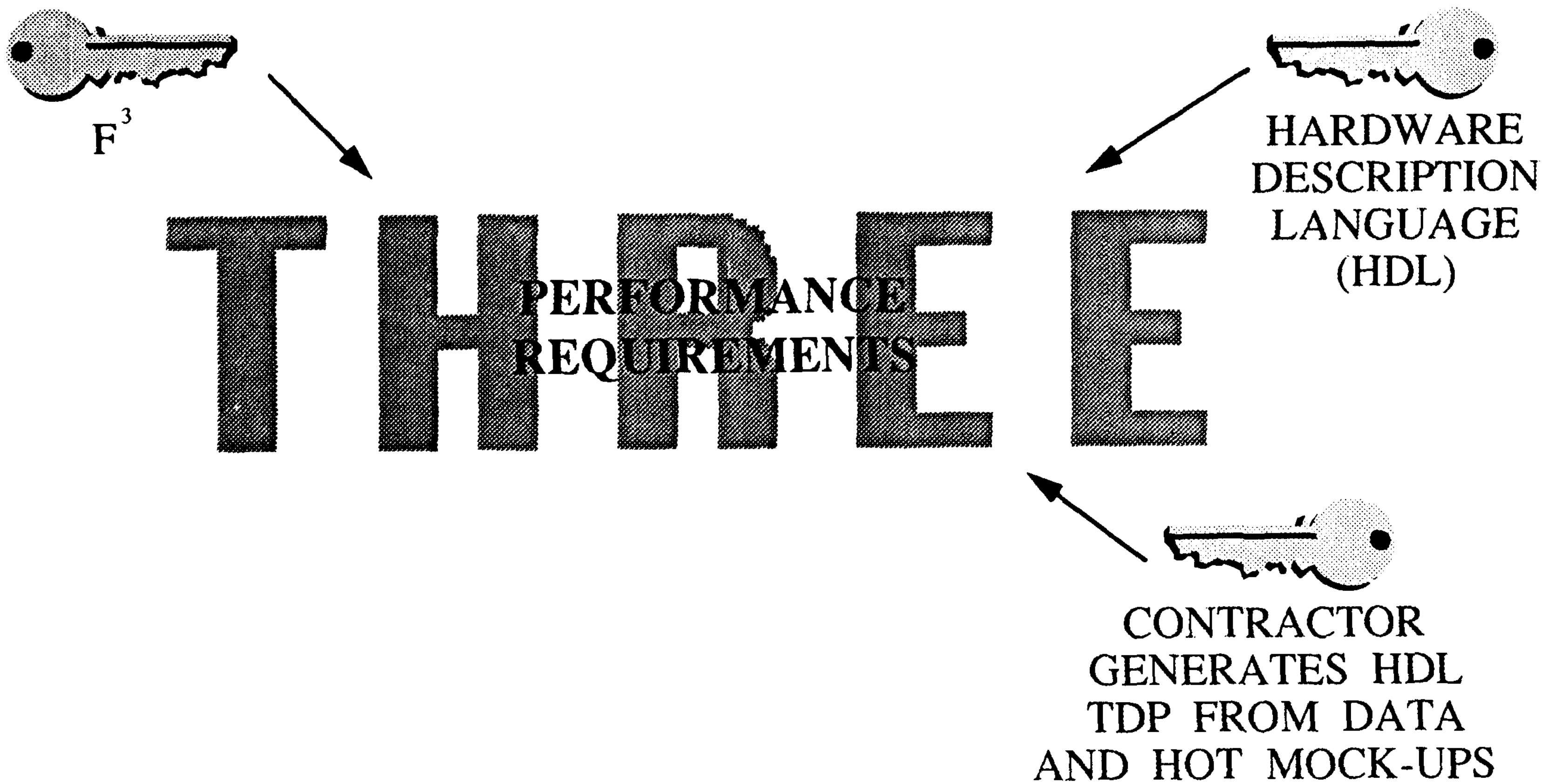
TWO

SIMILAR MANUFACTURING PROCESSES - IN ORDER TO REACH ECONOMIES OF SCALE, GROUP PARTS TOGETHER WITH SIMILAR MANUFACTURING PROCESSES TO ALLOW AN EVEN BASELINE FOR VENDORS IN A GIVEN INDUSTRIAL BASE TO COMPETE ON. THE PRESENT PROBLEM, NO CLEAR WAY TO GROUP THE PARTS. AN EFFORT IS UNDERWAY TO DEFINE A PROCESS FOR GROUPING PARTS TOGETHER. THE DEFINITION OF THE MANUFACTURING PROCESSES AND PROCEDURE FOR GROUPING IS CALLED GROUP TECHNOLOGY. BUT EVEN WITH GROUP TECHNOLOGY, WE MUST HAVE SUFFICIENT REQUIREMENTS, i.e., COMMODITY COMMONALITY TO ACHIEVE. NO QUESTION THAT THIS APPROACH WILL ENHANCE THE VENDOR BASE.

TECHNOLOGY INSERTION

THE BIG - FOUR

WE NEED TO TELL OUR VENDORS WHAT WE WANT NOT HOW TO BUILD IT



THE BIG-FOUR

THREE

PERFORMANCE REQUIREMENTS - THIS IS A TRICKY ONE - THROW AWAY THE OLD NOTION OF TDPs AND TECHNICAL DATA AND DEVELOP A NEW ONE WHICH EMPHASIZES WHAT WE WANT, NOT HOW TO BUILD IT. FOR EXAMPLE, VIRTUALLY ALL OF YOUR DOMESTIC EXPENDITURES ARE TO UTILITY, NOT TO A PRE-SPECIFIED TECHNICAL DESCRIPTION OF THE ITEM. THIS CAN BE ACHIEVED IN MANY AREAS WITH HARDWARE DESCRIPTION LANGUAGES WHICH TELL HOW AN ITEM SHOULD PERFORM. THIS IS PARTICULARLY GERMAINE TO THE ELECTRONICS WORLD, BUT WILL BE MUCH MORE DIFFICULT FOR UNIQUE ITEMS WE REQUIRE. THE BEAUTY OF THE CONCEPT IS ITS TRANSPORTABILITY INTO A FUTURE ENVIRONMENT WHICH IGNORES THE TECHNOLOGY OF THE DESIGN. WE CAN START GETTING THIS TODAY WITH VHOL, REVERSE ENGINEERING, AND MOCK-UPS.

TECHNOLOGY INSERTION

THE BIG - FOUR

LONG TERM VENDOR RELATIONSHIPS

THE BIG-FOUR

FOUR

MULTI-YEAR - TO REALLY GET ACQUISITION SAVINGS, YOU HAVE TO GO MULTI-YEAR-OPTIONS WON'T DO IT. THE OBSTACLE HERE IS TO BE ABLE TO DEFINE OUTYEAR REQUIREMENTS WITH SUCH ASSUREDNESS YOU CAN REACH THE ECONOMIES OF SCALE WITH SIMILARLY MANUFACTURED ITEMS. THIS POTENTIAL CONSTRAINT OF COMMODITY COMMONALITY AT THE REQUIRED SCALE IS BEING MORE FULLY EXPLORED. FUNDING STABILITY IS A KEY AND CONTRACTUAL FLEXIBILITY IS A KEY TO ENSURE SUCCESS OF THIS APPROACH. CONTRACTUAL FLEXIBILITY OF ALLOWING A RANGE OF NSNs TO BE DETERMINED EACH FISCAL YEAR WITH DOLLARS OR TOTAL QUALITY OF ITEMS AS A THRESHOLD IS BEING EXAMINED FOR EFFECTIVENESS.

TECHNOLOGY INSERTION

BACKGROUND

1 - MANAGEMENT CONCERN ★★★★ GEN. TUTTLE

2 - STUDY PHASE

* Established General Officer Steering Committee on O & S Cost Reduction - ★★★ TRADOC
  ★★★ AMC
* O & S Concept Studied at MSCs
* Army Science Board on O & S Cost Reduction

3 - IMPLEMENTATION PHASE

* Attack Life Cycle Costs

TECHNOLOGY INSERTION

IMPLEMENTATION

AMC MANAGED
OSCR OVERSIGHT

FAR CHANGES

POLICY

O & S COST MODELING

ACQUISITION STRATEGY

FUNDING

HARDWARE DESCRIPTIVE LANGUAGES

VALUE ENGINEERING

GROUP TECHNOLOGY

SALC TYPE CONTRACTS

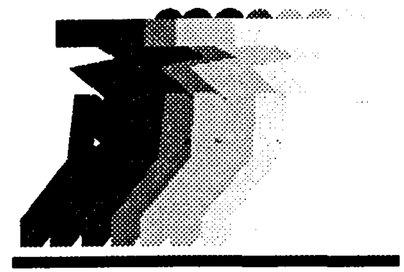
IMPLEMENTATION

THERE ARE MANY BUILDING BLOCKS TO THE IMPLEMENTATION AND ACCOMPLISHMENT OF TECHNOLOGY INSERTION. DEFINED HERE ARE THE CRITICAL AREAS THAT MUST BE WORKED AND ARE BEING ACTIVELY WORKED AT THE AMC AND SUBORDINATE COMMAND LEVEL. THE BUILDING BLOCKS ARE THE TECHNICAL AREAS INVOLVED IN THE PROCESS. THE OTHER AREAS INVOLVE THOSE OTHER FACTORS THAT MUST BE CHANGED OR INFLUENCED.

TECHNOLOGY INSERTION

WHEN ?

FY 91



FY 92

MICOM

A - Type
  (1) Mechanical Item
  (2) Electronics Item

B - Reverse Engineering/Value Engineering Methodologies

A - Candidate Selection Process

B - Group Technology

C - First Multi-year

WHEN?

JUST AS WE MUST WALK BEFORE WE RUN, TECHNOLOGY INSERTION WILL UNDERGO A TRIAL AND PROVEOUT PROCESS BEFORE IT CAN BE INSTITUTIONALIZED. VALUE ENGINEERING IS AN EXAMPLE. MICOM HAS UNDERTAKEN 2 MAJOR INITIATIVES IN FY 91 TO PROVE THE CONCEPT RESULTS WILL BE MEASURED TO DETERMINE THE MOST EFFECTIVE APPROACH. FY 92 WILL BEGIN THE INSTITUTIONALIZATION PROCESS WHEREBY A SYSTEMATIC PROCESS WILL BEGIN TO EMERGE TO IDENTIFY CANDIDATES, GROUP, AND CONTRACT.

TECHNOLOGY INSERTION

LOGISTICS R & D

1 - TECH BASE GENERIC O & S COST DRIVERS BEING DEFINED

2 - DEDICATE TECH BASE $ 4 %

3 - SOLVE O & S PROBLEMS WITH THIS MONEY, NOT PERFORMANCE PROBLEMS

LOGISTICS R & D

PARALLEL TO THIS EFFORT IS THE INITIATIVE WITHIN THE TECH BASE TO DEFINE THE 10 GENERIC O & S COST DRIVERS AND TO ATTACK THEM WITH 4% OF THE TECH BASE DOLLARS. THE PRIMARY MOTIVATOR WILL BE O & S PROBLEMS, NOT PERFORMANCE.

TECHNOLOGY INSERTION

SUMMARY

THE U.S. ARMY MANAGEMENT IS COMMITTED TO ATTACK LIFE CYCLE COSTS FOR FIELDED WEAPON SYSTEMS AND THOSE UNDER DEVELOPMENT

SUMMARY

O & S COSTS MUST BE IN THE MIND OF ALL OF OUR WEAPON SYSTEM DECISION MAKERS IN THE FUTURE. IT WILL BE LIKE TQM, A WAY OF THOUGHT AND LIFE. EACH PERSON IN THIS ROOM HAS A RESPONSIBILITY IN THE LIFE CYCLE COST OF A WEAPON SYSTEM. REMEMBER THAT.

OBSOLETE MICROCIRCUITS REVISITED

BY
ROBERT E. GIBBS
AND
TERRY L. MULLINS

Abstract

This paper revisits the obsolete microcircuit topic from the "options available" perspective. Options and alternatives that are available when a system is confronted with obsolescence in microcircuits are discussed.

The introductory section of the paper highlights the importance electronics has on the defense industry. This emphasizes the need to have options available to the Project and Logistics Managers to maintain system readiness when faced with obsolescence of critical parts. In addition, terminology used in the microelectronics area is briefly defined to familiarize the non-technical manager with key definitions and descriptions.

Options and alternatives available for microcircuit obsolescence are described and include Alternate Source Identification, Simple Substitution, Minor Engineering Change Requirement, Life of Type Buys, After-Market or Secondary Market Supply Houses, Reverse Engineering/Remanufacturing, Emulation, and Printed Circuit (PC) Board Redesign. The decision criteria used to influence the option to be selected is discussed in the paper.

The paper concludes with a discussion on dealing with change in the electronics field. No concrete solutions are available to totally resolve microcircuit obsolescence, but there are options available.

Introduction

It is common knowledge that electronics is a very important and critical management area in the defense industry. It is estimated that over 60 percent of the cost of Defense Missile Systems result from the electronics in the system. Likewise, microcircuits, being a major element in the electronics arena, are critical to the production, operation, and maintenance of both defense and commercial systems. Microcircuits can be very complex in nature and are an essential element in the success of advanced electronic systems. Since microcircuits are in great demand, they're very vulnerable in a highly competitive market. Researchers and manufacturers are constantly advancing technology in the microcircuit area to maintain and increase market share. This continuous technology advancement plays havoc on users in trying to plan production and maintain spare parts in older electronics systems. According to widely accepted industry practices, the typical life cycle that can be expected for a microcircuit family is 10 years. New technology introductions immediately begin affecting demand and supply before the end of the life cycle is approached on the older. This results in the microcircuit obsolescence that is being experienced today.

Background

It is often said, the defense industry makes up only about five percent of the overall electronics market. As a result, the defense industry has little leverage in influencing manufacturing plans and maintaining ongoing inventories of specific microcircuit families. This forces the defense industry to deal with constant technology advances and changing conditions. Since life cycle of a microcircuit family is about 10 years, a weapon system with a 30 year life will experience obsolescence in multiple technologies. In addition, future funding theory emphasizes development of new weapon systems but delaying production until a definite need is realized and maintaining/increasing the life of the ones already fielded. Therefore, defense systems experiencing advanced longevity deal with obsolescence in past and present technologies.

Obsolescence as referenced in this paper means the microcircuit is out of production and no longer being manufactured. This situation is due to old technology and declining market demand of continued production. Non-procurable means there is no known source of supply but inventory may be available in limited quantities from a source other than the original supplier.

The U.S. Army Missile Command has experienced microcircuit obsolescence problems like many other agencies. This prompted action by Command management to direct efforts for resolving problems and searching for solutions. Unfortunately, no exact procedure or methodology could be identified to resolve these complex problems. After many discussions and trips to other Government agencies and industry, no concrete solutions were found. However, it was found that options did exist, and based on the parameters surrounding the particular microcircuit involved, a corrective direction could be set in motion.

Obsolescence Resolution

Beginning the search for solutions to the complex obsolescence problems requires skills in predicting the future and accepting associated risks. Constant advances in microcircuit technology are expected and other factors contributing to obsolescence must also be realized which introduces uncertainty in setting any direction for resolution. The number one contributing factor is the pressure by manufacturers to compete in a very vulnerable market. Without warning, company management may direct a change in the manufacturing plan to eliminate a line with low profit margin or demand. In addition, today's market environment demands newer, more unique, faster, higher reliability, and increased flexibility in electronic components; thus constantly changing the commercial market demand which the defense industry is dependent upon. The name of the game is profit, and if the economics don't indicate profit growth, a market change can be expected. In conclusion, no matter how good a predictor we may be, change will occur which defies any logic previously used to predict what direction/option to follow. It is because of this inability to predict the future that no definite, readily adaptable, calved approach exists to resolve each problem as it occurs. The solution is almost always a family of solutions, each with its own unique time-cost identity for each unique problem. In this search for resolving microcircuit obsolescence, even though no concrete conclusions could be obtained, solution options were identified. These include: alternate source identification, simple substitution, minor engineering change, life-of-type buys, after-market or secondary market supply houses, emulation, reverse engineering/remanufacturing, and complete printed circuit board redesign. Each of these will be discussed separately.

Identifying existing **alternate sources** is one of the first options of resolving non-procurable problems. Even though a manufacturer may have ceased production of a microcircuit, inventory may still be available at one of the many distributors and suppliers throughout the United States. An extensive phone search of these sources may be viable in finding the desired quantities. Several sources of commercial data exist which may provide identification of alternate manufacturing sources, and attempting to identify an alternate supplier should be the initial step in resolving the impact of a possible obsolete part.

In the same vein as identifying alternate suppliers it may also be possible to resolve a parts availability problem by determining excess inventory at other agencies. Excess inventory from a production contract can be redistributed to meet user requirements at other locations and should be investigated. If an item is fairly common, Defense Electronics Systems Command (DESC) may also have an existing inventory of the particular item. Cannibalization is an alternative too. However, it's not an easy remedy for Army identified problems, and is not viewed as a viable long term solution.

The development of alternate sources of supply is the most cost-effective solution to resolving parts availability problems and provide the fastest solution. This alternative is very cost-effective for problems of low-demand and/or small quantities.

When evaluating the benefits of identifying a new source, consideration should be given to the existence and quality of technical data that is required for procurement. If adequate documentation cannot be obtained, then other alternatives must be pursued to develop the required technical data.

Substitution is the second alternative to pursue in resolving non-procurable problems and is viewed as part of the initial options to be considered. The same microcircuit may be available, but has been tested and qualified with higher specifications. For example, the Air Force may have higher specification requirements than the Army for the same microcircuit. Therefore, an Air Force item could be used for the Army requirement. Also commercial microcircuits could be obtained and tested according to military specifications by an approved facility. Identification of an acceptable substitution item will be difficult even when using the various sources of material and parts database systems that are available. Searching for a substitute part, based on technical characteristics of the required item, is possible but again it is highly unlikely to produce a verified part for use without testing. When a candidate part is found, it must be formally approved as substitutes which will require more time than finding an alternate source.

Minor engineering changes can sometimes be made to commercial parts and serve as substitutes in solving replacement problems. These instances occur because the design used a nonstandard requirement when compared to the commercial use. Minor engineering changes can be utilized to change to more common case styles and change lead finishes. Analyzing the case style may allow switching to more common types that are available. The lead finish required may not be readily available and may be changed depending on the technical parameters required. A slight change may identify more common ones for replacement of the same part. In accordance with any engineering change, care must be utilized to ensure one-to-one replacement actually occurs. Therefore, testing and validation may need to occur. When engineering changes are involved, implementation time can vary from short to extensive durations.

A **life-of-type** buy may be a viable solution for items which the last known manufacturer has provided notification of his intent to stop production, and no known substitutes or alternate sources exist. LOT buys is the process of buying total quantities required for the life of the particular system involved including spares. Future requirements are very difficult to predict and must coincide with the phase-out dates of the systems the items support. An inherent problem with this solution is the changing of phase-out dates which occur rather frequently. Traditionally, production contractors purchase the required quantities to complete delivery of contract requirements. However, extensions requiring additional buys and spare parts are left unsupported because of the unforeseen need along with the desire to reduce excess inventory. The additional buy is not available when the new production requirements are discovered. The original LOT quantity then becomes insufficient after the manufacturer has stopped production. For LOT buys to be implemented effectively, they should consider the immediate production requirements along with future and spares requirements. Determining these latter requirements is difficult, since production schedules are often revised over time. In addition, proper storage arrangements must be a consideration along with the desired configuration for future use.

After-market or **secondary supply** houses can be useful in avoiding obsolescence problems. They purchase technical packages and tools from original manufactures and maintain a production base for particular items in demand. Also they stockpile current items that are in a declining position and hold them in inventory to supply at a later date. These items are sometimes acquired in an unpackaged state which allows for specifying the required package style for the particular application. However, in utilizing these services, caution must be taken to verify the original manufacturing source and ensure all required quality controls are met by the producers or sellers. Sometimes foreign sources are used and imitations are obtained. In addition, cost of the particular item could be much higher than the original price paid.

Reverse engineering/remanufacturing may not be classified as a complete option to obsolescence except in rare occurrences. Reverse engineering process of developing a complete technical data package from a thorough examination of the physical item; i.e., taking physical dimensions, analyzing the functional operation, reviewing next higher assembly, etc. This process also serves as a way to get complete data on unknown or unspecified designs contained in a physical item.

The techniques of reverse engineering can determine the specifications for remanufacturing non-procurable parts. Reverse engineering and development of technical data may best be applied in providing a substitute component design for identifying the functional and specification requirements of components. However, it can be applied where manufacturing capability of the technology family exist but a complete technical data package is not available and the original manufacturer has ceased production. Obviously, another manufacturer would have to be willing to produce an item with old technology.

A technical data package created by the reverse engineering process can support the development of specific parts or assist in replacing the original part. The cost of performing reverse engineering to develop missing technical data must be recouped from savings resulting from the avoidance of a complete redesign effort. The reverse engineering process must identify the specific technical requirements and any undocumented characteristics that the contractor has used in the original system design. Systems may be designed to operate on the edge or fringe of parts specifications and slight variances are intolerable to the systems functioning properly. The reverse engineering process must identify these variances so a true replacement can be produced.

Emulation is the utilization of modern technology, materials, parts or components to replace an obsolete microchip to accept and deliver the same data, execute the same functions, and achieve the same results. For emulation to replace a non-procurable item, it is required to meet all form, fit, and function requirements of the original part. In addition, the part is also required to mimic the input and output requirements of the old part and to perform the required functions in the same manner as the original. Evaluation of this alternative requires complete technical and cost/trade-off analysis, along with projected demand data. Reverse engineering is utilized to determine the documented and undocumented functional requirements an emulated part is required to meet.

Microcircuit Emulation has become emphasized as a result of obsolescence. These engineering and manufacturing services required to perform emulation has created a cadre of commercial companies willing to enter the market. In addition to commercial companies, Sacramento Air Logistics Center at McClellon Air Force Base has in-house and contractor supported capability to perform emulation and other technical services. Other known Government efforts include the GEM program by Defense Logistics Agency developed by the David Sarnoff Research Center.

Since emulation requires a major engineering and design effort along with prototype manufacturing and extensive testing, a considerable amount of time (4 months to 2 years) could be required to execute this option for obsolescence resolution.

PC Board Redesign will be the last option and is the most expensive. However, conditions may dictate this option be exercised and be the best long-term solution. For example, if a board contains multiple obsolete components, it would be more feasible to redesign the board than to emulate each obsolete component. Other conditions, when PC board redesign may be chosen, involve the use of specialized components such as microprocessors and components with extremely high cost and low demands. Also, if weight and space limitations exist, complete redesign may offer an opportunity to eliminate obsolescence and improve operational conditions. Changes and improvements being made on higher assemblies, planned system improvements, and/or major engineering changes may warrant complete redesign. The final decision depends on the economics and conditions that exist at the time product improvement initiatives are considered. Redesign efforts should be addressed through product improvement programs.

As can be expected, this option would require even more time for execution and obtaining a successful product. However, under the right conditions, this may be the correct option to resolve long-term obsolescence.

Decision Criteria

With any decision, one can never be sure it's correct decision until it's been made, implemented, and a product obtained. Choosing the best path to follow to resolve obsolescence is not absolute. The decision criteria depends highly on the specific conditions and parameters that exist at the time obsolescence is experienced.

In general, sense of urgency (time when a final product is needed), cost/economics conditions including quantity required, present weapon system production status, risks which are acceptable and weapon system life expectancy are the key criteria which should be used in choosing an option.

Common sense also should be used when choosing an option to resolve obsolescence. For example, large amounts of design dollars should not be sunk into a system which is at the end of the life cycle and near retirement. Also, if only a small quantity is required, even if the unit cost is extremely high, the smarter decision is to purchase the small quantity from an after-market company and avoid engineering costs.

Alternate Source Identification should always be the first option to be pursued: it is the least costly alternative. This approach involves an extensive phone and source reference search for other electronic/microcircuit suppliers. Depending on resource availability to conduct the research, a source should be identified if one exists, within one to two weeks.

Simple Substitution should be the second alternative/option to research if alternate source identification doesn't produce a viable source of supply. Researching a simple substitution involves conducting functional analysis of the particular microcircuit to determine parameters which are required versus "nice to have". In reality, microcircuits used in the defense industry are primarily commercial items with military test requirements/specifications being invoked. Therefore, depending on the criticality of the function, flexibility and variability may be exercised to use another microcircuit. For example, a microcircuit used in the Air Force may be substituted for one in the Army. However, Air Force test requirements may be higher for the common microcircuit than that of the Army. Therefore, the Air Force item could be substituted for the Army requirement but not vice versa. Microcircuits operating within the same time and performance ranges may be substituted for each other depending on the criticality of the item.

Minor engineering change requirement should be the third step. Again, the functional criticality of the item needs to be analyzed. Flexibility is needed in performance and design to allow redesign opportunities. This option requires engineering effort, additional testing and possible prototype manufacturing thus increasing cost and time. An example of a minor engineering change would be to change lead finish from gold to tin. Again, the performance of gold versus tin would have to be analyzed to determine if the functionality of the microcircuit would still be acceptable. Another example may include changing the packaging type from an obsolete flat pack to a ceramic dip. In this case, a commercial packaging house could take this problem and engineer a solution. It should also be noted, when engineering changes are initiated, technical risks are introduced.

Life-of-type buy option requires two major criteria to be considered; funds availability and confidence in predicting future requirements. When reviewing life cycle models, changes can occur at any moment based on budget variations and other factors like profit margin targets, politics, contractual agreements on future production, and spares contracts, etc. Other considerations required for this option include logistical arrangements for long-term storage and determination of priority for inventory draws. Future technical changes in system configuration add risks to the decision process for determining required quantities and need to be investigated extensively before choosing this option. However, even if throwaway cost is involved due to choosing this decision, it may be used as a bridge to avoid having a system down due to the lack of components until an engineering redesign effort can provide a long term solution.

After-market or secondary source supply house is determined as an option depending on quantity required and system life prediction. Even an after-market supplier will eventually deplete inventories and cease production if demand is reduced. Therefore, after-market suppliers should be utilized for short-term and definite-known quantities. This option will provide a faster solution than going through major engineering redesign efforts. This option could also be utilized in combination with a longer term plan like emulation or complete redesign. Since after-market supplies are limited and demand can be very high, a greater unit cost is not unusual and can be 5 to 10 times the original cost. Again, this cost may be much lower than pursuing an emulation or redesign effort. The risks associated with this option primarily fall in the quality area. After-market companies procure part inventories from original manufacturers in various forms; wafers, dyes, masks, etc. Complete assembly and testing remains to be performed which can create quality risks. In addition, some parts may be imitation or foreign copies of the original items. Utilizing DESC approved manufacturing facilities may increase confidence in the after-market company.

The **reverse engineering/remanufacturing** option requires increased cost, schedule, and risks as compared to previously discussed alternatives. Again, future life cycle predictions should be accurate, continuous high demand should be evident, and present design should be stable and proven. Also the manufacturer should be willing to continue production utilizing the present technology before initializing this option. Recently, a microprocessor manufacturer announced a management decision to cease production and offered a life-of-type buy opportunity. An engineering and manufacturing company came forward with a proposal to produce this item after conducting a reverse engineering task to accurately define the technical data package. The reverse engineering process can be utilized where the technical data package is unavailable or incomplete. As previously discussed, conducting major engineering efforts, establishing new manufacturing lines/processes, conducting major tests, building prototypes to prove data package information, etc., are very costly, time-consuming, and involve high risks. All of this needs to be assessed when considering this option.

The **emulation** option should be considered for a long-term requirement of a microcircuit or PC board. The emulation engineering effort can be lengthy and costly. However, since emulation duplicates the form, fit, and function utilizing modern technology, the longevity of the newly engineered item will be procurable for most future requirements of a system. Predicting the life cycle of the involved system is very important in ensuring this is a good option to pursue. When major changes in design occur, technical risks are increased. Costs can vary due to the complexity of the item involved but would be higher than previously mentioned options. It has been estimated that an emulation effort could range from $50k to $1 million depending on complexity, testing, prototyping, etc., associated with design engineering requirements. Once an emulation effort is done, the engineering data can be shared among related elements in the joint military services. Also, capturing the specification, testing, and verification data pertaining to behavioral and functional parameters allows for transportability of today's designs to tomorrow's technology. These features result in technical data packages being available for future advances in technology.

PC Board redesign can be the most costly with the highest risk and the most time consuming option to resolve obsolescence. Before this type of investment in resources is made, high confidence in continuous system life needs to be prevalent. However, this approach should not be discounted an option. Multiple component obsolescence can be experienced on an individual PC board and total redesign or emulation of the board may be the most advantageous overall. Redesign also results in reduced microcircuit count and higher reliability. Other considerations for PC board redesign are major upgrades or changes in higher assemblies which include the PC board. Again, capturing redesign and subsystems in computer models containing specification, testing, and verification data for behavioral and functional parameters allow for transportability to tomorrow's design automation technology.

Conclusions

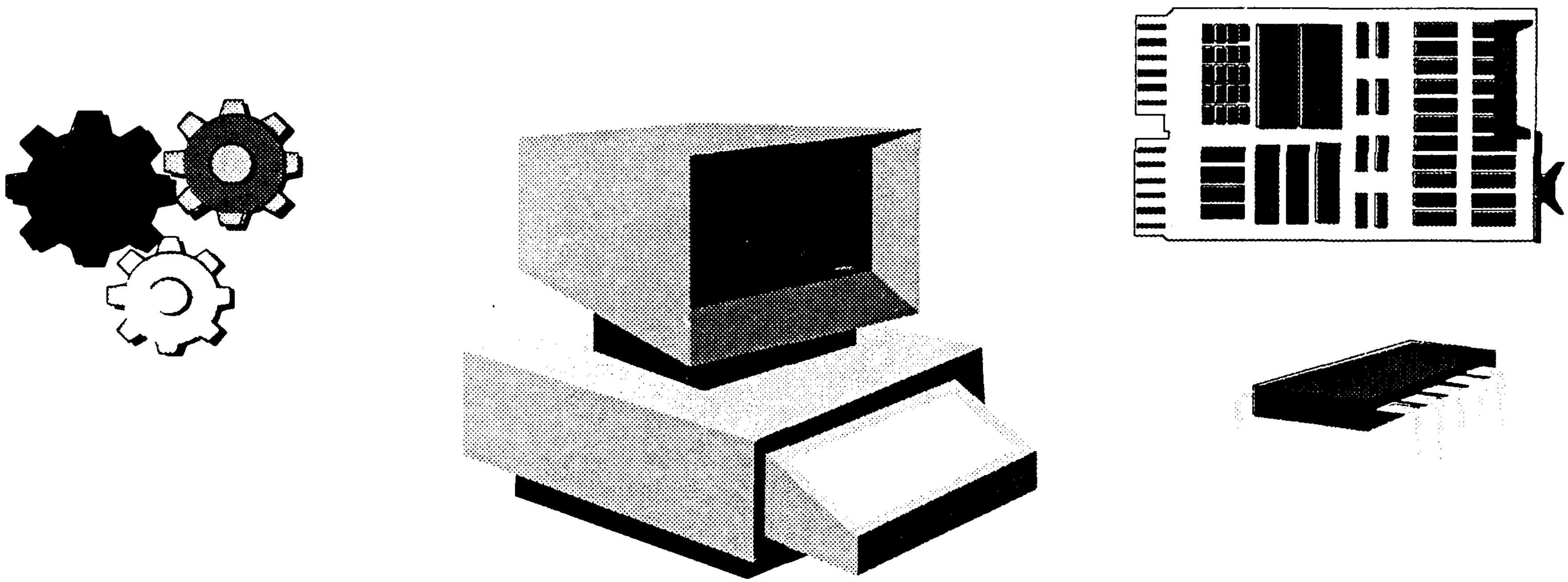
The electronic industry will continue to advance and many changes can be expected in the future. Therefore, we will be required to deal with change and consequently with obsolescence. The U.S. Army Missile Command is managing obsolescence by utilizing the options/alternatives discussed for today's obsolescence problems. However, avoiding future obsolescence requires planning and identification of available solutions before occurrence. A proactive management strategy identifies items most likely to become obsolete and can forecast their occurrence. This can be accomplished by conducting a technical assessment of the present state of obsolescence. This proactive approach allows for the prediction of obsolescence and increases the time to evaluate and select supporting options. In addition, periodic monitoring should occur for management of obsolescence issues and conditions influencing the production of microcircuits. Implementing a managed approach allows greater use of LOT Buys, substitution, emulation strategies, cheaper alternatives, etc., and reduces costly redesign.

Much has been gained from these experiences, but new ways to apply these lessons to new developmental activities must be identified. The U.S. Army Missile Command is now seriously examining the pursuit of VHDL modeling, experimenting with design for non-obsolescence contract clauses, educating prime contractors and government management personnel to a proactive mind-set rather than a reactive approach, and implementing of concurrent engineering philosophy. In addition, an "Expert System" is being pursued which will seek to structure these problems and solution options efficiently and effectively. The potential outcome is a win-win situation for the designer, producer, and support units in the field.

INDUSTRIAL OPERATIONS

OBSOLETE MICROCIRCUITS REVISITED

TERRY MULLINS



WHY IS ELECTRONICS IMPORTANT?

* MOST CRITICAL OF ALL TECHNOLOGIES FOR PEACE

[redacted] ACCOUNTS FOR LESS THAN 5% OF [redacted] MARKET

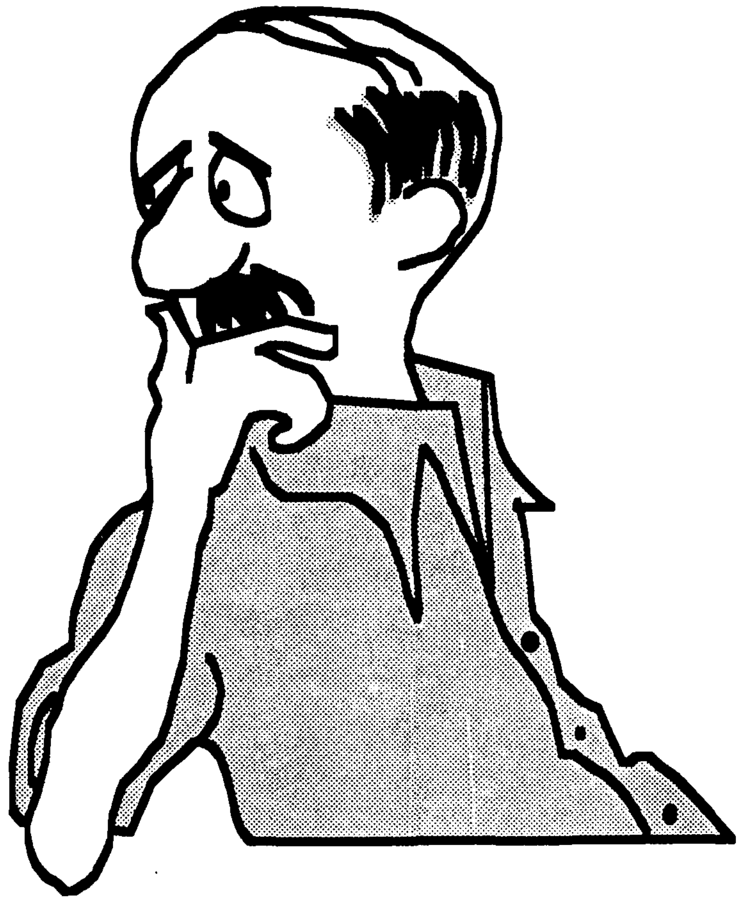
[redacted] OF A MODERN SYSTEMS [redacted] LDING BLOCKS OF [redacted]

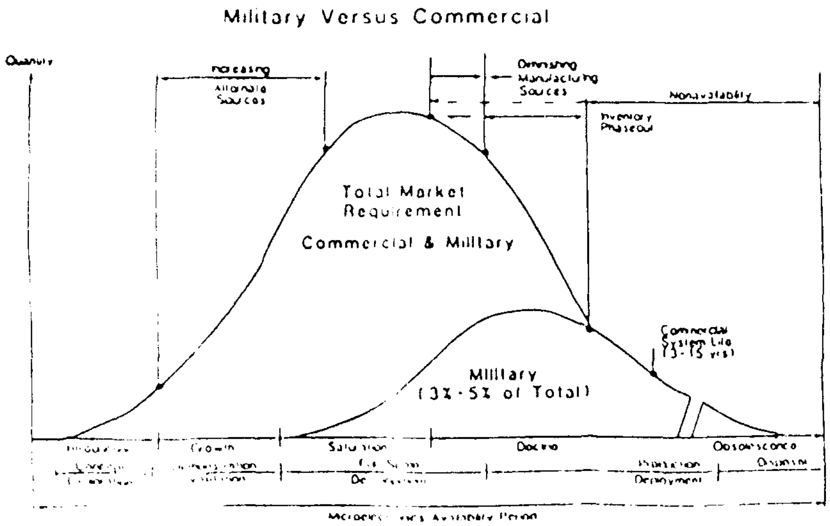
OBSOLESCENCE PROBLEM AREAS

* MANUFACTURING PROCESSES

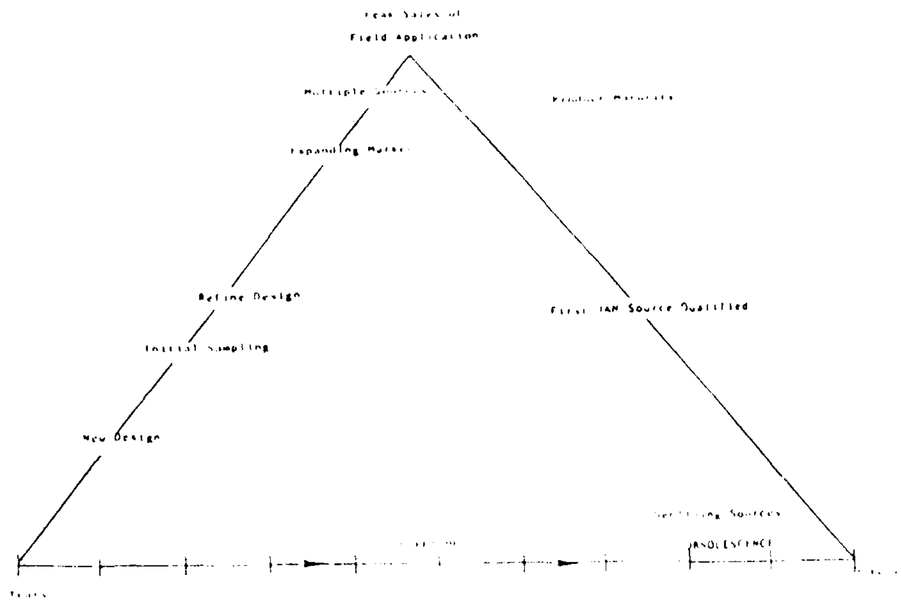
* DIMINISHED SOURCES:
  INTEGRATED CIRCUITS
  MATERIALS

* MANUFACTURING SOURCES:
  FOREIGN
  DOMESTIC
  QUALIFICATION





PRODUCT LIFETIMES



IC LIFE CYCLE MODEL

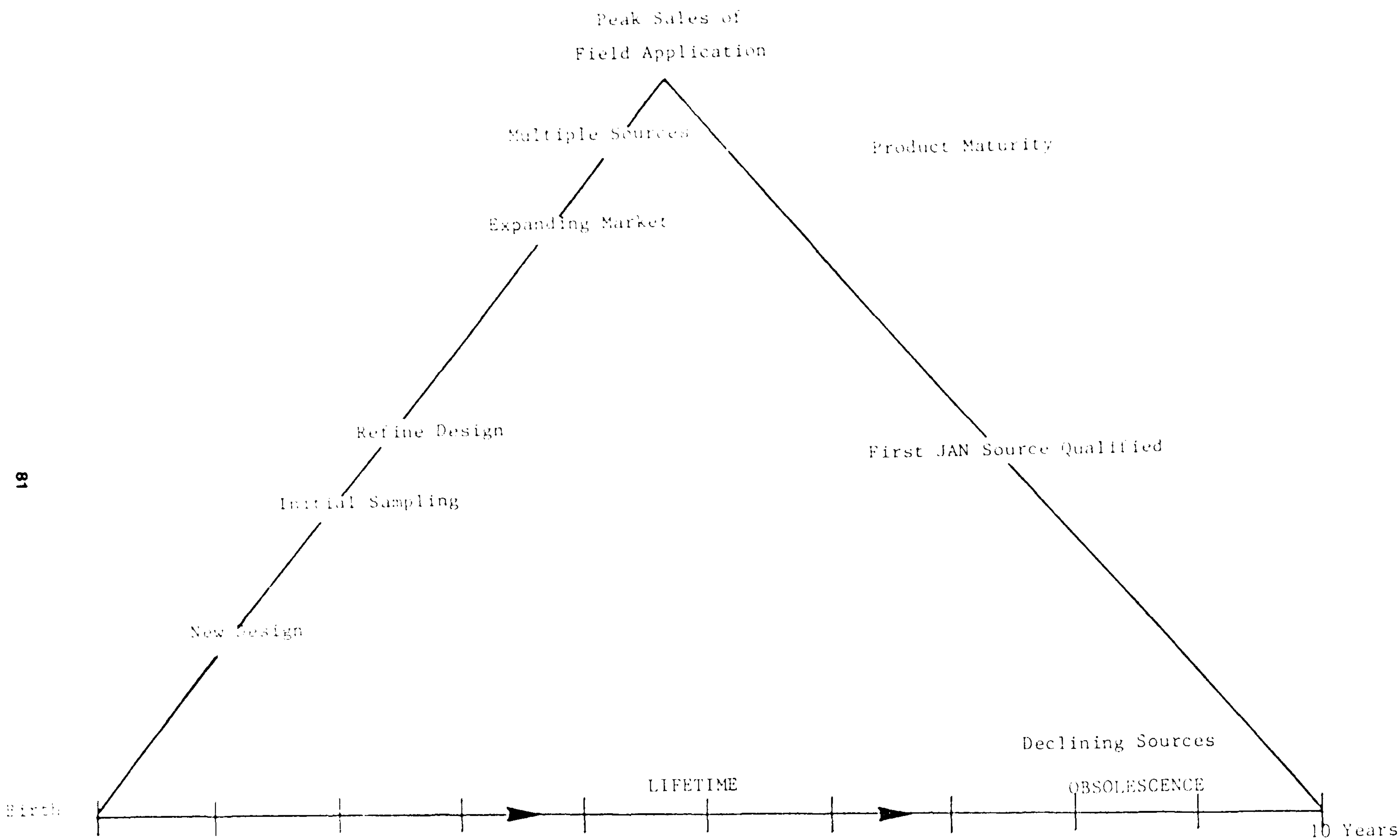
PRODUCT LIFE CYCLES

1. MICROCIRCUIT LIFE CYCLE 10 YEARS

2. FUNDING DICTATES 30 YEAR LIFE

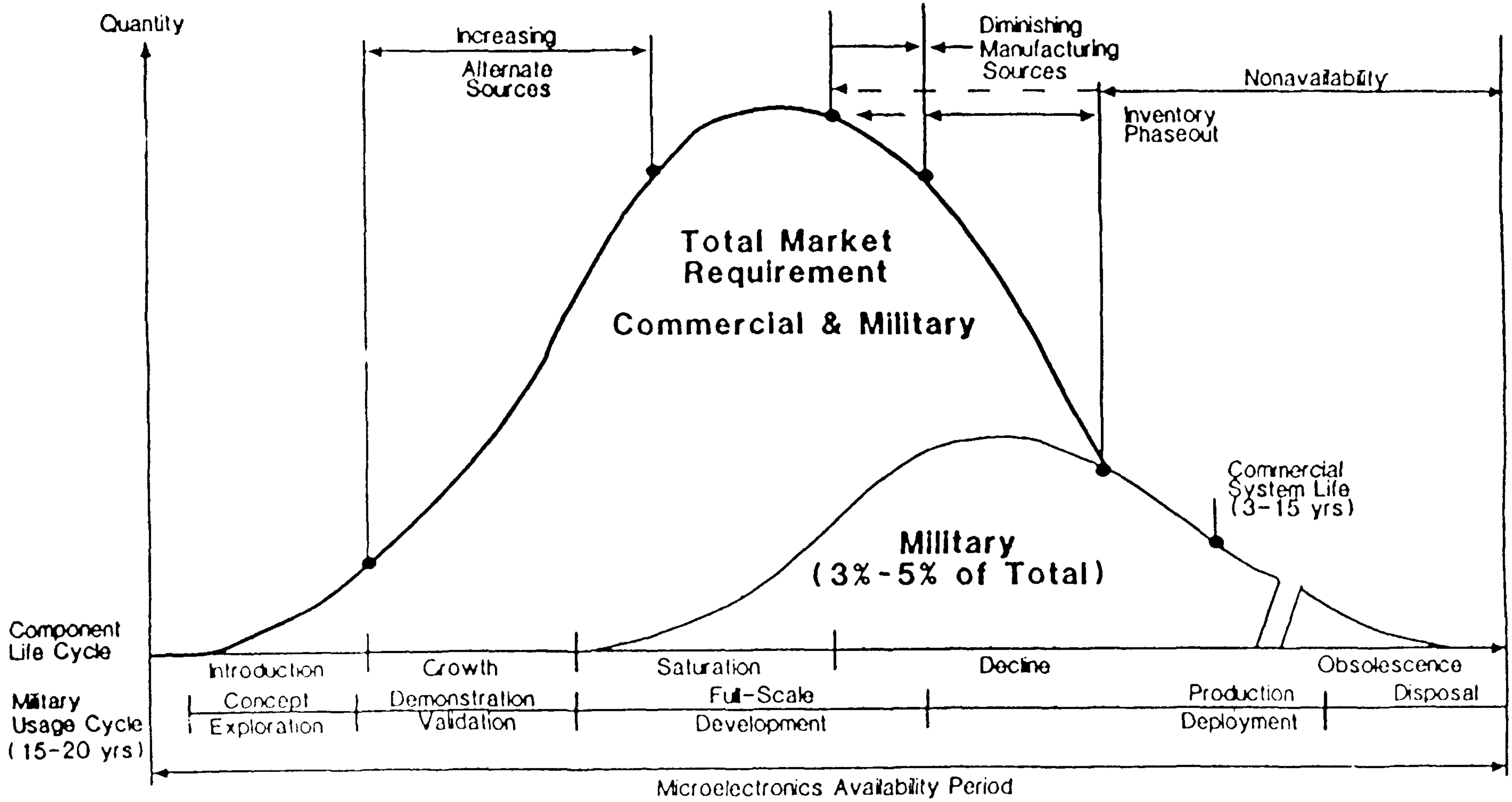
3. ADVANCED LONGEVITY REQUIRES DEALING WITH OBSOLESCENCE IN PAST AND PRESENT

4. COMPONENTS ONLY 5 YEARS OLD CAUSE MAJORITY OF PROBLEMS



IC LIFE-CYCLE MODEL

PRODUCT LIFETIMES
Military Versus Commercial



GOVERNMEMT DESIGN RULES INDUCE PROBLEMS

PRODUCT DEVELOPMENT AND DELIVERY CYCLES ARE LONG IN CONTRAST THE LIFE CYCLE FOR SEMICONDUCTOR TECHNOLOGY IS SHORT

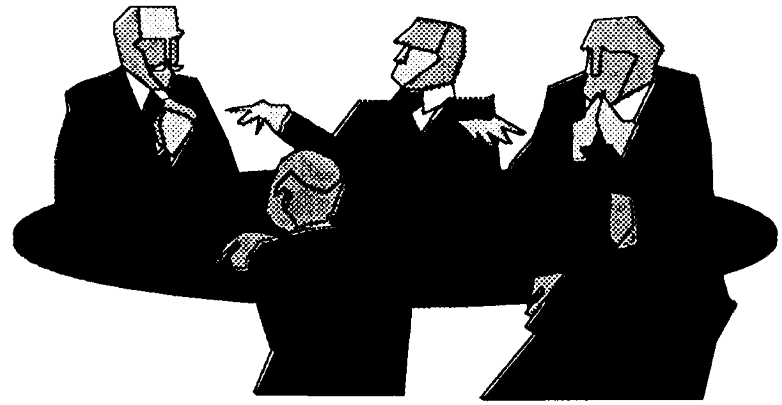
USE QUALIFIED STANDARD IC'S WHEREVER POSSIBLE

ONCE SYSTEMS AND SUBSYSTEMS ARE QUALIFIED NO CHANGES ARE TO TAKE PLACE IN PARTS CONTENT, MANUFACTURING, TESTING OR SCREENING

ACCEPTANCE OF A PART TO THE QPL OCCURS LATE IN THE LIFE CYCLE -- COMPOUNDING NONAVAILABILITY PROBLEMS

RESULT: WE FOSTER OBSOLESCENCE PROBLEMS

MICROELECTRONICS OBSOLESCENCE CAN BE MANAGED AND PLANNED FOR



EXISTING ENGINEERING EFFORTS CONSIST OF

1) REACTING TO TODAY'S OBSOLESCENCE PROBLEMS
2) PERFORMING TECHNICAL ASSESSMENTS ON SYSTEMS TO DETERMINE PRESENT AND FUTURE STATE(S) OF OBSOLESCENCE
3) MONITORING SYSTEM MICROCIRCUIT POPULATIONS AND TECHNOLOGY FOR DOWNTRENDS
4) DETERMINING THE "BEST" ALTERNATIVE TO INDIVIDUAL PROBLEMS
5) MAINTAINING EXPERTISE ON ELECTRONIC TECHNOLOGY DEVELOPMENTS

AVAILABLE OPTIONS

ALTERNATE SOURCES

SUBSTITUTION

MINOR ENGINEERING CHANGES

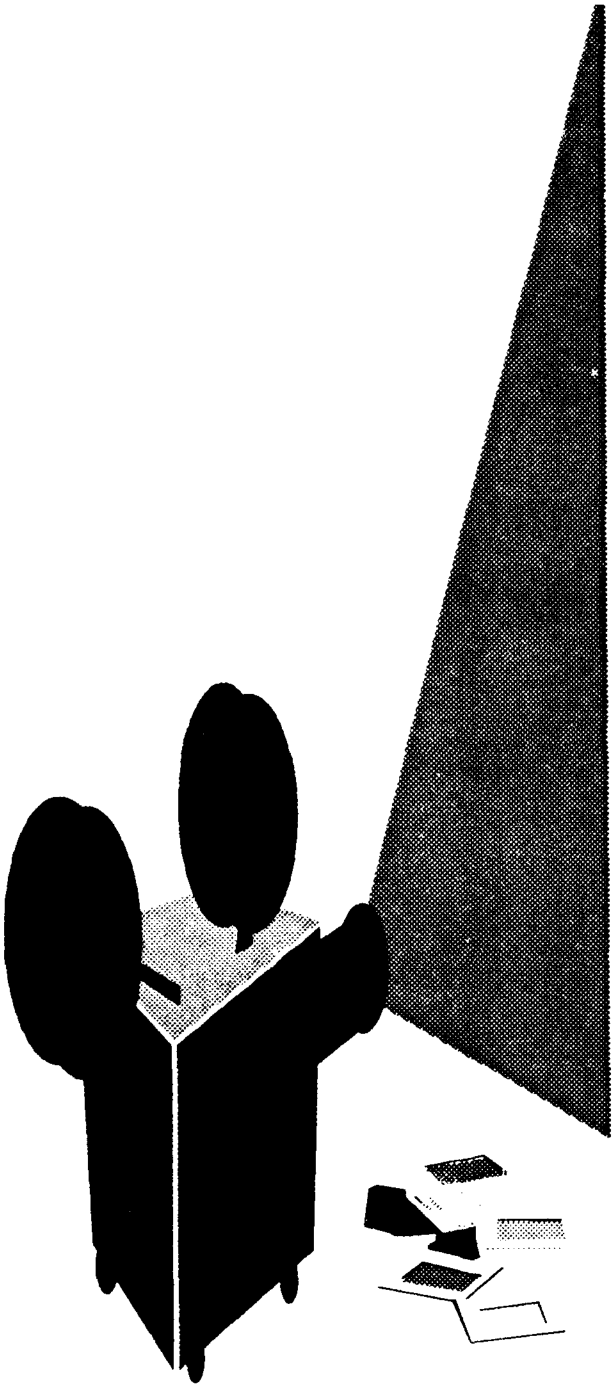
LOT BUY

AFTER -- MARKET OR SECONDARY SUPPLY

REVERSE ENGINEERING / MANUFACTURING

EMULATION

REDESIGN



RESOLUTION METHODS

* TECHNICAL ASSESMENTS -- SYSTEM / SPECIAL STUDY

* PRE -- DESIGN ANALYSIS:
  AVAILABILITY IN DESIGN TO PREVENT OBSOLESCENCE
  TECHNOLOGY AND COMPONENT TREND FORECASTING

* ALERT NOTIFICATION REACTION

* REPLACEMENT DECISION ANALYSIS:
  SUBSTITUTION
  LOT BUY
  ALTERNATE SOURCE
  DOCUMENTATION UPDATE -- PART QUALIFICATION
  EMULATION
  REDESIGN
  ALTERNATE MANUFACTURING PROCESS

* NONAVAILABILITY INVESTIGATION / ACTION:
  ANALYZE PROCUREMENT PROBLEMS TO AID PURCHASE

CONCLUSIONS

* TECHNOLOGY WILL ADVANCE
* OBSOLESCENCE CAN BE MANAGED BY USING OPTIONS / ALTERNATIVES
* PROACTIVE MANAGEMENT

  IDENTIFY OBSOLETE TRENDS AND FORECAST OCCURANCE

  TECHNICAL ASSESSMENT OF PRESENT STATE OF OBSOLESCENCE

MLRS MICROCIRCUIT OBSOLESCENCE LOGISTICAL RESEARCH AND DEVELOPMENT INITIATIVE

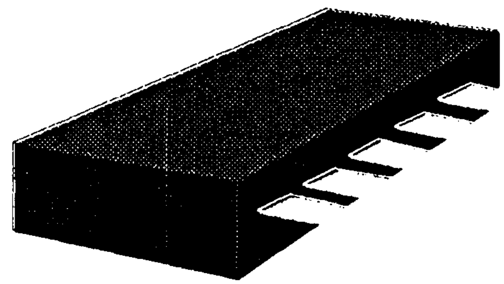
ABSTRACT

by David Moultrie

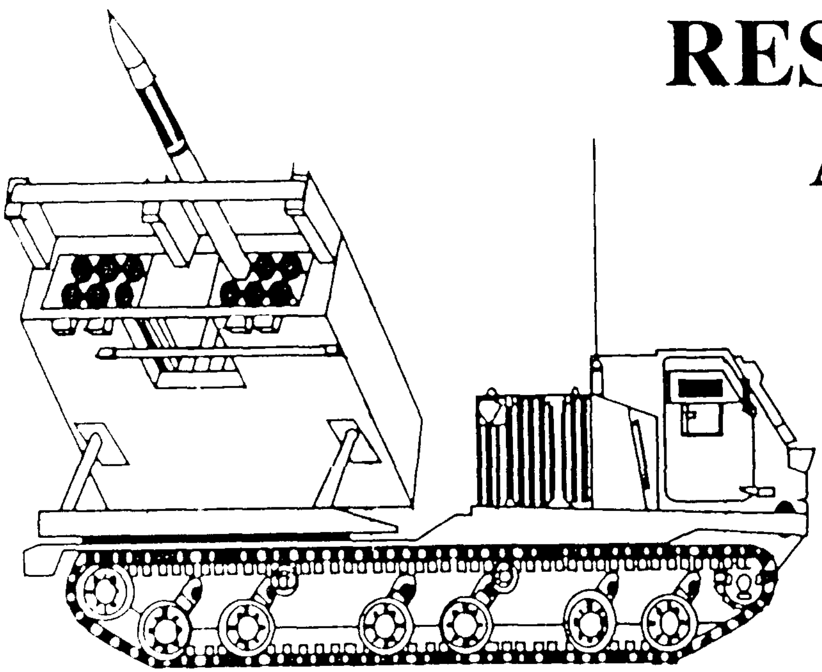
This paper presents a case history of the decisions and steps necessary to complete the MLRS Microcircuit Obsolescence Analysis. This type of analysis is a relatively new development in weapon system management. Microcircuit technology is advancing at an ever increasing rate and is producing more cases of obsolescence than ever before. This situation makes obsolescence management more important and essential for all systems.

This paper presents how problem identification, future problem prediction and problem corrections were made for the MLRS system. Special emphasis was made on Source Control Drawings (SCDs) and those microcircuits that were categorized as present and near future problems.

Many problems are being corrected (sometimes before they occur) by utilizing the presented options. The corrective options can be as simple as part substitution or as complex as an ASIC redesign of a circuit card. This paper will demonstrate a case study for one system.



MLRS MICROCIRCUT OBSOLESCENCE LOGISTICAL RESEARCH AND DEVELOPMENT INITIATIVE



HISTORY OF MLRS STUDY

Because of problems with microcircuit repair parts procurement, General Cianciola assigned Industrial Operations the task of aiding in the non--procurable microcircuit arena.

Industrial Operations created the Microelectronics Section to aide in this area. This new group's first actions were to aide Procurement in strategies to obtain the parts. After initial successes, it became apparent that many of the microcircuits were truly obsolete.

The Microelectronics Section canvased industry and other Defense Agencies to find out what solutions are available. The Microelectronics Section formulated its own strategies from what it learned and reported its findings to the MICOM community.

The MLRS project office was experiencing microcircuit obsolescence conditions and they contacted IO about performing an assessment on their system. The study was then commissioned.

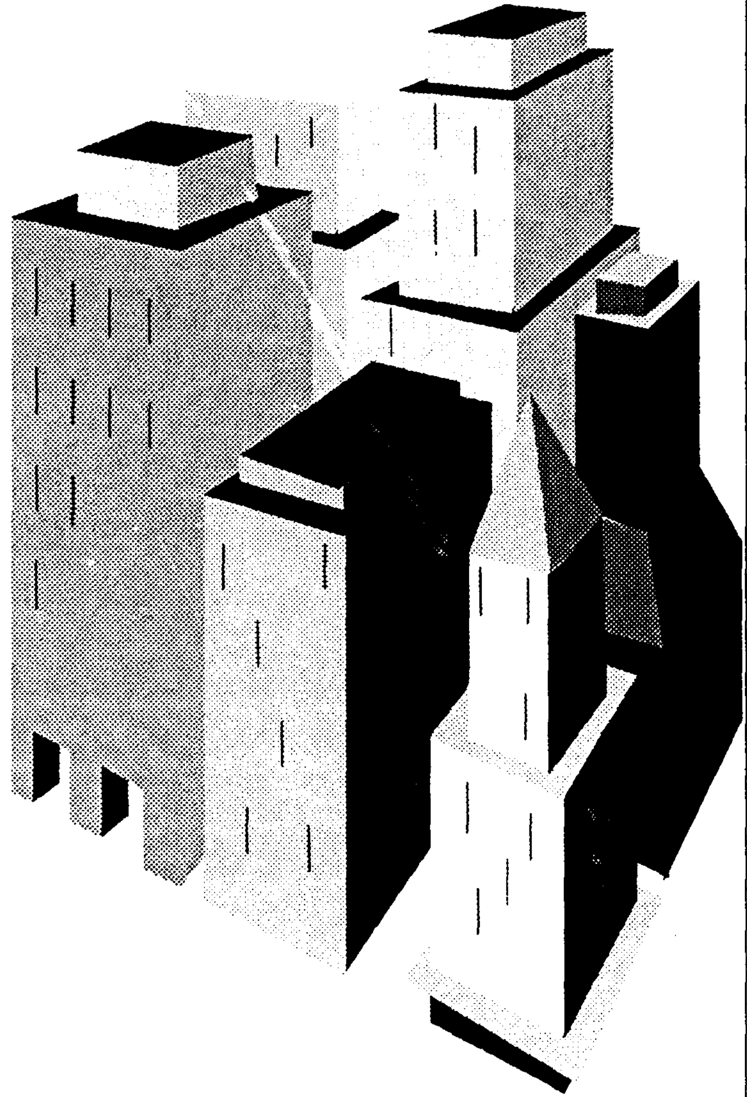
ANALYSIS STRUCTURE

TASK A

PROBLEM MICROCIRCUIT
CATEGORIZATION
AND IDENTIFICATION

TASK B

PROBLEM MICROCIRCUIT
CORRECTION OPTIONS,
COST PREDICTIONS, AND
FINAL RECOMMENDATIONS



TASK A

PART IDENTIFICATION

DATA GATHERING

PART ANALYSIS

TASK A

PART IDENTIFICATION

* MICROCIRCUIT LIST PROVIDED BY MLRS PROJECT OFFICE
* DETERMINE MANUFACTURER'S PART NUMBER FROM SCDS
* IDENTIFIED OTHER PART NUMBERS: MIL-M-38510 AND DESC

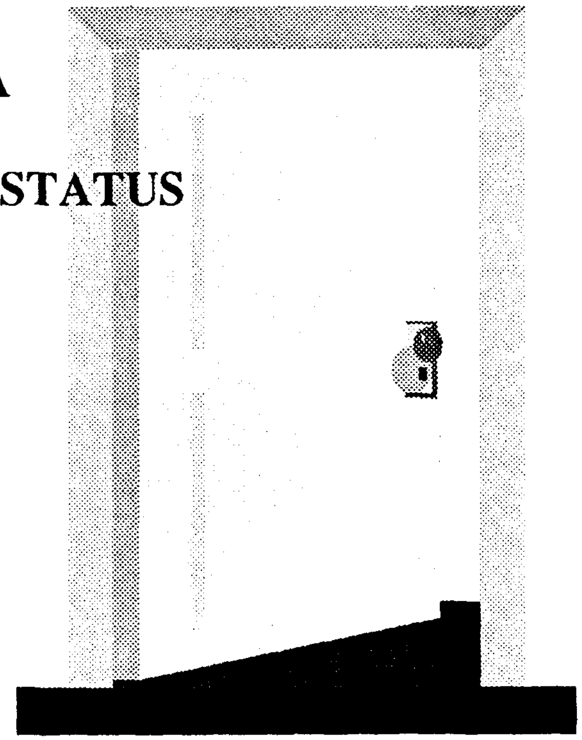
TASK A

DATA GATHERING

* CAPS, MANUFACTURERS, AND VENDORS FOR PART AVAILABILITY STATUS
* TACTECH FOR PREDICTION OF FUTURE AVAILABILITY
* VENDORS CATALOGS FOR TECHNICAL DATA

FUTURE SOURCES OF DATA

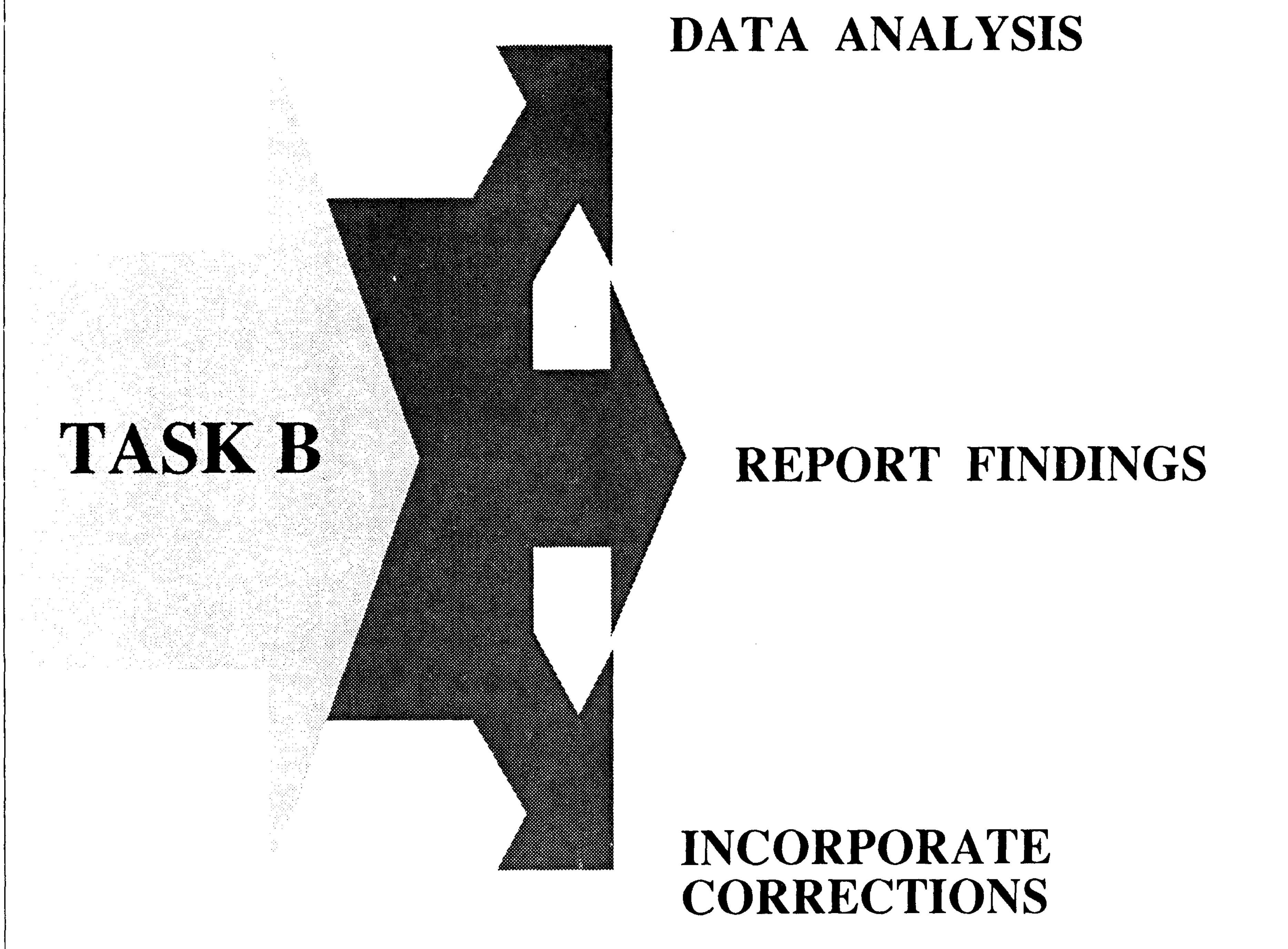
* IHS CD-ROM FOR PART AVAILABILITY STATUS
* CCSS FOR PART USAGE INFORMATION
* NAC, NAVAL AVIONICS COMMAND



TASK A

PART ANALYSIS

* DRAW CONCLUSIONS ON AVAILABILITY AND PROVIDE PREDICTION ON HOW LONG PART WILL REMAIN AVAILABLE IN MARKETPLACE
* RECONTACT DATA SOURCES IF WARRANTED
* CAPTURE ALL INFORMATION IN AN AUTOMATED DATA BASE
* COMPILE A LIST OF MICROCIRCUITS THAT ARE OBSOLETE OR MAY BECOME OBSOLETE WITHIN TWO AND A HALF YEARS OR LESS


TASK B
DATA ANALYSIS
REPORT FINDINGS
INCORPORATE CORRECTIONS

TASK B

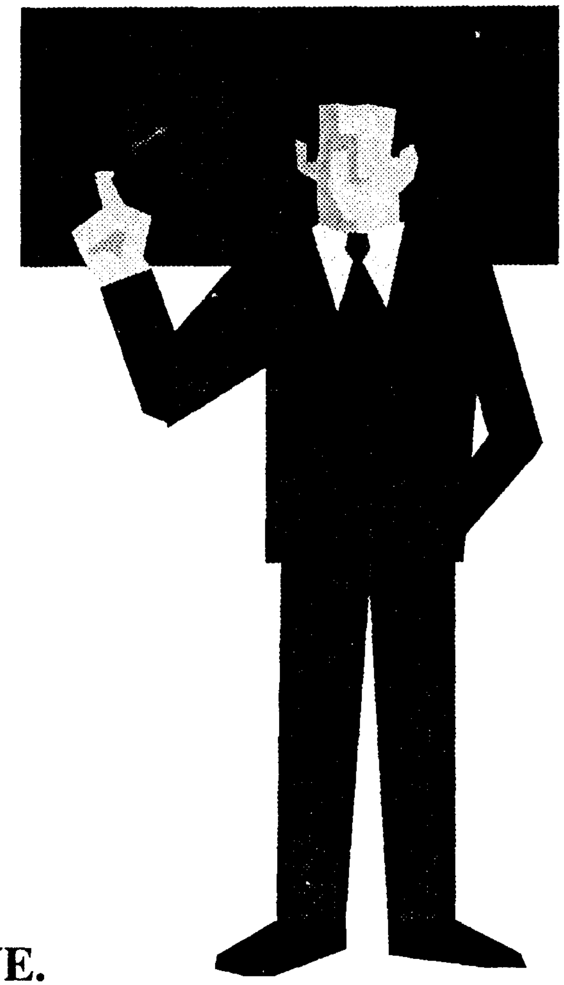
DATA ANALYSIS

* BUILT A MATRIX SHOWING PROBLEM MICROCIRCUIT USAGE (BOARD AND LRU LEVEL)

* QUERY DATA SOURCE FOR SUBSTITUTE PART CANDIDATES

* VALIDATE SUBSTITUTE PART. DETERMINE LEVEL OF TESTING REQUIRED TO CERTIFY. GIVE PREDICTION OF SUBSTITUTE PART AVAILABILITY.

* FOR REMAINING PROBLEM MICROCIRCUITS, PERFORM A TRADE OFF ANALYSIS TO SEE IF MICROCIRCUIT EMULATION, LIFE OF TYPE BUYS, BOARD REDESIGN, AFTER MARKET SUPPLIER OR BOARD ASIC REDESIGN IS THE BEST VALUE.



TASK B

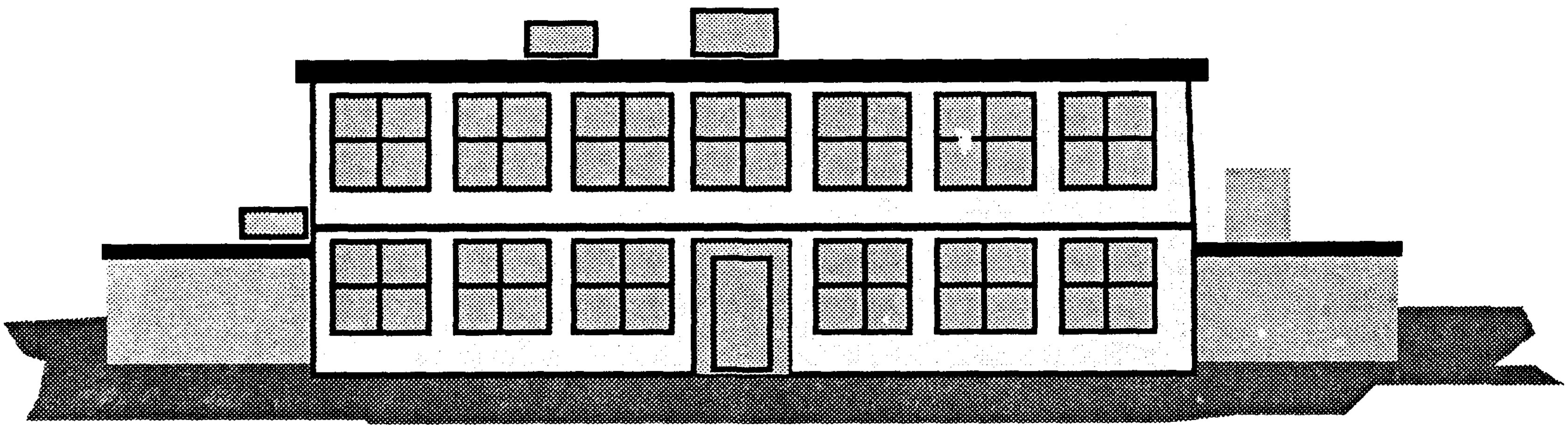
REPORT FINDINGS

* MLRS PROJECT OFFICE
* SELECT INDUSTRY - AND OTHERS

TASK B

INCORPORATE CORRECTIONS

* CIRCUIT CARD ASIC REDESIGN
* OTHER CONFIGURATION UPDATES, COORDINATED WITH PRIME CONTRACTOR AND OTHERS
* MAINTAIN CURRENT DATA BASE FOR FUTURE ANALYSIS



A DECISION SUPPORT SYSTEM FOR LOGISTICS IMPACT ASSESSMENT

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TASC, Reading, Massachusetts 01867

ABSTRACT

Budget reductions, diminishing and changing threat scenarios, and political pressures are forcing the way DoD acquires and manages weapon systems. The Army is not immune to these conditions. In the future there will be fewer people to perform logistics functions and fewer dollars to support existing and planned systems.

To overcome current and future logistics challenges, engineers and managers will find utility in decision aids and tools that help them to make cost-effective choices. This paper describes the conceptual framework, implementation and application of a Logistics Decision Support System (LDSS). The LDSS provides an analytic platform for quantifying the logistics metrics of a program and any of it's competing alternatives.

LDSS consists of a PC-based engineering workstation which hosts source and output databases and analytic and simulation models for conducting logistics analysis. Functional capabilities addressed by LDSS include:

- A Combat Capability Assessment model for projecting system readiness under steady-state and surge conditions as a function of logistics resources and mission parameters
- Life-Cycle Cost (LCC) and Economic Analysis models for projecting and comparing costs of alternative design, support and acquisition strategies
- A Reliability model for estimating reliability and performing sensitivity analysis on simple and complex networks
- A Test Resources Requirements model for assessing Unit Under Test (UUT) throughput at various levels of maintenance as a function of test equipment, manpower and other test resource parameters.

OVERVIEW

The structure of the Logistics Decision Support System (LDSS) consists of three basic components – the user interface, the database, and the model base (see Fig. 1).

The user interface is the most visible component to users. It links them with both the database and the model base. The key element in the development of the user interface is user friendliness. Users need to feel comfortable with the system in order to use it. Some of the features that enhance user friendliness include:

- Selection menus
- Full screen data entry and review
- On-line help
- Automated file or database management
- Query and search capabilities
- Tabular and graphics displays.

Integrating these features into the user interface increase its functionality and acceptability to the user which in turn increases the usefulness of the entire system.

The database serves as a repository of both model inputs and outputs. The main function of the database is storage and retrieval of this data which can be done using a formal Database Management System (DBMS). Defining the specific data elements to be stored and the data structures to be used are the most important steps in developing this database. CALS data collection and management initiatives are providing a solid foundation for this effort. Other data sources include the Logistics Support Analysis Record (LSAR) for new systems, and Army data collection systems such as Standard Army Management Information System (STAMIS) for fielded systems.

Five major categories of data are required for logistics impact assessment. They include: *parts data, support equipment data, operational data, standard cost factors, and scenario data*. Parts specific data consist of reliability, maintainability and cost parameters such as failure rates, repair rates, repair

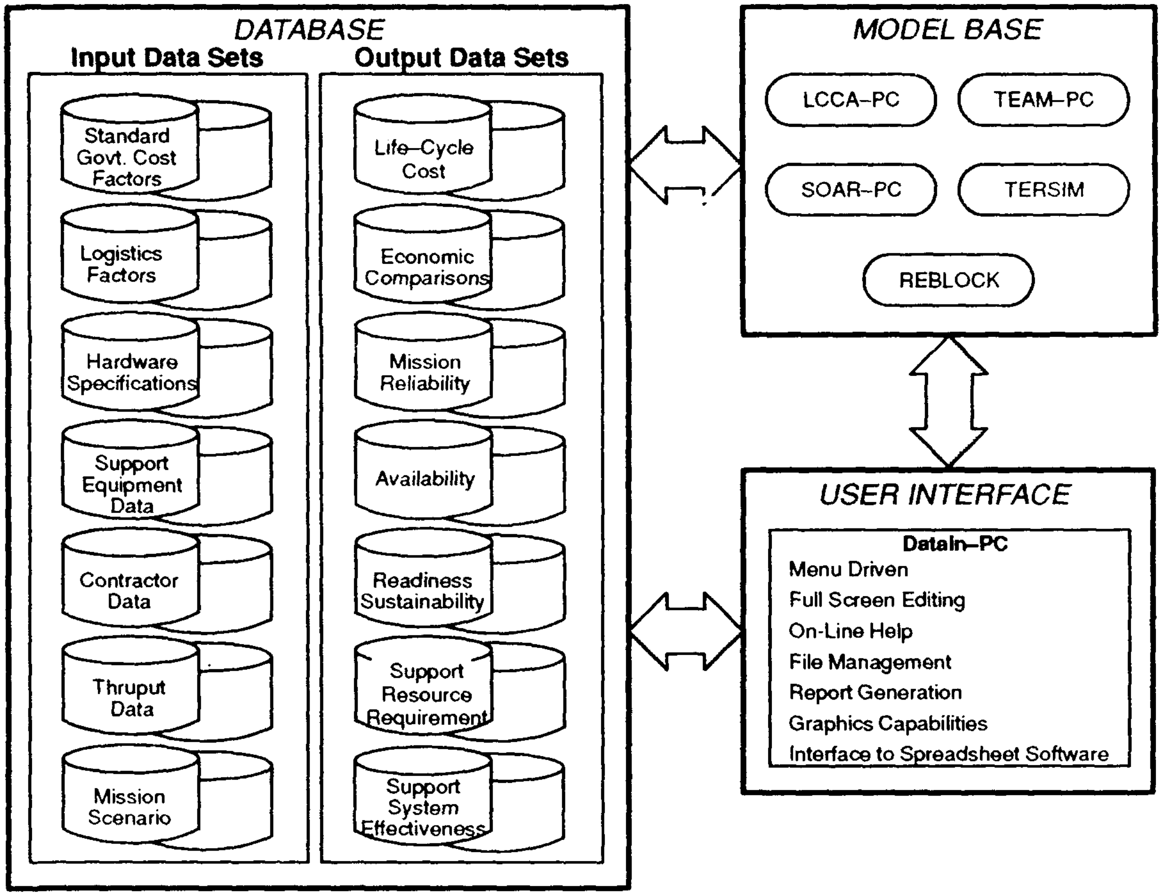

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Figure 1 Logistics Engineering Workstation

times, minimum spares levels, unit cost and repair cost. Support equipment data includes these types of parameters plus throughput rates, deployable quantities and availability requirements. Operational data includes operational parameters such as number of systems, mission length, mission requirements, abort rates, attrition rates, base repair capabilities and spares pipeline delay times. Standard cost factors are constants used during all evaluations such as labor rates and shipping costs. Finally, scenario data consists of parameters such as peacetime and wartime operating conditions, single or multiple base operations, two-level versus three-level maintenance, etc.

The model base contains a set of models, algorithms and processors required to evaluate logistics impact assessment measures of merit from the input data available in the database. For logistics impact assessment, the components of the model base should fit into the following categories:

- Mission Effectiveness
- Support System Effectiveness
- Mission Reliability/Availability
- Readiness/Sustainability
- Requirements Assessment (Spares, Support Equipment, and Manpower)
- Life-Cycle Cost/Economic Analysis.

The nature of logistics impact assessment tends to support the development of a model base that emphasizes simple and flexible tools. Sacrificing detailed analysis for ease of use and flexibility provides users with the ability to quickly evaluate the relative merits of several competing alternatives. Once decisions have been made, more detailed studies may be in order to capture the absolute impacts on goals. The model base must also be tailored to fit the application for which it is being designed. Therefore, techniques which are flexible or can be modified to fit various applications provide a more robust solution for a general model base design.

MODEL BASE

The models presented in this section represent the types of tools suited to the development of a model base for logistics impact assessment. The five models discussed are:

- SOAR™ (Simulation of Operational Availability/Readiness)

- TERSIM™ (Test Equipment Requirements Simulation)
- LCCA™ (Life-Cycle Cost Analyzer)
- TEAM (TASC's Economic Analysis Methodology)
- REBLOCK (REliability BLOCK Diagram Analysis Tool).

These models are by no means the only tools applicable to the problem and may not constitute a complete model base for all applications, however, they provide a basis for highlighting issues of significance.

SOAR

The SOAR model was developed as a general readiness and sustainability model for avionics systems. Like most readiness and sustainability models, it is based on the dynamic Palm's theorem, which was extended and made more flexible by implementing it within the framework of a systems dynamics model. Systems dynamics modeling uses continuous simulation to model the complicated interactions and feedback mechanisms prevalent within complex logistics systems. The simulation describe the dynamics of aircraft operations and maintenance processes with particular focus on the weapon system or subsystem under study. As the simulation progresses through time, state variables change based on rates (i.e., faulty units, repaired items, spares demands, etc.) which describe the dynamics of the system. Analytic relationships are used to calculate these rates based on the current value of key state variables (such as available stock levels and expected backorders) and inherent weapon system characteristics (such as reliability and maintainability). The flexibility provided by this approach allows the generic SOAR model to be tailored to several mission types (tactical fighter, bombing, airlift) and various support concepts.

The SOAR model consists of several modules, which address sortie operations, O-level maintenance and I-level maintenance. Figure 2 presents a general overview of how these modules work together and the parameters that affect model results.

SOAR generates three categories of results: mission availability, aircraft status, and support system status. Mission availability relates to the number of sorties or missions generated throughout the scenario or on a daily basis. Aircraft status measures include Fully Mission Capable (FMC), and not mission capable rates due to supply (NMCS) and maintenance (NMCM). Support system measures include: Expected Backorders (EBOs), awaiting maintenance and due in from depot quantities by Line Replaceable Unit (LRU), and repair queue length by support equipment. The nature of the systems dynamics approach also allows the flexibility to tailor results for other mission types.

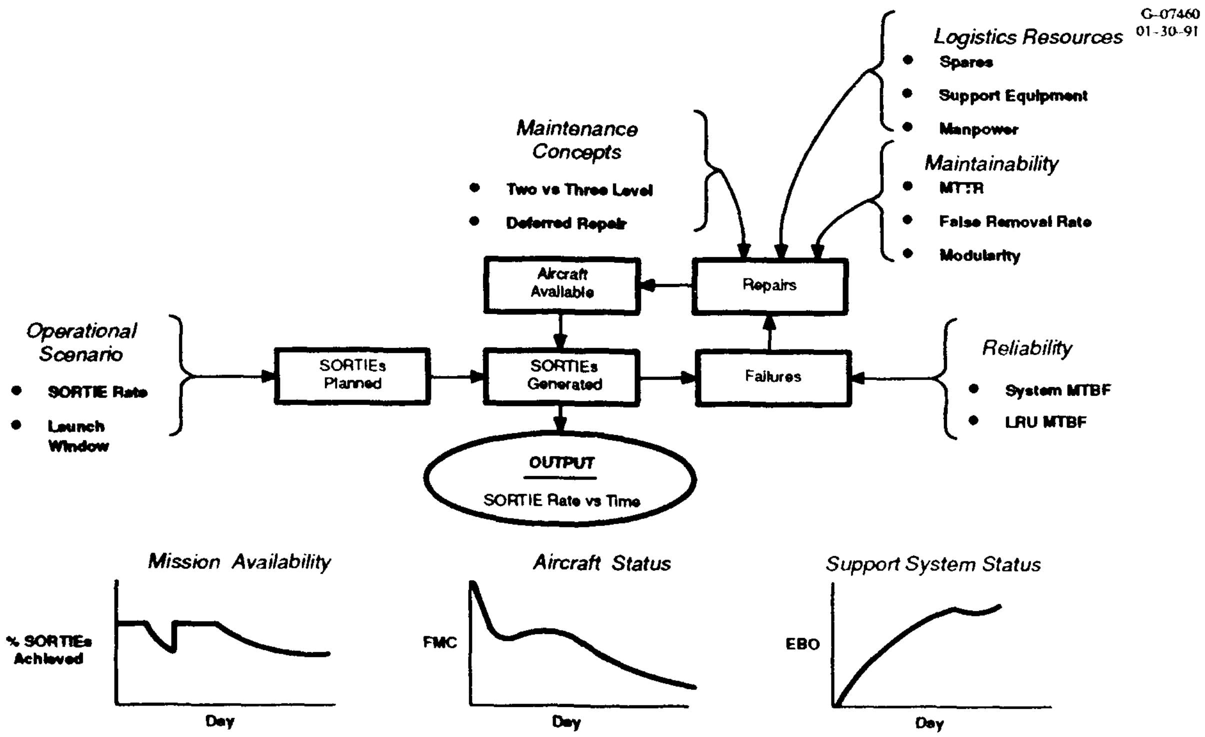

Figure 2 Overview of the SOAR Model

SOAR, LCCA and TERSIM are trademarks of The Analytic Sciences Corporation

TERSIM

The effectiveness of maintenance shops have a significant mpact on logistics support capabilities. In order to efficiently lan Automatic Test Equipment (ATE) acquisition and better alocate resources, rigorous analytic techniques are required to nalyze the throughput and utilization of maintenance shops. TERSIM meets this requirement through the use of discrete vent (Monte Carlo) simulation modeling. Figure 3 provides an overview of this model.

The model uses an empirical distribution of historical LRU arrivals to generate Unit Under Test (UUT) arrivals. UUTs can be tested on single or multiple testers based on pre-specified priorities. Heuristics embedded in the model implement these priorities.

The model sets up a separate queue for each tester. The size of the queue backlog is measured in terms of the time required to est all UUTs in the queue. The UUTs in each queue are processed in a First-In-First-Out (FIFO) order. In addition the model sets up separate queues for each piece of ancillary equipment. The model checks for all required resources and queues the UUT for missing resources. As resources are released it checks the existing queues for UUTs waiting for those resources and processes them.

Parallel to the UUT portion of the model, the causes of test station downtime are modeled. These include schedule confidence tests, test equipment, and ancillary equipment failures and scheduled maintenance and calibration activities. The times to perform these activities are input variables and are assumed to be constant. Equipment failures occur based on their Mean Time Between Failure (MTBF), assumed to be exponentially distributed. Two types of failures on test equipment are modeled: critical failures where the test being run is halted and the tester is immediately repaired, and non-critical failures where the test being run is completed before the test station is repaired. Scheduled maintenance (including calibration actions) is performed based on the interval between scheduled maintenance and the average time to perform this maintenance. Maintenance is performed on each tester at the time it is scheduled if the tester is not in use, or, if a UUT test is being run, the maintenance is performed at the completion of that test. Model outputs are shown in Table 1.

LCCA (LIFE-CYCLE COST ANALYZER)

Life-cycle cost (LCC) plays an important role in the assessing logistics impacts. Improvements in weapon system R&M typically increase acquisition costs through the use of high quality parts, stress screening, Test-Analyze-Fix (TAF) programs, etc. Savings, however, are accrued in O&S costs as a result of lower maintenance and spares requirements due to R&M improvements. In addition, the options, of additional test equipment quantities, increased mobilization, higher spares quantities, and other support resources alternatives impact LCC as well as decision criteria. Thus the goal of decreasing costs needs to be balanced with the other requirements in order to arrive at a cost-effective solution.

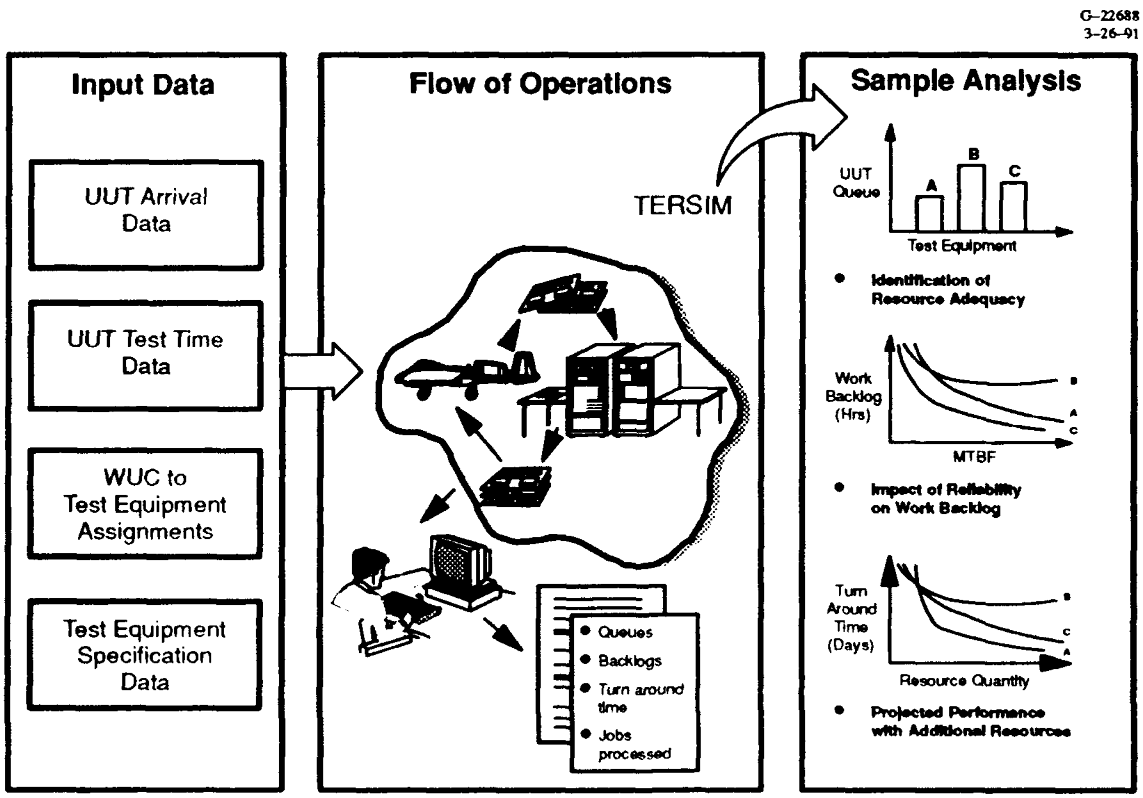

Figure 3 TERSIM Overview

LCCA is a generic life-cycle cost model used for front-end system design and analysis. LCCA has been applied since the mid-1970s to numerous acquisition programs, in source selections and has been widely used by both Government and industry. A training version of the model is being used by the Society of Logistics Engineers (SOLE) to teach a 40-hours, week-long LCC workshop. As depicted in Fig. 4, LCCA is an interactive LCC analysis tool.

In defining the input data the LCCA user must make a number of decisions relating to the deployment and support of the system under study as well as its hardware characteristics. The number and location of sites at which the system is to be deployed, the number of support echelons, specification of the repair, and capabilities of each repair site, along with operating rates and support factors, are defined via the input files. Hardware characteristics are defined in terms of R&M parameters, and system architecture and support requirements. Given these inputs, the program automatically allocates the support resources (spares, manpower, support equipment, etc.) to the particular maintenance echelon selected and computes the associated cost. Logic switches embedded in the cost equations and specified for each hardware item are used to account for the flow of maintenance actions at each repair location. Resource and cost requirements are computed accordingly.

The sensitivity of cost elements to variations in MTBF, repair rates, Built In Test Equipment (BITE), etc., can be easily analyzed with the automatic sensitivity analysis capability. This feature is used to generate changes to maintenance and design parameters and thus provide cost sensitivities to parameter variations. Other model features include unit cost weighted sparing and warranty effects analysis.

Table 1 TERSIM Outputs

METRIC	DESCRIPTION
Average Queue Time in Facility	Time-weighted average number of days each UUT is delayed in queue
Sample Variance	Sample variability S^2 in average time in facility
Average Queue	Time-weighted average number of UUTs awaiting maintenance from each resource
Maximum Queue	Maximum queue length for each resource
Final Queue	Number of UUTs queued for each resource at the end of a replication
Average Backlog	Time-weighted average of the time required to process all jobs queued for each resource

TEAM

Economic decision analysis as applied to weapon system management has been found to be particularly useful in evaluating the cost-effectiveness of implementing modification or replacement programs for existing, in-service systems. To be cost-effective, operating and support (O&S) savings as a result of R&M improvements (or other improvements) must offset the investment cost to acquire the proposed modification/replacement. TEAM was developed to compare the life-cycle costs (LCC) associated with the existing and proposed strategies and report amortization period and total cost impact statistics. Figure 5 presents representative analysis results.

TEAM automates the process of comparing the LCCs of competing strategies — the existing system referred to as the baseline or defender and the proposed mod/replacement referred to as the alternative or the challenger. TEAM requires as input the yearly cost streams of each strategy under consideration. In the LDSS architecture, LCCA is used to provide these streams. Only recurring O&S costs are relevant for the baseline system. Acquisition cost are considered to be sunk. The cost to develop, produce, operate, and support as applicable are relevant for the alternative. TEAM conducts the comparison using breakeven or differential costing in terms of constant, inflated or discounted dollars. The model also considers schedules in producing its adjusted cost stream and thus the cost comparison to more accurately reflect what it costs to simultaneously acquire a mod/replacement while maintaining the existing system. TEAM results are produced in spreadsheet formats to allow for subsequent analyses and results reporting.

REBLOCK

REBLOCK is a REliability block diagram analysis tool developed to assist the engineer in the areas of system reliability prediction and sensitivity analysis (see Fig. 6). REBLOCK uses a hierarchy of reliability block diagrams or networks to model any general system configuration including series, parallel, and non-series parallel systems. Failures are modeled at the component level, using the Exponential, Weibull, Log-normal, and Gamma distributions. REBLOCK computes reliability predictions and sensitivity measures for each level of the hierarchy.

REBLOCK is based on the structure breakdown of a system into a hierarchy. The levels of this hierarchy are: system, subsystem, assembly, and component. This hierarchy allows the user to assess the following:

- Reliability at the system, subsystem, and assembly level
- The impact of changes to lower level reliabilities on higher level reliabilities
- Tradeoff among subsystem, assembly, and component reliabilities.

The system represents the top level in the REBLOCK modeling hierarchy. It can range in scope from a single box (LRU) to an entire missile system. Systems are defined as a set

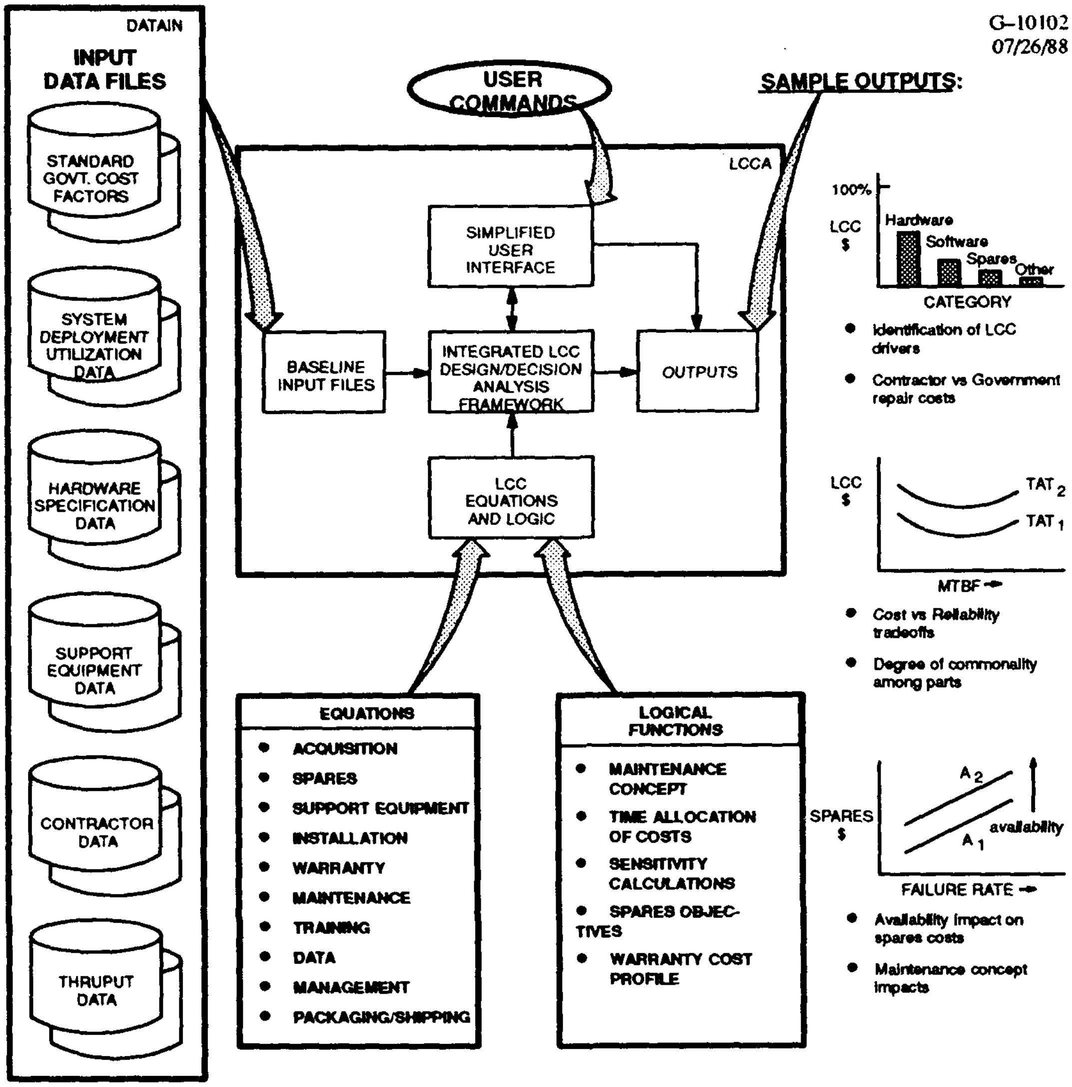

Figure 4 Life-Cycle Cost Analyzer (LCCA) Overview

of subsystems linked together as a network. Each subsystem is associated with a specific mission critical function and is comprised of multiple subassemblies. Subassemblies are made up of components which represent the lowest level in the REBLOCK hierarchy.

The mathematical foundation of REBLOCK is based on reliability block diagram analysis which calculates network reliability in the form of bounds. Bounds are calculated in lieu of exact values to minimize extensive numerical processing. The data used to calculate these reliability bounds include the network structure and component reliabilities within the network.

In addition to calculating the reliability of a network, it is desirable to calculate the sensitivity of a networks reliability to changes in component reliabilities. When the underlying network is coherent, and all component reliabilities are less than 1.0 and greater than 0, this sensitivity measure corresponds to the partial derivative of system reliability with respect to component reliability. The higher the sensitivity value, the greater the system level response to a change in component reliability. This is commonly referred to as a measure of reliability significance.

Network reliabilities and sensitivities are calculated at each level within the hierarchy over a user specified operating period. Model outputs (reliabilities and sensitivity) can be generated at each level of the model hierarchy and at various intervals over the operating period. REBLOCK is typically used to perform design tradeoff studies and reliability predictions during conceptual design, detailed design, and testing.

CONCLUSION

The Logistics Decision Support System discussed in this paper is consistent with the supportability improvement/cost reduction initiatives promulgated by the Army and MICOM. By integrating *weapon system mission effectiveness* (in terms of reliability and readiness) with *support system effectiveness* (in terms of test equipment throughput and spares requirements) a balanced system design can be achieved at lowest life-cycle cost. Design changes can be made through system

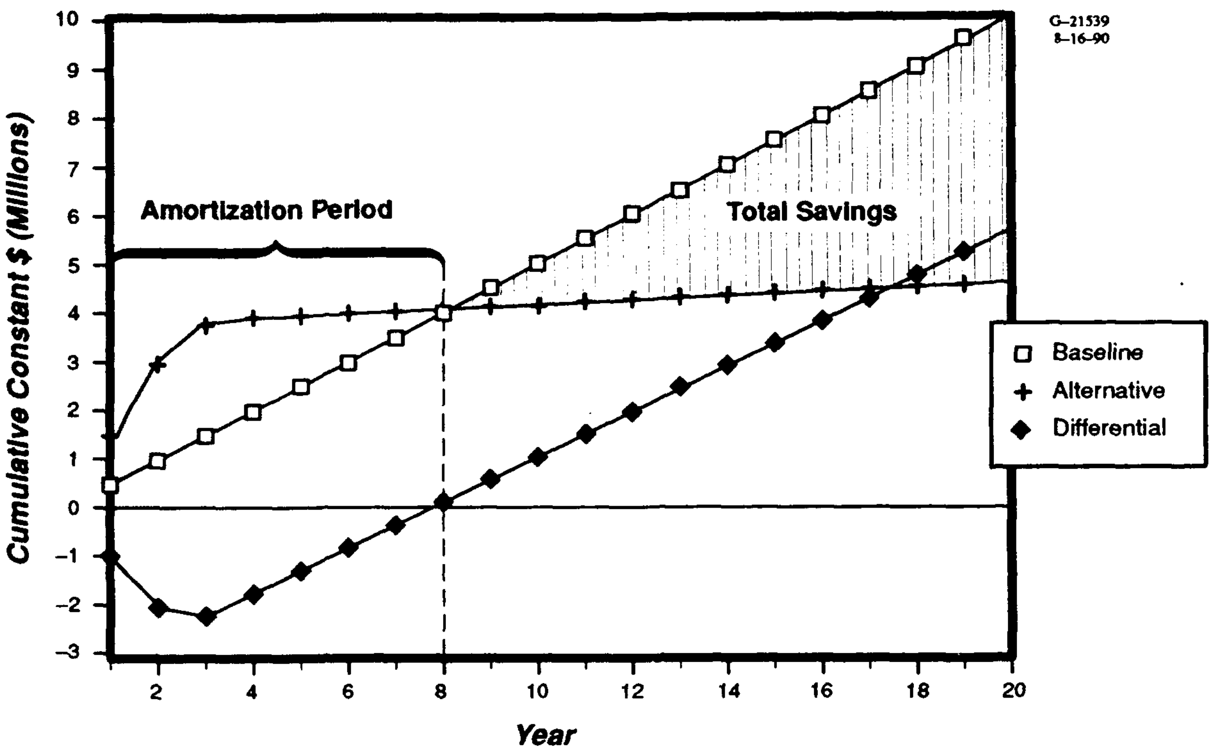

Figure 5 Representative Analysis Results

levelopment as the design matures. Once the weapon system is n production and fielded, modifications can be made consisent with O&S goals, utilizing the same methodology as in deign. Several benefits can be achieved with the LDSS:

- Integrated weapon system design or modification taking into account the critical design and support system parameters that impact LCC.
- Ties to Logistics Support Analysis Record (LSAR) to support weapon system development and to data systems (e.g., STAMIS) to support weapon system modification decisions.
- Quantification of Logistics objectives based on the critical design and support parameters.

In summary, the LDSS framework described in this paper is a powerful tool to accomplish logistics impact assessment during equipment life-cycle, planning, implementation, deployment and employment. Although this framework employs TASC developed tools, a suitable framework using Army models and databases — SESAME, OSAMM, CASA, STAMIS, etc. could be developed to address MICOM specific issues and goals.

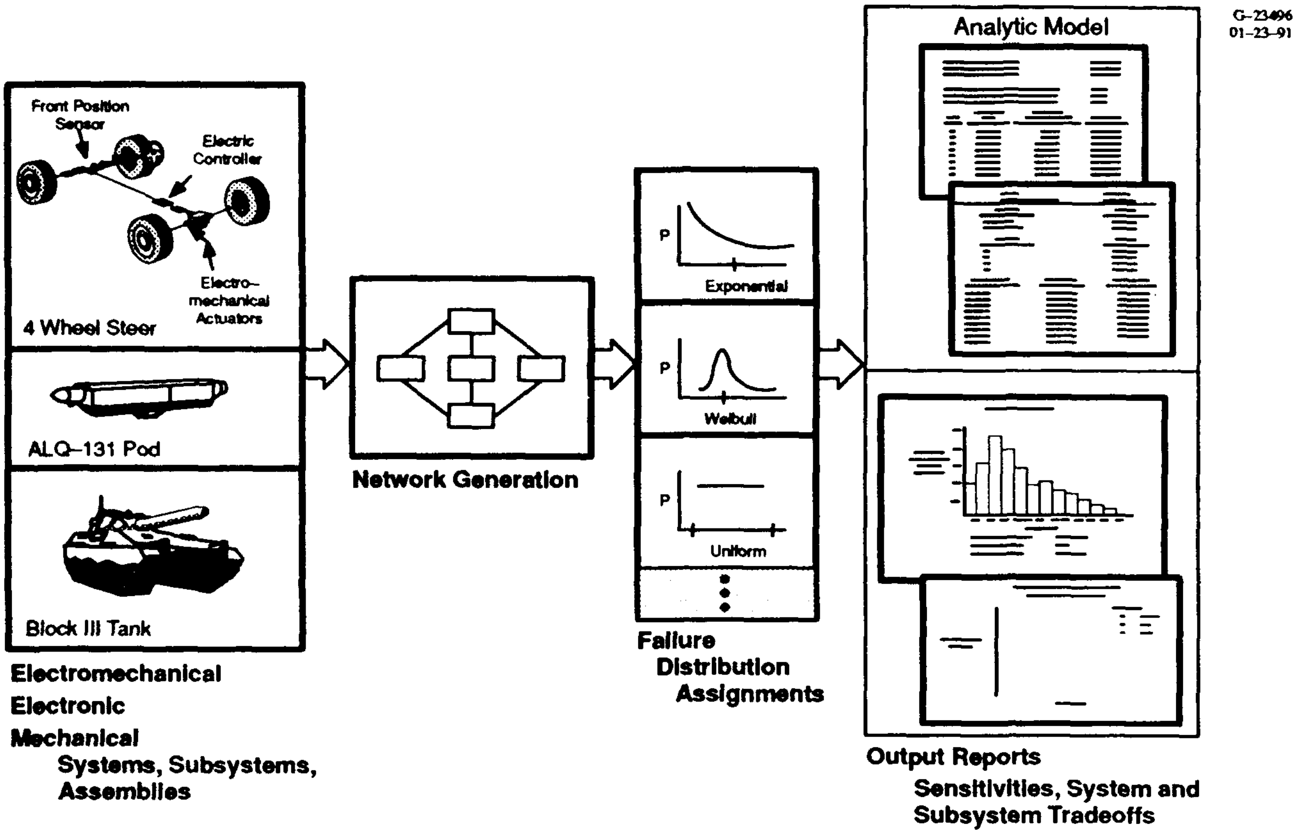

Figure 6 REBLOCK Overview

Impacts of Design for Testability

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U.S. Army Missile Command
Redstone Arsenal, Alabama

Testability of electronic circuits and systems is a key element in improving system readiness and reducing support costs. These are important factors as we look to the future for a meaner and leaner Army.

The entire support arena can benefit from such improvements. Two major areas to benefit from increased testability is the Test Program Set (TPS) area and the Built-in-Test (BIT) on operational systems.

As we look at the present requirements for large, complex Automatic Test Equipment (ATE) stations and the development of massive numbers of Interconnecting Devices (ICDs) to interface to the Units Under Test (UUTs), we must ask, "Is there a better way?". Increased testability would lead to a downsizing of the ATE and possible elimination of costly ICD development and support. Also, a reduction in the complexity of the test software would be realized.

In the BIT arena currently, the entire system may not be tested and requires augmentation by special ATE. As the device complexity increases we must address testability in the earliest stages of design. Many cost savings can be realized as a result of these efforts.

Impacts of Design for Testability

- Testability - A Management Perspective
- Testability Impacts on Built-In-Test (BIT)
- Testability Impacts on Test Program Sets (TPSs)
- The Shift

FIGURE 1

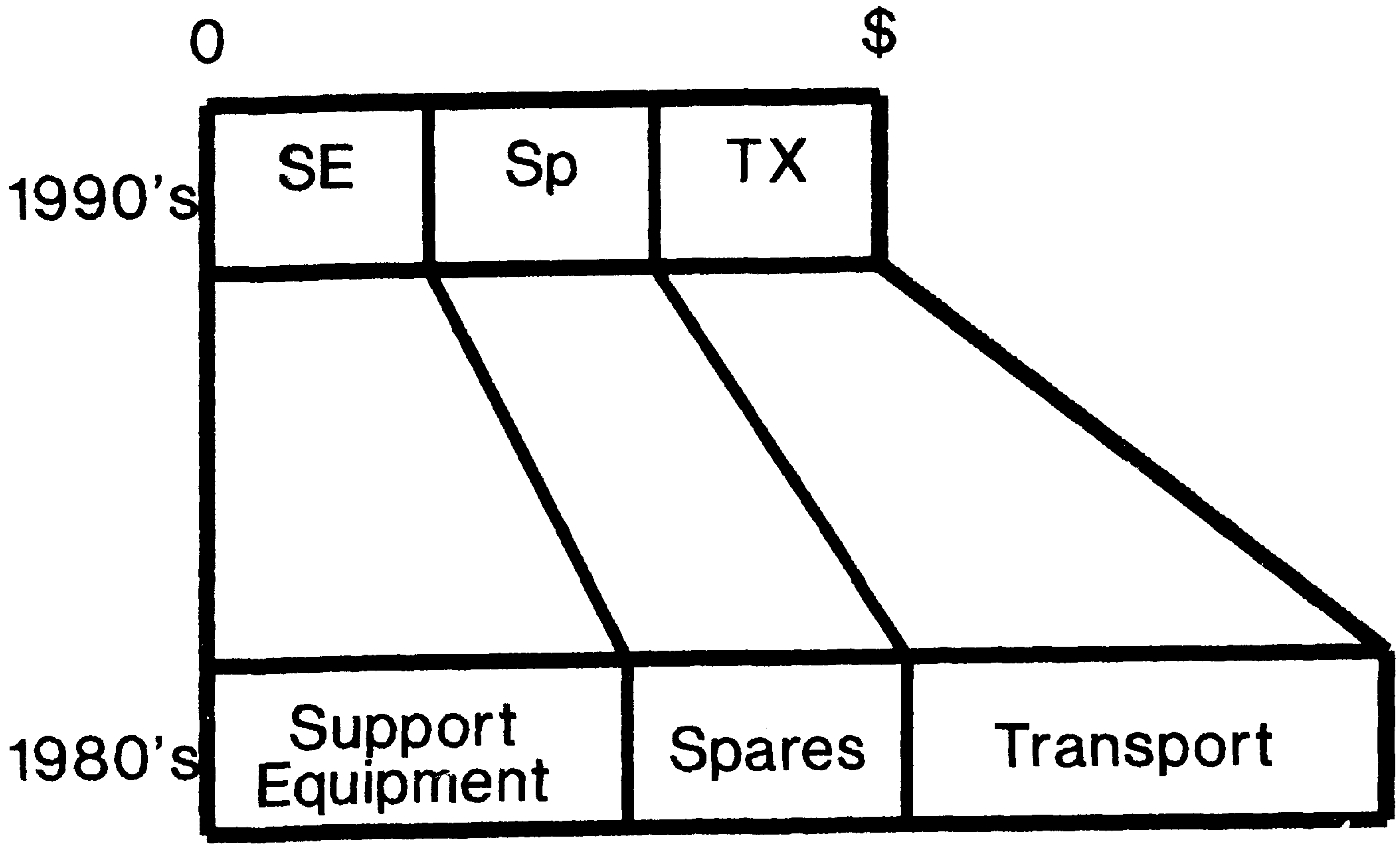
Testability
A Management Perspective

- Shrinking Budget

- Operational Requirements Increasing

- An Effective Design for Testability

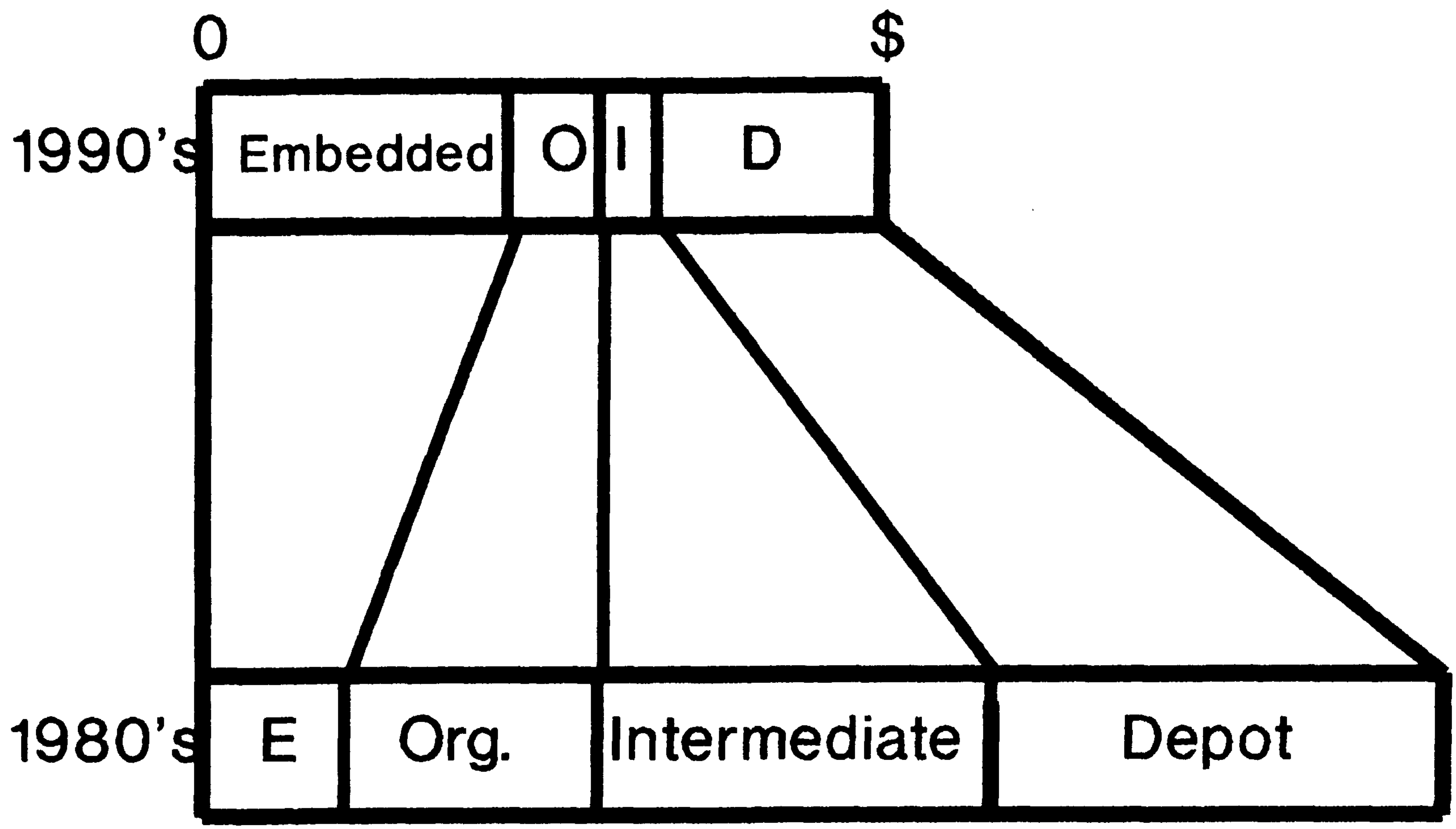
FIGURE 2



Support Asset Goals

FIGURE 3

There are several significant factors at play that call for a new look at testability in the defense acquisition environment of the future. One of these factors is the changing defense environment that results from a shrinking defense budget and changing military strategies. Defense dollars are already being reduced due to the reduction in the communist block threat, with extensive reductions expected in the 1990's. These reductions impact R&D as well as operations (personnel, number of weapons, skills, etc.). Future acquisition programs will require cost reductions in the front end of weapon system acquisitions as well as lower Operations and Support (O&S) costs. Mobility and cost constraints dictate that we minimize overall support assets, such as support equipment, spares and transportation needs. Figure 3 illustrates the support goals for the 1990's.



Support Mix Goals

FIGURE 4

At the same time, operational requirements are becoming more stringent. Requirements for mission reliability, mission success, safety, and availability are becoming more challenging. Advances in technology have led to more complex and integrated systems that require enhanced diagnostics to prevent diagnostic errors. Diagnostic problems in the field are leading to pressure on designers and developers to reduce cannot duplicates (CND) and retest OKs (RTOK), problems that add to manpower and logistics costs. Support environment goals for the 1990s and beyond are changing. Embedded diagnostics is becoming increasingly effective and affordable, leading to increased use and reductions in off-board support, with overall savings in the amount of support needed. Figure 4 illustrates the support mix goals for the 1990's.

Improvements Thru an Effective Design for Testability

- Decreased Off-Board Support
- Reduced Fault Isolation Times
- Eliminate (or greatly reduce) Intermediate Shops
- Eliminate (or greatly reduce) CNDs & RTOKs
- Eliminate (or greatly reduce) ATE & Maintenance Aids
- Reduced Spares

FIGURE 5

A weapons system that is down for repair cannot meet the enemy's threat. Innovative and cost effective approaches to maintenance will be mandatory in the coming decade. Any resources available will have to be used more effectively. The user will become more prominent and maintenance will be pushed down to the lowest level possible. Improving the performance of existing systems is a high priority. The primary improvement in performance is in availability and reduced support costs. Reduced support costs come mainly from reduced time to repair, lower spares requirements and decreases in test equipment costs. Figure 5 depicts the various advantages of an effective design for testability.

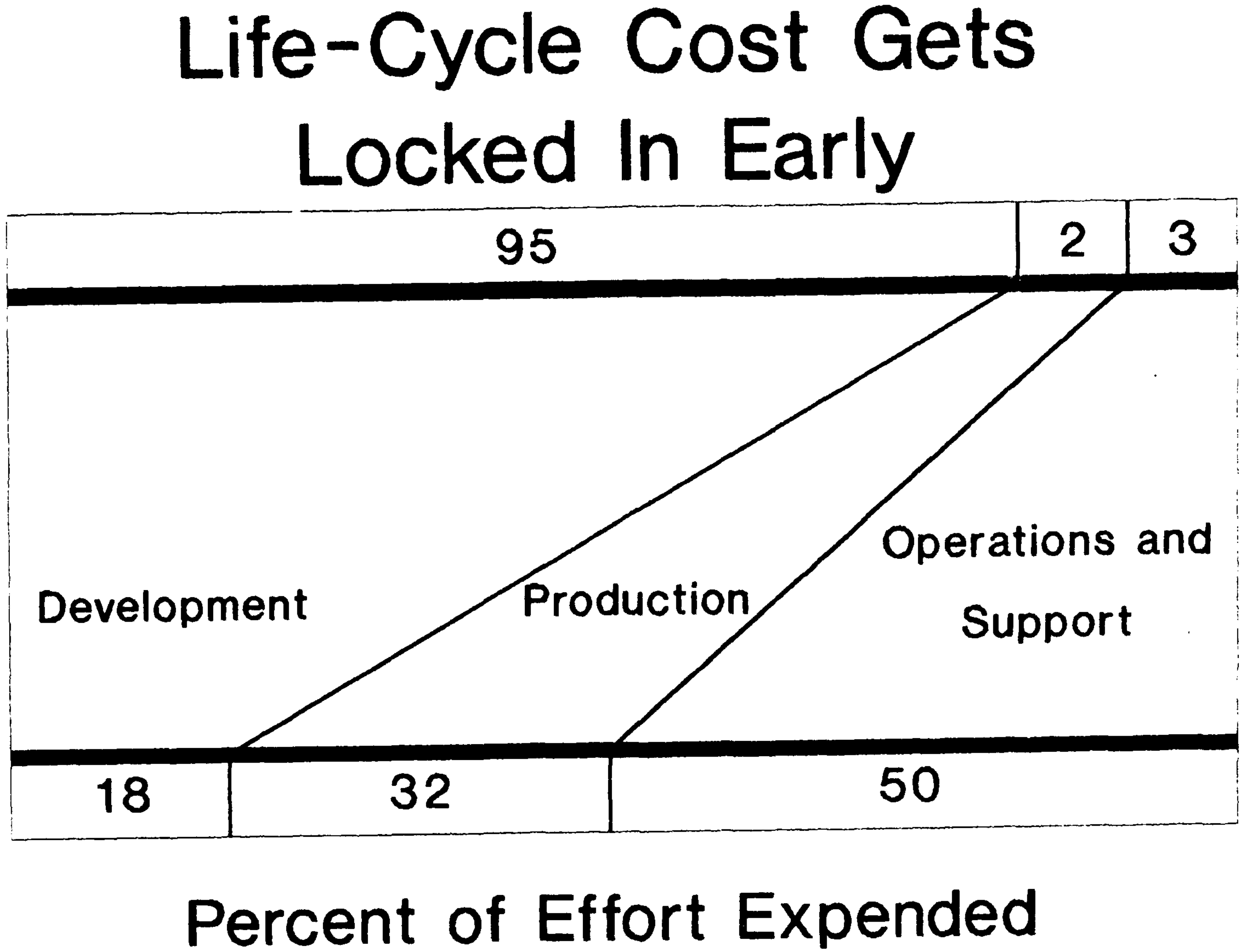
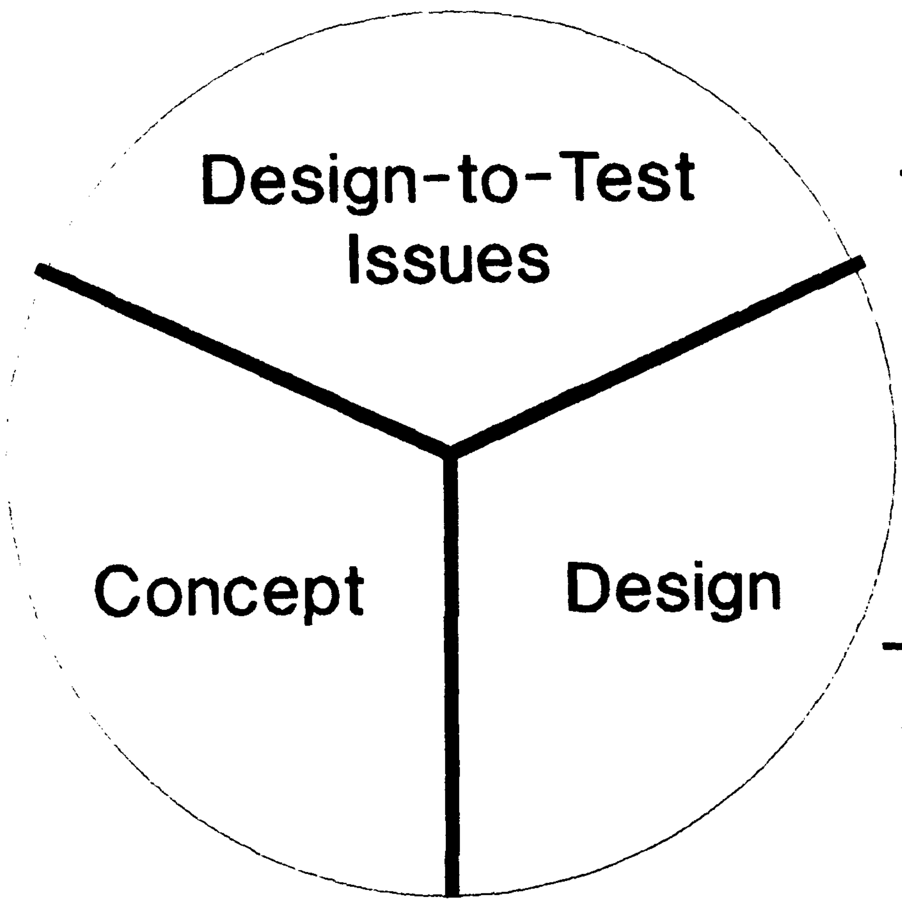

Life-Cycle Cost Gets
Locked In Early
95
2
3
Development
Production
Operations and
Support
18
32
50
Percent of Effort Expended

FIGURE 6

Where does testability happen? It must happen during the early stages of the development of a system. What we do with testability must be done right as we see the major effect of the development arena on life-cycle-costs. Figure 6 shows the critical nature of an effective design for testability during the development phase.



-1/3 of Design Cycle Spent On Design-to-Test Issues

-Lack of Properly Integrated Tools to Manage the Development Process With Testability

Percent of Development Costs

FIGURE 7

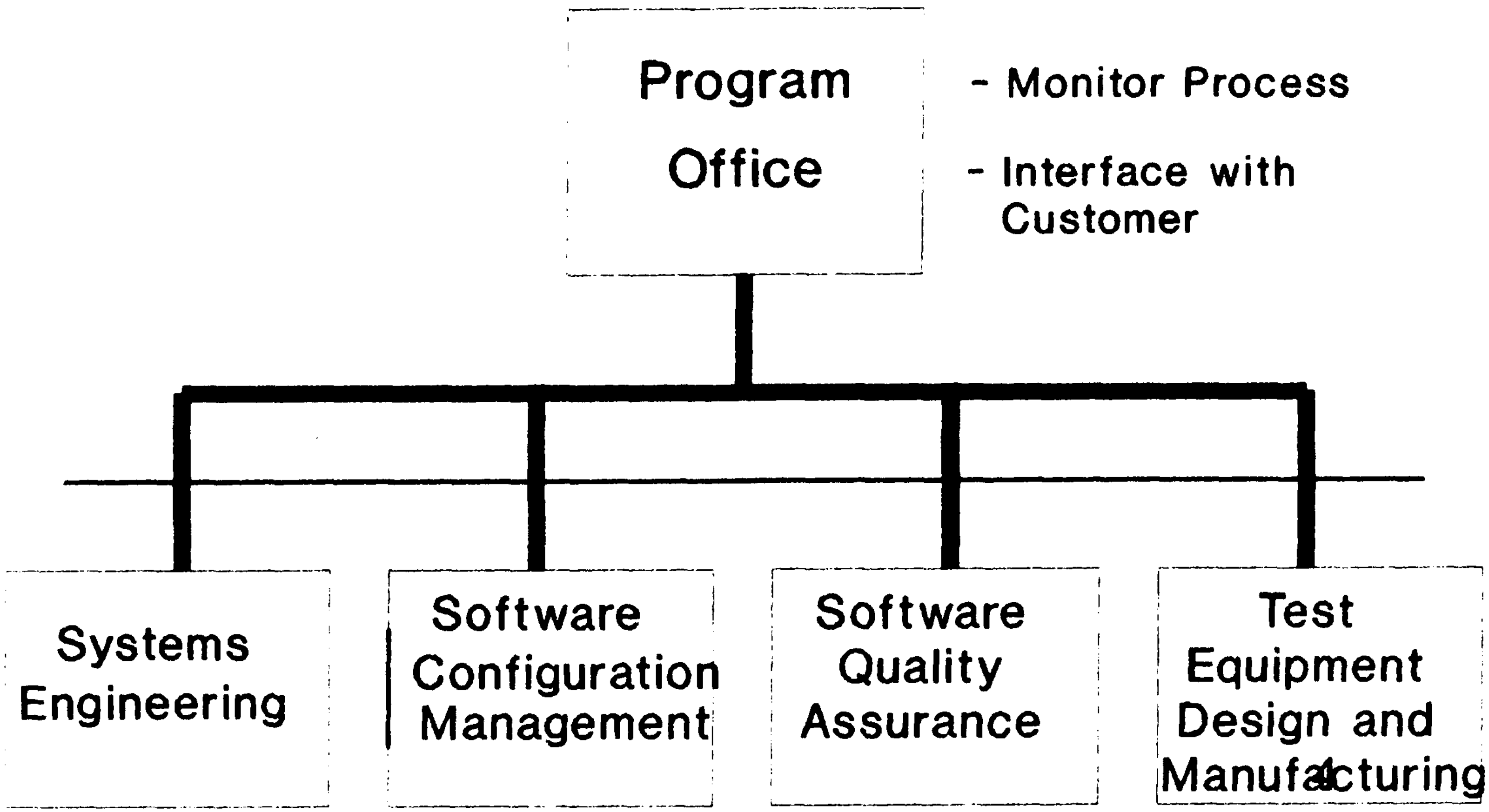
Figure 7 shows the relations of costs during the development phase. 1/3 of the design cycle (several leading firms have concluded) is spent on design-to-test issues, primarily because of the lack of properly integrated tools to manage this process.

The greatest single source of lost profit in the commercial world is being late to market. In the defense arena we are also schedule driven. When programs languish, they can be lost. Large sums of money are currently being spent to automate test programs and prepare diagnostics long after the design is complete. We are willing to pay large sums for Test Program Sets (TPSs) and enhanced electronic system performance. We must look backwards to an earlier interaction of design and test. The two disciplines must interact as peers in a concurrent environment.

Testability Impacts on Built-in-Test (BIT)

- Present
  - Limited Tests
  - Organizational Constraints

FIGURE 8



Project Organizational Structure

FIGURE 9

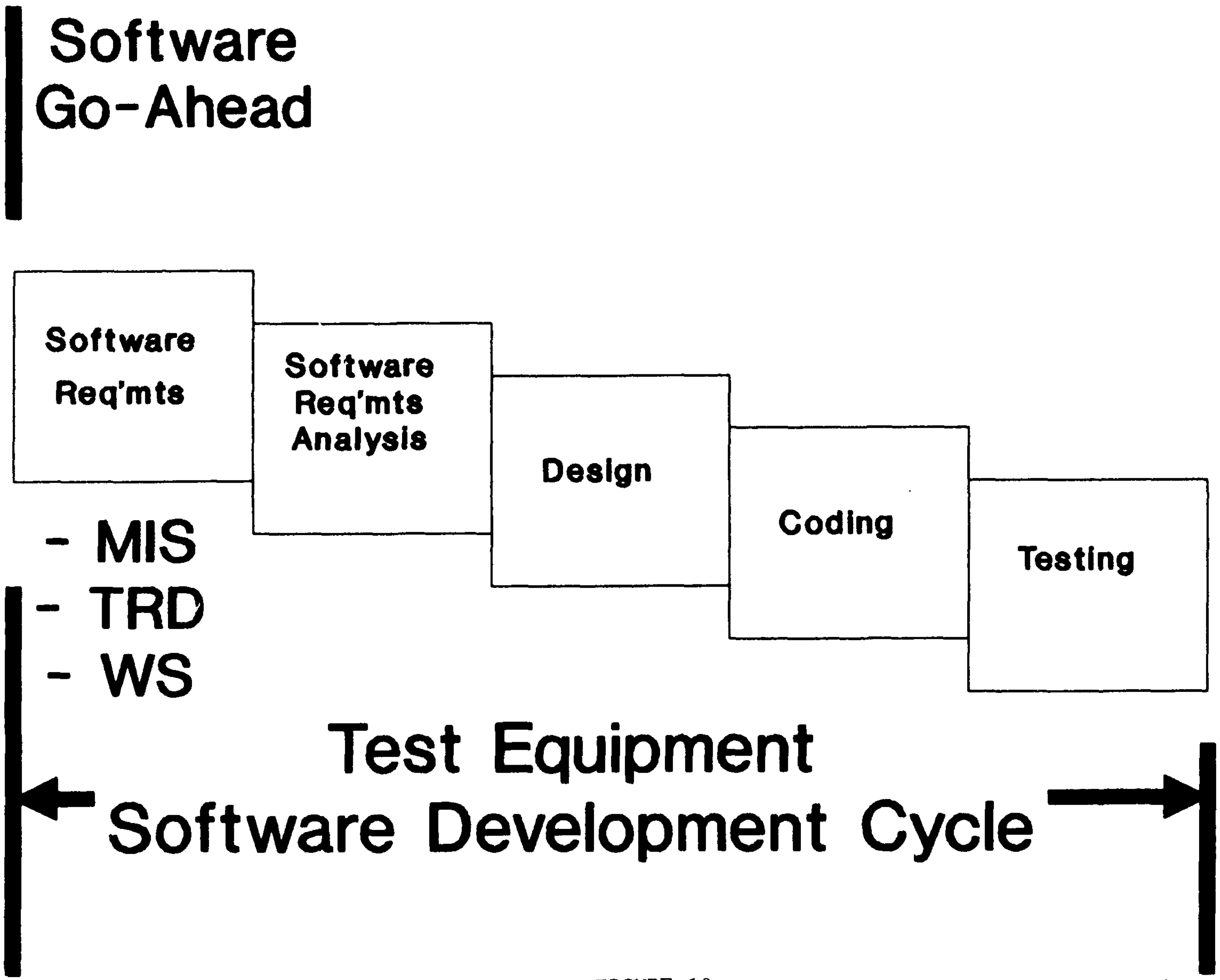

Software
Go-Ahead
Software
Req'mts
Software
Req'mts
Analysis
Design
Coding
Testing
- MIS
- TRD
- WS
Test Equipment
Software Development Cycle

FIGURE 10

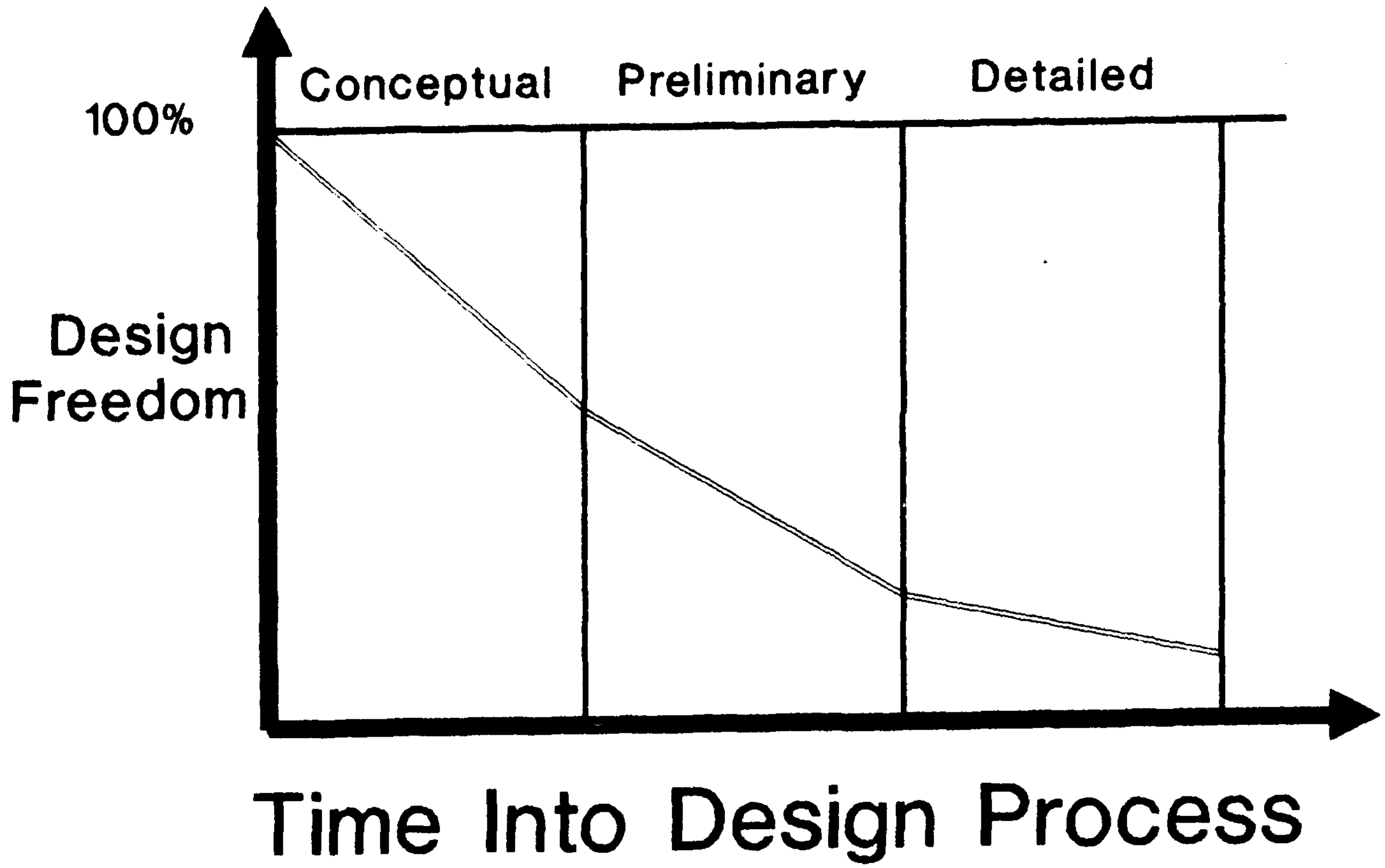

Conceptual
Preliminary
Detailed
100%
Design Freedom
Time Into Design Process

FIGURE 11

Figures 9, 10 and 11 show constraints on BIT design due to the organizational structure. Proper designs always have constraints such as schedule and resources. Due to time constraints, many test departments are developing programs that verify as little as 40% of the possible faults. This is occuring because BIT and Design-for-Testability (DFT) has not been considered properly. The traditional organizational structure as shown in figure 9 impedes the integration of testability into the design. The Systems Engineering group is separate from the Test group and others. Management is there to monitor the process and takes no active role in the daily routine of system development. The result as shown in figure 10 is that the System Engineers deliver the test requirements to the Test Engineers with designed in testability not properly addressed. This is the over-the-wall approach to system design. As figure 11 shows the decreasing design freedom as time progresses, we must realize the Test Engineers must be involved even in the conceptual phase of a design.

Testability Impacts on Built-in-Test (BIT)

- Future
  - Technology Advances
  - Tools and Techniques
  - Time to Go

FIGURE 12

Recent technology advances in built-in-test (BIT) promise vastly improved diagnostic ability. Increased testability can significantly mitigate current problems such as:

- CanNot-Duplicate (CND): Some systems do not reliably detect failures without incurring frequent false alarm and high CND rates.

- ReTest OK (RTOK): Test tolerance in BIT and intermediate level ATE are often incompatible, resulting in high RTOK rates.

- Fault isolation cannot be performed reliably to the desired level, resulting in removal of several components to cope with a malfunction caused by a single, faulty item.

Reducing or eliminating CNDs and RTOKs can prevent aborting of missions because of repeat malfunctions. An unambiguous fault isolation capability is absolutely essential for reconfigurability and fault tolerance in near term systems.

Recent technology advances, such as Very-High-Speed Integrated Circuits (VHSIC), Very-Large_Scale Integrated Circuits (VLSI) and Artificial Intelligence (AI) offer great potential for resolution of these problems. The increased capability to collect and process mission, safety, and maintenance data makes it possible to keep detailed equipment "medical records" that can be applied to improve fault isolation.

Increased system complexity mandates that tools and techniques be available to incorporate testability from the earliest stages of design. The Air Force's Rome Laboratory has a prototype under development for a CAD tool for BIT. BIT may be used to perform marginal checking and thereby detect incipient failures. BIT can be used in conjunction with a Time Stress Measurement Device (TSMD) to collect environmental data before, during, and after BIT recorded events.

The operational status of a system may be determined under actual operating conditions. This may show critical system performance parameters are not being maintained in actual operation. This may give insight to needed future design improvements. Also, BIT can be used as a maintenance aid to identify intermittent faults.

Minimization of required ATE test resources, reduced programming effort and resultant test-cost savings now are being achieved with Built-in-Test (BIT). The effort needed to implement BIT may or may not be significant, depending on the architecture of the end product and the ingenuity of the design engineer. The burgeoning interest in BIT is due to the increasing complexity of today's LSI devices and the assemblies containing them as well as the associated high-speed test requirements.

"THE 1-10-100 RULE"

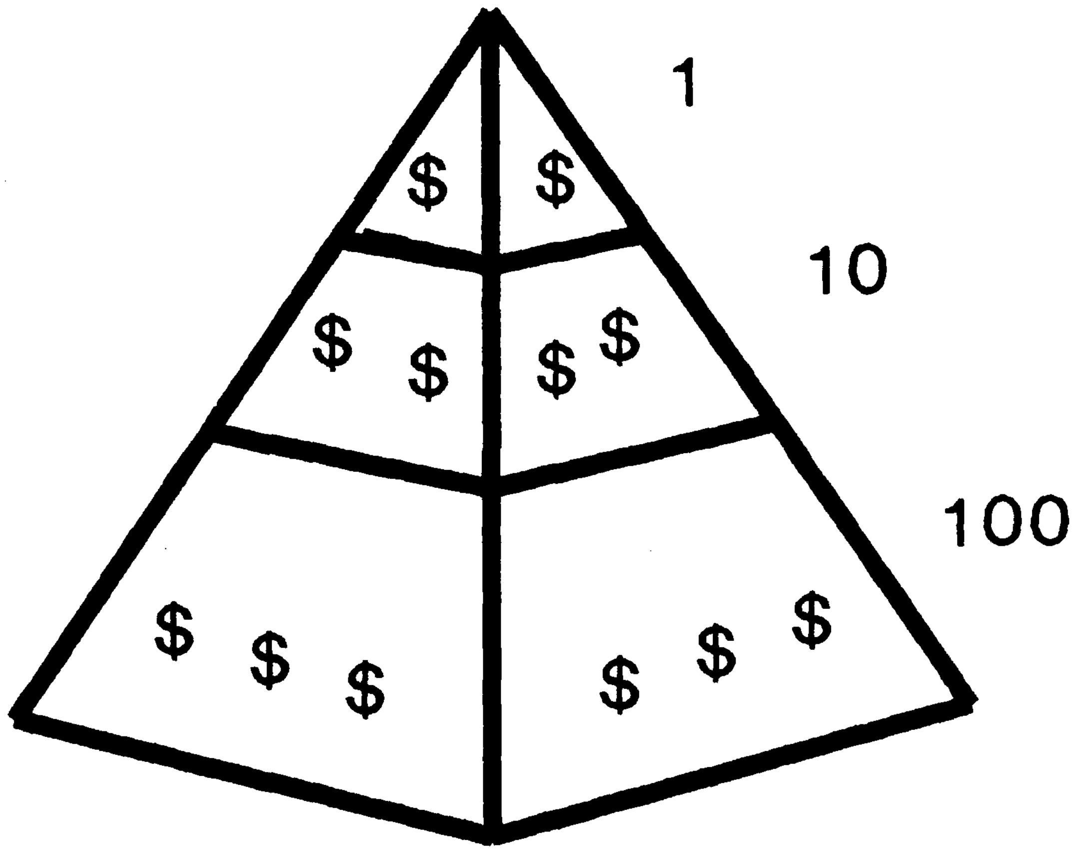


FIGURE 13

It is time to go with BIT to detect failures early to reduce support costs and increase system readiness. As figure 13 depicts the 1-10-100 rule, it is cheaper by an order-of-magnitude to detect and isolate the failure early at the chip or board level than at the system level in the field.

Testability Impacts on Test Program Sets (TPSs)

- Present
  - Automatic Test Equipment (ATE)
  - Enhance or Bust
  - A New Focus

FIGURE 14

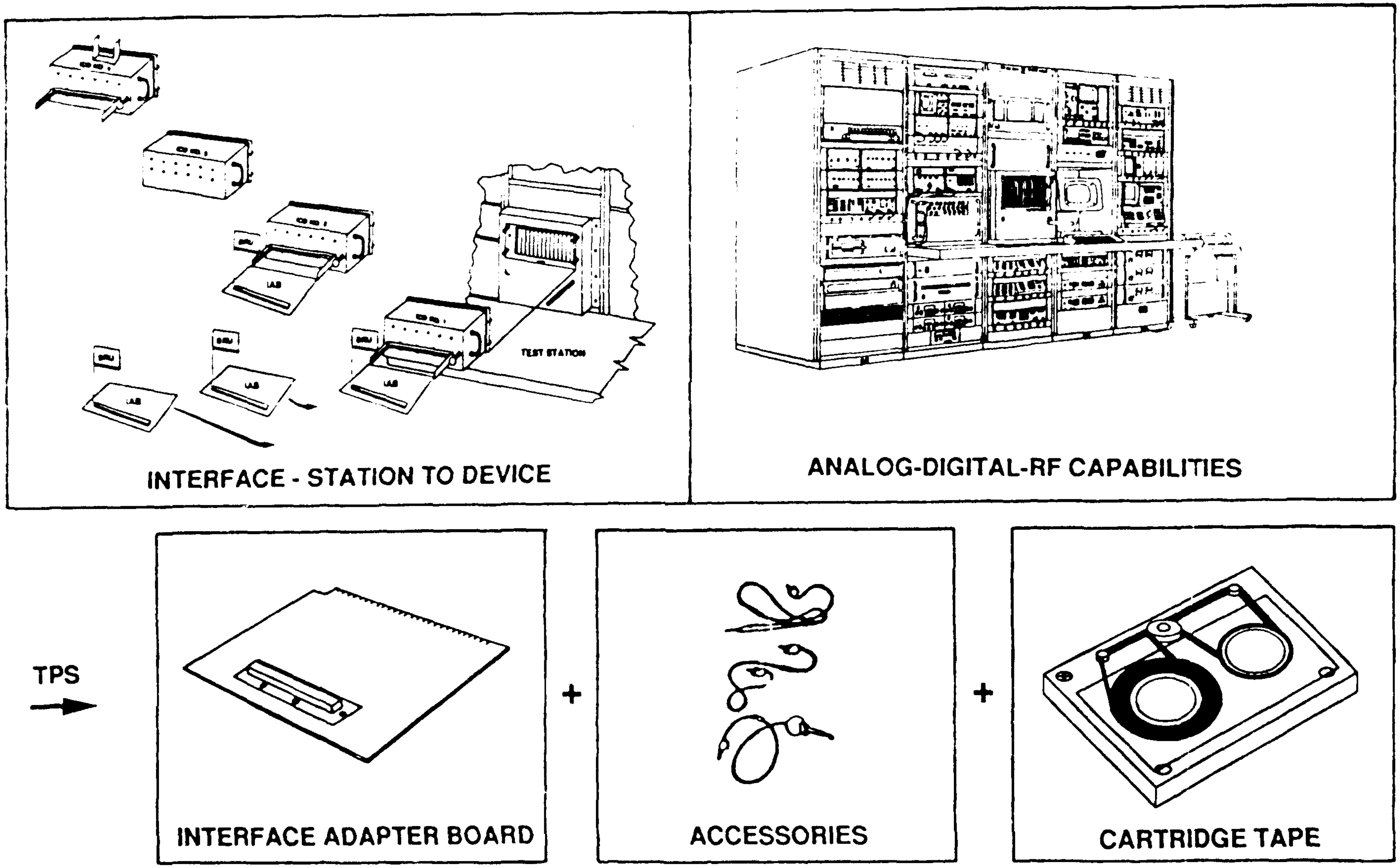

INTERFACE - STATION TO DEVICE
TEST STATION
IAB
ANALOG-DIGITAL-RF CAPABILITIES
TPS
INTERFACE ADAPTER BOARD
+
ACCESSORIES
+
CARTRIDGE TAPE

FIGURE 15

As shown in figure 15, the ATE can become very complex with all the required stimulus capabilities. Even with all this complexity, adequate testing may still not be possible if the Unit Under Test (UUT) does not have adequate test points and other testability features. As today's systems are becoming more complex an emulation capability is sometimes required by the ATE. This requires adequate documentation on the hardware and software of the system to develop test programs. An alarming situation can develop when this documentation is not forthcoming, as is the case on a Non-Developmental Item (NDI).

Once the UUTs are removed from their normal interconnections, then the ATE along with the Station-to-Device Interface and other TPS items must assume the role of the higher level system. This can lead to complex and prohibitively costly interface device requirements. These interface devices are required for the Shop Replaceable Units (SRUs) and the Line Replaceable Units (LRUs). The development and support costs of these devices continues to grow as their numbers increase and the operational system performance and complexity escalates.

The fundamental architecture of functional board ATE, as implemented in the current generation of test systems, has not changed substantially in the last few years. But, more significantly, it is not expected to change in the near future. The basic architecture of present ATE can support the functional test requirements for the next few years. However, it will be necessary to incrementally enhance the product features to keep up with the technology to be tested. Enhancement of the software is most critical, since it directly impacts the speed and cost of functional test-program generation and debug. Software improvements also are required to take full advantage of the hardware features.

Full-featured stations will test and diagnose the most complex CCAs if proper testability is part of the design. But, the acquisition cost of these high-performance testers is not insignificant. An application of the "80-20 rule" might be that 80% of the potential users can only afford 20% of the cost of the high-end functional testers. Some systems can be configured to meet a variety of testing demands. Users can minimize acquisition costs by purchasing only the options providing the features they require.

Electronics Engineering and manufacturing have begun to merge the design and test functions. They are combining application-specific automated test program generation tools with computer aided design tools. That technology has arrived and neither discipline diminished; however, a new focus is emerging. They are now converging on how to become more efficient at capturing design information and subsequent development of test program sets. In fact, more energy is focused in this area together than in either one previously. Why? The answer is simple: the need to reduce the expense of test program set development is critical in the competitive environment of newer and more dense designs of electronic components and circuit cards. In other words, accept innovation or lose out to competition.

This picture is a very exciting one to the customer who relies on both Automatic Test Equipment (ATE) and Test Program Sets (TPSs) for field level service of Circuit Card Assemblies (CCAs) and black boxes. However, it has not matured beyond the component level or off the factory floor where it has proven so effective in selling off quality components.

Testability Impacts on Test Program Sets (TPSs)

- Future
  - Emulation
  - Signature
  - Retrieve BIT
  - Design and Test Links

FIGURE 16

Emulator options are available to facilitate microprocessor-based board testing. Emulators initially were used to test and diagnose the microprocessor and the immediately adjacent ROM and RAM circuitry. But now, means are provided to test other circuits on the board, including I/O ports. With emulator-based testing, tests can be performed at full operational speed and only moderate external resources are required. Once again, complete documentation on the operational system is required to facilitate the emulation development.

When BIT is invoked, algorithms can be applied that ascertain a fault based upon signatures measured at crucial test points within the UUT. When interfacing a UUT that contains BIT features with an ATE, the test engineer's programming task is reduced, but other problems may surface. With BIT running at 40 MHz, stray capacitance from the attached probes and circuitry can cause difficulty. These effects can be mitigated with a split-pin architecture, allowing the driver/receiver pair to be separated.

Increasing numbers plan to use BIT and execute and retrieve the results from the BIT as part of the functional test, all under the control of a memory-based emulation tester. Greater numbers are utilizing custom and boundary scan. Shortly, all of the major board-test products will be able to handle BIT and DFT. As BIT and DFT increase, techniques such as boundary scan will revolutionize the electronics industry

As we enter the 1990s, the cost of test program development continues to receive intense scrutiny. One area of particular focus is the cost of developing diagnostic test programs for today's complex board designs. Test engineers are now recognizing the necessity to capture as much information as possible from the designer and design data bases in order to create test vectors in a timely manner.

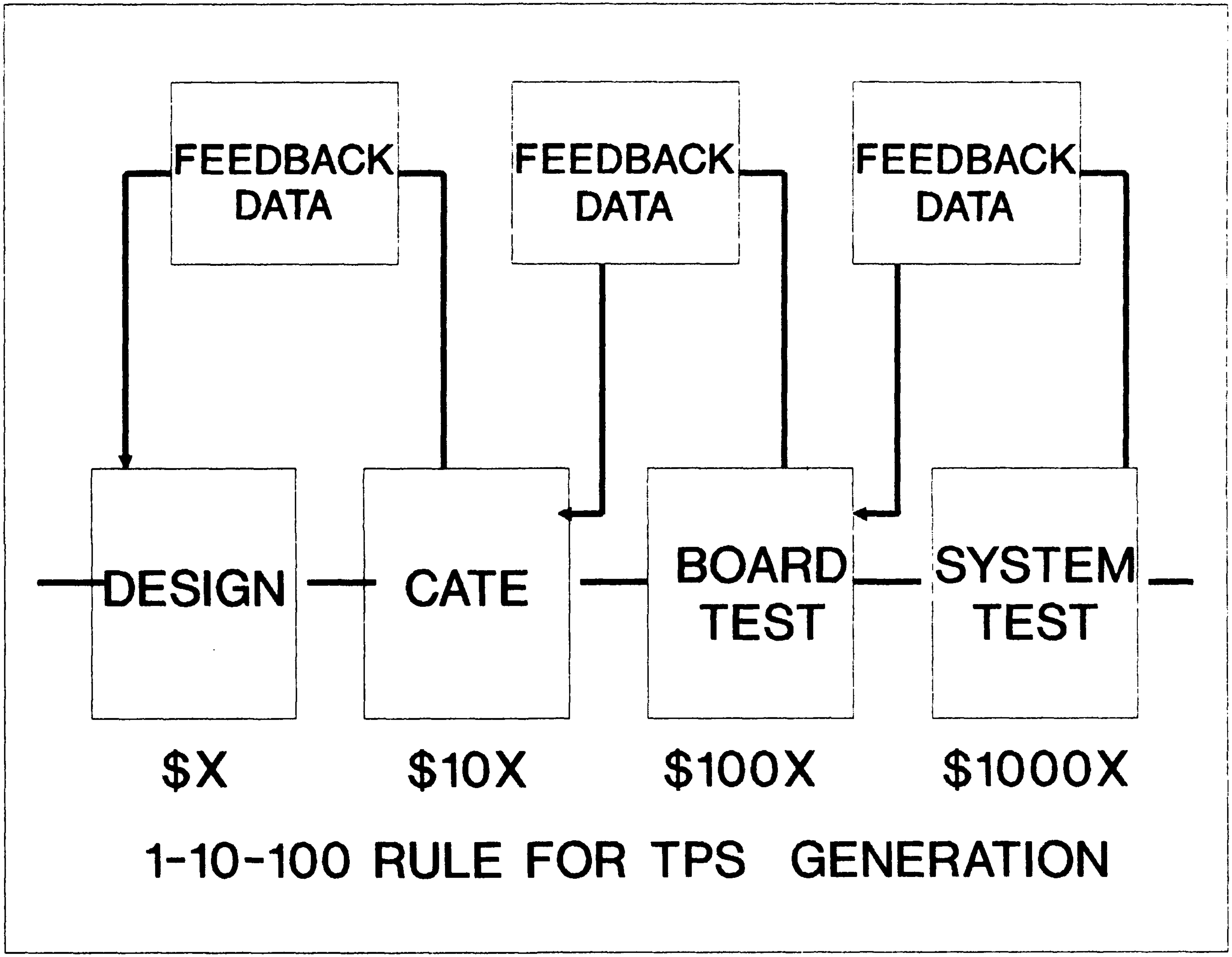

FEEDBACK DATA
FEEDBACK DATA
FEEDBACK DATA
DESIGN
CATE
BOARD TEST
SYSTEM TEST
$X
$10X
$100X
$1000X
1-10-100 RULE FOR TPS GENERATION

FIGURE 17

As shown in figure 17, the "1-10-100" rule can also apply to the cost of test program development: It is 10x more costly to develop the diagnostic test program at a later stage in the process. As much of the test program development must be pushed to the left as possible.

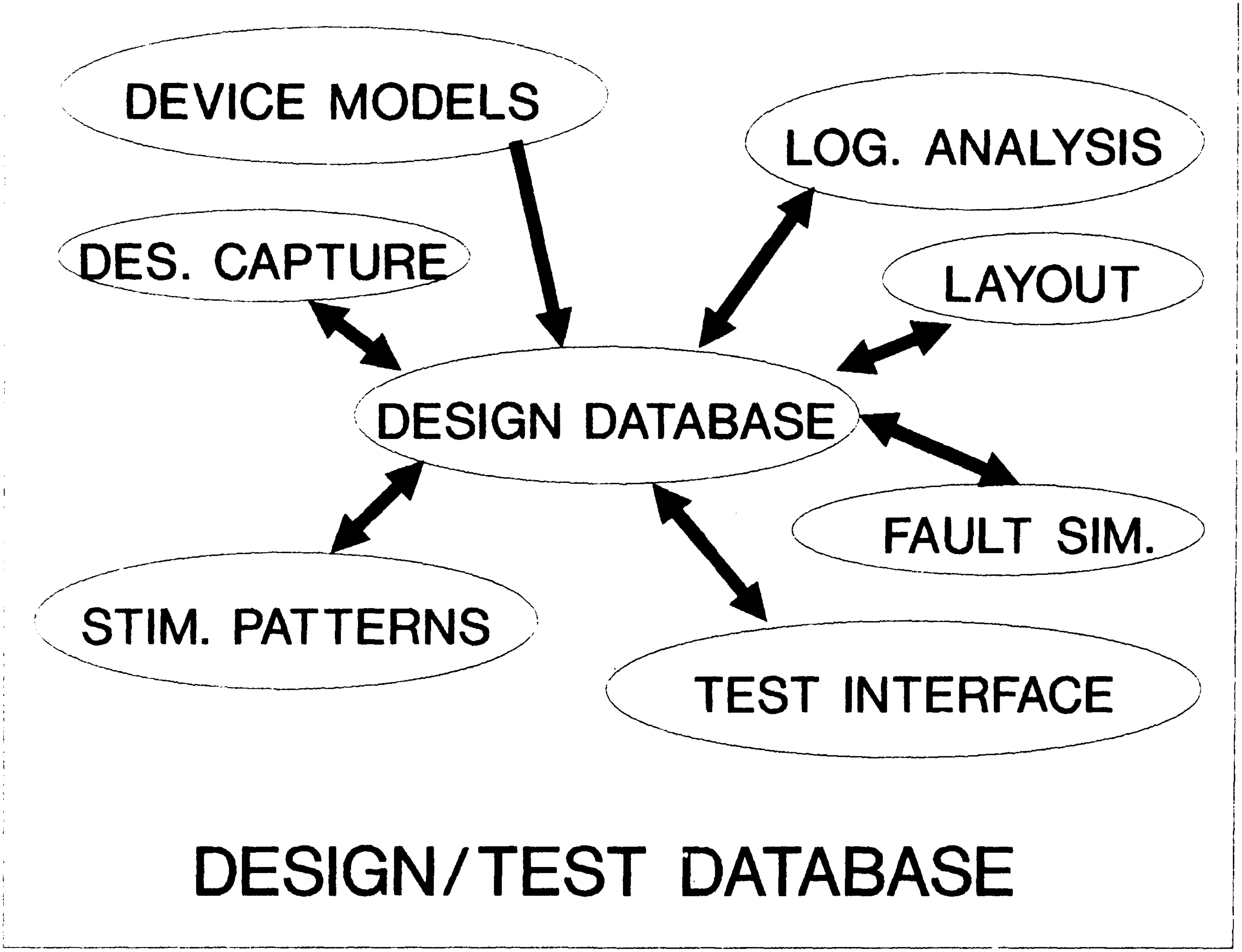

DEVICE MODELS
LOG. ANALYSIS
DES. CAPTURE
LAYOUT
DESIGN DATABASE
FAULT SIM.
STIM. PATTERNS
TEST INTERFACE
DESIGN/TEST DATABASE

FIGURE 18

As shown in figure 18, forward-thinking electronic manufacturers subscribe to a philosophy characterized by the emergence of concurrent engineering and what is being called computer-aided test engineering (CATE). They focus on items such as testability, scan, simulation and, most importantly, data-base transfer from design to test development, including diagnostic information. The close links among engineering, test engineering and manufacturing provide additional benefits such as the elimination of process and performance related problems.

Today, we must push to the left to take advantage of design data bases and simulation vectors in the test-development process. Simultaneous design and test engineering can eliminate an estimated 30% of program development. It is essential to provide design-to-test-to-design links, a means of electronically transferring all of the necessary data bases from design.

Design		CATE		Board Test
EDIF 2.00		Interactivity		Integration
- Schematic		Segmentation		Debug
- Netlist		Test Strategy		Test
Gerber	→	APG	→	Fault Detection
- Layout		Fixture Generation		Failure Analysis
CADDIF				
- Simulation				
- Scan				
- Fault Dictionaries				

Design - Test Links

FIGURE 19

As figure 19 shows, this is achieved primarily in software via industry standards such as EDIF, CADDIF and Gerber for data formats; UNIX and X-windows for a user environment; and Ethernet for data transfer. The EDIF 2.00 format allows the Computer-Aided-Engineering (CAE) system to write the schematic information to the EDIF reader of the test-engineering software. Displayed exactly as on the CAE station, the schematic provides the data bases necessary to run an Automatic-Program-Generation (APG) package for in-circuit/cluster tests and allows segmentation for in-circuit, cluster, scan, emulation or any other test technique.

For years, Gerber has been the standard for plotters, drill tapes and board layout. By electronically transferring the Gerber information, the test engineer has a view of the UUT when debugging and isolating faults.

Created in 1985, CADDIF provides the means for importing vectors from design simulators to component and board testers. Recent enhancements to the standard have included bidirectional links to the design simulator. CADDIF is equally well suited for transfer of scan vectors and diagnostic information or in-circuit test routines for complex ASICs or gate arrays.

At the diagnostic program development stage, one goal is to push to the left the use of the design simulator for fault simulation. Secondly, the test engineer must reduce, from the right, the need to debug the program on the capital-intensive ATE. Rule-validation software and off-line emulation of the tester performance are the means to this end. Simply put, rule validation ensures, up front, that a programmer cannot perform a task inappropriate at that given time.

Fast, automatic programming for lower cost test solutions will be the most pressing issue in the 1990s. Utilization of design data bases, automatic capture of this information and APG from this data will shorten programming times by as mush as 70% from today's approaches.

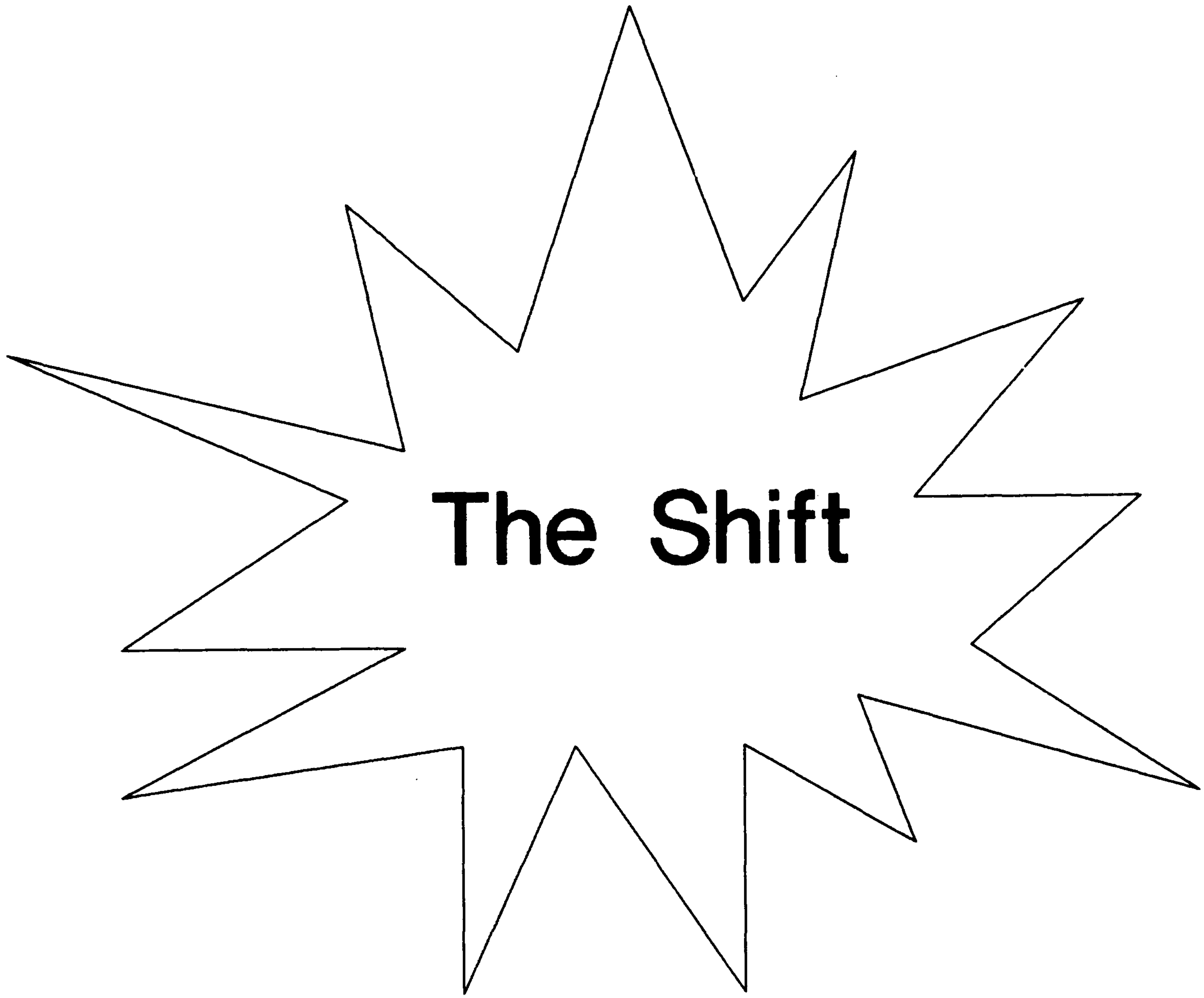


FIGURE 20

As the shift to incorporate DFT and BIT accelerates, the requirement for the functional testers will exist to meet the ever-increasing test rate, perhaps to 100 MHz or higher in 10 years.

Highly integrated design/test tools in a concurrent engineering environment will have a dramatic effect on productivity, shortening overall time to market. This is a major software architectural shift that customers have needed for years.

The most significant software impact to functional test will come from the design-to-test arena. As more ATE vendors develop the ability to integrate data from various simulators, program development will become easier and less time-consuming.

Industry leaders agree the current functional board test system architectures are capable of handling most functional test requirements for the next few years. It will be the enhanced software; DFT and BIT ; and the concurrent engineering environment that will make the difference.

REDUCING LOGISTIC DATA REDUNDANCIES

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INTRODUCTION

In today's environment, there are numerous logistic planning documents required during the weapon system development process. Some logisticians estimate that there are between 200 and 400 of these logistic plans. Logistic plans are management tools used to establish, integrate, control and evaluate the development of logistic programs that will support a particular weapon system. Logistic plans include such items as the: Integrated Logistic Support Plan (ILSP), Logistic Support Analysis Plan, Maintenance Plan, Navy Training Plan and the Technical Manual Organization Plan. These are not to be confused with logistic products. Logistic products are the **results** of the actions documented in logistic plans and are used to support the weapon system in the Fleet. Typical logistic products include technical manuals, training curricula and Maintenance Requirement Cards.

Navy program offices realized long ago that many of the current logistic plans contain redundant data. For example, a major ship acquisition office may have the requirement to develop a Support Equipment Plan to ensure that support equipment is acquired in a coordinated and efficient manner. The plan's requirements call for preparation of a milestone chart, point of contact list, discussion of the end-item's maintenance concept and description of the end-item. Another office staffer is tasked to prepare the ILSP. The ILSP is developed to provide each program with a measurable management assessment baseline. It serves as the basis for all ILS planning and control, and all ILS progress is measured against the ILSP. ILSP requirements include a milestone chart, point of contact list, discussion of the end-item and system maintenance concepts and description of the end-item and its systems. Have not the two authors duplicated information? They have. Similarly, four staffers are each tasked to prepare a specific computer resource plan. Each staffer will address the maintenance concept of the end-item, develop a milestone chart, prepare a point of contact list and develop a list of standard and non-standard computer hardware. Again, redundant data has been prepared. Preliminary research discovered an alarming redundancy rate in the entire logistic arena. Logisticians are spending unnecessary time and resources in generating duplicative data. This must stop. Logistics must become more efficient, particularly in this time of budget constraints.

How did the current situation develop? Logistic support is a very complex and detail oriented discipline. It covers many functional areas that must be integrated into an effective and efficient logistic support package. DoD Instruction 5000.2, Defense Acquisition Management Policies and Procedures, lists the ten elements of Integrated Logistic Support. These elements are:

- Maintenance Planning
- Manpower and Personnel
- Supply Support
- Support Equipment
- Technical Data
- Training and Training Support
- Computer Resources Support
- Facilities

- Packaging, Handling, Storage, and Transportation
- Design Interface

Each of these elements has its own planning documents and, in NAVSEA, each element is controlled by a separate office. Each of these offices is responsible for developing its own requirements, and each office works to establish complete and thorough requirements. As a result, these offices have created stand-alone procedures and plan requirements.

Logistics is an integrated discipline in which each element affects all other elements. Logistic plans must reflect this premise. Unfortunately, the requirements for logistic plans are not developed in an integrated fashion, but rather in the vacuum of the separate offices. Integrated control has been weak. The end result: proliferation of poorly integrated and redundant logistic plans and policies.

Streamlining of the logistic planning process is long overdue. Logistic streamlining will increase efficiency, decrease plan preparation time and cost and eliminate inconsistent and redundant data. NAVSEA initiated a study in January 1990 to discover logistic data redundancies. It was placed under the "Zero-Based Logistics" initiative of the NAVSEA Logistics Planning and Appraisals Branch. The "Zero-Based Logistics" initiative is defined in Hubert Upton's paper, "Management of Total Logistics Costs" (published in the Proceedings of the American Society of Naval Engineers Logistics Symposium, 1989) as:

> *The review of every logistic process and instruction to assess its affect on end-item supportability. Logistics will be useful and efficient, or it will not be done.*

NAVSEA's Zero-Based Logistic Initiative has eight goals:

- reduce logistic data redundancies
- eliminate unnecessary logistic work
- develop logistic plans at a lower cost
- reduce life-cycle costs of acquisition programs
- increase coordination between logistic codes
- provide streamlined logistic planning data as a foundation for the Computer-aided Acquisition and Logistic Support (CALS) initiative
- reduce program office logistic effort
- eliminate inconsistent data

PROCEDURES

Establish Study Parameters

Before beginning the effort, certain basic assumptions were set to define the scope of the project. The study was confined to:

- NAVSEA programs
- system/equipment procurements
- acquisition category (ACAT) I programs
- programs beginning at the Concept Exploration and Definition acquisition phase

Analysis centered on NAVSEA acquisitions due to the Command's desire to assess the redundancy problem in its own policies and procedures. A system/equipment acquisition was selected over a ship acquisition due to the fact that the majority of NAVSEA acquisitions are at the system/equipment level; the resulting assessment would be relevant to the majority of NAVSEA programs. The ACAT I assumption was levied so that the maximum number of acquisition/logistic plans could be studied. A large selection of plans was desirable in order to provide a thorough analysis. This was also the reason for beginning the study at the Concept Exploration and Definition phase. The earlier a program is initiated in the acquisition cycle, the more plans are required.

Identify Logistic Plans

To initiate the analysis, all of the required logistic plans were identified. This first step required research into the acquisition/logistic requirements documents. These documents specify the plans that are required during the acquisition process. They are:

- DoDDIR 5000.1 Defense Acquisition, 23 February 1991
- DoDINST 5000.2 Defense Acquisition Management Policies and Procedures, 23 February 1991
- NAVSEAINST 5000.39 Acquisition and Management of Integrated Logistic Support for Ships, Systems, and Equipment, 21 March 1988
- S0300-BD-PRO-010/020/030 Integrated Logistic Support Procedures Manual for System/Equipment, October 1989.

These documents dictate what acquisition and logistic planning is required for each program, based upon ACAT level. Following the review of each publication, the required plans were extracted. A second review was conducted to ensure that no plans were omitted. At the beginning of the study, DoDINST 5000.1 and DoDINST 5000.2 were in draft form. However, they were used because they had already undergone extensive review and the general consensus was that they would be signed as written.

The DoDINSTs provide the general framework within which all of the services plan for and develop logistic support. Each of the services provides more detail in service-specific implementing documents. NAVSEAINST 5000.39 is the requiring document for logistics in NAVSEA. Its purpose is to

> *establish policy for the design and development of Integrated Logistic Support for NAVSEA ships, systems and equipments. It also prescribes logistic planning requirements for each life cycle phase.*

The implementing document for NAVSEAINST 5000.39 is the Integrated Logistic Support Procedures Manual. Logistic plans were selected from this manual. An annex to this manual contains logistic milestone charts. The preparation of each logistic plan is a documented milestone on these charts.

A sample listing of the acquisition/logistic plans, generated from the sources discussed above, is shown in Figure 1.

Integrated Logistic Support Plan
Test and Evaluation Master Plan
Acquisition Plan
Operational Requirement
Tentative Operational Requirement
Phased Support Plan
Post Production Support Plan
Configuration Management Plan
Standardization Program Plan
Reliability Program Plan
Maintainability Program Plan
Maintainability Design Criteria Plan
System Safety Program Plan
Logistic Support Analysis Plan
Human Engineering Program Plan
Human Engineering Test Plan
Quality Assurance Program Plan
Level of Repair Program Plan
Maintenance Plan
Support Equipment Plan
Testability Program Plan
Supply Support Management Plan
Outfitting Operations Plan
Packaging Plan
Computer Resources Life Cycle Management Plan
Software Configuration Management Plan #1
Software Development Plan #1
Software Configuration Management Plan #2
Software Development Plan #2
Software Quality Assurance Plan
Technical Manual Validation Plan
Technical Manual Organization Plan
Technical Manual Verification Plan
Facilities Requirements Plan
Training Program and Training Equipment Plan
Equipment Facilities Requirements Plan
Navy Training Plan

Figure 1. Sample Listing of Acquisition and Logistic Plans

Extract Data Elements From the Logistic Plans

The redundancies between the logistic plans were assessed at the data element level. A data element, in the context of this study, is a specific and discrete piece of information. Examples include official nomenclature, training concepts, modifications and audits.

First, the data elements were extracted from the ILSP. This was because the ILSP had been selected as the baseline against which the other plans would be evaluated. It was selected because it is the primary logistic planning document produced in the acquisition process. The ILSP requires input from each of the logistic elements. It contains system descriptions and detailed schedules of logistic milestone events, lists the individuals responsible for those milestone events and details the procedures for accomplishing those events.

After selection of the ILSP as the evaluation baseline, the initial requirements of the ILSP were broken down into manageable data elements. For example, the following ILSP requirement can be broken down into 10 data elements.

> *Describe the maintenance concept for the system and the maintenance to be performed at each level, i.e., organizational, intermediate and depot. Address the Reliability Centered Maintenance (RCM) program, including analyses to be performed and documentation procedures. Also, describe the Level of Repair (LOR) program, including analyses to be performed and data products to be delivered.*

The specific data elements are:

- system maintenance concept
- organizational maintenance
- intermediate maintenance
- depot maintenance
- RCM program
- RCM analyses
- RCM documentation procedures
- LOR program
- LOR analyses
- LOR data products

Each of the ten logistic elements was broken down as in the example. Certain engineering fields closely related to ILS and required for inclusion into the ILSP, were also broken down into data elements. The engineering fields filling these qualifications are:

- configuration management
- reliability and maintainability
- availability
- system safety
- quality assurance

In total, the ILSP was divided into 148 data elements. A sample of these data elements are listed in Figure 2.

The other logistic plans could now be compared to the ILSP. To determine the data elements contained in the other logistic plans, the Military Standards, Command directives and Data Item Descriptions (DIDs) which governed each plan were reviewed. Plans identified in this study are prepared either by Government offices or contractors. The requirements for plans prepared by Government offices are contained in Military Standards or Command directives. DIDs are standard content and format requirements for contractor-delivered data products.

Reasons For Program Initiation
New/Upgraded Capabilities
Improvements in Mission Effectiveness
System/Equipment Description
Official Nomenclature
Diagram
Fleet Introduction Method
Program Highlights
Class Unique Characteristics
Master Program Schedule
Systems/Equipments Installed
Delivery Schedules
Modifications
Comparison to Other Systems
Milestones
Budgets
Documentation Procedures
Special Considerations for Operation
Special Considerations for Maintenance
System Maintenance Concept
Reliability Centered Maintenance Program
Level of Repair Program
System Nomenclature
System Part Number
System Application
System Operation/Maintenance Concept
System Configuration
System Construction
System Technology Features
Maintenance Plan Summary
Maintenance Assist Module/Standard Electronic Module Plans
Special Considerations for Operation
Tools, Maintenance Aids, and Test Accessories at each Level
Automatic Test Equipment
ATE Test Program Sets
Built-in Test
Built-In Test Equipment
Mechanical Test Instruments
Special Purpose Test Equipment
Calibration Equipment
Support Equipment Requirements Documents
Support Equipment Procurement Responsibilities
Development of Calibration Procedure
Utilization of Micro Miniature Repair
Exchange Pool
Supply Support Planning
Provisioning Technical Documentation Acquisition Requirements
Naval Provisioning Requirements
Interim Support Planning
Government Furnished Materials List
Hazardous Materials
Packaging Requirements
Standard Computer Hardware
Standard Computer Software
Non-Standard Computer Hardware
Non-Standard Computer Software
Software Lifecycle Maintenance Activity
Tactical Digital Standards Compliance
Tactical Digital Standards Waivers
Requirements for Technical Manuals
Technical Manual Acquisition Approach
Technical Manual Development Approach
Validation Requirements
Verification Requirements
Certification Planning
Printing Planning
Distribution Planning
Engineering Drawing Acquisition Requirements
Preventive Maintenance System Documentation Requirements
Hardman/Logistic Support Analysis Use
Skills Required for Operation
Skills Required for Maintenance
Grade Required for Maintenance
Grade Required for Operation
Navy Training Plan Number
Training Concepts
Technical Training Equipment & Location
Technical Training Devices
Configuration Items
Methods of Identifying Equipment Characteristics
Methods of Documenting Equipment Characteristics
Control of Engineering Change Proposals
Audits
Configuration Management Requirements for Design Agents
Failure Modes, Effects, and Criticality Analysis Tasks to be Performed
Operational Availability
Mean Time Between Failure
Mean Time to Repair
Mean Logistic Down Time
System Safety Plan Organization
System Safety Plan Conduct
Hazard Analysis Procedures
System for Collection/Analysis of Data
System for Deficiency Correction
Ships Identified

Figure 2. Sample Listing of ILSP Data Elements

During the course of this study, certain logistic plans within the computer resources element were found to have two DIDs cited for each plan. The plans were indexed against the Acquisition Management Systems and Data Requirements Control List (AMSDL) part 2. This section of the AMSDL lists current DIDs. Both DIDs were found to be current. As such, each plan was arbitrarily assigned a number (i.e. a "1" or a "2"). This was done in order for these plans to appear as separate entities and not be mistaken as duplicate entries.

Compare the Data Elements to Determine Redundancies

After identifying the data elements in the plans and the ILSP data elements, a matrix was developed to tabulate the data. The ILSP data elements were placed along the top horizontal axis of the chart ("x" axis) and the acquisition/logistic plans were placed along the left vertical axis ("y" axis). The data elements of the acquisition/logistic plans were then compared against the ILSP. When an acquisition/logistic plan and the ILSP contained the same data element, an "x" was placed in the corresponding cell of the matrix to indicate a redundancy.

In many comparisons, exact matches were not possible. Many plan requirements were worded differently from the ILSP. Some inference was required. In these cases, the plan data elements were re-evaluated to capture their exact intent. In other cases, the NAVSEA logistic element managers were consulted and asked to supply a definition in order to make a better comparison. **Data definition is a central problem facing the CALS initiative.** Most services and their sub-commands require the same information, but each may define it in different terms, give it a different name or structure it in different ways.

The resulting matrix illustrated an alarming number of redundancies. A portion of this matrix is provided in Figure 3.

FINDINGS

The next step was to find the number of actual matches. Along the "x" axis there were 730 matches. Out of the 148 ILSP data elements, 122 contained at least one match. The remaining ILSP data elements contained no redundancies. This equates to an 82% redundancy rate for the ILSP when compared to the logistic plans. Most logistic programs are tailored to some degree, and not all of the identified logistic plans would be required. The intent of this effort was to demonstrate that within any program, the probability of data redundancy was high. These findings show this to be true. Figure 4 shows a sample of the data element redundancies.

Another tally was made along the "y" axis of the matrix. This tally was useful in evaluating each logistic element and the redundancies between plans of the same field. Figure 5 shows a few of these results. This second tally indicated that in all logistic elements, some redundancies occurred between plans of the same field. As a result, these redundancies occur between two or more logistic plans and the ILSP.

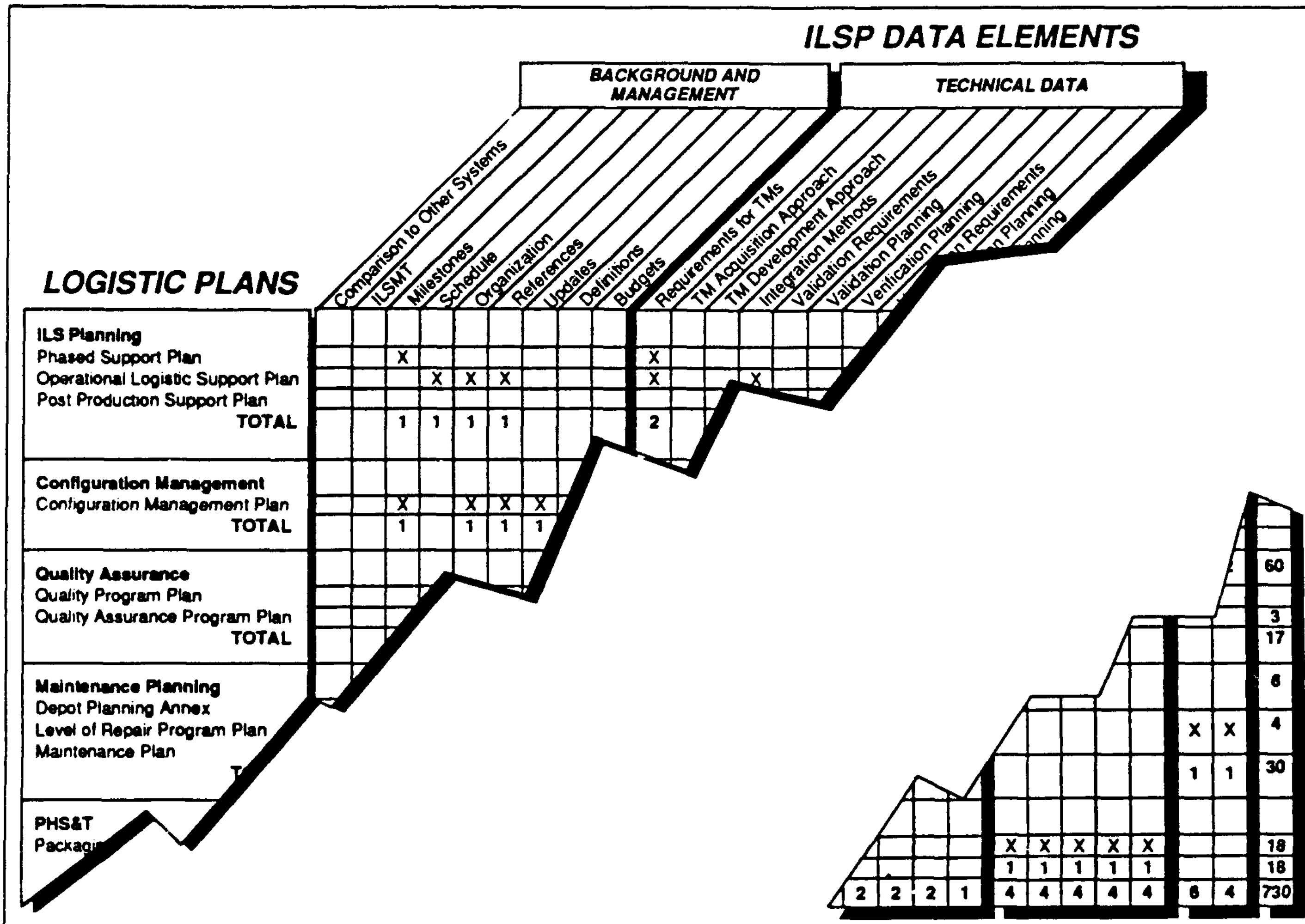

Figure 3. Selected Portions of the Redundancy Matrix

As the findings show, there are tremendous data redundancies between the acquisition/logistic plans and the ILSP. There are also many redundancies in the plans of each logistic element. This duplication increases the time required to prepare the various plans, raises costs and introduces the probability of inconsistent data.

If the analysts in a program office are each tasked to prepare a logistic plan, it is likely their plans will contain redundant data. For example, the first analyst is tasked to prepare a Phased Support Plan. The Phased Support Plan identifies the support required to accomplish the Maintenance Plan, and contains overall management information and specific system data for an orderly transition to the final support capability. The second is tasked to prepare the Maintenance Plan. The Maintenance Plan provides a concise narrative of maintenance actions, technical factors for each repairable item and identifies the system/equipment maintenance requirements. Each of these plans requires a listing of tools by maintenance level (i.e., organizational, intermediate, depot). If preparing these charts takes three days, then one of the analysts spent three unnecessary days on the task. Could the first listing of tools not be used in both documents?

Data Element	Redundancies
Reasons For Program Initiation	10
System/Equipment Description	16
Official Nomenclature	19
Milestones	15
Tools, Maintenance Aids, and Test Accessories at each Level	22
Government Furnished Material List	12
Skills Required for Operation	15
Skills Required for Maintenance	11
Training Concepts	12
Technical Training Devices	10
System for Collection/Analysis of Data	13
System for Deficiency Correction	11

Figure 4. A Sample of Data Element Redundancies

Logistic Field/Plan	Redundancies
ILS Planning	22
Phased Support Plan	
Operational Logistic Support Summary	
Reliability & Maintainability	6
Reliability Program Plan	
Maintainability Program Plan	
Computer Resources Support	8
Computer Resources Life Cycle Management Plan	
Software Configuration Management Plan #1	
Software Configuration Management Plan #2	
Technical Data	5
Technical Manual Validation Plan	
Technical Manual Organization Plan	
Training & Training Support	5
Training Program and Training Equipment Plan	
Equipment Facilities Requirements Plan	

Figure 5. Selected Redundancies by Logistic Field

The program office's cost is probably doubled for this effort. Twice the amount of employee time, materials and support is used in this example.

Again, using the same example, the possibility exists that one of the analysts may omit a tool or place a tool in an improper category. Then, when both of these documents are distributed to other personnel, the error will be compounded in further efforts. An informal assessment was performed on one NAVSEA project to determine if inconsistent data between plans was, in fact, a potential problem. In this assessment, there were two Operational Availability (Ao) figures, two totals of items to be procured and two different program lengths. The Ao percentages were documented in the Test and Evaluation Master Plan and the Operational Requirement. The Test and Evaluation Master Plan describes the detailed hardware and support tests that the program will undergo and the results that must be achieved before the item is considered ready for introduction to the Fleet. The Operational Requirement is a statement containing performance and related operational parameters for the proposed concept or system. One Ao value was 98% and the other 99%. Even though there was only a 1% difference, only one was correct. Which one was it? The Acquisition Plan, which describes how the program manager will execute his program, listed a total of 5000 items for procurement over a 5 year program length. The Logistic Requirements and Funding Plan, which documents the funding required for ILS, called for the total acquisition of 5016 items over 7 years. Which set of figures was correct? Although errors in data development may be combatted by quality assurance, reducing data redundancies will avoid inconsistencies and confusion and limit the compounding affect.

RECOMMENDATIONS

What can be done to resolve these duplicative situations? The following ommendations were derived:

1. Evaluate the logistic plans in each functional area and consolidate them into as few plans as possible. Recommend elimination of duplicative plans. Determine which plans must exist as stand-alone plans.

2. Reformat the NAVSEA ILSP into a two-part document. Part I will contain common information from all logistic fields as well as all administrative data. Part II will contain logistic annexes that will discuss logistic processes, plans and concerns that are unique to a specific logistic element.

3. Perform a study of historical costs for each plan. Use this information in conjunction with Recommendation 1 to determine cost benefit. Include historical accounts of employee time required to prepare each plan. Include this data in a revision to SL-000-AA-LOG-010, Life Cycle Cost Estimating Guidance for the Logistic Requirements and Funding Plan (December 1988) to be used as guidelines in projecting logistic funding required for new programs.

4. Submit recommendations to other related logistic initiatives that will benefit from the results of this study. These include DoD CALS, the NAVSEA Process Action Team on Reducing Logistic Dependency, the NAVSEA Logistic Support Analysis (LSA) Improvement Effort and the Computer-aided Acquisition Logistic and Management System (CALMS), NAVSEA's automated logistics planner.

5. Conduct the above efforts in an integrated fashion, so that findings in one sub-effort may be exchanged between all sub-efforts.

CONTINUING EFFORTS

To implement the recommendations listed above, NAVSEA has initiated several projects and has laid plans for the implementation of others.

Recommendation 1 is underway. This effort entails interviews with NAVSEA logistic element managers. In these interviews, decisions are being made as to whether a logistic plan must exist as a stand-alone document or if it can be combined with the ILSP. Redundant data will be subsumed by Part I of the ILSP; non-redundant information will be moved into Part II (logistic element annexes) of the ILSP. If the situation dictates that a stand-alone plan is required, an element-specific process will be developed to obtain information from the ILSP to eliminate any inconsistencies. This will entail a search through the ILSP to extract the required data and move it to the stand-alone plan. To conclude this effort, revisions will be made to the applicable NAVSEA directives that govern NAVSEA logistic plans.

Recommendation 2, reformatting the NAVSEA ILSP, has begun and is partially complete. Part I of the ILSP has been formatted to include all management and logistic information required for a specific program, eliminating the need for it to be repeated elsewhere. The research required to format Part II of the ILSP has been combined with Recommendation 1. Logistic plans that are eliminated will be reviewed a second time. That information not redundant to the ILSP data elements and still necessary will be placed in a logistic annex to the ILSP. There will be one annex for each logistic element. These annexes, when grouped together, will form Part II of the ILSP.

Besides reducing redundancies, improving efficiency and eliminating inconsistencies, this entire project has an additional goal of reducing cost. The authors anticipate that such a reduction will occur if all goals are met. Unfortunately, there is no complete guide to the costs of each and every logistic plan. Recommendation 3 will provide this complete guide. Costs for all acquisition/logistic plans will be gathered from historical accounts for the past five years. This data is available from NAVSEA's database that contains all Logistic Requirement and Funding Plan submittals. Time requirements will also be collected to give management personnel an additional tool to gauge efficiency. Once these costs and time requirements are known, cost savings may be determined. If a logistic plan contains 20% redundancies (against the ILSP), it may be roughly assumed that a percentage of the plan cost may be saved when redundancies are removed. This effort will conclude with a revision to the NAVSEA Life Cycle Cost Estimating Guidance for the Logistics Requirement and Funding Plan. Updating this manual will provide program personnel a more complete basis for determining the cost of logistic products.

In implementing Recommendation 4, data obtained from this study will be submitted to other projects within DoD and NAVSEA. There are four related efforts that could benefit from the results of this study. First, information which would be beneficial to the CALS initiative will be passed to the DoD policy office. Second, results will be reported to the NAVSEA Process Action Team for Reducing Logistics Dependency. This team was developed with the purpose of reducing the ships', systems' or aircrafts' dependency on logistics to an absolute minimum.

Third, coordination will be maintained with the NAVSEA LSA Improvement Effort which is currently streamlining and integrating the LSA process. Plans are in place to compare LSA data elements with logistic plan data elements and prepare a list of the matches. This will show how the LSAR can be used as source data to develop portions of the logistic plans. Fourth, the results of this study will be forwarded to the NAVSEA CALMS office for inclusion in the automated logistics planning program.

Recommendation 5 requires that all work be done in an integrated fashion. This coordination has been established. Each of the recommendations has a staff member from the NAVSEA Logistics Planning and Appraisals Branch assigned to that project. Each of these analysts is charged with reporting progress and findings at regularly scheduled integration meetings. They are further responsible for reporting back to their individual projects the status and findings of the other projects which are involved in the integration meetings. Integration eliminates the problem of creating logistic requirements in a vacuum. Obviously, many of the recommended efforts depend on information from another effort, (i.e., data from Recommendation 1 feeds Recommendations 2 and 4). This integration is also necessary to ensure that these efforts do not create further redundancies.

CONCLUSION

In conclusion, this study has shown that a sizeable portion of required acquisition and logistic planning data is redundant. Such duplication results in higher costs, reduced efficiency and creates consistency problems. Recommendations to eliminate these redundancies, when complete, will create a new way of doing business in the acquisition field. This new way of business will bring greater integration, reduced costs and ensure greater efficiency with fewer errors.

ZERO BASED LOGISTIC INITIATIVE

REDUCING LOGISTIC DATA REDUNDANCIES

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U.S. ARMY MISSLE COMMAND
LOGISTICS RESEARCH AND DEVELOPMENT WORKSHOP
28 AUGUST 1991
HUNTSVILLE, ALABAMA

HUBERT UPTON

MR. UPTON'S EXPERIENCE IN THE LOGISTICS ARENA COVERS A WIDE RANGE OF ELEMENTS. HE HEADED THE LOGISTICS ORGANIZATION AT A NAVAL SHIPYARD AND SERVED AS THE DIRECTOR OF LOGISTICS FOR A CLOSED CIRCUIT TELEVISION DETACHMENT. HE HAS SERVED AS ILS MANAGER FOR TRAINING DEVICES FOR SEVERAL ANTI-SUBMARINE WARFARE (ASW) TRAINERS FOR THE NAVY. HE WAS PROGRAM MANAGER/ILS MANAGER FOR SEVERAL EARLY WARNING (EW) ELECTRONICS SYSTEMS WHILE EMPLOYED BY THE ARMY. HE SERVED AS A TEAM LEADER IN SEA 90 AND WAS RESPONSIBLE FOR CONDUCTING AUDITS ON MANY NAVSEA SYSTEMS. IN HIS PRESENT POSITION, HE HEADS THE LOGISTICS PLANNING BRANCH IN NAVSEA. HE WAS THE PRINCIPAL AUTHOR OF NAVSEAINST 5000.39 WHICH ESTABLISHED A NEW THRUST FOR NAVSEA LOGISTICS. MR. UPTON IS ACTIVE IN THE DEVELOPMENT AND APPLICATION OF LCC AND LSA TECHNIQUES FOR NAVSEA SYSTEMS. MR. UPTON HOLDS A BS DEGREE FROM OLD DOMINION UNIVERSITY AND IS A MASTER'S CANDIDATE AT GEORGE MASON UNIVERSITY.

PROBLEMS IN LOGISTIC PLANNING

- Lack of integrated logistic policy making decisions causes a proliferation of the number of logistic plans prepared for an acquisition program.
- Existing plans contain numerous data redundancies.
- Due to basic similarities among the Services in the acquisition planning process, the situation may exist throughout the Department of Defense.

1

PLANNING REQUIREMENTS

- During the acquisition process, all programs (regardless of Service) prepare logistic planning documentation.
- ACAT I programs require more logistic planning documentation than ACAT II, III, and IV programs.
- Every acquisition program must consider which logistic elements apply to their efforts (e.g. Maintenance Planning, Supply Support, Technical Data).
- Within each logistic element, there are one or more plans that must be prepared (e.g. Technical Data/Technical Manual Plan, Technical Data Acquisition Plan, and Technical Manual Validation Plan).

2

ZERO – BASED LOGISTICS

- The review of every logistic process and instruction to assess its affect on end – item supportability.
- Review of the existing logistic data and plans to determine areas of redundancies.
- Consolidation of the individual plans into one concise and all encompassing logistic plan.

3

GOALS OF ZERO – BASED LOGISTICS

- Reduce logistic data redundancies
- Develop logistic plans at a lower cost
- Reduce life – cycle cost of acquisition programs
- Increase coordination between logistic codes
- Reduce program office logistic effort
- Eliminate inconsistent data
- Provide streamlined logistic planning data as a foundation for the Computer – aided Acquisition and Logistic Support (CALS) initiative

4

APPROACH

- We identified 56 logistic plans required for an ACAT I acquisition.
- We compared the data requirements of these plans against the data requirements of the Integrated Logistic Support Plan (ILSP).
- We evaluated the redundancies and began the process of incorporating the logistic element plans into one program plan baseline.

5

FINDINGS

- During our study of the Naval Sea Systems Command acquisition planning process, we discoverd a redundancy rate among the logistic planning documents of

82%

- The most common redundancies included information such as:
  - Organization (identifying personnel) x34
  - ILSMT (identifying and describing) x25
  - Reasons for program initiation x15
  - System description x23

6

FUTURE

- This process will be automated and will eliminate the need for printed planning information.

- This effort will eliminate the major stumbling block in the CALS initiative – –

CONSISTENT DATA DEFINITION

7

EXAMPLE

PART I

- INTRODUCTION
- REASONS FOR PROGRAM INITIATION
  - PURPOSE
    - OBJECTIVE
    - PERFORMANCE
    - COMPARISON
  - CHARACTERISTICS
    - FEATURES
    - INTERFACE
    - CRITICAL CHARACTERISTICS
    - DIAGRAM
    - SYSTEMS/EQUIPMENTS INSTALLED
- SCHEDULES
  - CONSIDERATIONS
  - DELIVERY
  - PROGRAM
  - FLEET INTRODUCTION
  - REPLACEMENT/PHASE-OUT
  - MILESTONES
- ORGANIZATION
  - PERSONNEL
  - INTERRELATIONSHIP
    - SPONSOR
    - PROGRAM OFFICE
    - CONTRACTOR
    - SUPPORT ACTIVITIES
    - TEST ACTIVITIES
    - TRAINING ACTIVITIES
    - OTHER ACTIVITIES
- BUDGET
- MISCELLANEOUS
  - REFERENCES
  - UPDATES
  - ACRONYMS, ABBREVIATIONS

PART II

- MAINTENANCE PLANNING
- SUPPORT EQUIPMENT
- SUPPLY SUPPORT
- PHS&T
- COMPUTER RESOURCES
- TECHNICAL DATA
- FACILITIES
- MANPOWER AND PERSONNEL
- TRAINING AND TRAINING SUPPORT
- DESIGN INTERFACE
  - HUMAN ENGINEERING
  - LSA
  - CONFIGURATION MANAGEMENT
  - SAFETY
  - QUALITY ASSURANCE
  - STANDARDIZATION
  - CORROSION PREVENTION
  - HAZARDOUS MATERIAL
  - NUCLEAR HARDENING

SESSION II

RESEARCH, DEVELOPMENT, AND ENGINEERING CENTER

SESSION CHAIRMAN:

JOHN V. DAVIS
CHIEF, MANUFACTURING TECHNOLOGY DIVISION
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REDSTONE ARSENAL, ALABAMA

INTRODUCTION

According to the American Defense Preparedness Association and others, over 85 percent of Life Cycle Costs is locked in before detailed design is completed. If that is anywhere close to accurate, then one could conclude that the technical and scientific community has great opportunity and responsibilities. There opportunities and responsibilities cover a broad spectrum within the totality of what we call systems design. This will be seen from the variety of papers in this session which cover topics dealing with everything from standards for use in detail design to reduction of maintenance time as a function of training course length and structure. In each of the seven papers, I believe we will learn a good deal more about the contributions that technology can make to life cycle cost reduction and the achievement of what's commonly called the "ilities," without sacrificing weapon performance parameters.

Obsolescence - An Old Age Problem

By Dr. Richard Lane

No longer in use, outmoded in style, design, or construction are the words used to define obsolete. One might consider other words to describe this act, such as, gracefully aging, evolutionary process, the unrelenting march of progress, etc. All these descriptions seem rather harmless and the process of obsolescence is taken as an occurrence as natural as other laws of nature. Like many acts of nature, their occurrence can have significant perturbations and secondary effects on their surrounding.

The announcement by major Integrated Circuit (IC) manufacturers in the early to mid-eighties to discontinue the military series of 5400 digital Transistor-Transistor-Logic (TTL) devices created a very serious problem for the military community. The number of military systems utilizing these devices as well as the different types and numbers involved is staggering.

This presentation considers some of the difficulties created by the digital integrated circuit obsolescence and the effect it had on one of our anti-aircraft missile systems. The lessons learned from this experience has hopefully provided insight into this problem that may help minimize the impact of future obsolescence issues.

Slide 1 - This representation shows the first commercially produced IC available from Texas Instruments. This device was produced in 1960 and was designated the SN502.

Slide 2 - The shift in IC application is shown graphically in this foil. Also represented is the economical realities of IC supply and demand.

Slide 3 - This foil depicts the technology life cycle associated with various digital IC devices.

Slide 4 - The first major encounter with obsolescence was in the early 1980 with the decree by Raytheon that a multi-million dollar program would be needed to solve the non-availability of integrated circuit components. Through Government efforts and direction, numerous viable avenues were made known to solve this problem.

Slide 5 - This foil gives some devices and technical areas where obsolescence will cause serious problems in the future if not addressed now. Due to the technologies and the levels of integration involved, serious problems will result if these components become unavailable.

Slide 6 - Shown in flowgraph form is a guide to solving potential obsolescence issues associated with IC devices.

Obsolescence - An Old Age Problem

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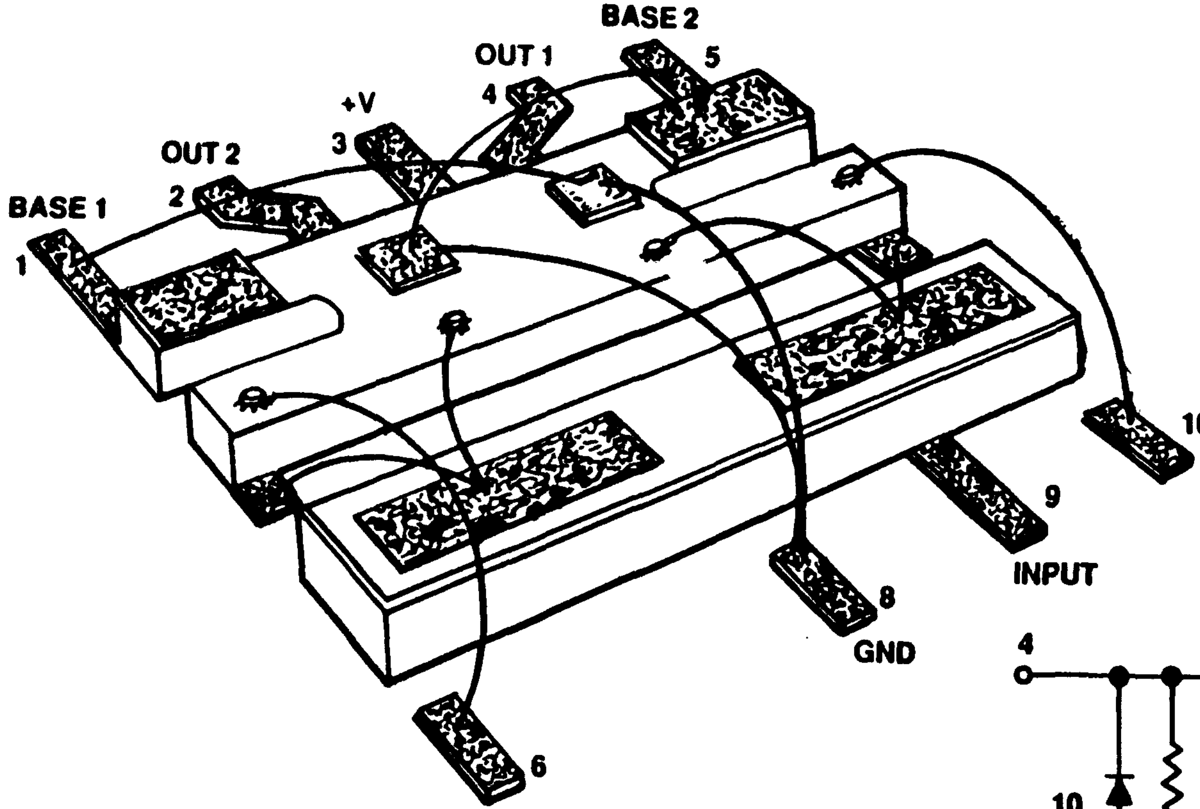
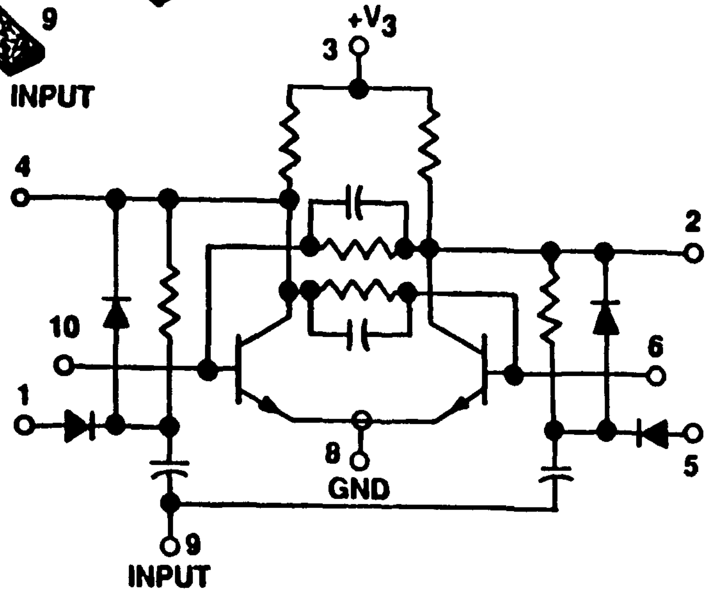
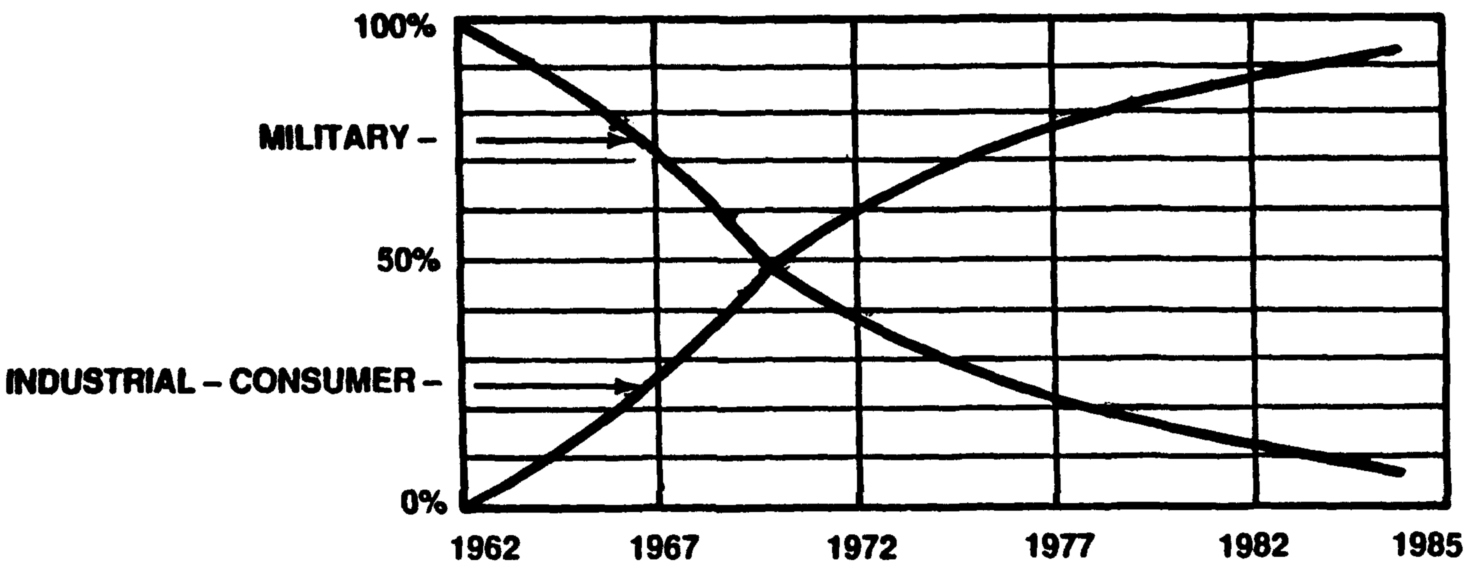


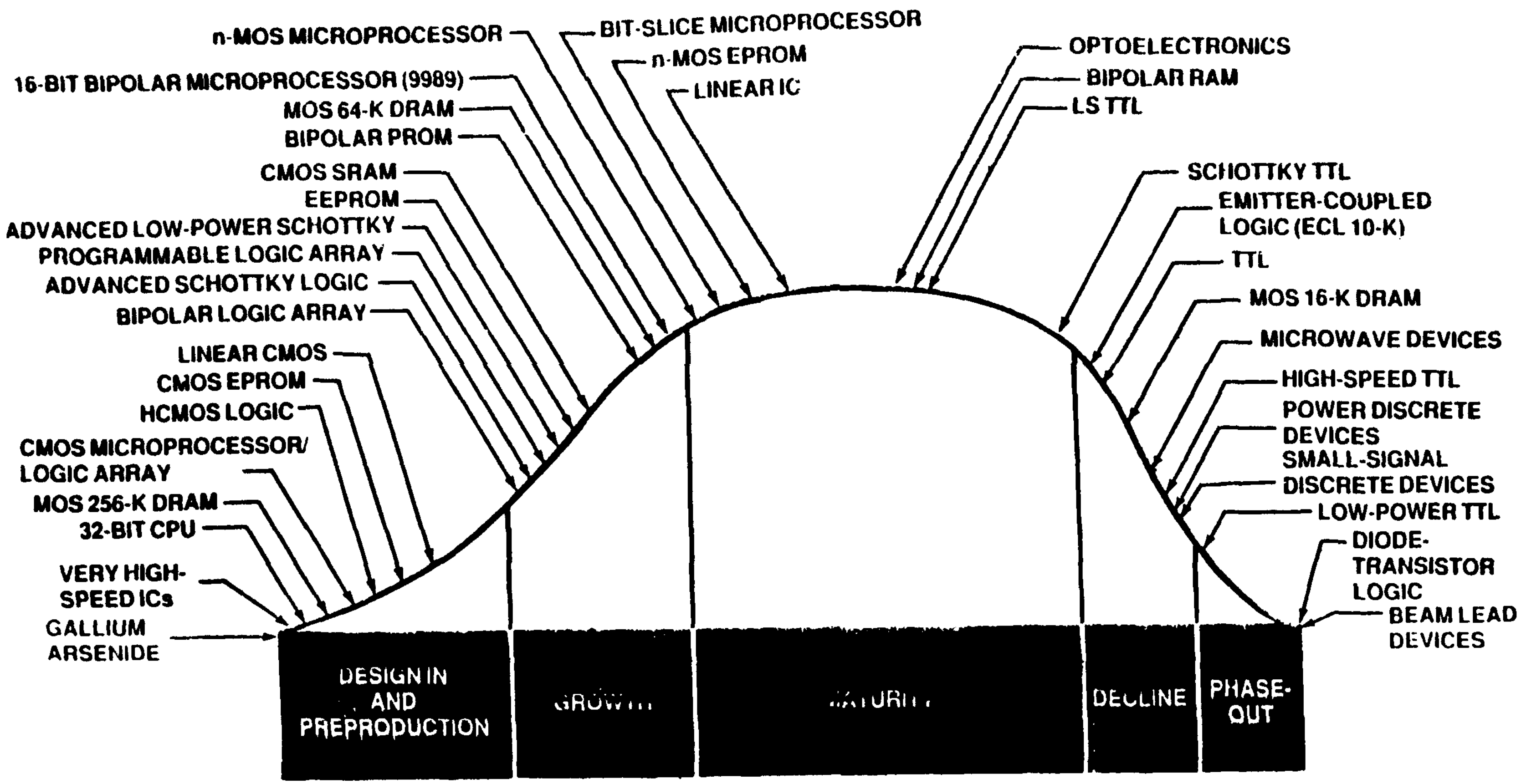


MESA CONSTRUCTED INTEGRATED CIRCUIT SN502



SHIFT IN IC APPLICATIONS

Technology Life Cycle Chart



The First Encounter

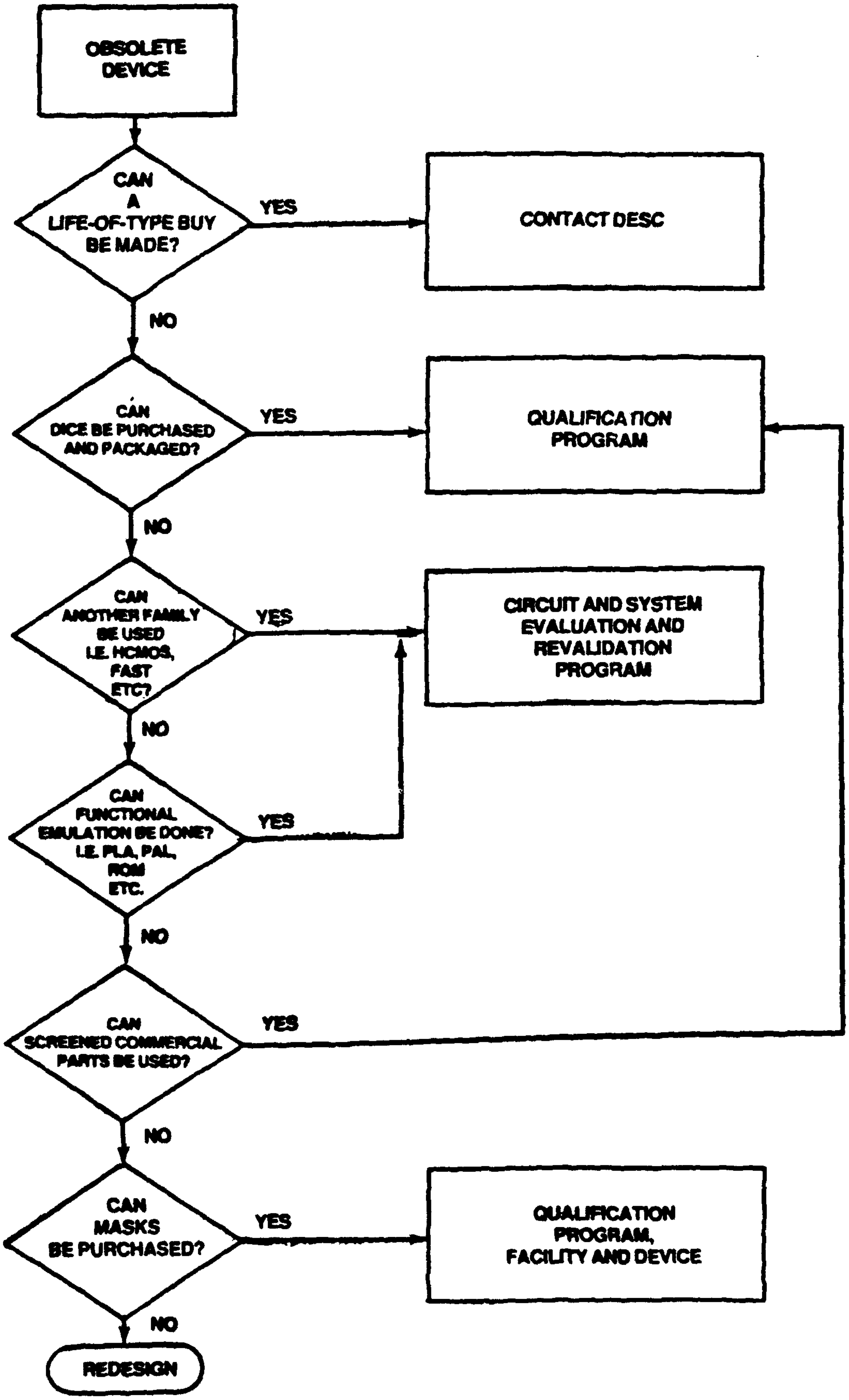
* PATRIOT
  - Re-design Decree
  - Government Recommended Options

* Impact on other MICOM Systems

Future Obsolescence and Logistic Problems

* MCM - Multi Chip Module (Hybrids)
* VHSIC - Very High Speed Integrated Circuits
* MIMIC - Millimeter and Microwave Monolithic Circuits
* ASIC - Application Specific Integrated Circuits
* GaAs - Gallium Arsenide Technology
* NBC/NS - Nuclear Biological Chemical/Nuclear Survivability Problems

Obsolescence Alternatives



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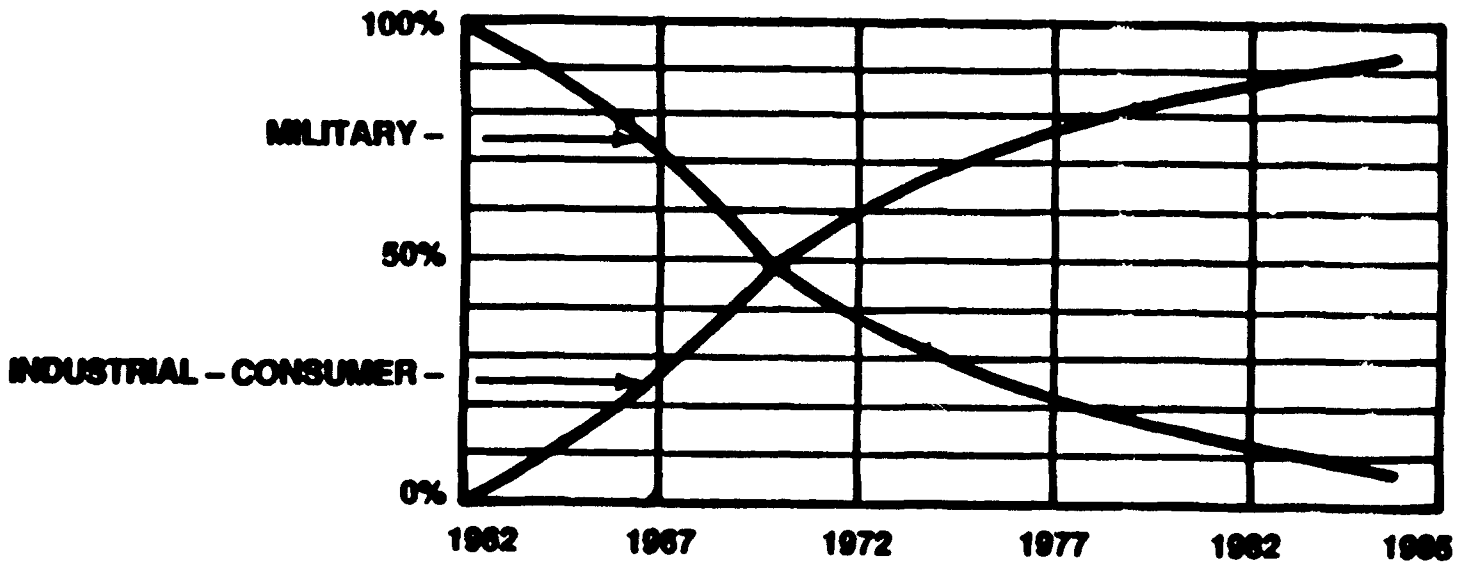
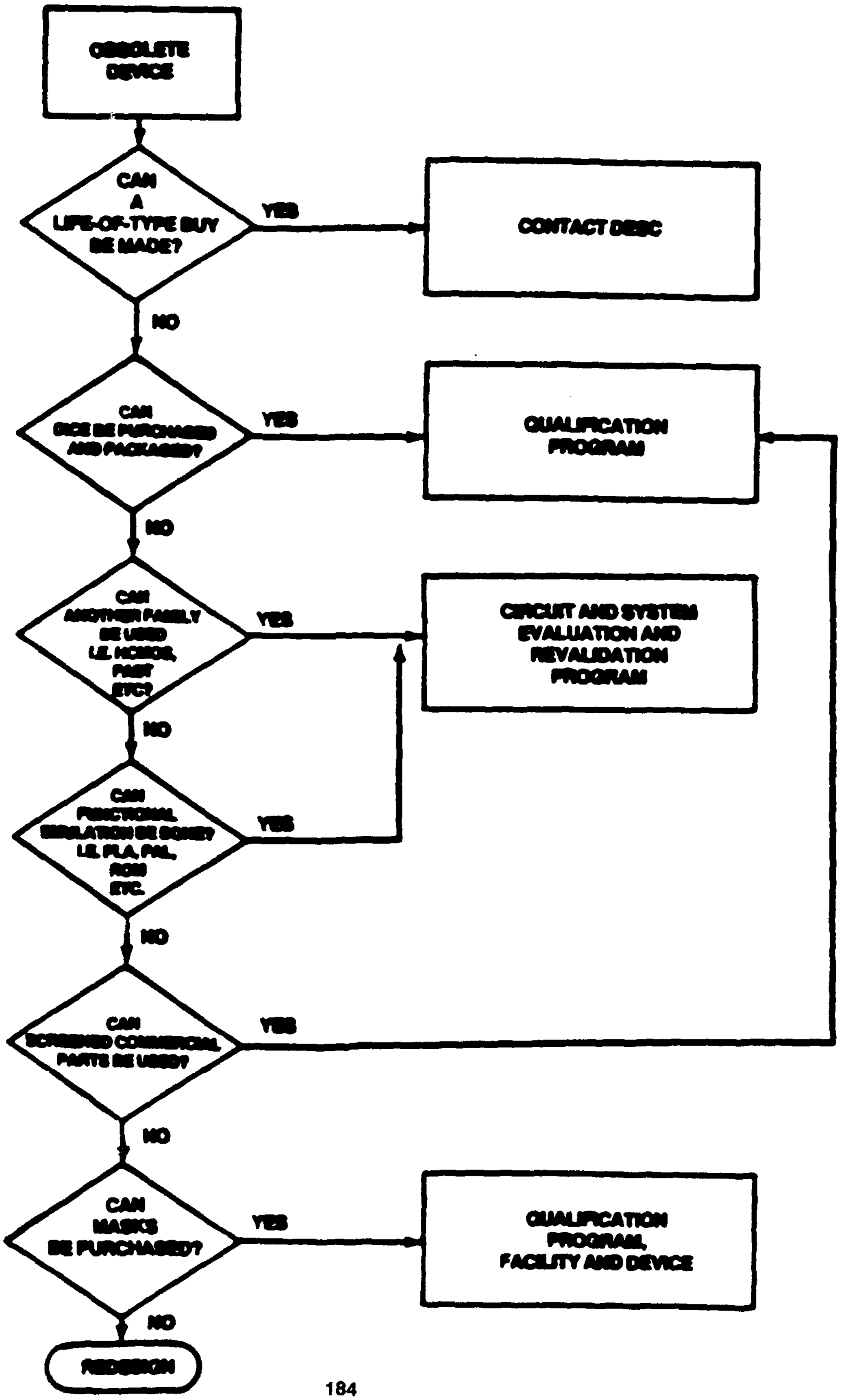
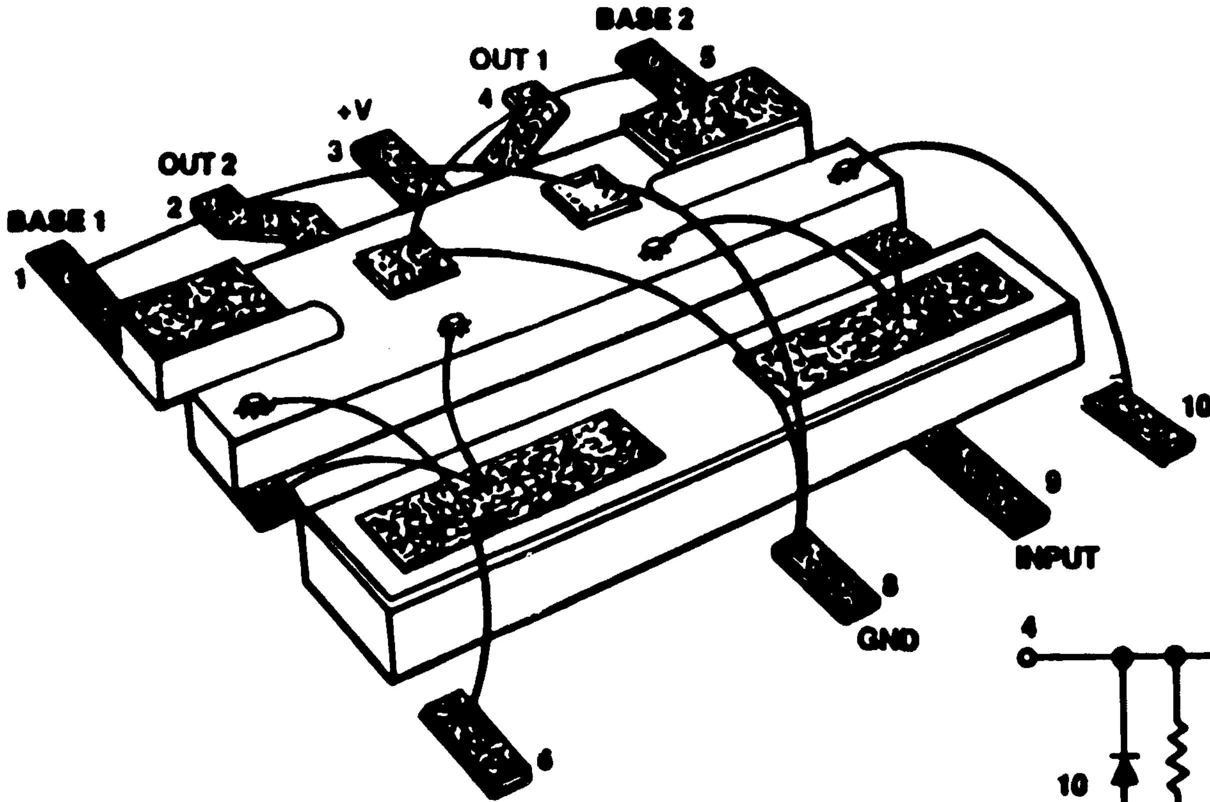
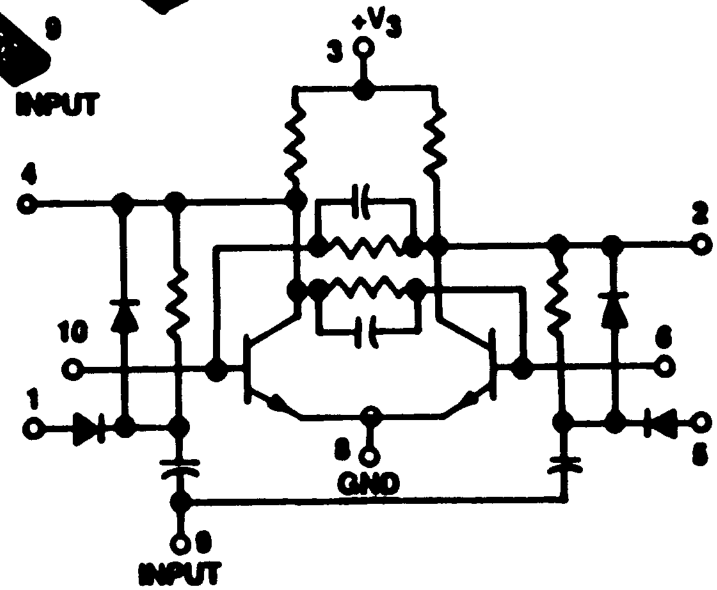


SHIFT IN IC APPLICATIONS

Obsolescence Alternatives

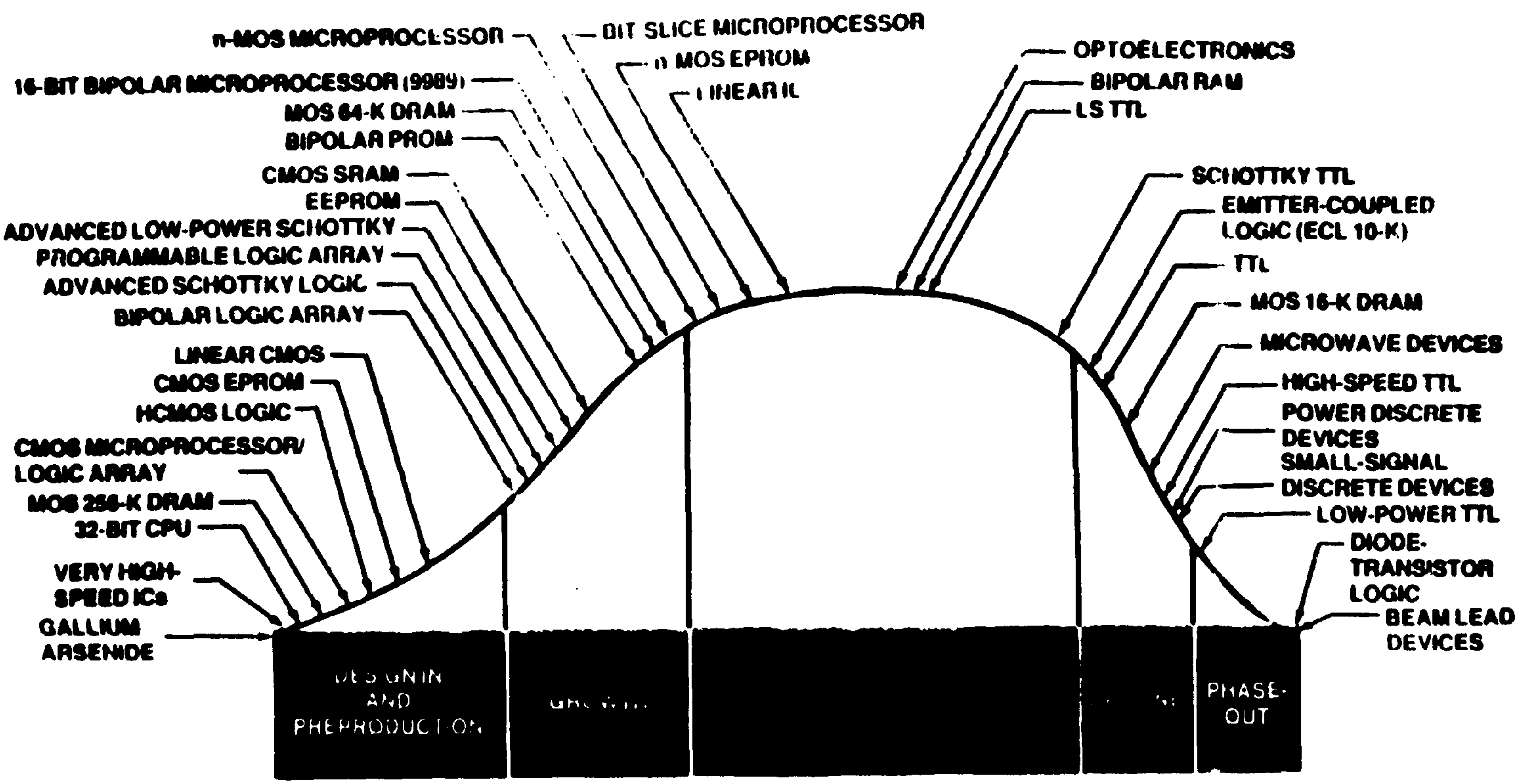






MESA CONSTRUCTED INTEGRATED CIRCUIT SN502

Technology Life Cycle Chart



The First Encounter

- PATRIOT
  - Re-design Decree
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Future Obsolescence and Logistic Problems

- **MCM** - Multi Chip Module (Hybrids)
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- **NBC/NS** - Nuclear Biological Chemical/Nuclear Survivability Problems

MILITARY STANDARDS ARE COST-EFFECTIVE

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ABSTRACT

The Military Standards System is complex and may appear to be overwhelming to the newcomer. Military standards are an indispensable element of the Department of Defense standardization program with the mission to develop, establish, and maintain a comprehensive and integrated system of documentation. This technical documentation system must support design, development, engineering, procurement, manufacturing, maintenance, and supply management. Standardization is a mandatory requirement for the military services and is the system that is used to establish requirements to be met by contractors. Two simplified examples will illustrate the flexibility of the military standard system used in conjunction with the design and procurement of military hybrid microcircuits.

KEYWORDS
Hybrid Microcircuit
Military Standards
Standardization
Cost-Effective

INTRODUCTION

The Military Standard System (MSS) can be complex and can appear as overwhelming. The user not thoroughly familiar with the system considers it as an unbearable, unworkable nightmare. The Military Standards System is that indispensable element that is necessary for the cost-effective research, design, engineering, production, quality control, reliability, equipment fielding, maintenance, and competition among perspective contractors. The use of the words, "Military Standards," should cause us to think of the word, "standardization." Military Standards are the method of standardizing on a set of requirements which may be tailored for a specific system, purpose, or item. The mission of the Department of Defense (DOD) with respect to standardization is to develop, establish, and maintain a comprehensive and integrated system of technical documentation in manufacturing, maintenance, and supply management. It is very important to note that the most common method of becoming familiar with MSS is the day-to-day educational process. This educational process provides the user with the basic methods to track down the necessary information and then properly process it to satisfy the end requirement. Any user with a closed mind or who does not want to enter into the educational process will not survive as an understanding and acceptable user of the standards system. Standardization has become a mandatory requirement for both the military services and industry. It is also the tool that provides for mass production and the distribution of goods to the civilian population.

PURPOSE

The Department of Defense mission for standardization is to develop, establish, and maintain a comprehensive and integrated system of technical documentation in development, manufacturing, maintenance, and supply management. The words, "Military Standard," should cause us to think of the word, "standardization." Standardization is a mandatory requirement for the military services and industry. A proven economic principle is that standardization is the tool that provides for "cost-effective" mass production and the distribution of goods to the military and also to the civilian population. It is a fact that the military, government contractors, and industry have written standards to maintain cost-effective operations. Without written standards, operations would be in a constant turmoil due to personnel rotation, termination, and miscommunication; the unnecessary rejection of good product or acceptance of product which should be rejected, there would be a very limited base line for training programs, lack of a standard vocabulary, and the continual "reinventing of the wheel." Technical progress would be minimal.

FAMILIARIZATION WITH THE SYSTEM

User unfamiliarity with the standards system is the greatest drawback to cost-effective operation. This is true whether it is the military, Government, or industry system. Huge sums of money are wasted by people who proceeded without understanding the requirement or plead ignorant to the existence of a requirement. The written standards system is simple. There either is or isn't a requirement. It is not uncommon that unfamiliarity with a standards system presents a user mental block which overcomes the desire to become familiar with and use the standards system. When this occurs, it is necessary to attack the system instead of retreating from it. A mental block may occur when a person proceeds into any unknown domain which appears as insurmountable. When in this situation, the first question usually asked is, "Where do I start?" The object of any educational process is to learn how to find basic information and methods to process the information to satisfy the end requirement. Two pertinent hybrid microcircuit examples are provided which illustrate the flexibility of the MSS.

MILITARY STANDARDIZATION DOCUMENTS

The design, development, procurement, and maintenance of military equipment requires an enormous family of military documents. The complete listing or indexing of unclassified military documents is contained in the DOD Index of Specifications and Standards (DODISS). The DODISS is used by the military services, other defense activities, and industry. The DODISS contains data on unclassified federal, military, and adopted industry specifications, standards, handbooks, and related standardization documents.

DOD Standardization Mission

The Defense Standardization and Specification program established specific standardization objectives to:

a. Improve the operational readiness of the military services.

b. Conserve money, manpower, time facilities, and natural resources.

c. Optimize the variety of items (including subsystems), processes, and practices used in acquisition and logistics support.

d. Enhance interchangeability, reliability, and maintainability of military equipment and supplies.

e. Ensure that products of requisite quality and minimum essential need are specified and obtained.

f. Ensure that specifications and standards are written to facilitate tailoring of prescribed requirements to the particular need.

g. Assure that specifications and standards imposed in acquisition programs are tailored to reflect only particular needs consistent with mission requirements.

Specifications

Specifications are prepared for items (and processes relative to the manufacture of items) which vary in complexity from resistors to missile weapon systems. They establish requirements in terms of complete design details or of performance but in most instances, in terms of both design and performance. Specifications may cover a single item such as a resistor or hundreds of items such as microcircuit or semiconductor families which for each single style may have many materials, several finishes, and a variety of package sizes.

Standards

Standards are documents created primarily to serve the needs of designers and to control variety. They may cover materials, items, features of items, engineering practices, processes, codes, symbols, type designations, definitions, nomenclature, test, inspection, packaging, and preservation methods and materials. Standards also define and classify defects and standardize the marking of materials, items, parts, and components of equipment. Standards represent the best solution for recurring design and engineering and other logistics problems with respect to the items and services needed by the military services.

Relationship Between Standards and Specifications

There is a relationship between standards and specifications. Standards function in procurement through the medium of specifications, thus they are used to standardize one or more features of an item such as size, testing, value, and detail of configuration. In equipment specifications they are referenced to standardize on those design requirements which are essential to interchangeability, compatibility, reliability, and maintainability. Standards are prepared to provide the designer with the descriptions and the data normally required for selection and application. Standards disclose or describe the technical features of an item in terms of what it is and what it will do. In contrast, the specification for the same item describes it in terms of the requirements for procurement. Reference to other documents in standards to complete a description should be resorted to only when it is impracticable to do otherwise.

Drawings

Drawings are referenced in many standardization documents. Conversely, specifications and standards are often referenced in drawings to identify the materials, processes, and standard items incorporated in assemblies and equipment. A standard item is defined as a material, part, component, subassembly, or equipment identified or described in military, federal, or adopted documents.

Handbooks

A handbook is a reference document which brings together procedural and technical or design information related to commodities, processes, practices, and services. A handbook may serve as a supplement to specifications or standards to provide general design and engineering data. The use of handbooks as references is optional.

STANDARDIZATION AND QUALIFICATION

Standardization is the adoption of engineering criteria to achieve the objectives of the standardization program. Once the military specification is approved, it becomes essential that a readily available source of manufacturers and distributors are identified and approved for delivery of the qualified product. This is accomplished by inserting qualification requirements in the approved specification. The justification for qualification is considered necessary if one or more of the following criteria apply:

a. The time required to conduct one or more of the examinations and tests to determine compliance with all of the technical requirements of the specification will exceed 30 days (720 hours).

b. Quality conformance inspection would require special equipment not commonly available.

c. It covers life survival or emergency life-saving equipment.

d. The application is critical; failure of the part or equipment would jeopardize successful completion of the mission or pose a significant risk to life or property.

MILITARY STANDARD 454

MIL-STD-454, "Standard General Requirements for Electronic Equipment" is highly recommended and should be a key reference document in the library of each engineer or technical person involved in the electrical, electronic, quality, reliability, or materials engineering fields. MIL-STD-454 is utilized by DOD for the design, development, and production of all electronic hardware. The 75 requirements included in MIL-STD-454 are found in Table 4.

COST-EFFECTIVELY UTILIZING THE MILITARY STANDARDS SYSTEM FOR HYBRID MICROCIRCUITS

Two hybrid microcircuit examples are provided to illustrate the simplicity of the MSS when the user is familiar with the system. A pertinent point is that there are DOD standards and also military service standards (Army, Navy, and Air Force). DOD standards apply to all miltary services. The military services also have standards which can be tailored to meet specific system or item requirements. The cost-effective solution to each example is that standardization greatly simplifies the problem solution.

EXAMPLE NUMBER ONE: Designing a hybrid microcircuit to meet Army Missile Command (MICOM) requirements.

Statement of Problem: A hybrid microcircuit design engineer has only experience designing hybrids for commercial applications and has no experience utilizing the MSS. This designer's company desires to compete to produce hybrids which meet MICOM requirements. The company assigns this design engineer to their MICOM hybrid microcircuit project. There is no help available within the company. There are schedule and time constraints to be met.

MICOM Requirements: The hybrid microcircuit contains a variety of chips, including integrated circuits, semiconductors, resistors, capacitors, and coils. The hybrid must be hermetically sealed in a leadless chip carrier for mounting on a printed circuit board. It is also stated that the military requirements must be met for: (1) derating of electronic parts, (2) parts selection and control, (3) electromagnetic interference controls (4) reliability, and (5) electrostatic discharge controls. The prominent question in the mind of this designer is, "Where do I start?"

Solution to Example 1: MIL-STD-454 is the DOD document that specifies the design requirements for electronic equipment. Government contractors should be familiar with and focus on this prime document. MIL-STD-454 is designed to provide substantial cost savings for the Government and its contractors.

The designer proceeds to MIL-STD-454, which presents the fundamental design requirements for 12 general electronic specifications (Army, Navy, and Air Force). It consolidates all electronic equipment design and construction requirements into 75 subject headings which are defined as requirements. The 12 general electronic specifications are in the Foreword of MIL-STD-454. One of these 12 general electronic specifications is the MICOM specification MIL-STD-11991 which tailors the MIL-STD-454 hybrid requirements to meet MICOM requirements. The basic government contract will require the use of MIL-STD-454 and MIL-STD-11991 for design of the hybrids. MIL-STD-11991 will invoke specific requirements to the general requirements of MIL-STD-454. These two documents are used interchangeably with the order of usage priority specified. The information required by the hybrid designer is found in Table 1, Use of Standardization Documentation to Solve Hybrid Design Problem Number One. Table 1 illustrates the simplicity and interchangeability built into the system for a cost-effective solution to this hybrid design problem. The key is familiarity with the specification system.

EXAMPLE NUMBER TWO: A hybrid microcircuit manufacturer desires to become a military certified manufacturer.

Statement of Problem: A longtime commercial only hybrid microcircuit manufacturer is interested in becoming a military certified hybrid manufacturer. The company has directed a cost feasibility study be made to determine the required potential investment. The company has no experience with military requirements. The company initially desires to limit its business to MICOM.

Solution to Problem 2: MIL-STD-454, Requirement 64, is the starting point for Table 2, which flows through the problem solution. Beginning with Item 1 and MIL-STD-454 and proceeding through Item 7 allows the study team to itemize the requirements necessary to become a certified facility. Table 2 flows in a logical sequence. References in Requirement 64 begin the tracking process. The user proceeds through the sequence of items 2 through 7, compiling the available information for each item. This process began by knowing that MIL-STD-454 is the starting point to gather and compile the necessary information. This is true for any military hybrid microcircuit. A preliminary cost and schedule projection can then be developed to aid management in making the decision whether or not they should become a MICOM certified facility.

CONCLUSIONS

MSS is cost-effective when the user is familiar with the system. Neither Government nor industry can operate cost-effectively without a system of written standards. Familiarization prevents "reinventing the wheel" each time an unfamiliar requirement is encountered. Experience has proven that many potential problems are simplified or solved when the user is knowledgeable of the pertinent standards system. The two examples verify the versatility of the system. Military hybrid microcircuit manufacturers must utilize the standards system to be cost-effective and remain competitive.

BIBLIOGRAPHY

1. Defense Standardization Manual - DOD 4120.3-M, Defense Standardization and Specification Program Policies, Procedures, and Instruction," August 1978.

2. "Military Standard 454, Rev L, Standard Requirements for Electronic Equipment," 20 September 1988.

References 1 and 2 are unclassified military documents which are public domain. The author's use of references 1 and 2 is necessary to retain the military approved requirements, definitions, and philosophy for military standards and standardization.

TABLE 1. Use of Standardization Documentation to Solve Hybrid Design Problem Number One

Item No.	Nomenclature	MIL-STD-11991 Paragraph No.	MIL-STD-454 Requirement No.	Military Document No. (See Table 3)
1.	Derating of Parts	3.1.11	18	MIL-STD-1547
2.	Part Selection	3.2.3	22	MIL-STD-965
3.	EMI Controls	3.3.11.2	61	MIL-STD-461
4.	Reliability	3.3.5	35	MIL-M-38510
5.	ESD Control	3.2.2.5	75	DOD-STD-1686
6.	Hybrid Microcircuit	3.2.3.38.1.1	64	MIL-M-38510
7.	Capacitor Chip (Ceramic)	3.2.3.38.1.1.3	2	MIL-C-55681
8.	Capacitor Chip (Tantalum)	3.2.3.38.1.1.4	2	MIL-C-55365
9.	Inductor Chip	3.2.3.38.1.1.6	14	MIL-M-38510
10.	Integrated Circuit Chip	3.2.3.38.1.1.1	64	MIL-M-38510
11.	Leadless Chip Carrier	3.2.3.38.2	64	MIL-M-38510 Appendix C
12.	Printed Circuit Board	3.2.3.19	17	MIL-P-46843
13.	Resistor Chip	3.2.3.38.1.1.5	33	MIL-R-55342
14.	Sealing	3.2.3.38.1.1.7	64	MIL-STD-883
15.	Semiconductor Chip	3.2.3.38.1.1.1	30	MIL-S-19500

TABLE 2. Use of Standardization Documentation to Assist in the Example Two Cost Study

Item No.	Document No. (See Table 3)	Locator Key	Paragraph Page No.	Reference To (See Table 3)
1.	MIL-STD-454	Micro Dev	V	Req. 64
		Foreword	iii	MIL-STD-11991
		Reliability	4.1.2	MIL-M-38510
		Qual Assur	4.1.5c	MIL-M-38510, Appendix G
		ESD	4.1.6	DOD-STD-1686
		Packages	4.4	-------
2.	MIL-STD-11991	Hybrid IC	3.2.3.38.1.1	MIL-STD-454, Req. 64 MIL-M-38510, Appendix G MIL-STD-883, Method 5008
3.	MIL-M-38510	Qual Assur	Req. 3.4	MIL-STD-883, Method 5008
		Certification	3.1.4.2	MIL-STD-1772
		Appendix G	20.1	MIL-STD-1772
4.	DOD-STD-1686	Scope	1.1	DOD-HDBK-263
5.	MIL-STD-883	Test Proc	Meth. 5008	MIL-M-38510
6.	MIL-STD-1772	Scope	1.1	-------
		Qual Assur	4.1.2	MIL-M-38510, Appendix A
7.	DOD-HDBK-263	Scope	1	-------

Abbreviations:

Micro Dev	- Microelectronic Device	Qual Assur	- Quality Assurance
Req.	- Requirement	ESD	- Electrostatic Discharge
App.	- Appendix	IC	- Microcircuit
Meth.	- Method	Test Proc	- Test Procedure

TABLE 3. Titles of Specifications Referenced in Tables 1 and 2

ITEM NUMBER		SPECIFICATION	
Table 1	Table 2	Number	Title
1	-	MIL-STD-1547	Parts, Materials, and Processes for Space and Launch Vehicles
2	-	MIL-STD-965	Parts Control Program
3	-	MIL-STD-461	Electromagnetic Emission and Susceptability Requirements for the Control of Electromagnetic Interference
4,6,10,11	3	MIL-M-38510	Microcircuits, General Specification for
5	4	DOD-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts Assemblies and Equipment
-	6	MIL-STD-1772	Certification Requirements for Hybrid Microcircuit Facilities and Lines
7	-	MIL-C-55681	Capacitors, Chip, Multi-Layer, Fixed Unencapsulated, Ceramic Dielectric, Established Reliability, General Specification For
7	-	DOD-HDBK-263	Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment
8	-	MIL-C-55635	Capacitors, Chip, Fixed Tantulum, Established Reliability, General Specification For
9	-	MIL-C-83446	Coil, Chip, Radio Frequency
12	-	MIL-P-46843	Printed Wiring Assemblies
13	-	MIL-R-55342	Resistor, Fixed, Film, Chip, Established Reliability, General Specification For
14	5	MIL-STD-883	Test Methods and Procedures for Microelectronics
15	-	MIL-S-19500	Semiconductor Devices, General Specification For
Column Heading	1	MIL-STD-454	Standard General Requirement for Electronic Equipment
Column Heading	2	MIL-STD-11991	Electronic, Electrical and Electromechanical Equipment, Guided Missile and Associated Weapons Systems, General Specifications For

TABLE 4.

Individual Requirements

Requirement 1 – Safety Design Criteria – Personnel Hazards
Requirement 2 – Capacitors
Requirement 3 – Flammability
Requirement 4 – Fungus-Inert Materials
Requirement 5 – Soldering
Requirement 6 – Bearings
Requirement 7 – Interchangeability
Requirement 8 – Electrical Overload Protection
Requirement 9 – Workmanship
Requirement 10 – Electrical Connectors
Requirement 11 – Insulating Materials, Electrical
Requirement 12 – Fastener Hardware
Requirement 13 – Structural Welding
Requirement 14 – Transformers, Inductors, and Coils
Requirement 15 – Metals, Corrosion Resistance
Requirement 16 – Dissimilar Metals
Requirement 17 – Printed Wiring
Requirement 18 – Derating of Electronic Parts and Materials
Requirement 19 – Terminations
Requirement 20 – Wire, Hookup, Internal
Requirement 21 – Castings
Requirement 22 – Parts Selection and Control
Requirement 23 – Adhesives
Requirement 24 – Welds, Resistance, Electrical Interconnections
Requirement 25 – Electrical Power
Requirement 26 – Arc-Resistant Materials
Requirement 27 – Batteries
Requirement 28 – Controls
Requirement 29 – Electron Tubes
Requirement 30 – Semiconductor Devices
Requirement 31 – Moisture Pockets
Requirement 32 – Test Provisions
Requirement 33 – Resistors
Requirement 34 – Nomenclature
Requirement 35 – Reliability
Requirement 36 – Accessibility
Requirement 37 – Circuit Breakers
Requirement 38 – Quartz Crystals and Oscillator Units
Requirement 39 – Fuses and Fuse Holders
Requirement 40 – Shunts
Requirement 41 – Springs
Requirement 42 – Tuning Dial Mechanisms
Requirement 43 – Lubricants
Requirement 44 – Fibrous Materials, Organic
Requirement 45 – Corona and Electrical Breakdown Prevention

CONTENTS - Continued (TABLE 4.)

Designing Accelerated Tests for Accurate Life-Cycle Predictive Technology

Michael J. Cronin
Mechanical Technology Inc.
Latham, New York

Second MICOM Logistics Workshop

27 August 1991

The challenges in logistics support confront the breadth of engineering issues full face. Systems degrade and become less effective over time as a result of design, manufacture or materials. The unique military life cycle challenges engineers at all levels to put forth the best combinations of skills and materials to produce the most effective weapons systems that will last a required lifetime and require little or none for maintain them and keep them mission qualified.

This is the text for the attached slides.

Slide 1 Title

Slide 2. Agenda

This discussion begins with a brief introduction to Predictive Technology. We will cover a definition of Predictive Technology, some of the tools used, and the unique military life cycle. The basics of accelerated life-cycle testing will be covered. Finally, the challenges to cost effective logistical support will be presented.

Slide 3., Acknowledgement

Bob Kuper has been spearheading the Predictive Technology effort within AMCCOM. Some of the ideas presented here are from his insights. His efforts have brought to the forefront the necessity for a coordinated effort in Predictive Technology.

Slide 4. Predictive Technology - Definition

The two main Objectives of Predictive Technology are the early detection of failure mechanisms during the unique military life cycle and the development of enhanced predictive capability. The Goal of Predictive Technology is to meet all required characteristics over the entire life cycle of each military system.. These can be exemplified by these two questions:

1. Will the systems be 100% operational after planned (or unplanned) extended storage, transportation, handling and use?

2. If designed for one lifetime, will it survive two lifetimes (extended-life reliability)?

Slide 5. Predictive Technology - Tools

The tools of predictive technology are embedded in Accelerated Life-Cycle Testing (ALCT). ALCT is required for accurately predicting logistical support. Degradation initiation processes, mechanisms, and rates must be accurately predicted. The system environments, both internal (controllable) and external (uncontrollable) must be considered and properly simulated in accelerated testing.

Slides 6.& 7 Predictive Technology - Military Life Cycle

The Military Life Cycle is unique because of long term storage and handling. The Military Life Cycle can only be properly understood and simulated through Predictive Surveillance. When done properly, Predictive Surveillance will efficiently and effectively establish failure mechanisms and the feedback will be used to calibrate and verify the results of accelerated tests and engineering models.

Predictive surveillance comes from the three corners of this triangle. It begins with feedback from the Research, Development, Test, and Evaluation activities. The results are integrated into production and quality control of the item. Finally, feedback from the stockpile logistical support lines is used to monitor and upgrade predictive models and life estimates.

Slide 8. Accelerated Life-Cycle Tests

Accelerated life-cycle tests can be applied at many stages in an items life. From initial material selection, component testing, subassembly trials, or complete item assemblies. Test levels are selected to answer specific questions efficiently.

Slide 9. Accelerated Life-Cycle Tests - Model Development

Model development is one on the first steps in ALCT. Model development starts with a mathematical model. An equation is develop. Initial on-hand or estimated preliminary data can be used as feedback to establish initial coefficients and exponents.

Slide 10. Accelerated Life-Cycle Tests - Statistical Experimental Design (SED)

SED is very useful, even necessary, for efficient model development. Multiple factor (variable) experimentation, rather than changing one factor at a time, is easily conducted. In fraction factorial experimental design, specific sample subsets of the design matrix are used to streamline the experimentation process, resulting in fast and effective parameter design.

Slide 11. Accelerated Life-Cycle Tests - Statistical Experimental Design.

SED is used to optimize models. Noise (variability) in engineered systems is reduced by optimizing S/N (signal to noise, or response to variability) ratios. Both internal (controllable) and external (uncontrollable) noise sources are optimized.

Using SED, parameter levels can be chosen which are least sensitive to internal noise and sometime external noise. SED is used to conduct no or low cost trials on complex systems. An optimized model con be run without any hardware development.

Slide 12 Accelerated Life-Cycle Tests - Analysis

Analysis techniques of experimental results includes both traditional western statistics and more recently, Taguchi concepts and methods.

Slide 13. Accelerated Life-Cycle Tests

A typical accelerated life-cycle test may include these steps.

Slide 14. Accelerated Life-Cycle Tests - Problems Encountered

Determining which degradation processes are active, which are dominant, competing, or synergistic, or if new mechanisms are being introduced by the test method are often a difficult process. Long time exposures can mask the real problem and often sophisticated materials analysis and failure analysis is required to solve the puzzle. The primary mode of failure or degradation may change with conditions. Determining the degree of similitude and obtaining statistically significant results can be viewed as the same question.

Statistical experimental design will assist in unraveling the secrets. Properly performed fractional factorial design will help answer the questions about degradation mechanisms and help establish the correct test methods and model parameters.

Slide 15. Accelerated Life-Cycle Tests - Problems Encountered with Unique Military Life Cycle

No other organization encounters a worldwide environment for long term storage and logistical support. The weapons systems are subjected to unspecified and constantly changing environments which are solely mission dependent. Getting accurate logistical feedback is hampered by mission change, the different people assigned over time, inherently slow channels of communication, and inadequate training for positive, uniform feedback. These problems mandated any model be flexible and continually verified as the weapons systems progress through their ever changing environments.

Slide 16 Accelerated Life-Cycle Tests - Solution to Problem

The solution to the problem of reducing logistical support costs is to field proven systems that have been adequately characterized and modeled for long term degradation. The key to this is timely, complete, and accurate FEEDBACK. Predictive Surveillance input into accelerated testing and modeling will enhance our understanding and peek our ability to predict remaining life.

Slides 17 & 18 Challenges in Logistical Support - Determine Remaining Life

The real challenge in logistical support is determining the remaining useful life and what it will cost to keep the system useful. Normal life models will examine single mechanism degradation systems. Logistical life equations will include the combined effects of the constantly changing environment (mission) and the multiple processes of transportation, storage, handling, and operation.

This requires that models used for logistical support be flexible and allow for variable, time dependent, inputs and variable, time dependent, parameters.

Slide 19 Challenges in Logistical Support - Feedback

Feedback from logistical support lined is absolutely necessary for cost effective logistical support. Full time surveillance of critical items should be done at discrete intervals, not just maintenance points. Data for each life segment (transportation, handling, storage, and use) should be gathered. The data can be transmitted to a life-data clearing house and the remaining life can be calculated with the latest update of the flexible models. Then the algorithms can be used to help make economic, safety, life, and reliability decisions.

MTI 91P31

DESIGNING ACCELERATED TESTS FOR ACCURATE LIFE-CYCLE PREDICTIVE TECHNOLOGY

Prepared by

Michael J. Cronin
Mechanical Technology Incorporated
Latham, New York

Prepared for

Second MICOM Logistics
Research and Development Workshop

27 August 1991

AGENDA

Predictive Technology

- Definition
- Tools
- Military Life Cycle

Accelerated Life-Cycle Tests

- Model Development
- Statistical Experimental Design
- Problems
- Solutions

Challenges in Logistics Support

- Determining Remaining Life
- Feedback

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ACKNOWLEDGMENT

Robert Kuper

Chief, Predictive Technology Branch
Product Assurance and Test Directorate
Army Research, Development, and Engineering Center
Picatinny Arsenal

PREDICTIVE TECHNOLOGY

Definition

Objectives

- Early detection of failure mechanisms during unique military life cycle
- Development of enhanced predictive capability

Goal

- To meet ***all*** required characteristics over the ***entire*** life cycle

Questions

- Will the weapons/defense systems be 100% operational after planned extended storage, transportation, and handling?
- If designed for one lifetime, will it survive two lifetimes (extended-life reliability)?

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PREDICTIVE TECHNOLOGY

Tools

Accelerated Life-Cycle Testing

- Required for predicting logistics support
- Must accurately predict initiation processes, degradation mechanisms, and degradation rates
- Must consider environments
  - Internal (controllable)
  - External (not controllable/semicontrollable)

PREDICTIVE TECHNOLOGY

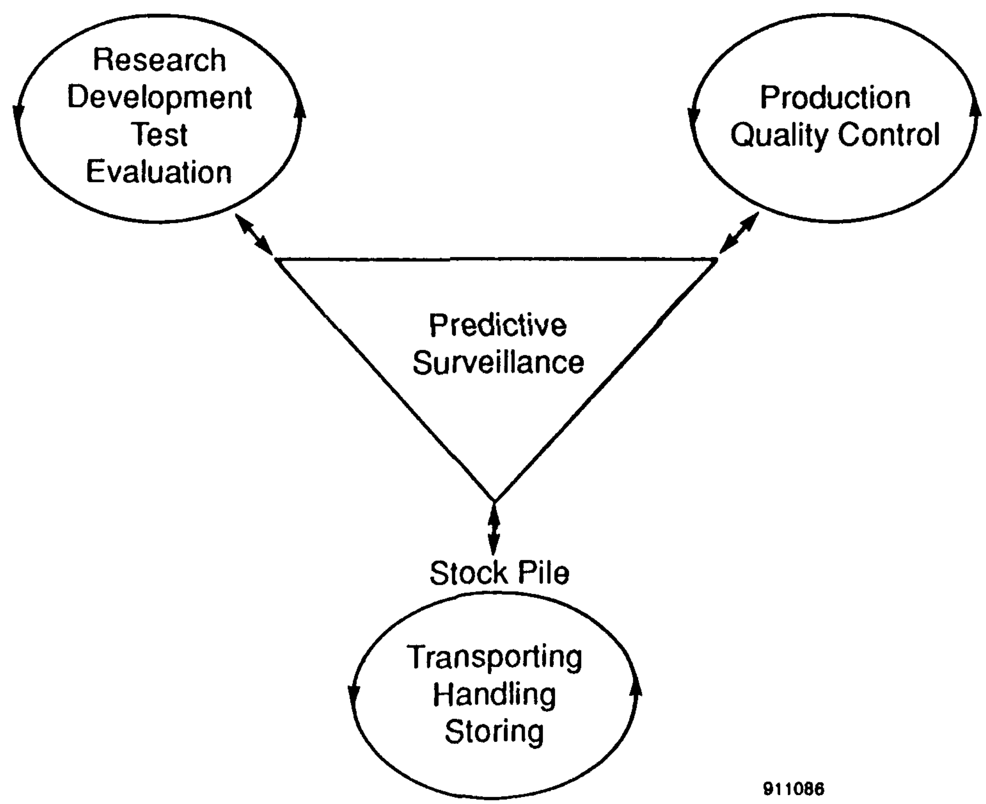
Military Life-Cycle Concept

Predictive Surveillance Necessary

- For feedback
- To determine failure mechanism
- To calibrate and verify the results of accelerated tests

PREDICTIVE TECHNOLOGY

Military Life-Cycle Concept



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ACCELERATED LIFE-CYCLE TESTS

- Materials
- Components
- Subassemblies
- Complete assemblies

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ACCELERATED LIFE-CYCLE TESTS

Model Development

- Mathematical model
- Equation
- Use feedback
- Parametric design
  - Coefficients
  - Exponents

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ACCELERATED LIFE-CYCLE TESTS

Statistical Experimental Design

- Model development
- Multiple factor experimentation
- Fractional factorial design
- Sampling (specific, not random)
- Parameter design

ACCELERATED LIFE-CYCLE TESTS

Statistical Experimental Design

- Optimize model
- Reduce noise (variability)
  - — S/N ratio
  - — Internal and external noise
- Determine parameter level
  - — Least sensitive to variation
- Conduct no-cost trials
  - — Complex systems

ACCELERATED LIFE-CYCLE TESTS

Analysis

- Traditional western statistics
- Taguchi concepts and methods
  - — Concurrent statistics
  - — Signal/noise ratio
  - — Trend analysis
  - — Tolerance design

ACCELERATED LIFE-CYCLE TESTS

- Run accelerated tests
- Run one set at actual values (similitude)
- Analyze results
- Calibrate
- Verify results represent reality
- Compare to continuous logistical feedback
- Update model

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ACCELERATED LIFE-CYCLE TESTS

Problems Encountered

- Degradation processes (determine which is (are) active for any given environment)
- Competing or synergistic effects
- New degradation mechanism introduced by test method
- Selection of the correct parameters to study
- Development model, coefficients, and exponents
- Degree of similitude
- Statistically significant results
- Primary mode of failure may change with conditions

Statistical experimental design will overcome many of these problems

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ACCELERATED LIFE-CYCLE TESTS

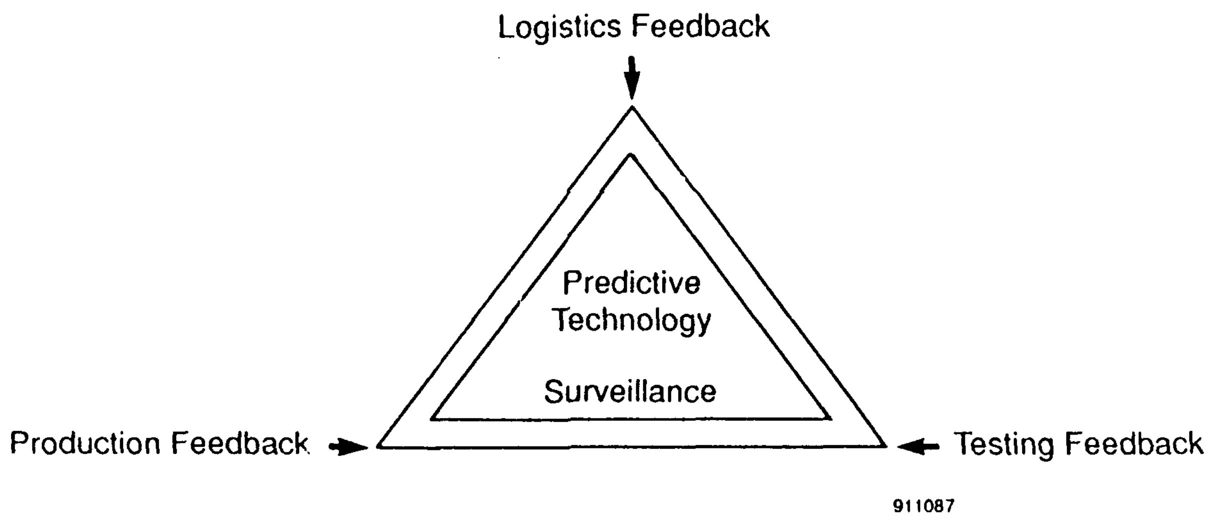
Problems Encountered with Unique Military Life Cycle

- Worldwide environments
- Unspecified environment (mission)
- Changing environments
- Feedback channels
  - — Constantly changing with mission
  - — Different person
  - — Slow channels of communication
  - — Training requirement for positive, uniform feedback
- Verification of an ever-changing model

ACCELERATED LIFE-CYCLE TESTS

Solution to Problem

Feedback



Timely, complete, accurate

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CHALLENGES IN LOGISTICS SUPPORT

Determine Remaining Life

Normal life equations

- Concern actual use
- Typically one primary mechanism

Logistics life equations

- Multiple primary mechanism
- Transportation (worldwide and intertheater)
- Storage
- Handling

Requires flexible model

- Variable inputs
- Variable parameters

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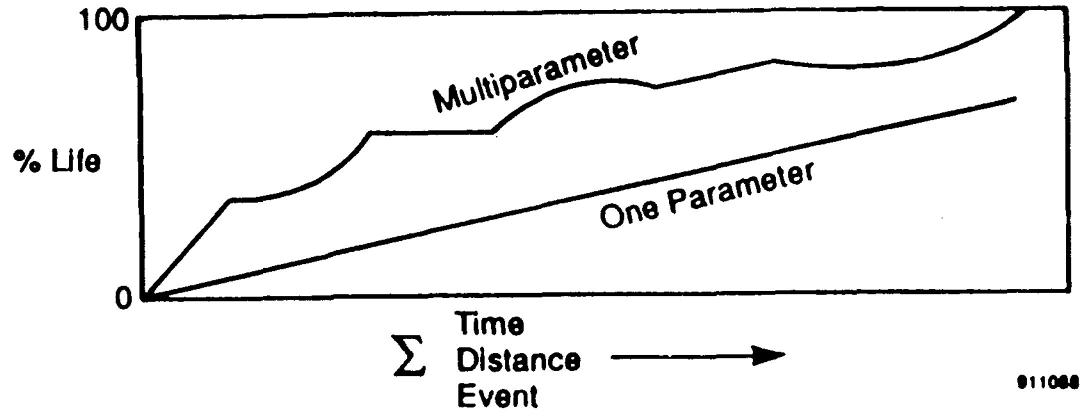
CHALLENGES IN LOGISTICS SUPPORT

Determine Remaining Life



$$\% \text{ Life} = \sum_{V_i} \Sigma \text{ Transportation } \Sigma \text{ Handling } \Sigma \text{ Storage } \Sigma \text{ Operation}$$

Example:	Linear (Number of Miles)	Exponential (Height of Drop)	Arrhenius (Temperature, Humidity, Corrosion)	? (Duty Cycle)

Can calculate remaining life by summing portions of lives used

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CHALLENGES IN LOGISTICS SUPPORT

Feedback

- Absolute necessity
- Full-time surveillance
  - — Monitor and record unique data for each segment of life (transportation, handling, storage, usage)
- Collect at end of each period of life segment
- Transmit to life-data clearinghouse
- Calculate actual remaining life
- Develop decision algorithms (economics, time, safety, reliability)

An Artificially Intelligent Parametric Processor

for

Realtime Design Supportability Feedback.

By Curtis M. Low

Slide 1

The purpose of this paper is to investigate approaches to providing the designer with realtime supportibility feedback at the CAD terminal.

Slide 2

The problem with supportibility design reviews is that the wait and redesign cost the contractor too much time and the government too much money.

Slide 3

In 1981, I developed the concept of linking supportibility modeling to the CAD system. In the mid 1980's, we looked at adopting a support/CAD linked system for AMCCOM. This paper investigates approaches for putting the support/CAD parametrics in an artificial intelligence framework.

Slide 4

In an AI System, changes are updated from a set of rules within the system and no Human action is needed.

Slide 5

Four processes within the AI framework are examined by this paper.

Slide 6

Universal Models can be thought of as a kind of factorial analysis. In factorial analysis, the concern is how many factors does it take to explain 95% of the variance. The factors and then identified and used to estimate.

Slide 7

In an AI environment, the CAD operator would have to input Universal Factors in addition to the CAD input for the system to self update.

Slide 8

A statistical Database/Regression Analysis system can be structured within an AI framework. A process like Partial F must be used to regress the equations.

Slide 9

The Partial F approach evaluates the statistically significance of each possible variable that could be added. The most statistically significant variable is selected and added to the equation. The process is repeated for all nonselected variables until there are no more statistically significant nonselected variables.

Slide 10

The third approach is a CAM style approach. CAM stands for computer aided manufacturing. Hardware on the CAD is linked to CAD drawn interfaces to production machines. When motion and component assembly are added, you get an assembly line model.

Slide 11

Support modeling is similar to CAM. The production machine interfaces are replaced with tool, test equipment and human interfaces for the support tasks. When motion is added, time and resources can be estimated for each task. Tasks can be linked using reliability data to produce CAD supportibility modeling.

Slide 12

Within the AI framework, new components would be linked with similar items already having support modeled. The support approaches would be evaluated statistically and the most likely assigned to the new component. The computer system would then develop support modeling for the new component based on this most likely support approach.

Slide 13

The CAD level statistics approach involves differences. Lines are differences in pen position from start to stop. Cost and availability can be described with differences that are related to statistical variance.

Slide 14

Regression analysis approaches are available that can work with differences. Take two data sets of raw data: Y is the dependent variable set and X is the independent variable set. The first row of the data array below the Y data set subtracts the first Y element from each Y element. The second row subtracts the second Y element from each Y element etc. The array below the X data set does the same for the X data. This leaves two arrays of differences. Dividing each Y array value by the corresponding X value produces the b parameter array of estimates at the bottom of the page. The b estimates can be reduced to a single value in many different ways.

Slide 15

All four approaches show promise. A lot of work has yet to be done but realtime design feedback for supportibility is definitely possible.

Slide 16

Fly Before You Buy is the current concept driving our procurement process. With realtime feedback, you have the modeling equivalent of a fly while you design system. In the far future, this design process might be put in an AI environment to automatically design optimal designs within the constraints of available technology and customer needs.

MISSILE LOGISTICS CENTER

An

ARTIFICIALLY INTELLIGENT

PARAMETRIC PROCESSOR

for

REALTIME

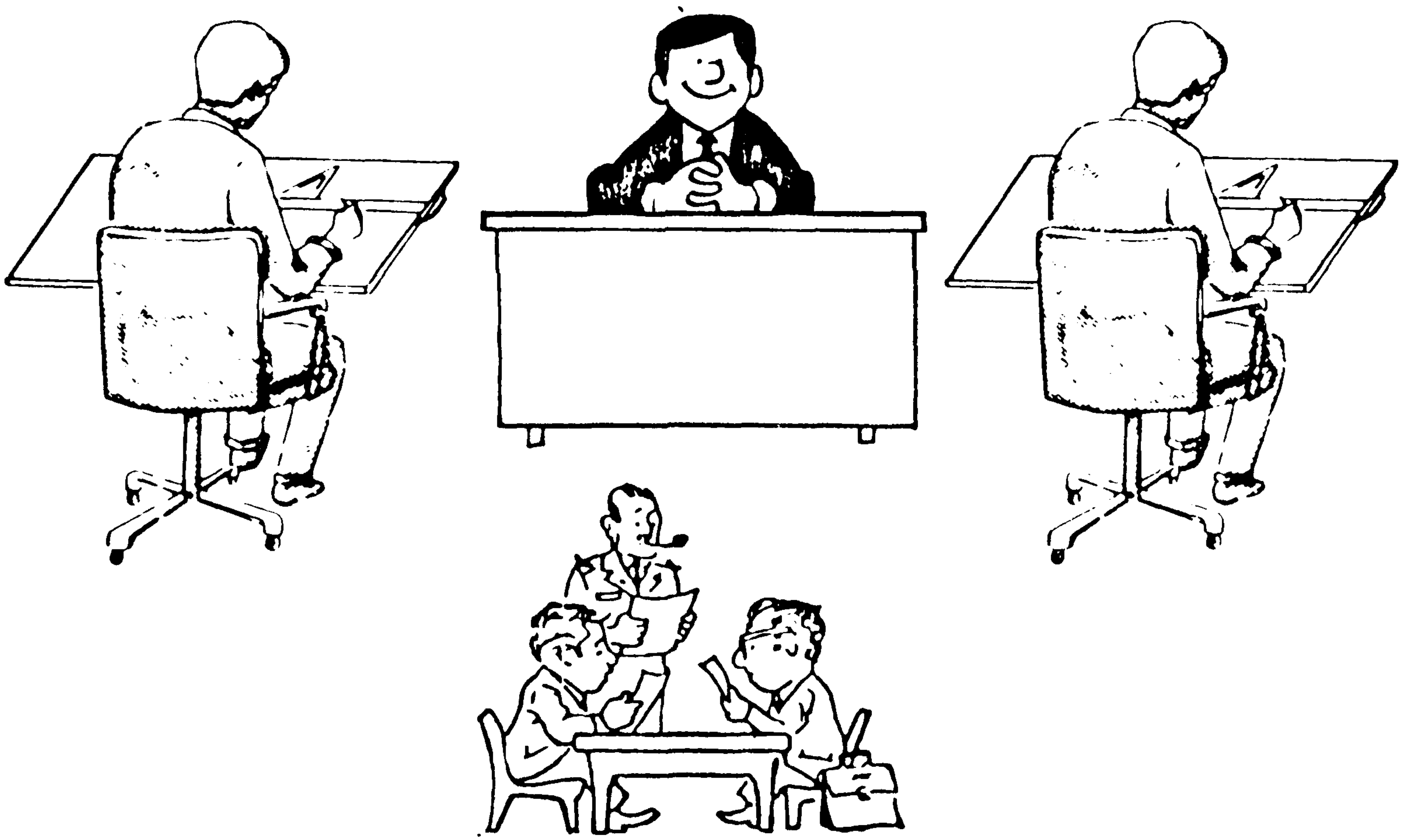
DESIGN SUPPORTIBILITY

FEEDBACK

MISSILE LOGISTICS CENTER

THE DESIGN FOR SUPPORTIBILITY PROBLEM

HURRY DESIGN AWAIT REVIEW HURRY REDESIGN



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BACKGROUND

1980-1981	SUPPORTIBILITY MODELING
MAY 1981	LINK CAD
JULY 1981	CAD/PRICE MODEL - ISPA CONFERENCE
NOV 1981	FMC CORP PLAN / COMPUTER SECTION
1985-1986	AMCCOM - CAD COMMITTEE
SEPT 1986	PARAMETRIC PAPER - ADODCAS CONFERENCE
1991	AI PAPER - MICOM CONFERENCE

STILL BLUE SKY

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ARTIFICIAL INTELLIGENCE

SYSTEM OPERATES

CHANGES OCCUR

UPDATE FOR CHANGE

- RULES TO UPDATE
- NO HUMAN ACTION

SYSTEM STILL OPERATES

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OVERVIEW

UNIVERSAL MODELS WITH AI

STATISTICAL DATABASE WITH AI

CAM STYLE LOGISTICS WITH AI

CAD LEVEL STATISTICS WITH AI

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UNIVERSAL MODELS

FACTORIAL ANALYSIS

- WEIGHT
- ELECT COMPLEX
- MECH COMPLEX
- ENVIRONMENTAL COMPLEX

FEW FACTORS

UNIVERSAL COSTING/AVAILABILITY

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UNIVERSAL MODELS WITH AN AI SHELL

CAD PARALLEL WITH COST/AVAILABILITY DATABASE

- UNIVERSAL FACTORS ADDED TO CAD

CHANGE

- CAD PLUS UNIVERSAL FACTORS

RULES

- UNIVERSAL MODEL

UPDATED CAD/COST/AVAILABILITY DATABASE

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AI STATISTICAL DATABASE

CAD PARALLEL WITH COST/AVAILABILITY DATABASE

CAD PARALLEL WITH COST/AVAILABILITY DATABASE

CHANGE

- CAD

RULES

- REGRESSION LOOP
- PARTICIAL F
- RESULTING EQUATIONS USED TO UPDATE

UPDATED CAD/COST/AVAILABILITY DATABASE

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PARTICIAL F ALGORITHM

PARTICIAL F

- SIGNIFICANCE OF ADDED VARIABLE

EACH VARIABLE EVALUATED

- UNUSED VARIABLES EVALUATED IN LOOP
- MOST SIGNIFICANT ADDED TO EQUATION
- STOP WHEN NONE SIGNIFICANT ADDITION

BUILDS REGRESSION ESTIMATING EQUATIONS

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CAM SYSTEM

- CAM
    - CAD
    - PRODUCTION MACHINE INTERFACE
- ADD MOTION
- LINK COMPONENTS
- GET ASSEMBLY LINE MODEL

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CAM APPROACH TO SUPPORT

- SUPPORT TASK
  - CAD - HARDWARE
  - SUPPORT TASK INTERFACE
  - MOTION ADDED
  - QUANTIFY SUPPORTIIBILITY
    - TIME AND RESOURCES
- LINK COMPONENTS
  - RELIABILITY DATA ADDED
- GET CAD SUPPORTIBILITY MODEL

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CAM STYLE AI

CAD/SUPPORT(CAM) SYSTEM

CHANGE

- CAD

RULES

- IDENTIFY SIMILAR COMPONENTS
- LINKED TO THEIR SUPPORT DATA
- STATISTICALLY COMPILE SUPPORT DATA
- UPDATE FOR MOST LIKELY SUPPORT CONCEPT

UPDATED CAD/SUPPORT(CAM) SYSTEM

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CAD LEVEL STATISTICS

- CAD LINES
  - DIFFERENCES IN PEN POSITION
- COST DIFFERENCES
  - STATISTICAL VARIANCE
- AVAILABILITY DIFFERENCES
  - STATISTICAL VARIANCE

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PARAMETERS FROM DIFFERENCES

$$Y = \begin{matrix} 7 \\ 3 \\ 2 \\ 1 \end{matrix} \qquad X = \begin{matrix} 15 \\ 7 \\ 6 \\ 3 \end{matrix}$$

DIFFERENCE

0	4	5	6		0	8	9	12
-4	0	1	2		-8	0	1	4
-5	-1	0	1		-9	-1	0	3
-6	-2	-1	0		-12	-4	-3	0

PARAMETERS

$$b = \frac{Y(I)-Y(J)}{X(I)-X(J)}$$

?	.50	.44	.50
.50	?	1.00	.50
.44	1.00	?	.33
.50	.50	.33	?

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CONCLUSIONS

These approaches show promise.

A lot of work still needs to be done.

Realtime design feedback is possible.

MISSILE LOGISTICS CENTER

LONG TERM

FLY BEFORE YOU BUY

FLY AS YOU DESIGN

OPTIMAL DESIGNS WITH AI LOOPING

CONCURRENT ENGINEERING INITIATIVES AT THE U.S. ARMY MISSILE COMMAND ABSTRACT

Patricia T. Martin
Robert Shackelford
PED, SEPD, RD&EC, MICOM

The defense community is looking at a future of reduced funding and fewer production programs. More emphasis is being placed on developing, and then shelving, technical data packages. There is a need for adapting to these trends in order to improve our global competitiveness. Concurrent Engineering is a philosophy which will help us adapt to the new way of doing business.

Concurrent Engineering is broadly defined as "a systematic approach to the integrated concurrent design of products and their related processes, including manufacture and support. (IDA) It is important that all requirements are included in the earliest phases of the design. Therefore, the entire organization must be involved in the CE process. It is important that the organization understands the Concurrent Engineering approach, develops an implementation plan, and informs personnel of their responsibilities.

There are numerous tools and techniques to assist in implementing the Concurrent Engineering philosophy. These are divided into two areas: programmatic and technical elements. One of the most important programmatic elements is the use of multidiscipline design teams. These design teams ensure that all of the requirements are included in the design upfront. When a multidiscipline team is developed, there is a tendency for each member to "push" their requirements into the design. Quality function deployment is a structured methodology for ensuring that the customer's requirements are met through prioritization of the design elements.

The U.S. Army Missile Command has been involved in the development and use of several technical CE tools and techniques. Basically, these tools are structured into a building block arrangement. The first block is the extensive use of Computer Aided Design/Computer Aided Manufacture in the design process. The second block is the development of intelligent engineering tools which capture engineering knowledge and use this knowledge to analyze designs for manufacturability, testability, and supportability. The third block is the use of rapid prototyping techniques.

Rapid prototyping techniques, such as stereolithography and the Quick Turn Cell (QTC), allow the designer to make models of the design within several days or even hours.

A major initiative in the Computer Aided Logistics Support (CALS) effort is the development of digital rather than paper storage of technical weapon system data. This plan would enable engineers, logisticians, procurement, and other personnel to use and share data in a efficient manner. A test bed similar to the Purdue University's QTC being implemented at the U.S. Army Missile Command should be integrated as part of this CALS effort. The QTC is a true Computer Integrated Manufacturing (CIM) system that uses a feature based designer, automated process planner, NC post processor, and milling machine to create rapid prototypes. As technical data is developed in the CALS paperless environment, machineable designs could be sent to the testbed for modeling. This prototyping would certainly highlight manufacturing, support, and reliability concerns which could then be addressed and corrected.

The benefits of the CE philosophy have already been documented by the Institute of Defense Analysis through a survey conducted at several contractor facilities. Similar results have also been noted by MICOM contractors and inhouse organizations. Incorporation of the CE philosophy will ensure lower cost designs, higher quality products, and improved global competitiveness.

CONCURRENT ENGINEERING INITIATIVES AT THE U.S. ARMY MISSILE COMMAND

PATRICIA MARTIN
ROBERT SHACKELFORD
PRODUCTION ENGINEERING DIVISION
SYSTEM ENGINEERING
AND PRODUCTION DIRECTORATE,
R D & E CENTER

FUTURE TRENDS FACING MICOM AND DEFENSE COMMUNITY

- GLOBAL COMPETITIVENESS
- REDUCED FUNDING
- MORE RESEARCH AND DEVELOPMENT, LESS PRODUCTION
- MORE AUTOMATION FROM DESIGN THROUGH PRODUCTION

CONCURRENT ENGINEERING, A PHILOSOPHY TO HELP US ADAPT

THE CONCURRENT ENGINEERING APPROACH

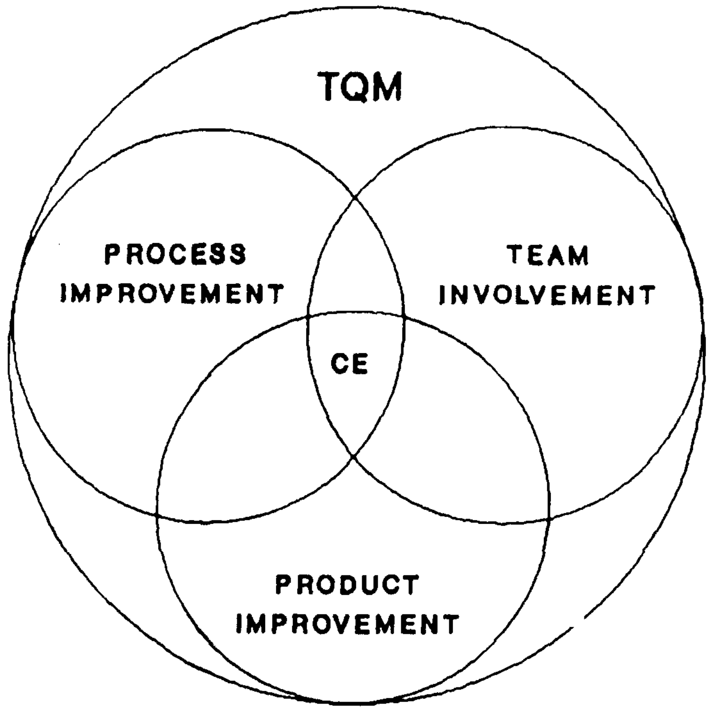
CE IS:

A SYSTEMATIC APPROACH TO THE INTEGRATED CONCURRENT DESIGN OF PRODUCTS AND THEIR RELATED PROCESSES, INCLUDING MANUFACTURE AND SUPPORT. (IDA)

WHAT IT MEANS TO MICOM...

THE HORIZONTAL INTEGRATION OF FUNCTIONAL DESIGN ELEMENTS TO ENSURE TIMELY DELIVERY OF LOW COST QUALITY PRODUCTS.

MICOM'S TQM STRATEGY



TQM
- IMPLEMENTING CULTURAL CHANGE - MANAGEMENT COMMITTMENT - PAT'S ESTABLISHMENT - TRAINING PROGRAM IMPLEMENTED - DEDICATED STAFF OFFICE

CONCURRENT ENGINEERING
- INVOLVE CONTRACTORS - RFP CHANGES - QFD IMPLEMENTATION - MULTI-DISCIPLINARY DESIGN TEAMS - GOVT/PRIME/SUBCONTRACTOR WORKING SESSIONS

BACKGROUND:

CHARACTERISTICS OF A GOOD CE APPROACH

- MANAGERIAL SUPPORT
- TEAM CONCEPT
- PROCESS COMPREHENSION
- SPECIALIZED TRAINING
- APPLICATION OF ADVANCED LEVEL TOOLS
- TECHNOLOGY TRANSFER
- CONSISTENT WITH TQM PHILOSOPHY

MICOM IMPLEMENTATION

- START WITH A MULTIDISCIPLINED GOVERNMENT DESIGN TEAM
- DEFINE PROGRAM REQUIREMENTS BY IDENTIFYING CUSTOMER NEEDS
- IDENTIFY THE OPTIMUM CE DESIGN FLOW PROCESS
- INCORPORATE COMMONALITY WITHIN DESIGN
- SPECIFY IMPLEMENTATION OF CE PHILOSOPHY IN RFP/CONTRACTS
    - ALLOW CONTRACTOR FLEXIBILITY
- MEASURE PROGRESS OF IMPLEMENTATION THROUGH THE USE OF MILESTONE EVENTS OR GATES
    - INTERNAL AND CONTRACTOR IPRs
    - MILESTONE REVIEWS
    - PRRs
    - PDR/CDR

FUNCTIONAL DESIGN ELEMENTS AT MICOM

CUSTOMER (USER, PEOs)

CENTERS

- MLC
- RD&EC
  - ADVANCED SENSOR
  - PROPULSION
  - GUIDANCE AND CONTROL
  - SEPD
  - SYSTEM SIMULATION & DEVELOPMENT
  - STRUCTURES
  - WEAPON SCIENCES
  - TEST & EVALUATION
  - SOFTWARE
  - PAD (END OF FY 91)

STAFF OFFICES

- INTEGRATED LOGISTICS SUPPORT
- SAFETY
- LEGAL
- INTERNATIONAL COOPERATIVE PROGRAMS
- SYSTEMS ANALYSIS & EVALUATION

CONCURRENT ENGINEERING PROCESS RESPONSIBILITY MATRIX

FUNCTIONAL ELEMENTS / PROCESSES	RQMTS DEFINITION	RQMTS ANALYSIS	CONCEPTUAL STUDIES	MAT'L OPTIMIZATION	MFG METHODS AND TECH	ANALYZE DTC GOALS	ANALYZE TESTABILITY	ESS	ANAL TOOLING/TEST EQUIP	PARTS STANDARDIZATION	MAINTAINABILITY	TRANSPORTABILITY	PACKAGING/STORABILITY	TRAINING	DESIGN FOR ASSEMBLY
DESIGN	⊗	⊗	⊗	X		X	X	X		X	X	X	X	X	X
MFG	X	X	X	⊗	⊗	⊗	X	X	⊗	⊗		X	X	X	⊗
QUALITY	X	X	X	X	X	X	⊗	⊗	X	X	X	X	X	X	
LOGISTICS	X	X	X			X			X	X	⊗	⊗	⊗	⊗	

DETAILED DESIGN

X INDICATES PARTICIPANT
⊗ INDICATES LEAD FUNCTIONAL RESPONSIBILITY

ELEMENTS OF CE

HELPING US ADAPT TO THE FUTURE

PROGRAMATIC ELEMENTS

- QUALITY FUNCTION DEPLOYMENT (QFD)
- MULTIDISIPLINE DESIGN TEAMS

TECHNICAL ELEMENTS

- COMPUTER AIDED DESIGN (CAD)
- COMPUTER AIDED MANUFACTURING (CAM)
- COMPUTER INTEGRATED MANUFACTURING (CIM)
- INTELLIGENT ENGINEERING TOOLS
- RAPID PROTOTYPING

PROGRAMMATIC ELEMENTS OF CE HELPING US ADAPT TO THE FUTURE

QFD

- A STRUCTURED PROCESS FOR IDENTIFYING CUSTOMER REQUIREMENTS AND ENSURING THOSE REQUIREMENTS ARE BUILT INTO EVERY PHASE OF THE DESIGN BY ALL NECESSARY FUNCTIONAL ELEMENTS.
- ENSURES MULTIDISCIPLINE DESIGN. DIRECTS AND OPTIMIZES R&D.

MULTIDISIPLINE DESIGN TEAMS

- PROVIDE PRODUCIBILITY, QUALITY, RELIABILITY, AND SUPPORT INPUT AS WELL AS PERFORMANCE INPUT EARLY IN THE DESIGN.
- WILL HELP ENSURE DESIGN IS PRODUCIBLE BEFORE PRODUCTION OR SHELVING OF TDP.

RESULTS OF CONCURRENT ENGINEERING PROCESS

- MAXIMUM USE OF UNIDIRECTIONAL COMPONENT PLACEMENT ON HOMS CCAS FOR EASE OF WAVE SOLDERABILITY (DESIGN FOR MANUFACTURING)
- MAXIMUM USE OF TEST POINTS ON HOMS UUTS (DESING FOR TESTABILITY)
- MORE EFFICIENT CONNECTOR PLACEMENT AND TYPES OF HOMS HARDWARE (DESIGN FOR TESTABILITY)
- EARLIER RECOGNITION OF KEY TESTING PARAMETERS ON HOMS UUTS (DESIGN FOR TESTABILITY)
- REDUCTION OF PARTS COUNT BY INCORPORATION OF ANALOG ASICS (IMPROVED RELIABILITY, DESIGN FOR ASSEMBLY)
- REDUCTION OF CIRCUIT CARDS BY REPACKAGING (REDUCED TEST ADAPTERS)
- INCLUSION OF ENVIRONMENTAL STRESS SCREENING REQUIREMENTS IN DESIGN (DESIGN FOR TEST)
- USE OF PADS ONLY ON CCA OUTER LAYERS (DESIGN FOR ASSEMBLY/REWORK)

TECHNICAL ELEMENTS OF CE
CAD/CAM, CIM

- PROVIDES PLATFORM FOR EARLY DESIGN ANALYSIS INCLUDING: INTERFERENCE FIT, ASSEMBLY, MASS PROPERTIES, TOLERANCE STACKING, ETC.
- PROVIDES MEDIUM FOR MULTIDISCIPLINE TECHNICAL COMMUNICATION WITH WORKSTATIONS AND NETWORKS.
- PROVIDES ENGINEERS WITH TOOLS TO PLAN AND IMPLEMENT MFG PROCESS IN DESIGN PHASES. EXAMPLES: NC PROGRAMMING, SHEET METAL FOLDING, SHOP FLOOR CONTROL.

TECHNICAL ELEMENTS OF CE
INTELLIGENT ENGINEERING TOOLS

ARTIFICAL INTELLIGENCE FOR PRODUCTION MANAGEMENT

- NAVY BEST PRACTICES HYPERMEDIA RESEARCH TOOL
- PRODUCTION READINESS REVIEW EXPERT SYSTEM
- SIMULATION MODEL GENERATOR FOR WITNESS (WISDOM)
- STATISTICAL PROCESS CONTROL TOOLBOX (SPCT)

COMPUTER AIDED DESIGN FOR MANUFACTURE

- DESIGN AID FOR MANUFACTURING PROCESS SELECTION (DAMPS)
- DESIGN FOR INJECTION MOLDING (DFIM)
- DESIGN ANALYSIS FOR NET SHAPES (DANS)
- COMPATIBILITY BASED FORGING EQUIPMENT SELECTOR
- BOOTHROYD DEWHURST DESIGN ANALYSIS SYSTEMS

TECHNICAL ELEMENTS OF CE
RAPID PROTOTYPING

- PROVIDES ENGINEERS WITH PHYSICAL MODELS IN DAYS OR EVEN HOURS
- PROVIDES TESTBED FOR PRODUCIBILITY
- ALLOWS MORE DESIGN INTERATIONS
- MICOM'S SYSTEMS INCLUDE:
  - THE QUICK TURN CELL (QTC) DEVELOPED BY PURDUE UNIVERSITY AND THE NATIONAL SCIENCE FOUNDATION. SYSTEM INCLUDES FEATURE BASED DESIGNER, AUTOMATED PROCESS PLANNER, NC CODE GENERATOR, AND MILLING MACHINE.
  - STEREOLITHOGRAPHY. ALTERNATIVE APPROACH FOR COMPLICATED GEOMETRIES.

CONCURRENT ENGINEERING
THE BOTTOM LINE

EXAMPLES OF BENEFITS TO DOD CONTRACTORS

75% REDUCTION IN VARIABILITY

85% REDUCTION IN NUMBER OF DEFECTS

30% REDUCTION IN PRODUCT DEVELOPMENT COST

50% REDUCTION IN ASSEMBLY COST

30% REDUCTION IN PART LEAD TIMES

62% REDUCTION IN INVENTORY

60% REDUCTION IN SCRAP/REWORK COST

33% REDUCTION IN DEVELOPMENT TIME

SOURCE- R.I. WINNER (IDA) "CONCURRENT ENGINEERING: AN OVERVIEW FOR AUTOTESTCON"

PAYOFF

- ACHIEVE MISSION OBJECTIVES
- ENSURE GLOBAL COMPETITIVENESS
- LOWER COST DESIGNS
- HIGHER QUALITY
- SHORTEN DEVELOPMENT TIME

DATA COLLECTION ISSUES

TRAINING, AVAILABILITY, AND REPAIR TIME

DR. JEFFREY L. RIGGS

UNIVERSITY OF ALABAMA IN HUNTSVILLE

AND

HILTON SYSTEMS, INCORPORATED

(VG-1)

OUTLINE

University of Alabama in Huntsville Research

- Objective
- Definitions
- Basic Premise
- Overview
- Results
- Conclusions

Logistic Research and Development Opportunities

- A_a versus Training Follow-on Research
- Realities of DoD Budget Reduction
- Logistic Research Data Needs

Summary

(VG-2)

JR/JH(VG-2)

Achieved Availability as a Function of Technician Training

8/90 - 12/90 STUDY OBJECTIVE

- Develop a methodology to articulate the relationship between technician training and system availability
- Demonstrate the methodology using Strawman data for MOS 104-27K10.

OBJECTIVES MET

(VG-3)

JR/JH9102

Definitions

$$\overline{M} = \text{Mean active maintenance time} = \frac{\sum_{i=1}^{\#\text{ tasks}} (\text{Rate } i)(\text{Completion Time } i)}{\sum_{i=1}^{\#\text{ tasks}} (\text{Rate } i)}$$

MDT = Mean maintenance downtime, including active maintenance downtime, administrative delays, and logistic delays.

$$\text{MTBM} = \text{Mean time between maintenance, corrective and preventive:} = \frac{1}{\sum_{i=1}^{\#\text{ tasks}} (\text{Rate } i)}$$

(VG-4)

22-025a-0491

Definitions

A_o = Operational availability = Probability that a system, when used under stated conditions in an <u>actual</u> operational environment, will operate satisfactorily. $= \dfrac{MTBM}{MTBM + \underline{MDT}}$

Best Indicator - Data (ALDT) hard to acquire

A_a = Achieved availability = Probability that a system, when used under stated conditions in an <u>ideal</u> support environment (readily available tools, spares, personnel, etc.) will operate satisfactorily. $= \dfrac{MTBM}{MTBM + \overline{M}}$

Satisfactory Indicator - Control Variable Isolated

Note:

(1) $A_o \leq A_a$

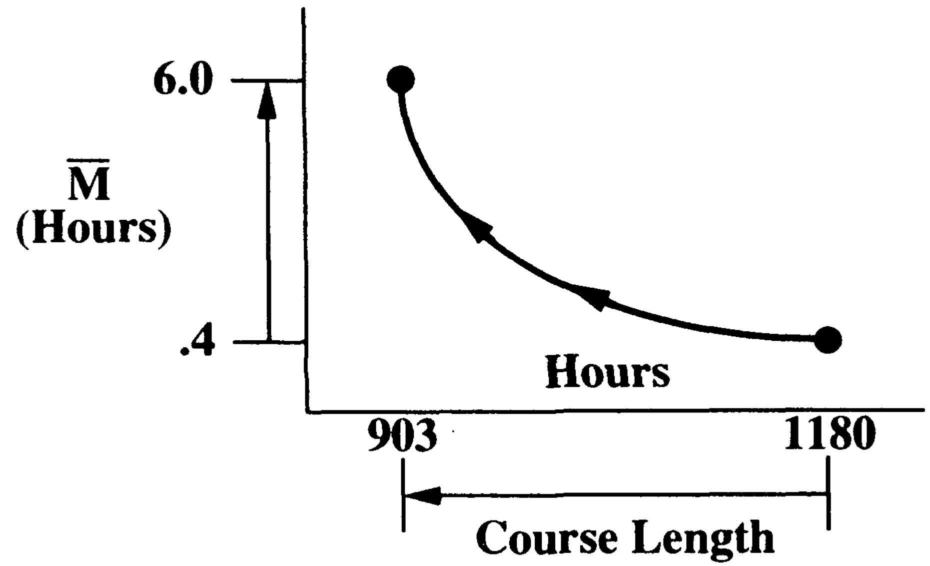
(2) Data on (Maintenance Time) vs. (Training, λ, Refresher Courses, Expert Systems, Etc.) is needed.

(VG-5)

22-025b-0491

Basic Premise

1 Decrease Course Length ⟶ 2 Increase $\overline{M}$ ⟶ 3 Decrease A_a



$$A_a = \frac{MTBM}{MTBM + \overline{M}}$$

Illustrative Example

Before Course Reduction:

MTBM = 9.3 , $\overline{M}$ = .4

$$A_a = \frac{9.3}{9.3 + .4} = .96$$

After Course Reduction:

MTBM = 9.3 , $\overline{M}$ = 6.0

$$A_a = \frac{9.3}{9.3 + 6.0} = .61$$

(VG-6)

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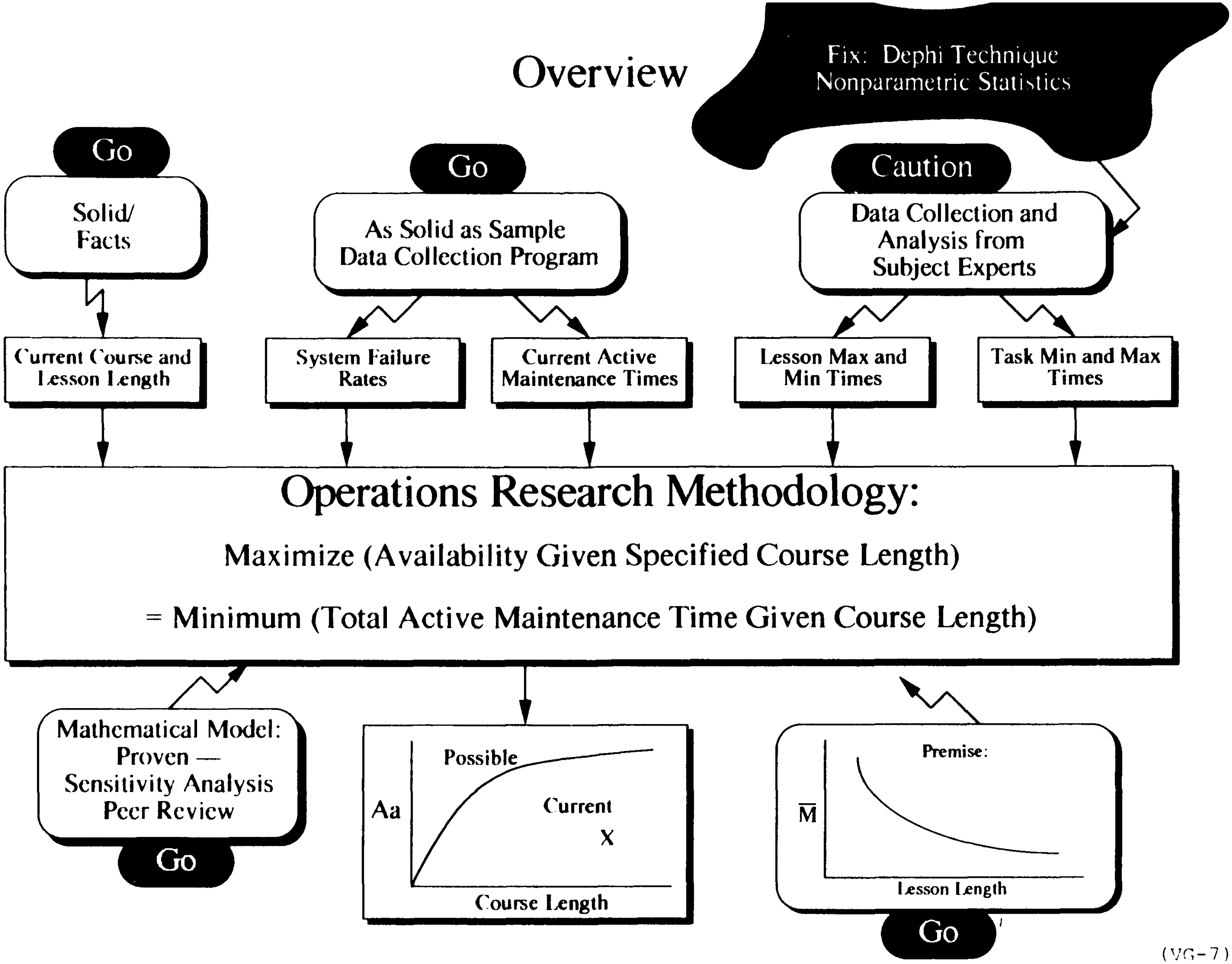
Overview



(VG-7)

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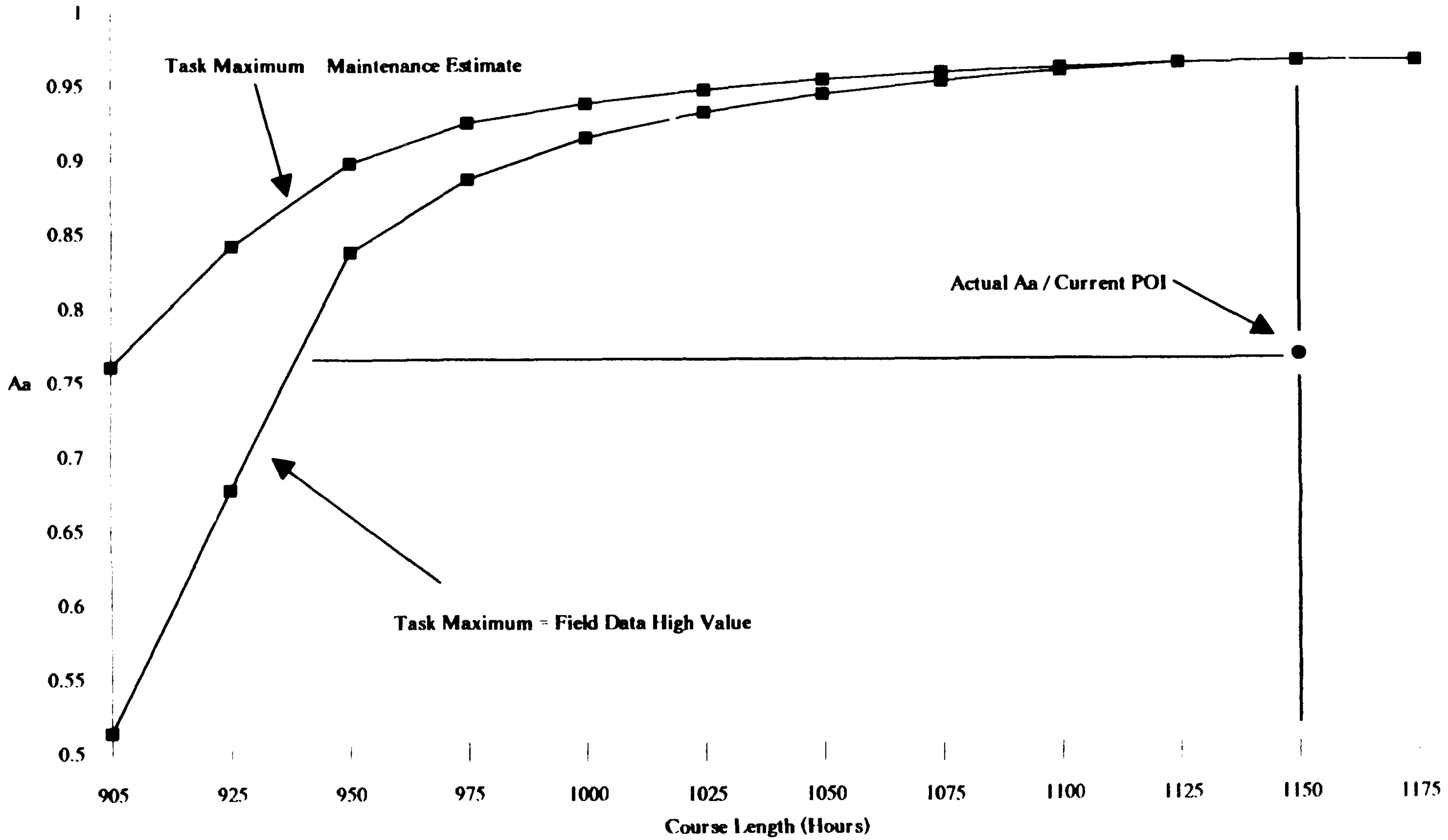


Actual Vs. Methodology Aa

(VG-8)

Conclusions

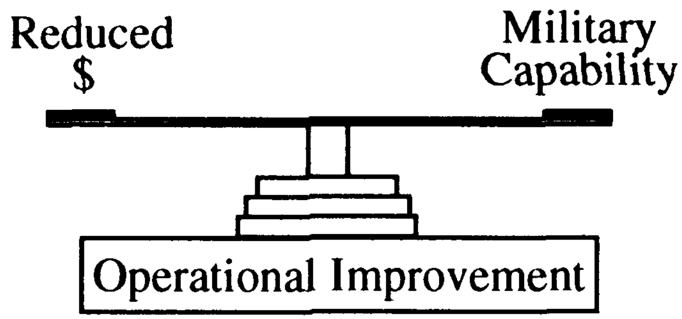
- *Operations Research Methodology Valid:*
  - Extensive Sensitivity Analysis (1/91 - 2/91)
  - Accepted for Publication - "Logistics Spectrum," Refereed Journal of the Society of Logistics Engineers
- *Data:*
  - Failure Data From PAD Sufficient
  - Lesson Data (MIN & MAX) and the Task Data (High, Low, and Lesson % Contribution)
- *Requiring Further Analysis:*
  - Data Collection
  - Expert Systems
  - Built-in-Test/Built-in-Test-Equipment
  - Engineering Changes/System Upgrades
  - Tradeoff Methodology - Availability Versus Cost

(VG-9)

22-031-0491

LOGISTIC RESEARCH AND DEVELOPMENT OPPORTUNITIES

- Commercial/Business Oriented Operations Research
- Training versus A_a Follow-on Task
- Realities of DoD Budget Reduction



(VG-10)

JR/JH9117

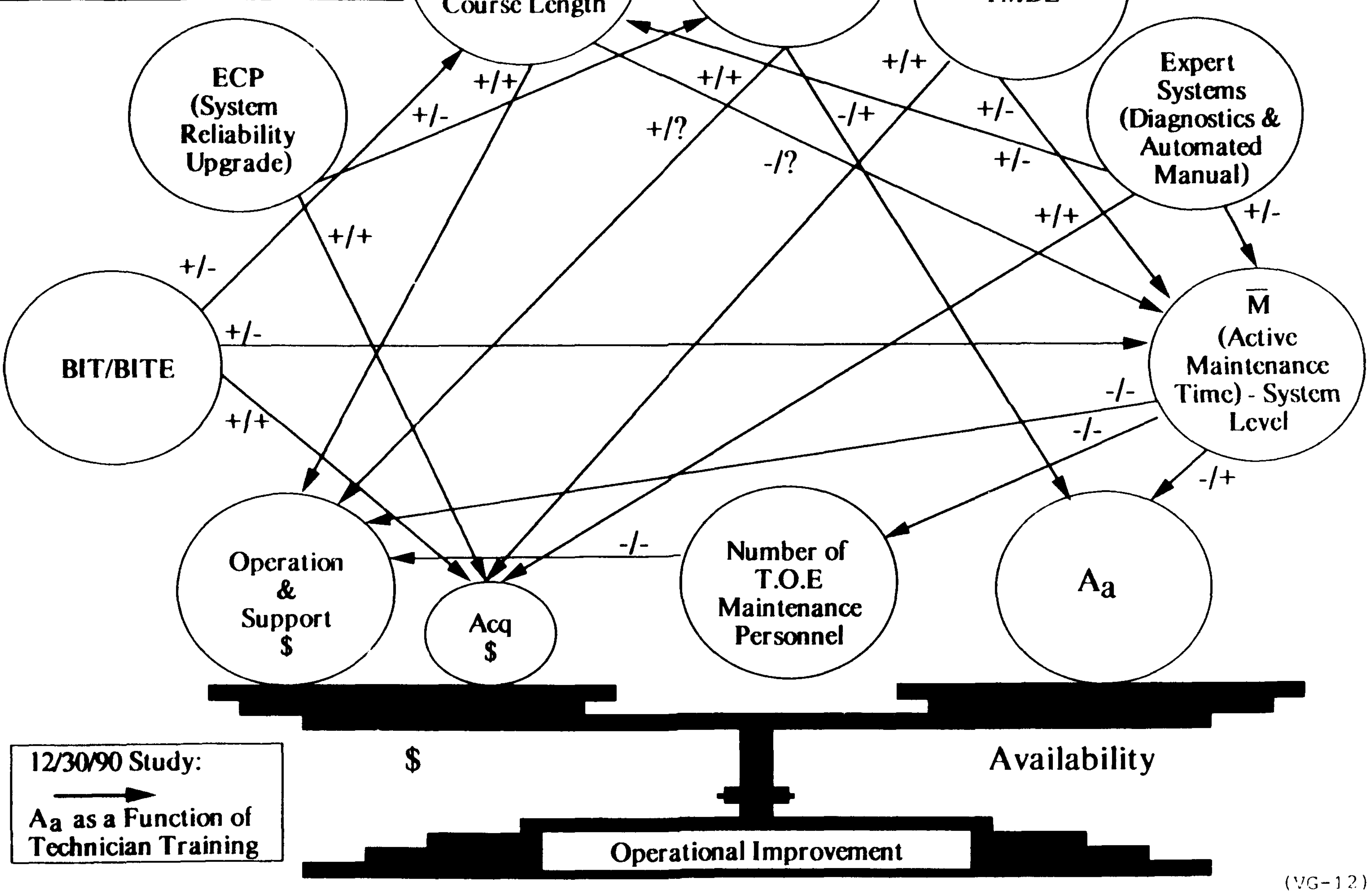
A_a Versus Training Follow-on Research MLRS PMO and OMMCS

- Methodology for Collecting Subjective Data (Delphi Technique + Non-parametric Statistics).
- Sensitivity Analysis of Methodology to Input Variables.
- Pareto Analysis of Failure Rates (λ) and Active Maintenance Time ($\overline{M}$), Linkage to Fixes:
  - Expert Systems
  - OJT
  - Course Length
  - BIT/BITE
  - Refresher Courses
  - TMDE
- Repeat Demonstration on a Mature System with Substantial Historical Data.

(VG-11)

22-034-0591

Budget Reduction



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(VG-12)

LOGISTIC RESEARCH DATA NEEDS

In-Hand:

- System Failure Rates
- Active Maintenance Times
- Administrative And Logistic Delay Times

Missing = Active Maintenance Times As A Function Of

- Task Versus Lesson Length(s)
- Technician/Refresher Courses
- Technician/Time Since Completing Course
- Learning Curves With And Without Expert Systems
- Learning Curves With And Without BIT/BITE
- On-The-Job-Training (OJT) Versus Formal Course Lengths
- Upper Limit On OJT Usefulness

(VG-13)

JR/JH(VG-13)

SUMMARY

- Logistic Research And Development, O&S Cost Reduction And Business Oriented Operations Research Are Inseparable
- Dramatic Results, A_a Versus Course Length
- Other Dramatic Results Are Possible With More Data Linking Human Performance With System Performance

(VG-14)

JR/JH(VG-14)

Jeffrey L. Riggs is a member of the faculty of the Department of Management Information Systems and Management Science at the University of Alabama in Huntsville. In addition, he preforms operations research analyses with Hilton Systems, Inc. of Huntsville. His teaching includes graduate and undergraduate courses in probability, statistics, and operations research. His research interests include logistics modeling and decision and risk analysis. He received his B.S. Degree from the U.S. Naval Academy, M.S. in Industrial Engineering from the University of Missouri, M.A. in Management from Webster University, and Ph.D. in Systems Engineering from the University of Alabama in Huntsville. Before joining academia, his experience included six years as a missile battery commander and R&D project engineer in the Marine Corps and 12 years as a civilian operations research analyst and project engineer.

"Shelf Life Concerns for Optical Fiber Dispensers"

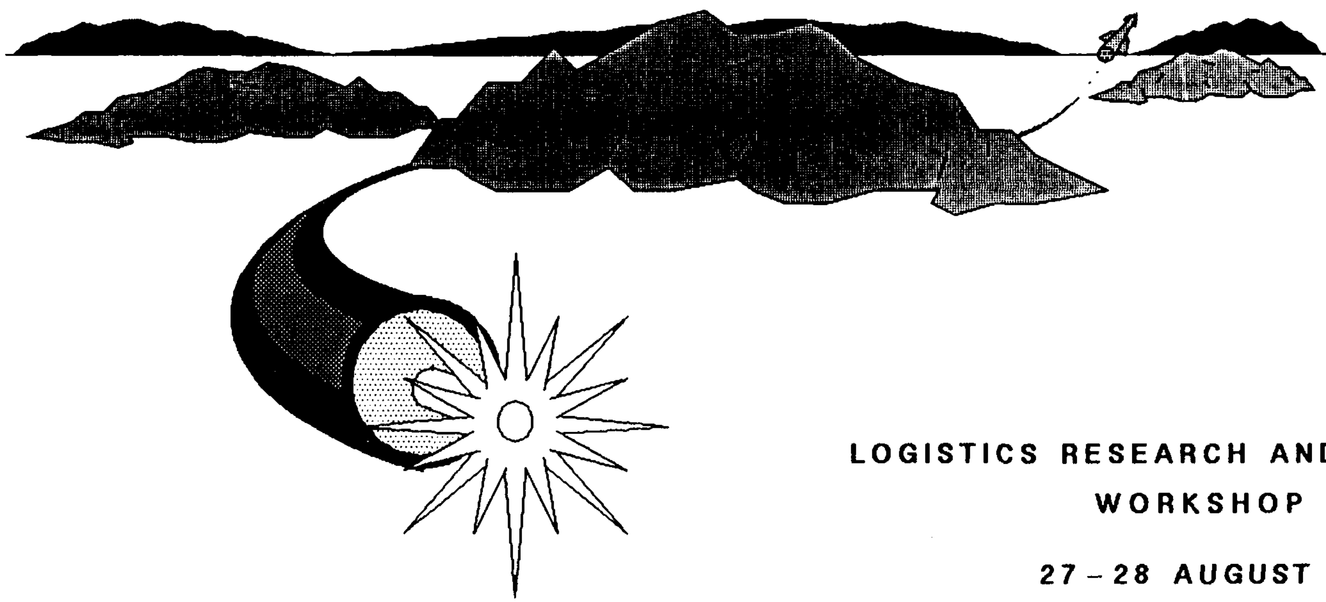
Julie I. Locker
U.S. Army Missile Command
Research, Development and Engineering Center
System Engineering and Production Directorate
Manufacturing Technology Division

Advancement in fiber optics technology has provided DoD with unique system capabilities. The use of fiber optics in military systems provides non-line of sight capabilities, high data rates, and resistance to electromagnetic interference. For fiber optic guided missile applications, the fiber is used as the control datalink between the missile and the gunner's station. The fiber is wound onto a bobbin and mounted in the aft end of the missile. This bobbin/fiber assembly (dispenser) must be subjected to environmental testing to insure long term survivability.

Recent tests on dispensers have revealed problems in establishing appropriate accelerated aging profiles which accurately predict long term storage effects. Temperature cycling between extreme temperature ranges (-40 to 70 degrees celsius) has produced an aging phenomena which is characterized by physical defects known as "earthquaking" and "birchbarking". These physical defects have raised concern over the temperature profiles which were used and most importantly the root cause of these defects. Research efforts have provided answers which attribute these defects to material properties of each dispenser component and their interaction with each other.

Tests are being conducted by MICOM's Manufacturing Technology Division to determine the strength degradation in optical fiber as a result of the aging process. Test results to date indicate that there are several parameters which must be controlled to insure long term storage reliability of optical fiber dispensers. These parameters include various manufacturing processes and handling operations which must be evaluated to determine processes which subject the fiber to potential damage and how these processes can be improved.

SHELF LIFE CONCERNS FOR OPTICAL FIBER DISPENSERS



LOGISTICS RESEARCH AND DEVELOPMENT
WORKSHOP

27 – 28 AUGUST 91

JULIE I. LOCKER
U.S. ARMY MISSILE COMMAND
MANUFACTURING TECHNOLOGY
(205)842 – 7648

FOG ADVANTAGE

NON – LINE OF SIGHT CAPABILITIES

HIGH DATA RATE CAPABILITIES

RESISTANCE TO ELECTROMAGNETIC INTERFERENCE

DISPENSER COMPONENTS

mantech missiles

BOBBIN

- GRAPHITE COMPOSITE/FILAMENT WOUND
- GROOVED EPOXY BASE LAYER

OPTICAL FIBER

- SINGLE MODE, 125/250 UM DIAMETER
- EPOXY ACRYLATE BUFFER COATING
- HIGH STRENGTH

ADHESIVE

- PRE—APPLIED
- WET/WIND APPLICATION
- UV CURED
- THERMAL CURED

SHELF LIFE REQUIREMENTS

mantech
missiles

ARMY REGULATION 70—38

"RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF MATERIEL FOR EXTREME CLIMATIC CONDITIONS"

TEMPERATURE RANGE = −37 TO −46 C (COLD)
33 TO 71 C (HOT/STORAGE)

PROFILES FOR ACCELERATED AGING

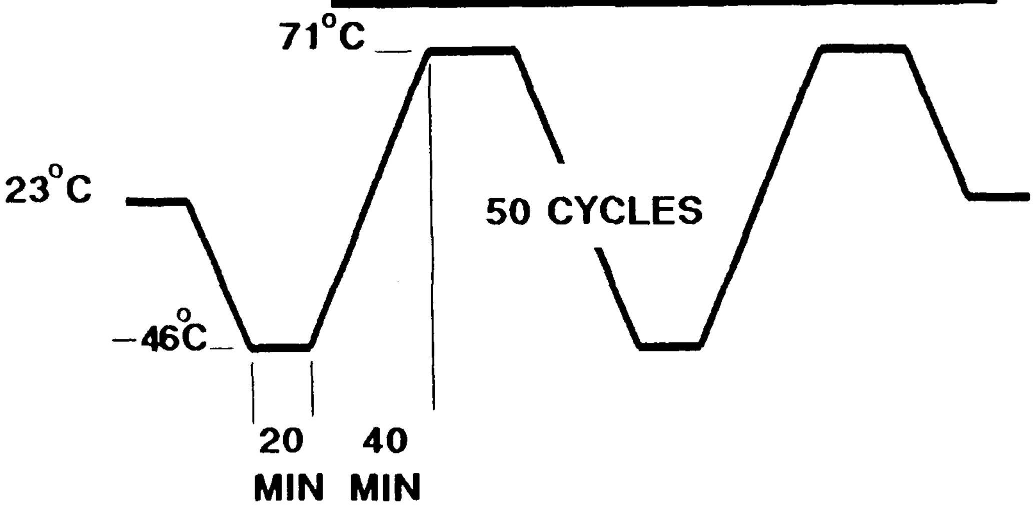
TRANSPORTATION CYCLE
DESIGN LIFE

CYCLING PROFILES

mantech *missiles*

TRANSPORTATION CYCLE

DESIGN LIFE CYCLE 1



AGING PHENOMENA

PHYSICAL CHARACTERISTICS

- EARTHQUAKING
- BIRCHBARKING
- SLUMPS

MATERIAL PROPERTIES

- COEFFICIENT OF THERMAL EXPANSION MISMATCH
- MECHANICAL STRENGTH DEGRADATION
- STATIC FATIGUE

STRENGTH DEGRADATION

mantech
missiles

DYNAMIC TENSILE TESTER – MICOM/MT
- TEST 10 FIBERS SIMULTANEOUSLY
- STRAIN RATE = 4%/MINUTE
- FIVE METER GAUGE LENGTH

TESTING GOALS
- DETERMINE DEGRADATION EFFECTS OF EACH MFG PROCESS IN ADDITION TO AGING/LONG TERM STORAGE EFFECTS

DATA ANALYSIS TOOLS
- WEIBULL STATISTICAL ANALYSIS

WEIBULL DISTRIBUTION

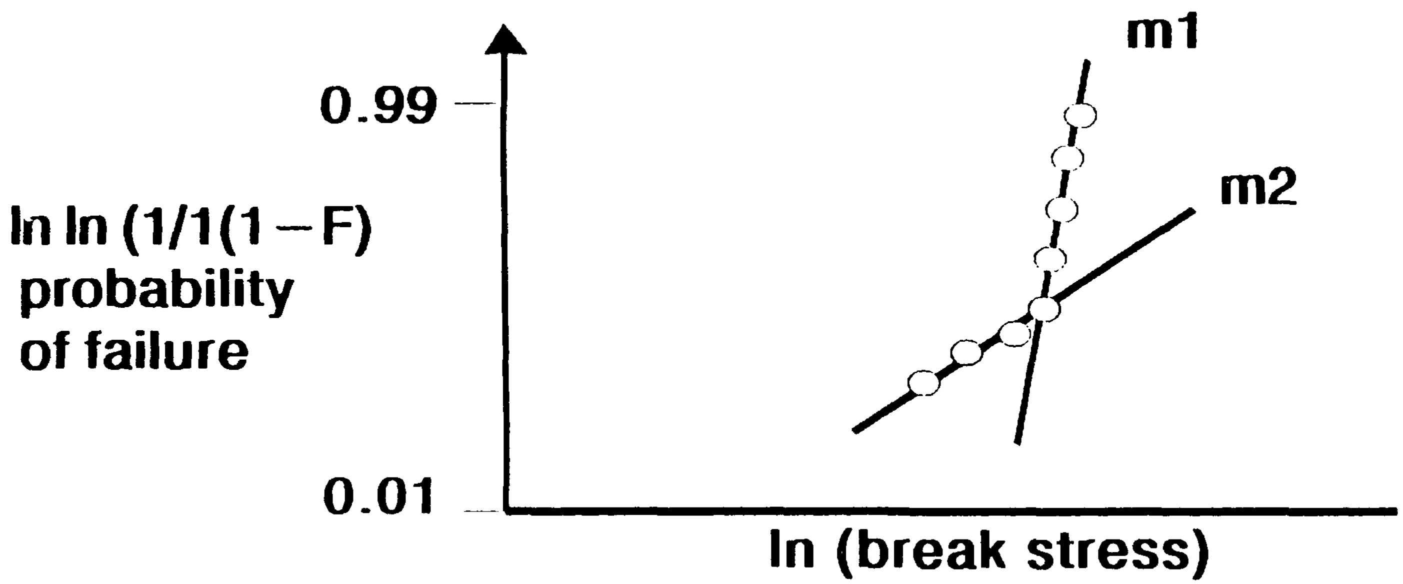
MEDIAN RANK METHOD

F = CUMULATIVE FAILURE PROBABILITY
= (I−0.3)/(J+0.4)

FOR I = 1,2,3 ... J WHERE

I = RANK OF INDIVIDUAL BREAK (LOWEST TO HIGHES KPSI)

J = TOTAL NUMBER OF BREAKS



MANUFACTURING PROCESSES

OPTICAL FIBER FABRICATION
- PREFORM FABRICATION
- DRAW PROCESS
- PROOF TESTER

DISPENSER ASSEMBLY
- SCREENING SYSTEM FOR FLAW DETECTION
- FIBER WINDING
- HANDLING PROCEDURES

STORAGE/AGING EFFECTS

CONCLUSIONS

mantech missiles

- ADDITIONAL RESEARCH EFFORTS ARE NEEDED TO ADDRESS SHELF LIFE CONCERNS FOR OPTICAL FIBER DISPENSERS
- TEMPERATURE PROFILES MUST BE DEVELOPED TO SIMULATE LONG TERM AGING EFFECTS ON DISPENSERS
- HANDLING PROCEDURES MUST BE DEVELOPED TO INSURE INTEGRITY OF DISPENSERS
- MANUFACTURING PROCESSES MUST BE IMPROVED TO REDUCE HANDLING REQUIREMENTS
- MATERIAL PROPERTIES OF DISPENSER COMPONENTS MUST BE CHARACTERIZED TO INSURE SYSTEM RELIABILITY OVER REQUIRED TEMPERATURE RANGE

SESSION III

TEST, MEASUREMENT, AND DIAGNOSTIC EQUIPMENT

SESSION LEADER:

James R. Jones
U.S. Army TMDE Activity
Redstone Arsenal, Alabama

Introduction

Lord Kelvin said, "When you can express what you are talking about in numbers you know something about it." The logical extensions of measurement, which are test and diagnostics, are currently being augmented, in our search for knowledge, by prognostics, the science of predicting or forecasting future behavior of systems based on past and present behavior. This session deals with a number of areas of applied research and development in these disciplines.

A Low-Cost Micromachined Thermally Isolated Resistance Structure for Dynamic Thermal Scene Simulation Compatible with Standard CMOS IC Fabrication Technology

Michael Gaitan, NIST

Abstract

A silicon micromachined thermally isolated resistance structure capable of producing thermal radiation has been developed [1]. The device can be operated as an IR point source that is suitable for dynamic thermal scene simulation (DTSS) [2]. The fabrication of this device is completely compatible with standard complementary metal-oxide-semiconductor (CMOS) integrated circuit (IC) foundry processes. The important feature of the IC design that differs from normal CMOS circuit design is the definition of an area which we call *open* that is composed of active area, contact cut, and pad. This area is needed to expose selected areas of the silicon substrate. An mask-less etch in ethylenediamine-pyrocatechol (EDP) solution which attacks the exposed *open* areas is required form the free-standing thermally isolated structure [3] after receipt from the IC foundry. The resulting micromachined structures are suspended plates consisting of polysilicon resistors encapsulated in the field and CVD oxides. The main advantages of this technology are low manufacturing cost and the integration of digital and analog circuits for decoding, A/D conversion and current drive on the monolithic DTSS IC.

Work is in progress at NIST, Simon Fraser University in Burnaby, Canada, and the Center for Applied Optics in Huntsville to characterize and optimize the device, design and manufacture static IR targets, and design and manufacture of a DTSS. The specific applications targeted for this device are fieldable test units for IR imagers and integration of test targets within imaging systems for self test. Work is also in progress to investigate the technology for low-contrast applications and for large area (20x20 cm^2) targets manufactured by wafer scale integration.

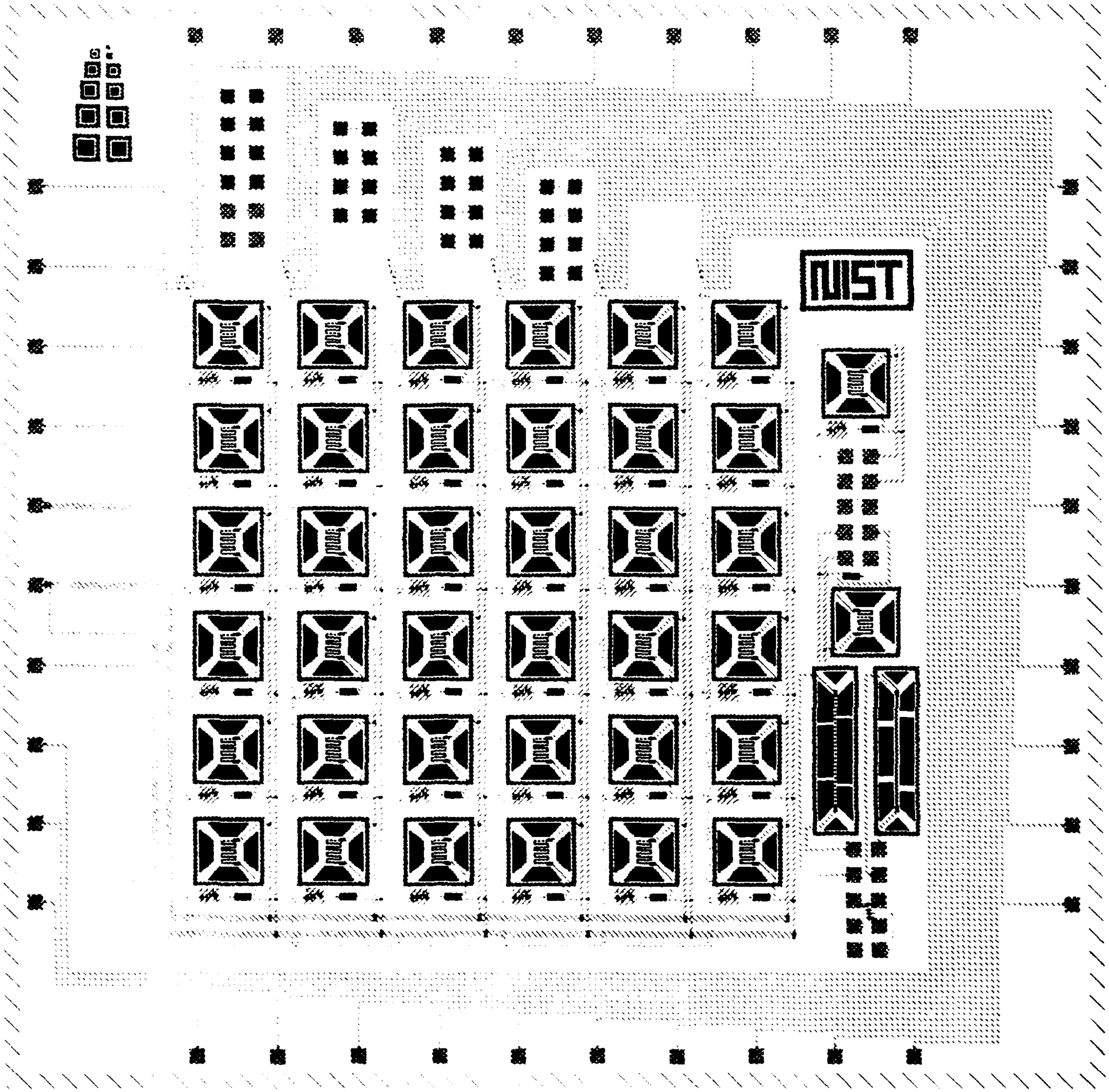
Results will be presented on the pixel design considerations, digital and drive circuit designs for communication with computer driven images, IR characterization measurements, device reliability measurements, and a 6x6 pixel array DTSS currently submitted for fabrication.

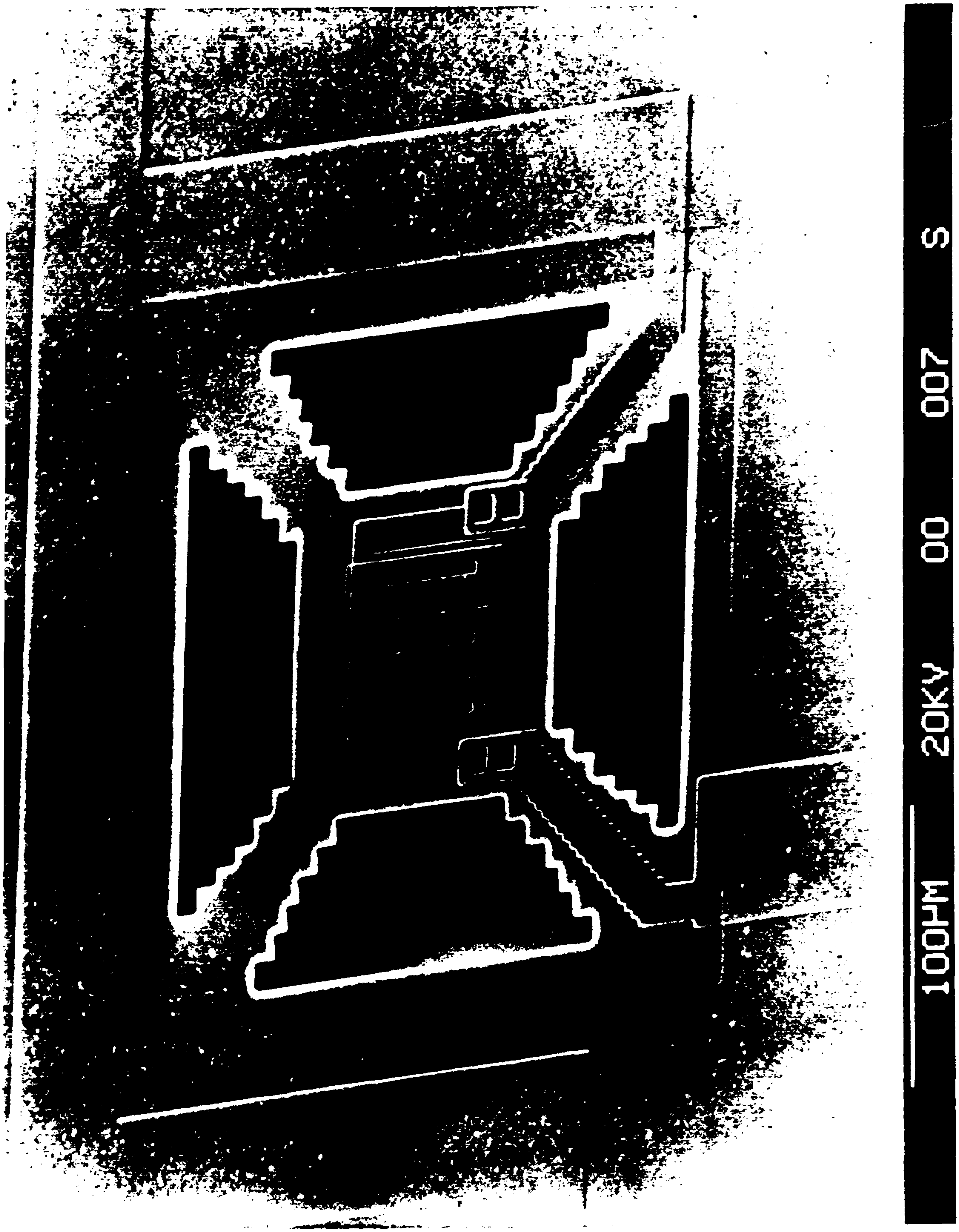
[1] M. Parameswaran, et. al., "Micromachined Thermal Radiation Emitter from a Commercial CMOS Process," *IEEE Elect. Dev. Lett.*, vol. 12, no. 2, p15, 1991.

[2] A. P. Prichard, "Dynamic IR Scene Generation: Basic Requirements and Comparative Display Design," *Proc. SPIE*, vol. 904, p144, 1988.

[3] M. Parameswaran, et. al., "A New Approach for the Fabrication of Micro-machined Structures," *Sensors and Actuators*, vol. 19, p289, 1989.

This work is supported by the Navy (NOSC) and the Army (Redstone Arsenal).


NIST


100HM 20KV 00 007 S

A Low-Cost Micromachined Thermally Isolated Resistance Structure for Dynamic Thermal Scene Simulation Compatible with Standard CMOS IC Fabrication Technology

Michael Gaitan PhD
Semiconductor Electronics Division
National Institute of Standards and Technology
Gaithersburg, MD 20899
(301) 975-2070

NOSC

TECHNICAL CHALLANGE

- Field Testing of Focal Plane Arrays (FPAs)
- FPAs are used in expensive systems
- New Generations of FPA require more advanced Tests
- These facts make Fieldable test targets a NECESSITY

INTRODUCTION

IR Point source to be discussed: Minature "Light Bulb"

Silicon Micromachined Structure

Fabricated in Standard CMOS process

LOW COST

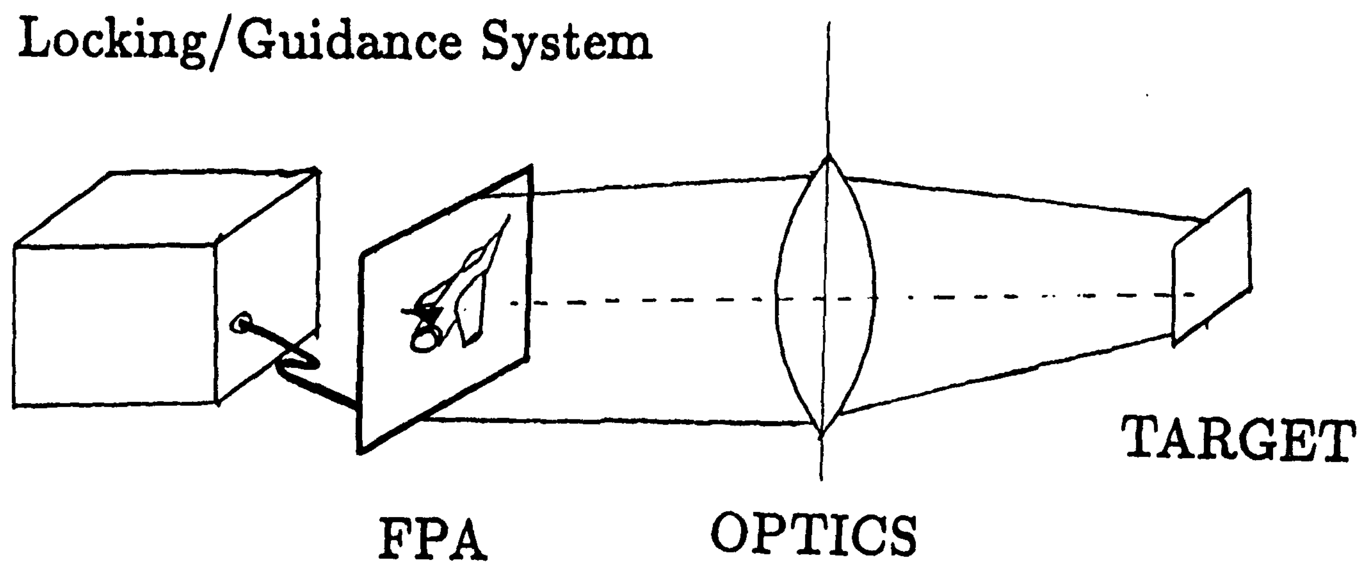
Test Targets for FPAs

For Calibration and Thermal Scene Simulation

BIT/BITE

Field and Depot Testing

THERMAL SCENE SIMULATION



SILICON MICROMACHINING

def: Three dimensional sculpting of silicon and silicon dioxide.

In general: silicon micromachined devices are realized in a custom fabrication process.

A new idea has recently been proposed in the research community: To use the layers available in a standard CMOS IC process to manufacture the devices whenever possible.

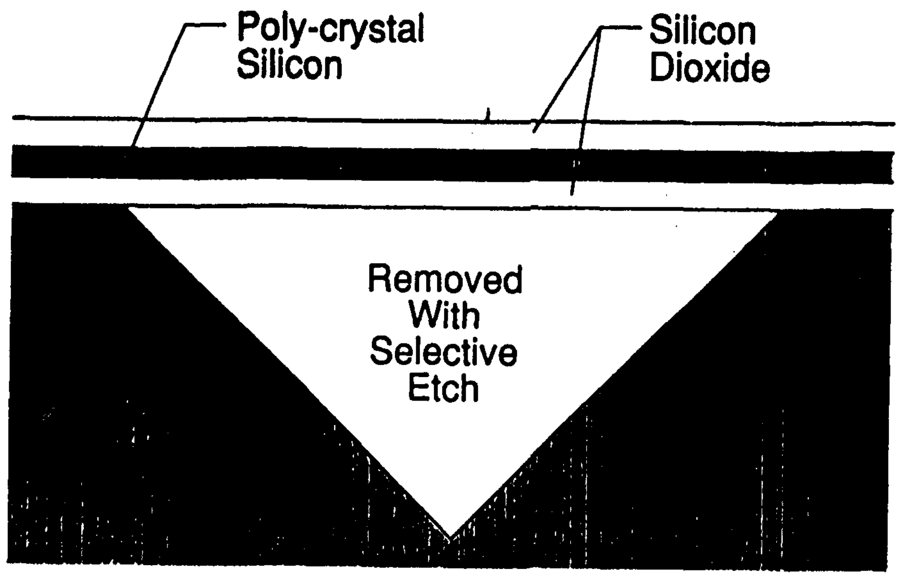
Example: Analog Devices Accelerometer, $5 per chip.

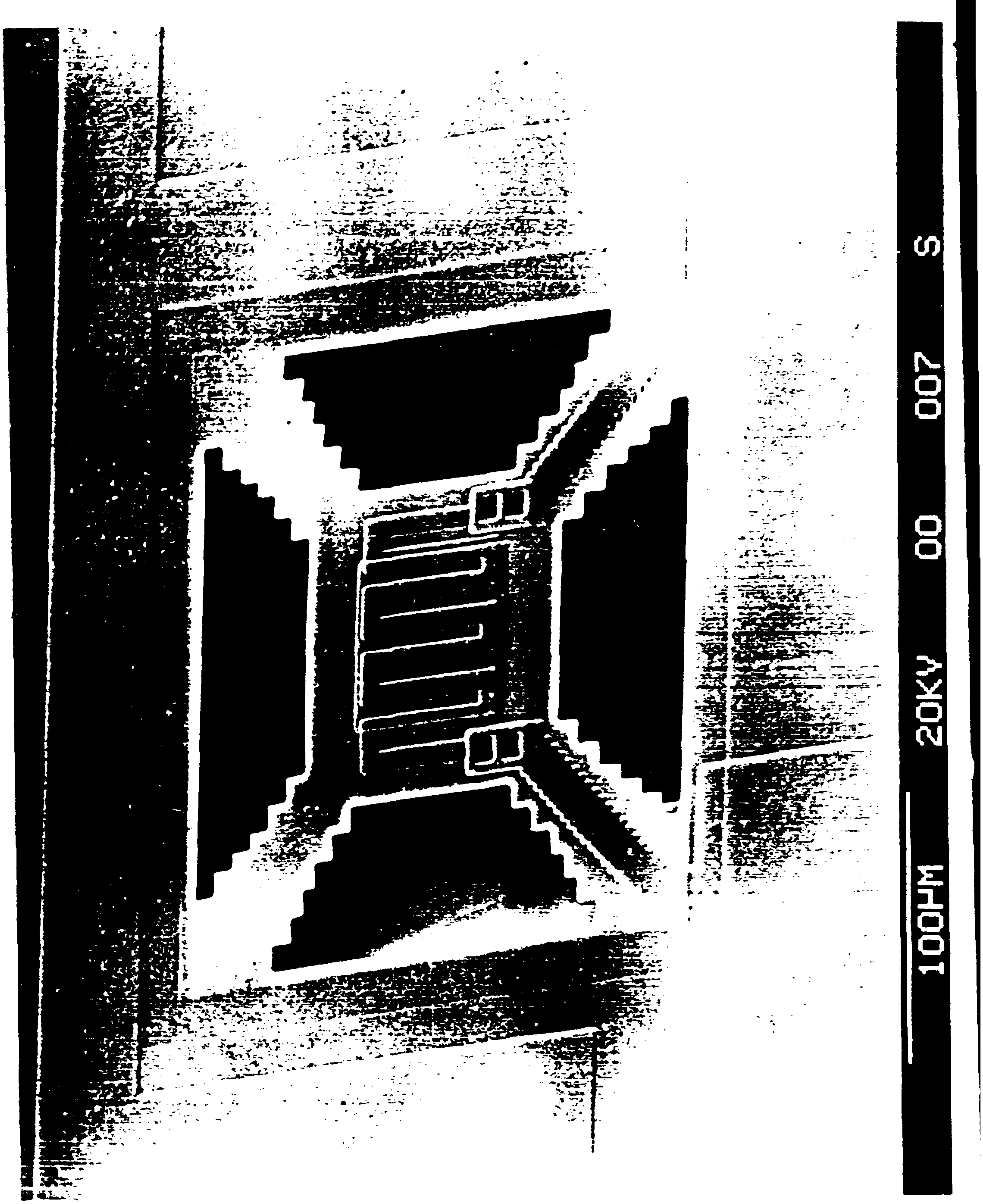
SILICON MICROMACHINED IR POINT SOURCE

The device is a polysilicon resistor encapsulated in glass and is composed of layers available in standard CMOS circuits.

An additional maskless anisotropic etch step is used to realize the device: A suspended "trampoline" structure.

The device is a miniture light bulb in a CMOS IC.




100µM
20KV 00 007 S

APPLICATIONS

Built In Test/Built In Test Equipment (BIT/BITE)

- Fieldable Targets need to be low cost and small
- Systems can be tested in the field just before deployment

Low Contrast Applications

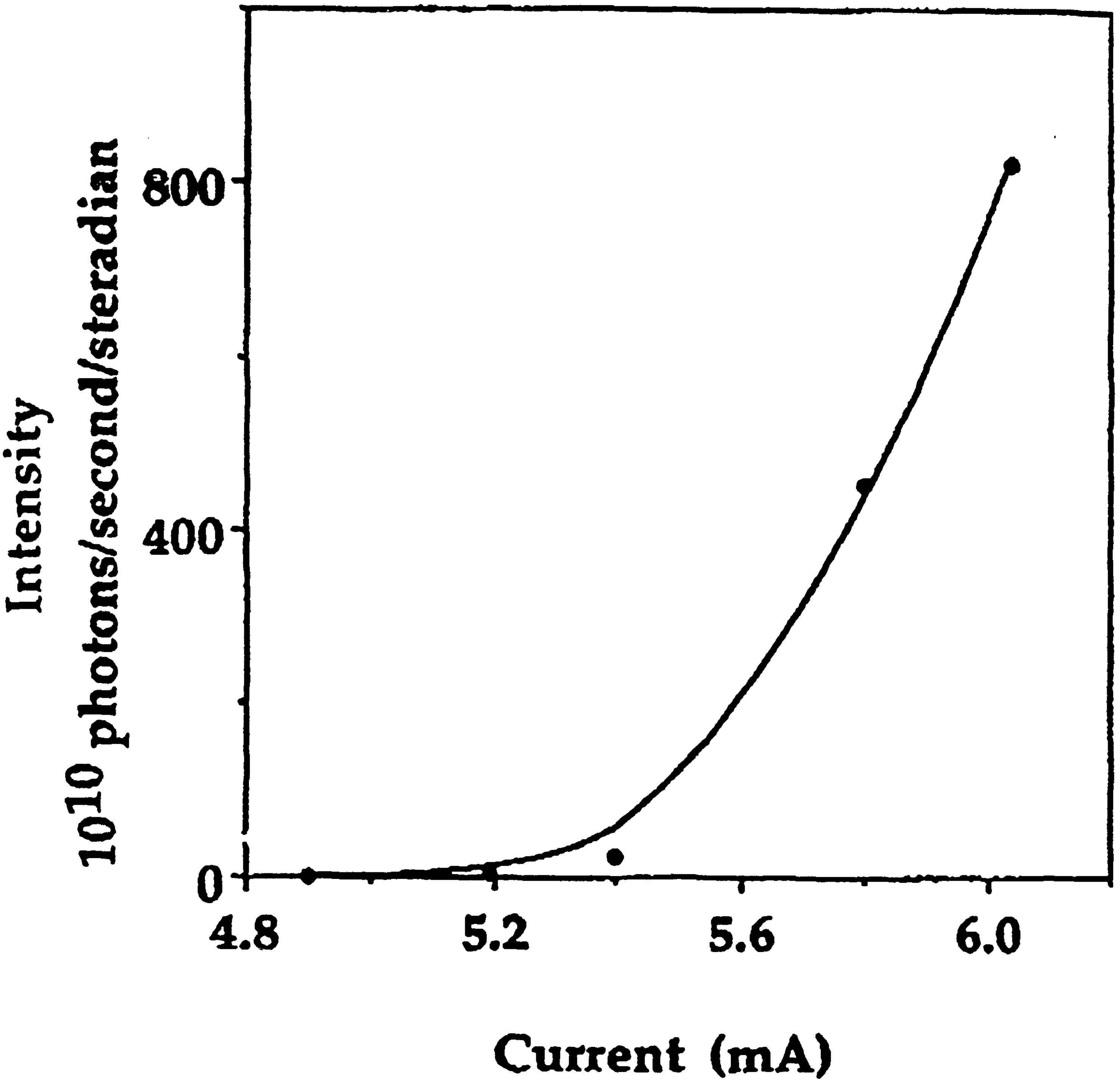
Large Area Targets: Wafer Scale Integration

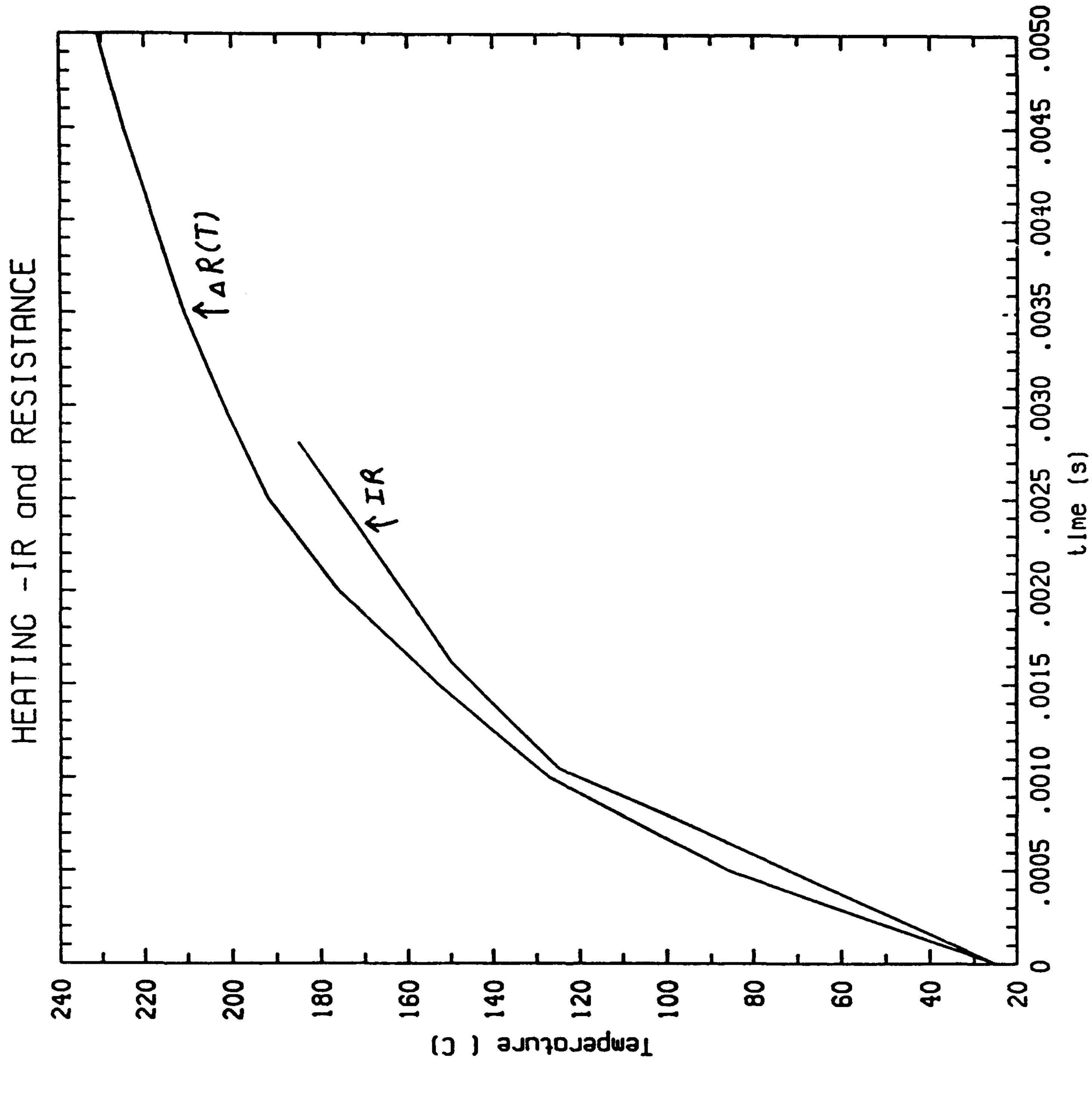
Programmable Static Targets

- MRTD - Eliminate Human Factor in the Test
- Programmable line spacing and width

Dynamic Thermal Scene Simulation

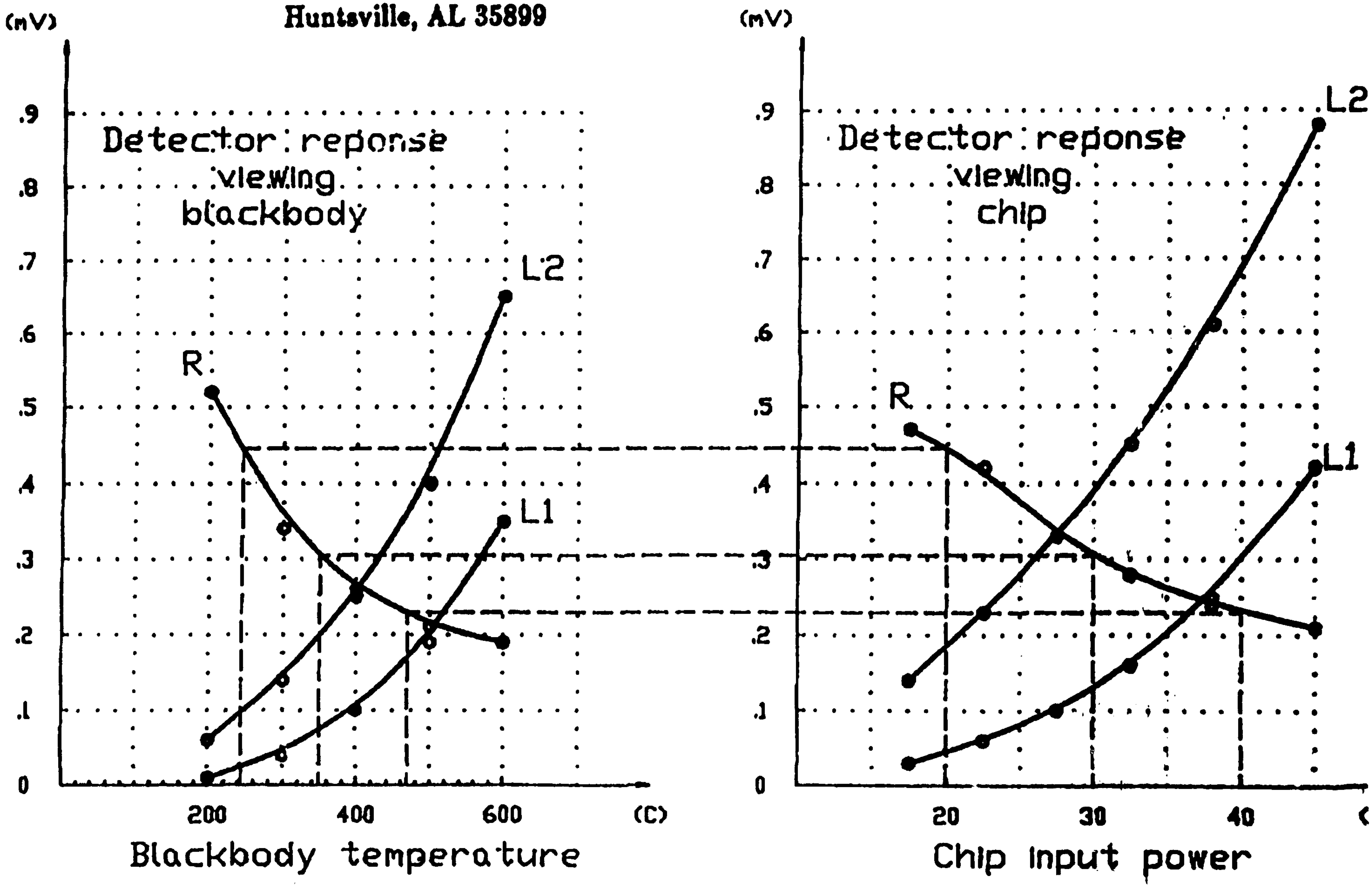
- Fieldable Targets
- Laboratory Test Targets

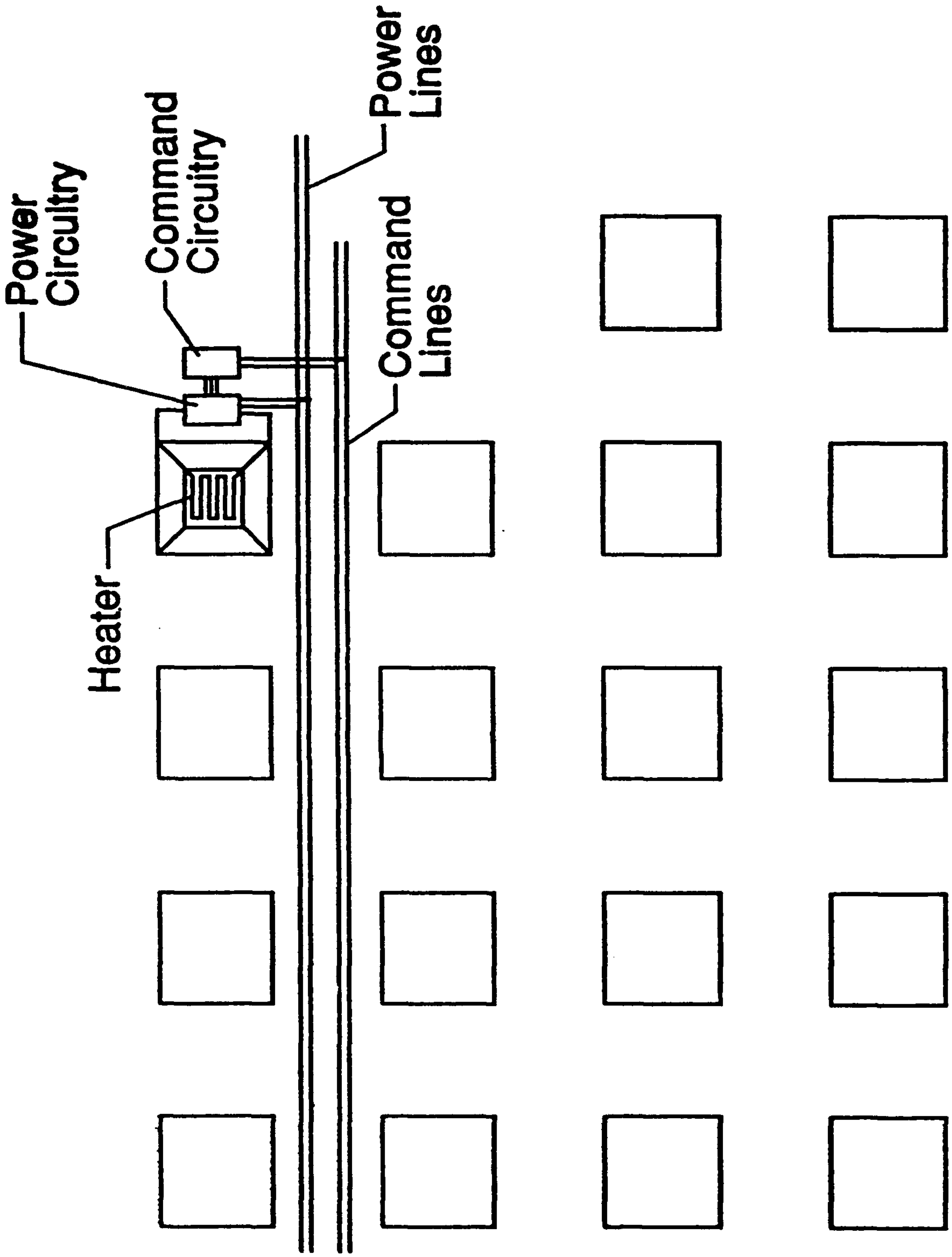

Intensity
10^{10} photons/second/steradian
800
400
0
4.8
5.2
5.6
6.0
Current (mA)


HEATING -IR and RESISTANCE
Temperature (C)
240
220
200
180
160
140
120
100
80
60
40
20
0
.0005
.0010
.0015
.0020
.0025
.0030
.0035
.0040
.0045
.0050
time (s)
ΔR(T)
IR

Center for Applied Optics
University of Alabama in Huntsville
Huntsville, AL 35899

13 MARCH 1991
C. Feng & R.B. Johnson




Power Circuitry
Command Circuitry
Power Lines
Command Lines
Heater

TWO APPROACHES

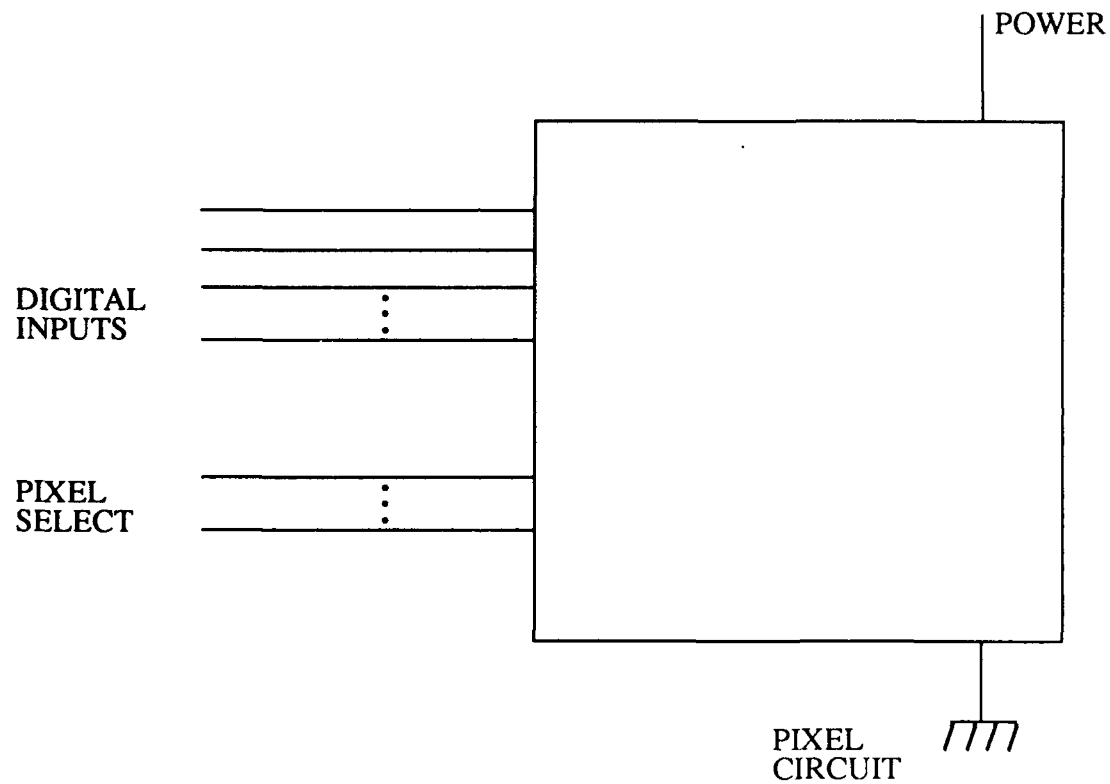
STATIC APPROACH

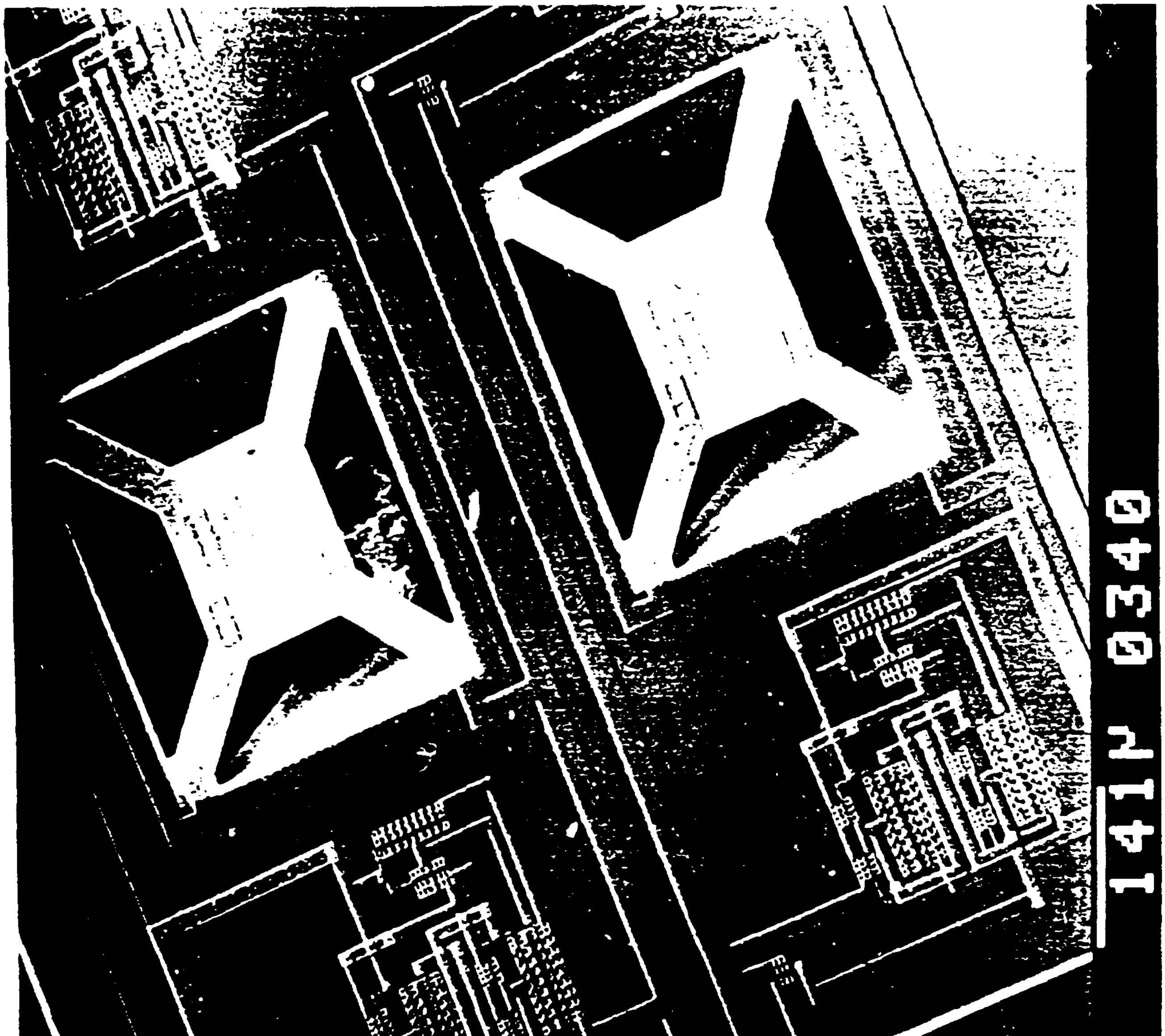
- Each Pixel has its own memory and D/A converter
- Intensity information is stored on memory

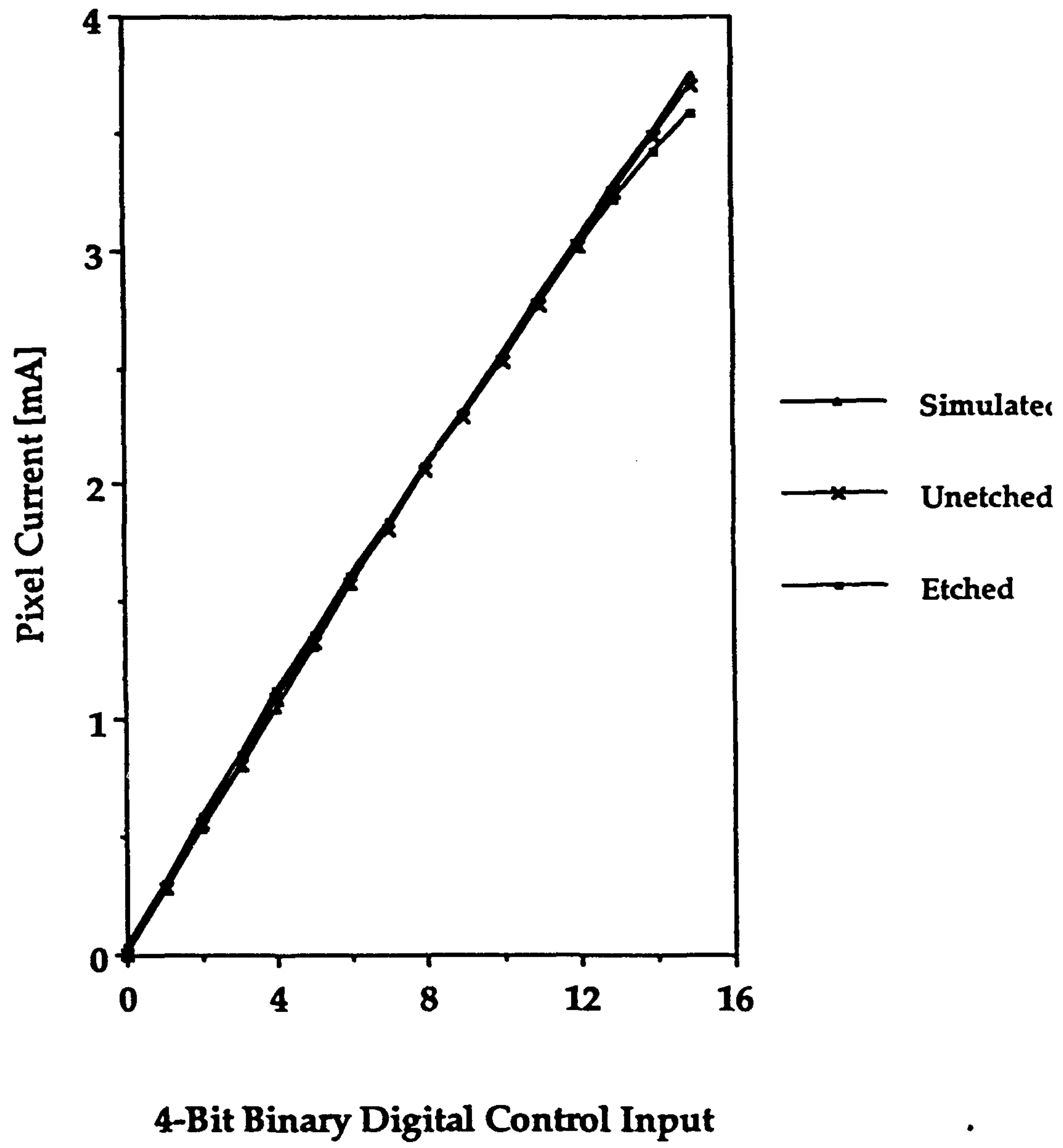
DYNAMIC APPROACH

- Dynamic Drive Transistor
- One D/A on the chip
- Information must be updated like a DRAM

STATIC APPROACH

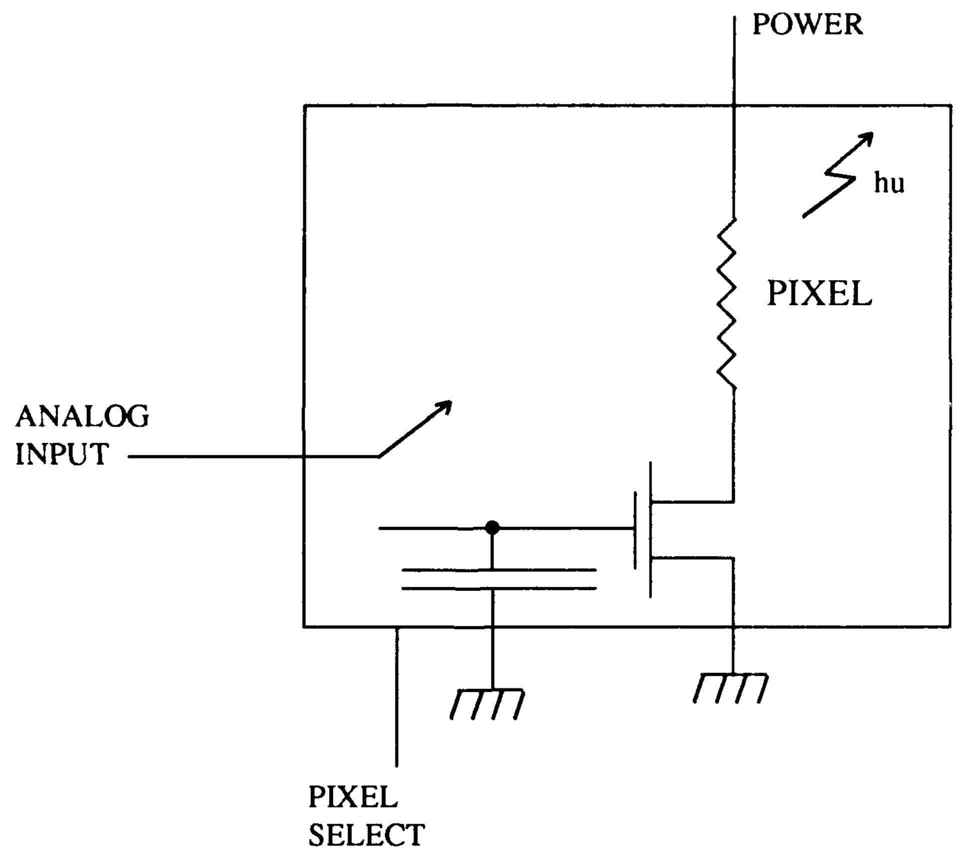


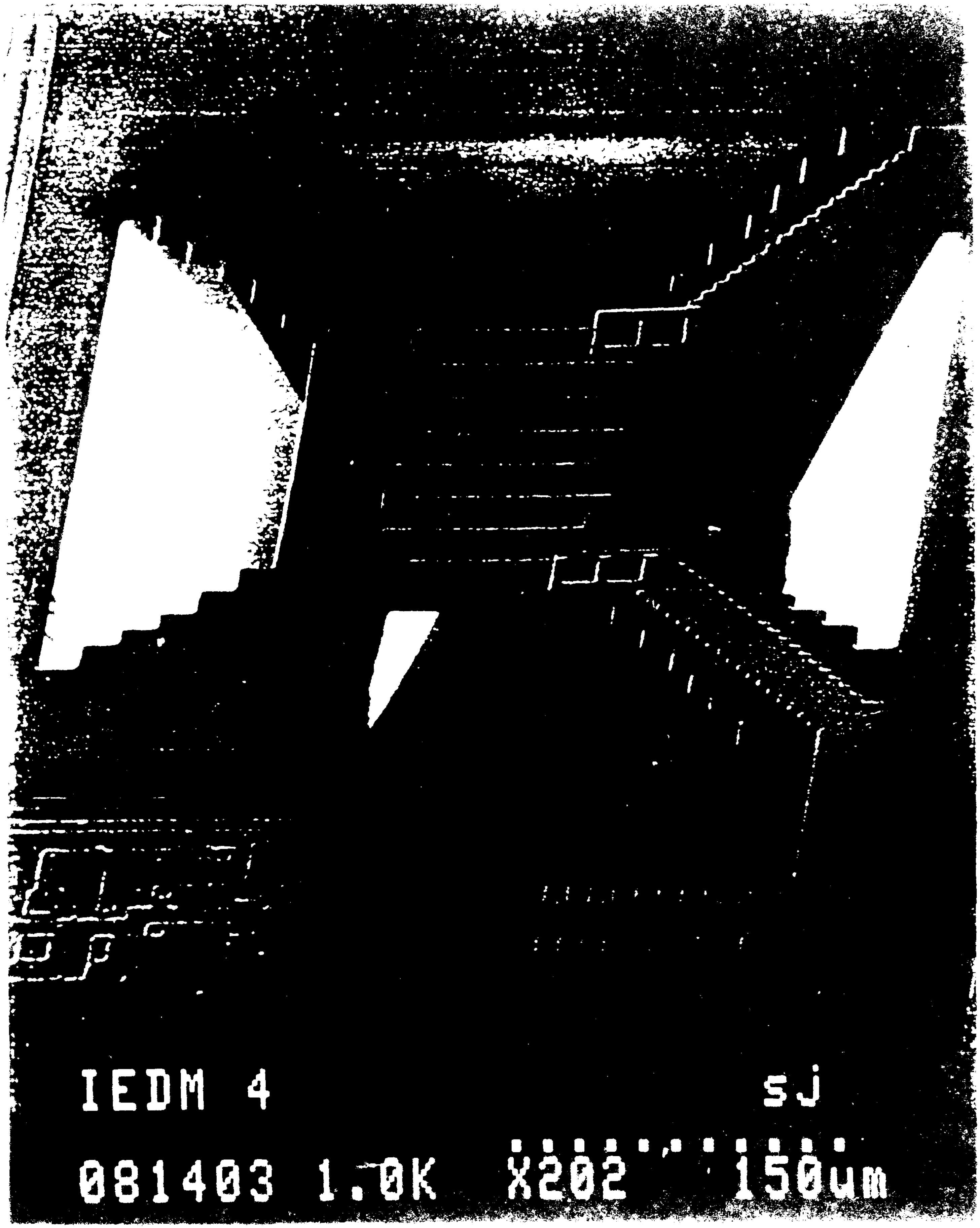

25KU 071X 141µ 0340



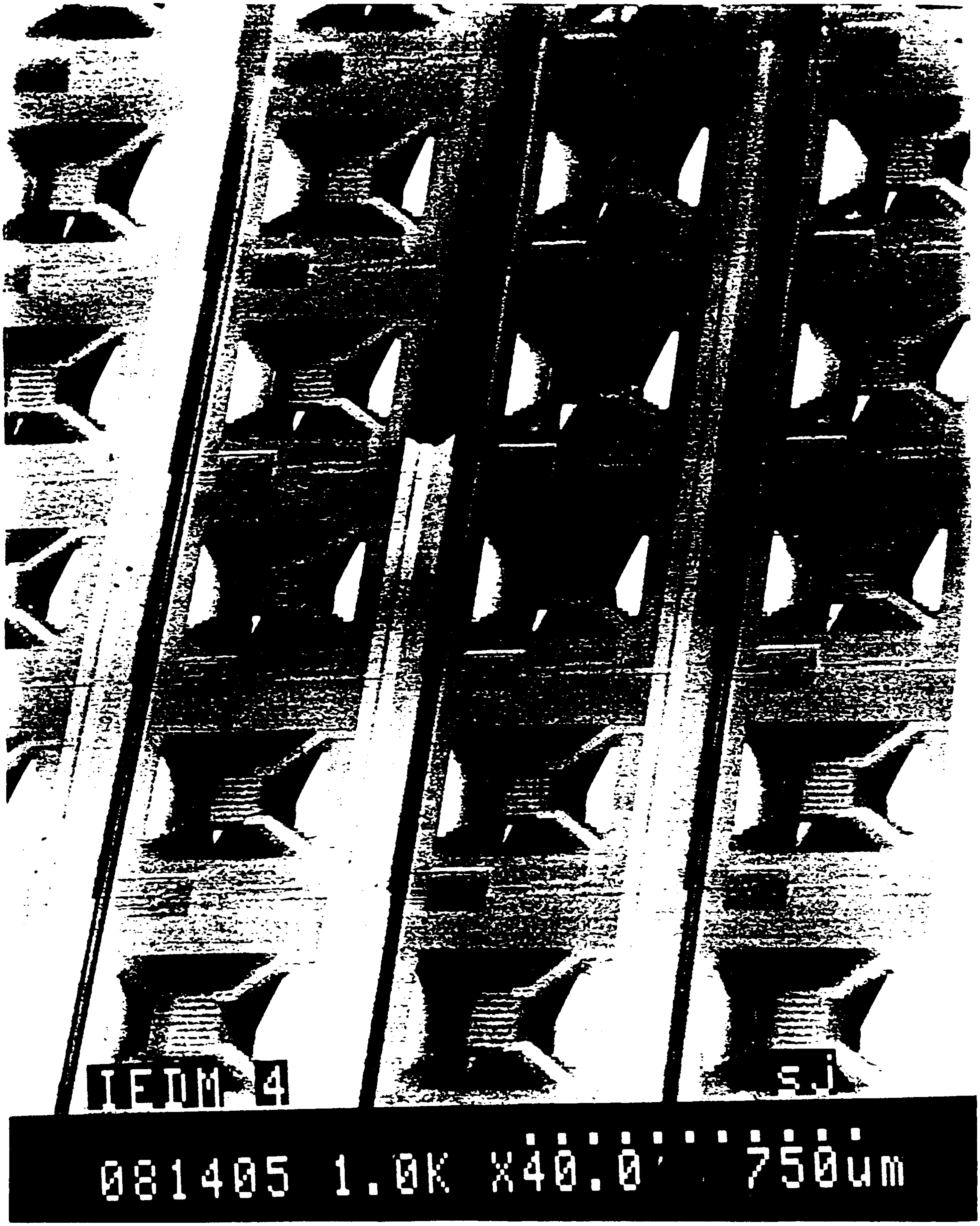
Pixel Current [mA]
4
3
2
1
0
0
4
8
12
16
4-Bit Binary Digital Control Input
Simulatec
Unetched
Etched

DYNAMIC APPROACH





IEDM 4
sJ
081403 1.0K X202 150um


IEDM 4
S.J
081405 1.0K X40.0 750um

COST PROJECTIONS

Small fieldable targets

- Cost is proportional to chip size

  8mm x 9mm chip prototypes are currently purchased for $350 ea. in quantities of 32

- Large quantities will lower cost, possible under $50

Medium Area Targets

- Larger size chips may be available from some foundries

  3cm x 3cm Targets may be available for under $5K

- Multi Chip Modules: Assemble chips in mosaic

Large Area Targets: Targeting under $100K

- 5cm x 5cm WSI devices have been demonstrated (DARPA)
- Larger Sizes are possible with this technology

CONCLUSION

A device was presented for use in Dynamic Thermal Scene Simulation (DTSS)

It is a silicon micromachined IR point source

- The device is fabricated in a Standard CMOS foundry
- An additional maskless etch is required to realize the structure
- The device can deliver an equivalent detector black body response

Two Approaches are being investigated

- Static approach
- Dynamic approach

A Laser Doppler Displacement Meter Vibration Sensor in Mechanical Diagnostics

Charles P. Wang
Optodyne, Inc.
1180 Mahalo Place
Compton, CA 90220

OPTODYNE

LASER DOPPLER DISPLACEMENT METER (LDDM™)

* A PRECISION POSITION-MEASURING DEVICE OPERATING ON THE PRINCIPLE OF LASER RADAR

* A UNIQUE AND PATENTED DEVICE USING A LASER, AN OPTICAL CHIRP, AND HETERODYNE DETECTION

* MAJOR FEATURES:
  HIGH ACCURACY, HIGH VELOCITY, LONG RANGE, COMPACT, LOW COST, AND USER FRIENDLY

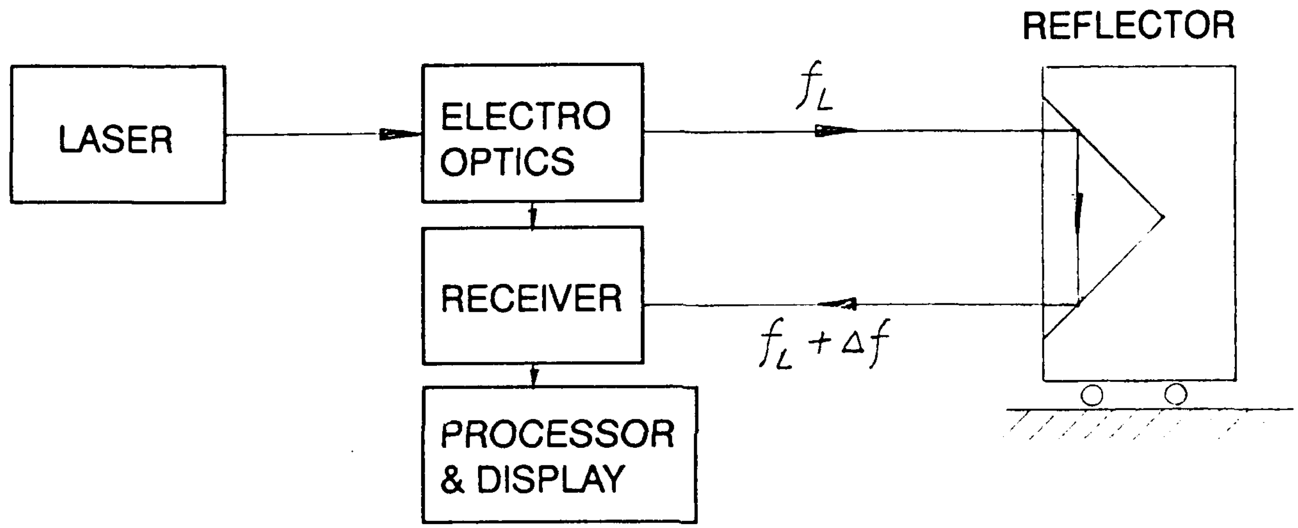
* HIGH ACCURACY POSITIONING AFFORDABLE

* REVOLUTIONIZING METROLOGY AND LINEAR POSITIONING

* MORE THAN 200 UNITS IN THE FIELD

* NIST TRACEABLE

How the LDDM works:



Doppler Frequency Shift

$$\Delta f = \frac{2V}{c} f_L \qquad \frac{\phi}{2\pi} = \frac{2 f_L}{c} X + \text{CONST}$$

$$t = 0,\ X = 0,\ \phi = 0$$

$$X = \frac{c}{2 f_L}\left(N + \frac{\phi}{2\pi}\right)$$

N = A quad B or up/down pulses
ϕ = Analog Phase, 0-5 volts

MAJOR FEATURES

HIGH ACCURACY

HIGH MAXIMUM VELOCITY

LONG RANGE

COMPACT, PORTABLE, AND RUGGED

EASY SET-UP

STAND ALONE AND TURN-KEY OPERATION

ENGLISH AND METRIC UNITS

DUAL LARGE LED DISPLAYS

ERROR INDICATOR AND COMPENSATION

COMPUTER INTERFACE FIRMWARE

USER FRIENDLY SOFTWARE

AUTOMATIC DATA COLLECTION

NO BACKLASH

NO WEAR

NO INTERFEROMETER

NO CRITICAL ALIGNMENT

NO FINE TUNING OR ADJUSTMENT

NIST TRACEABLE

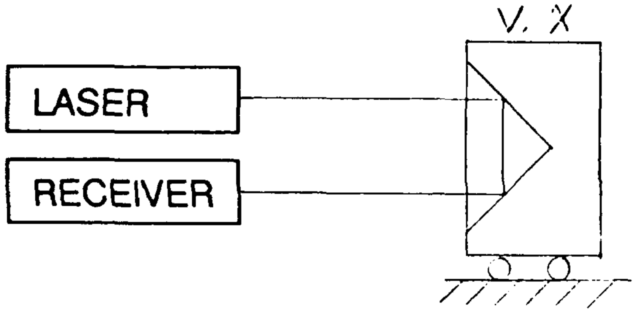
NMTBA / VDI STANDARD

AFFORDABLE

THE PRECISION POSITIONING TECHNOLOGY

* INTERFEROMOETRY - FRINGE PATTERN GENERATED BY TWO BEAMS
  - FRINGE SHIFT DUE TO DISPLACEMENT OF ONE ARM
* DOPPLOMETRY - DOPPLER EFFECT, FREQUENCY CHIRP AND ELECTRO-OPTICAL DETECTION

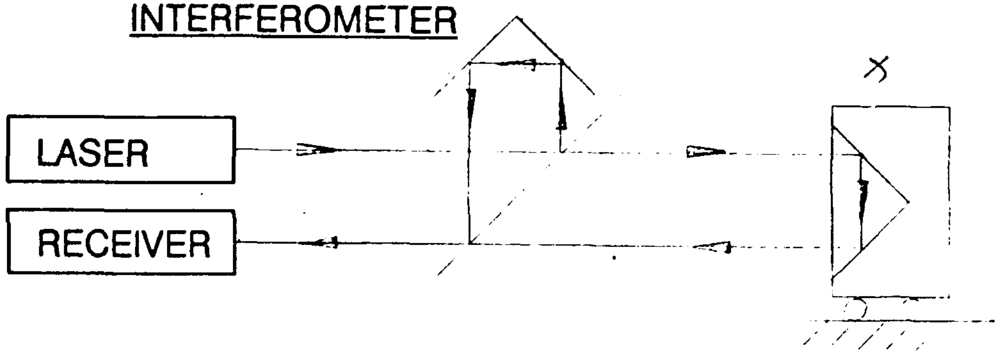
LDDM



DOPPLER FREQUENCY SHIFT
→ VELOCITY, DISPLACEMENT

* MODERN ELECTRO-OPTICS
* DIGITAL AND RF ELECTRONICS
* COMPACT AND FAST

INTERFEROMETER



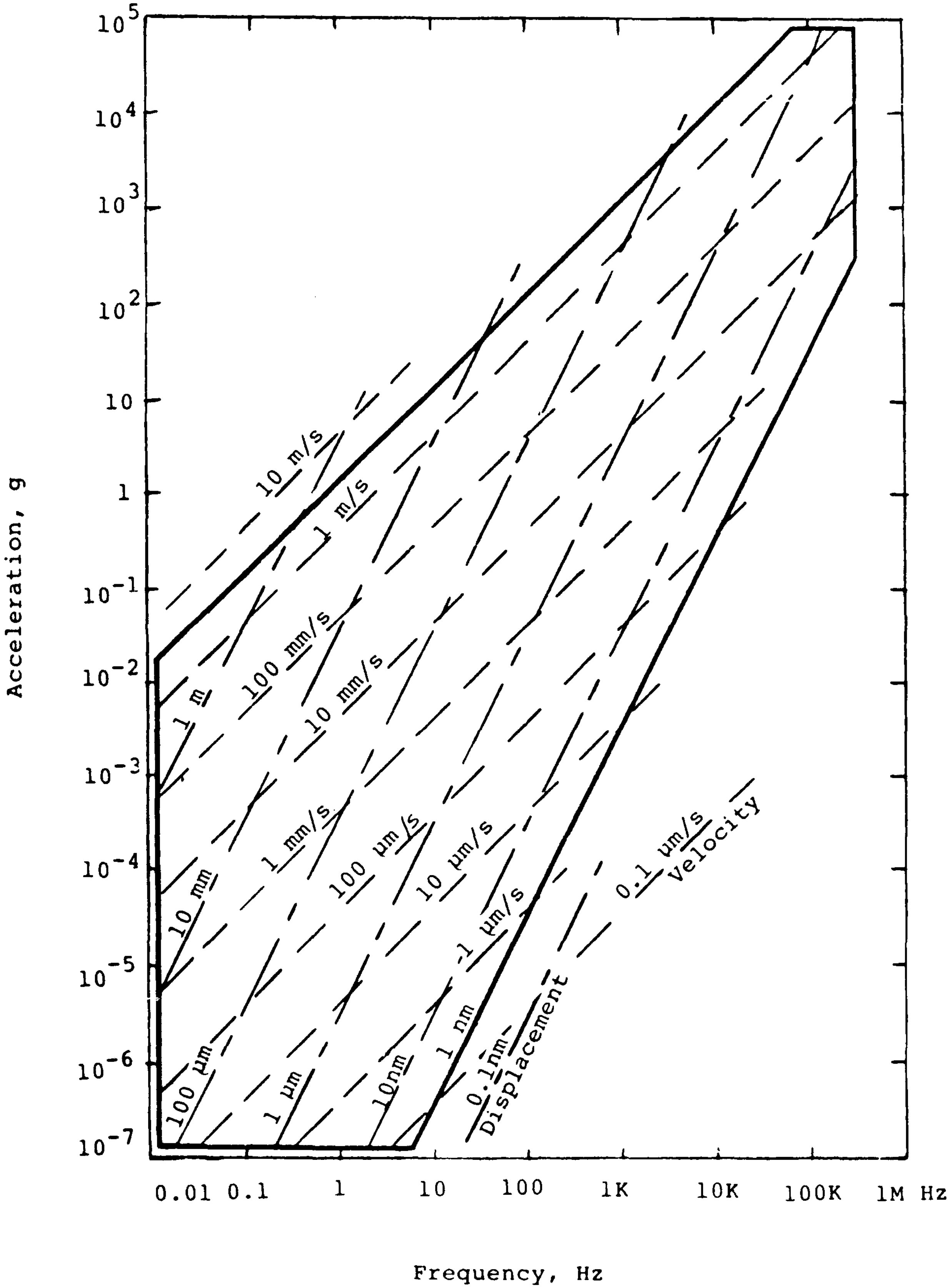
FRINGE SHIFT
→ DISPLACEMENT

* POLARIZED LASER BEAM
* PRECISION AND EXPANSIVE OPTICS
* BULKY AND SLOW

A Comparison of LDDM, Interferometer and LDV

	LDDM Vibration Sensor	INTERFEROMETER	LDV Vibrometer
Laser Accuracy	10E-6	10E-7	10E-6
Resolution	1.2 nm	9.6 nm	1 micron/sec
Max. Speed	2500 mm/sec	10 mm/sec	100 m/sec
Data Rate	800 K data/sec	4 K data/sec	1 K data/sec
Frequency Response	80 K Hz	400 Hz	100 Hz
Signal-to-Noise Ratio	High	High	Low
Alignment & Setup	Easy	Difficult	Difficult
Reflector Type	Flat Mirror, 1/4" DIA Retrorflector, or Flat Surface	Flat Mirror, or 1/2" DIA Retroreflector	Flat Surface
Remarks	Compact/ Low Cost Measures the phase of Doppler Effect	Large Size/ High Cost Counts Fringes	Need long average time to improve S/N. Measures the frequency of Doppler effect

LDDM III Vibration Sensor
Range nomograph



Major Capabilities

Measurement Range:

	Displacement	1.2 nm to 2.5 m
	Velocity	0 to 2 m/sec
	Acceleration	0 to 100,000 g

Accuracy:

	Displacement	1 ppm
	Velocity	0.1%
	Acceleration	0.2 %

Sampling Rate:

Up to 800,000 data/sec

Data Size:

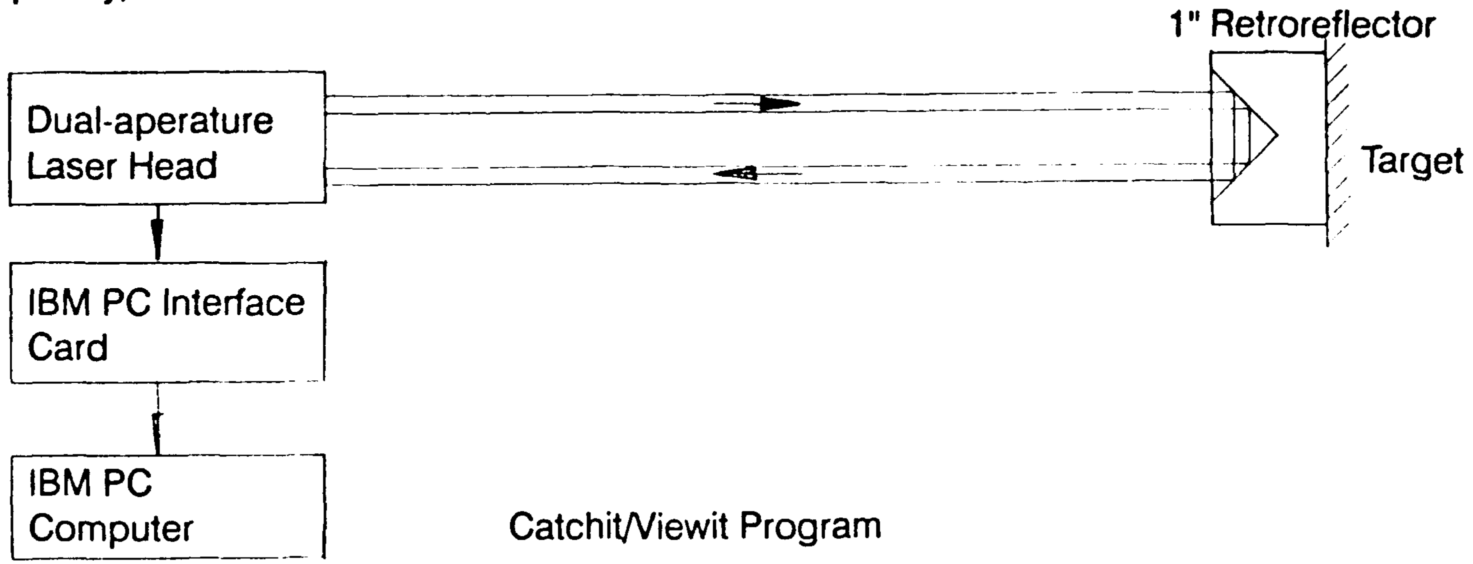
64 K x 2 Byte per record

Data Analysis:

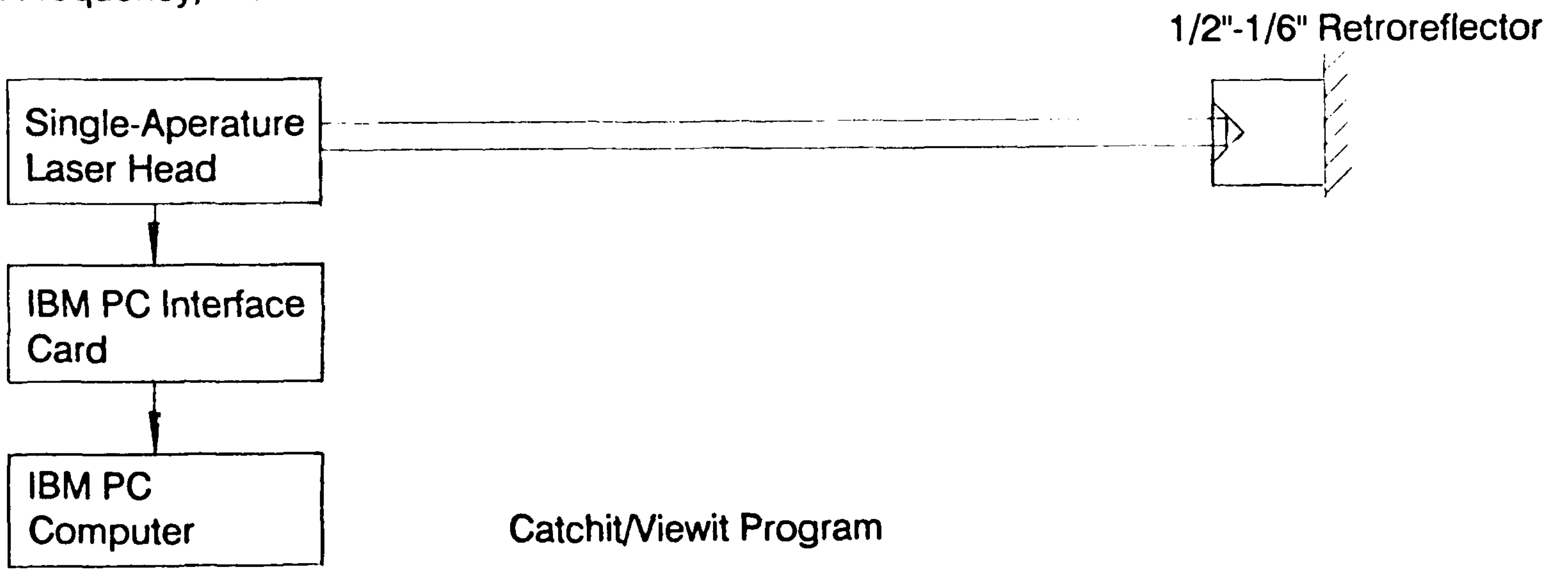
Displacement, Velocity, Acceleration, FFT, PSD, Filter, SRS

Vibration Sensor

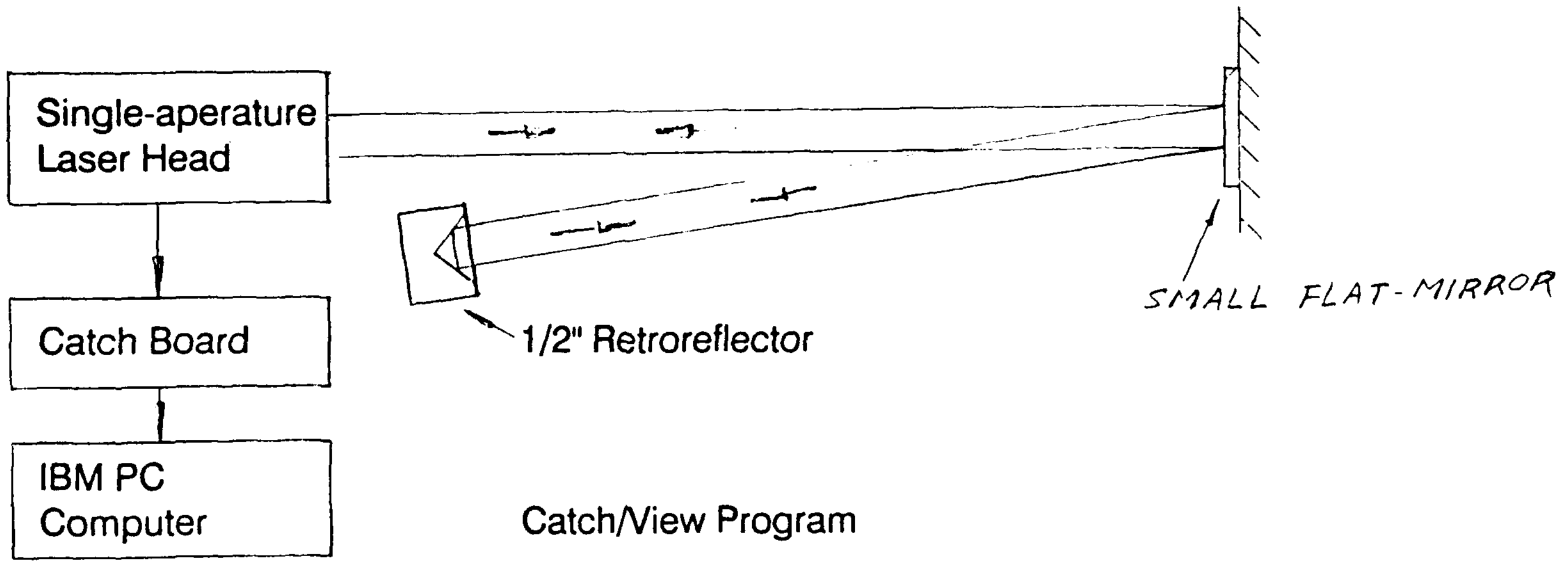
I) Low frequency, <100Hz



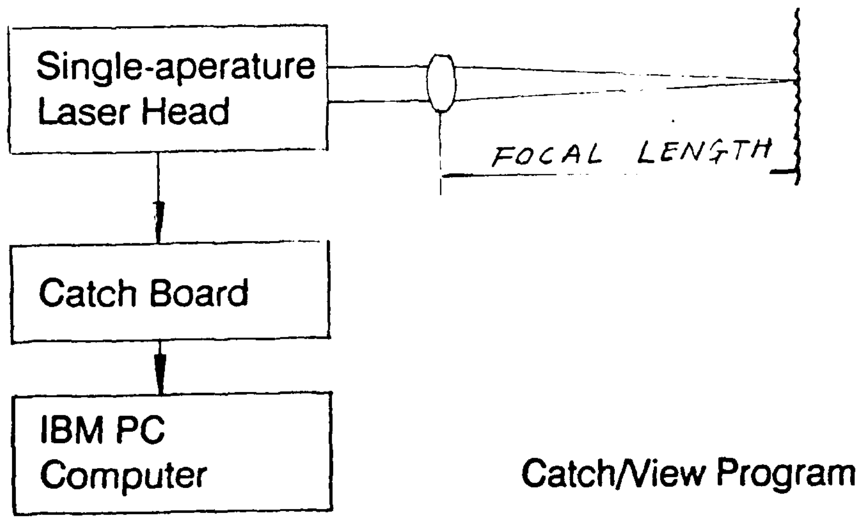
II) Median Frequency, <4 kHz



III) High Frequency, <100 kHz

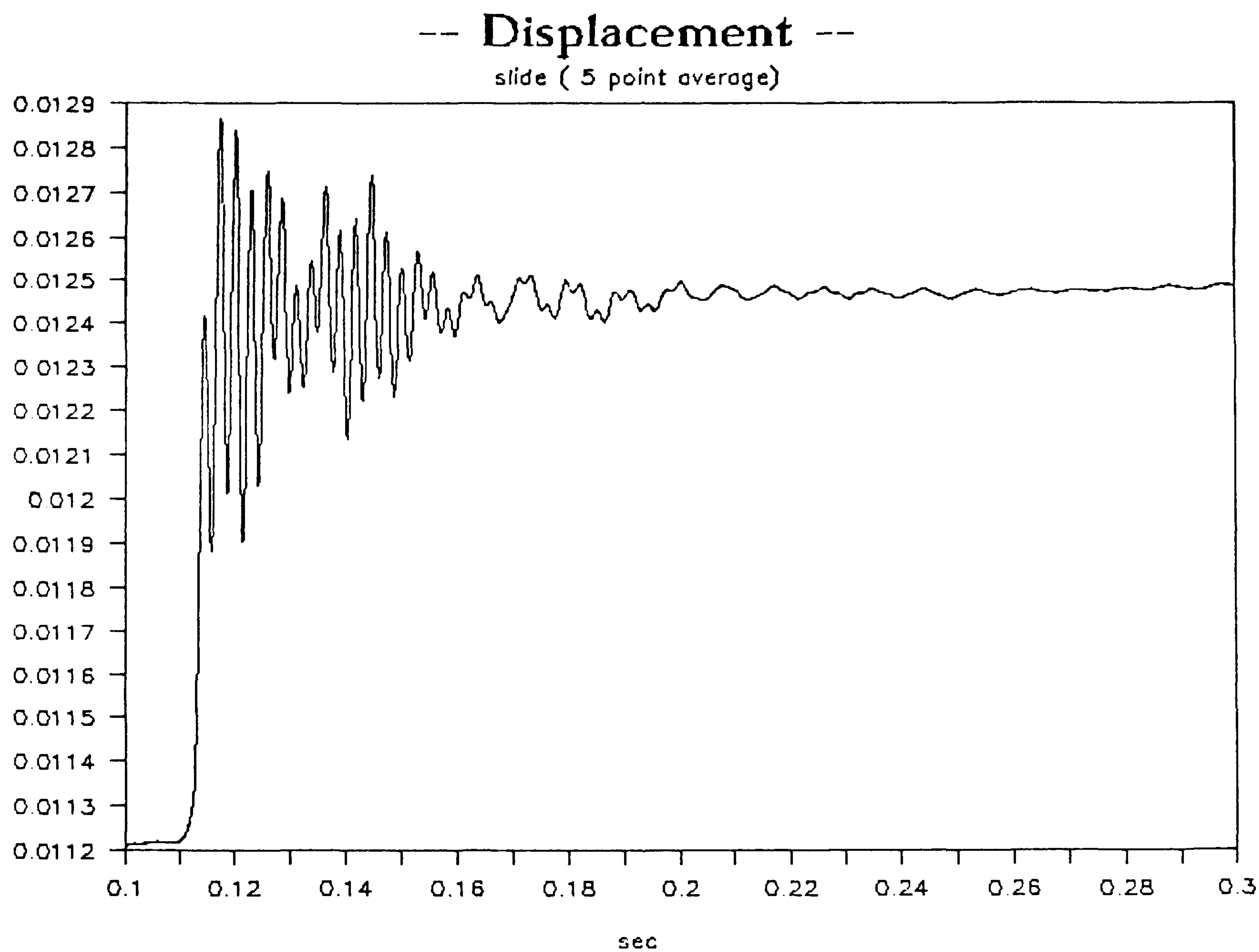


IV) High frequency, non-contact

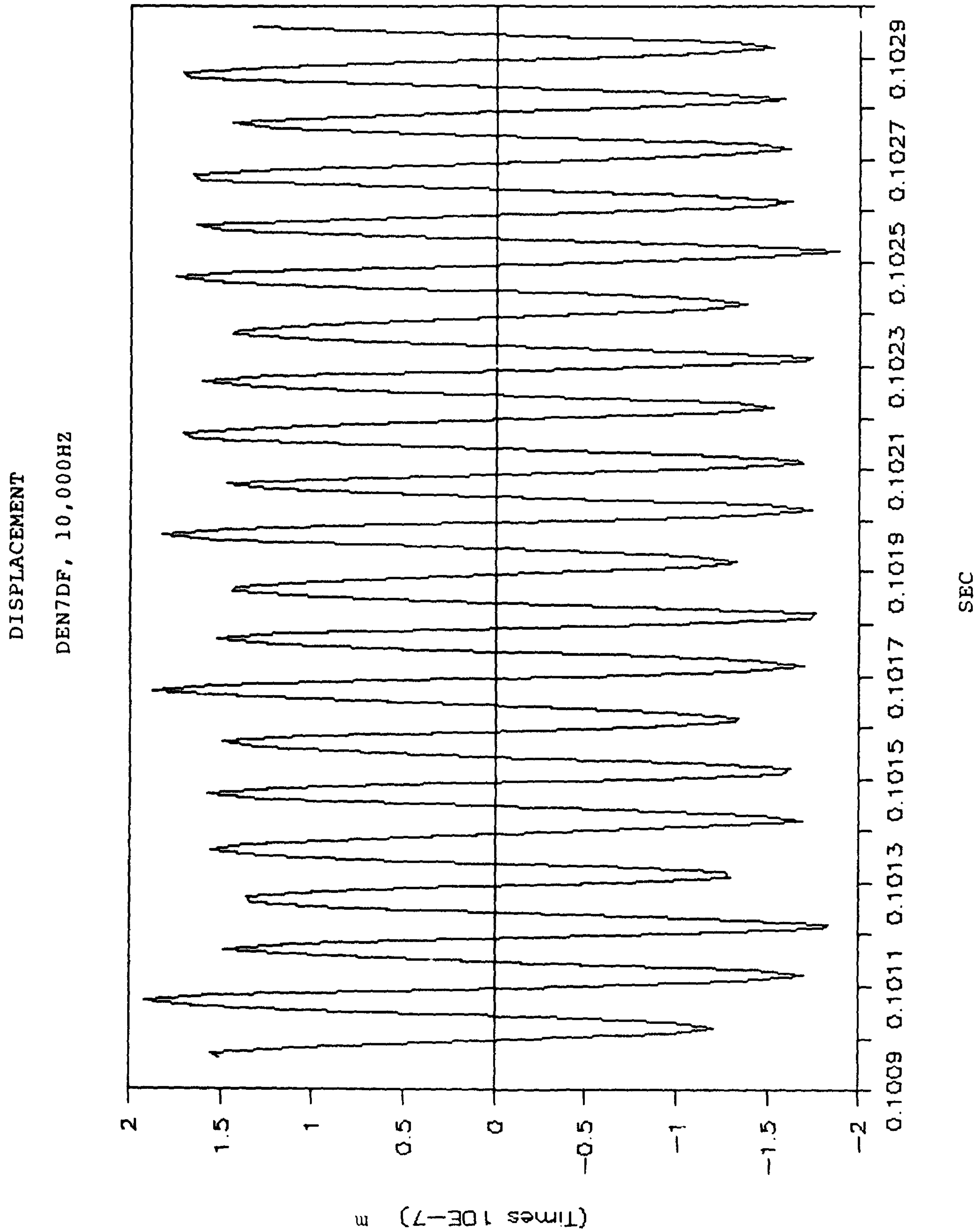


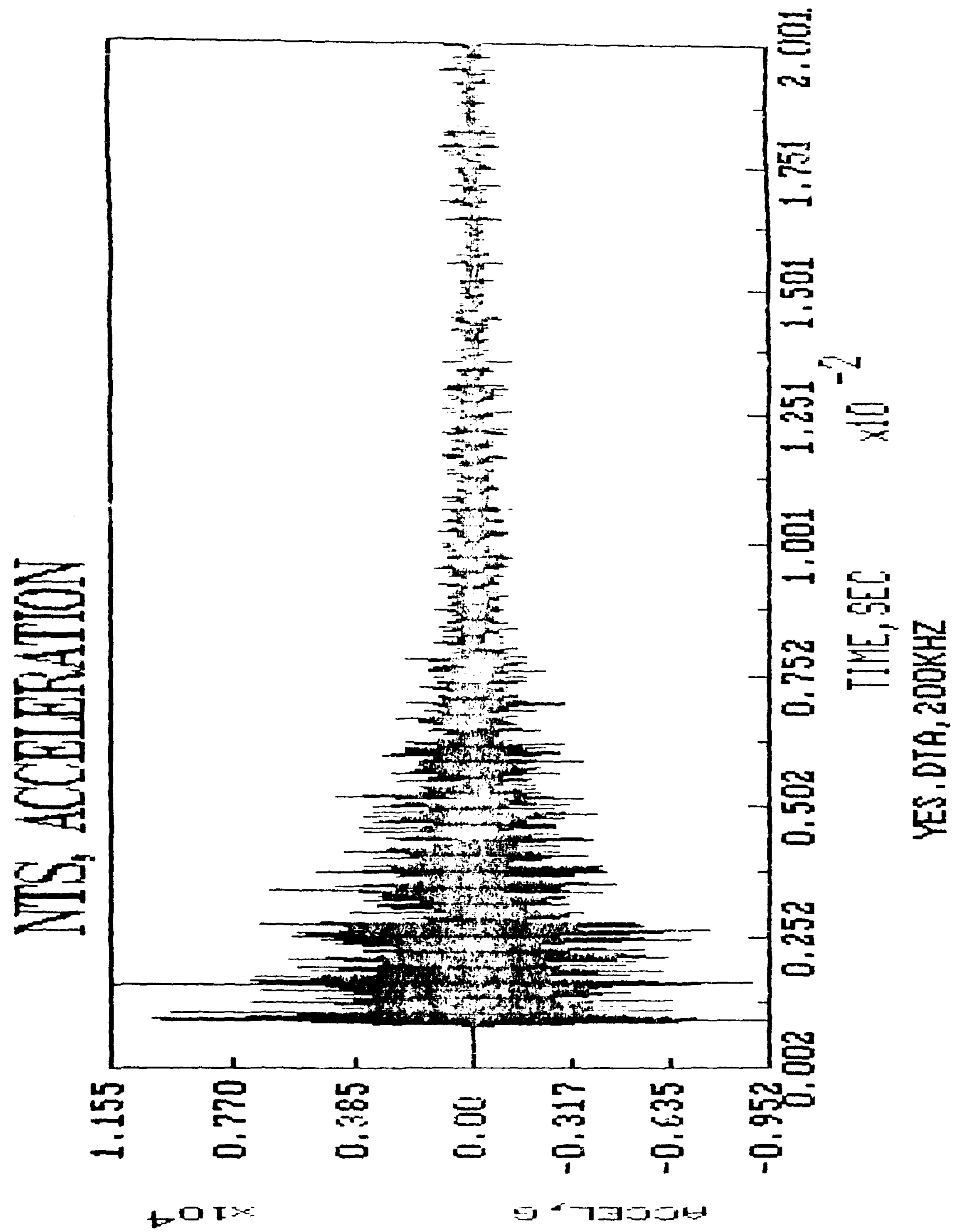
LDDM Vibration Sensor

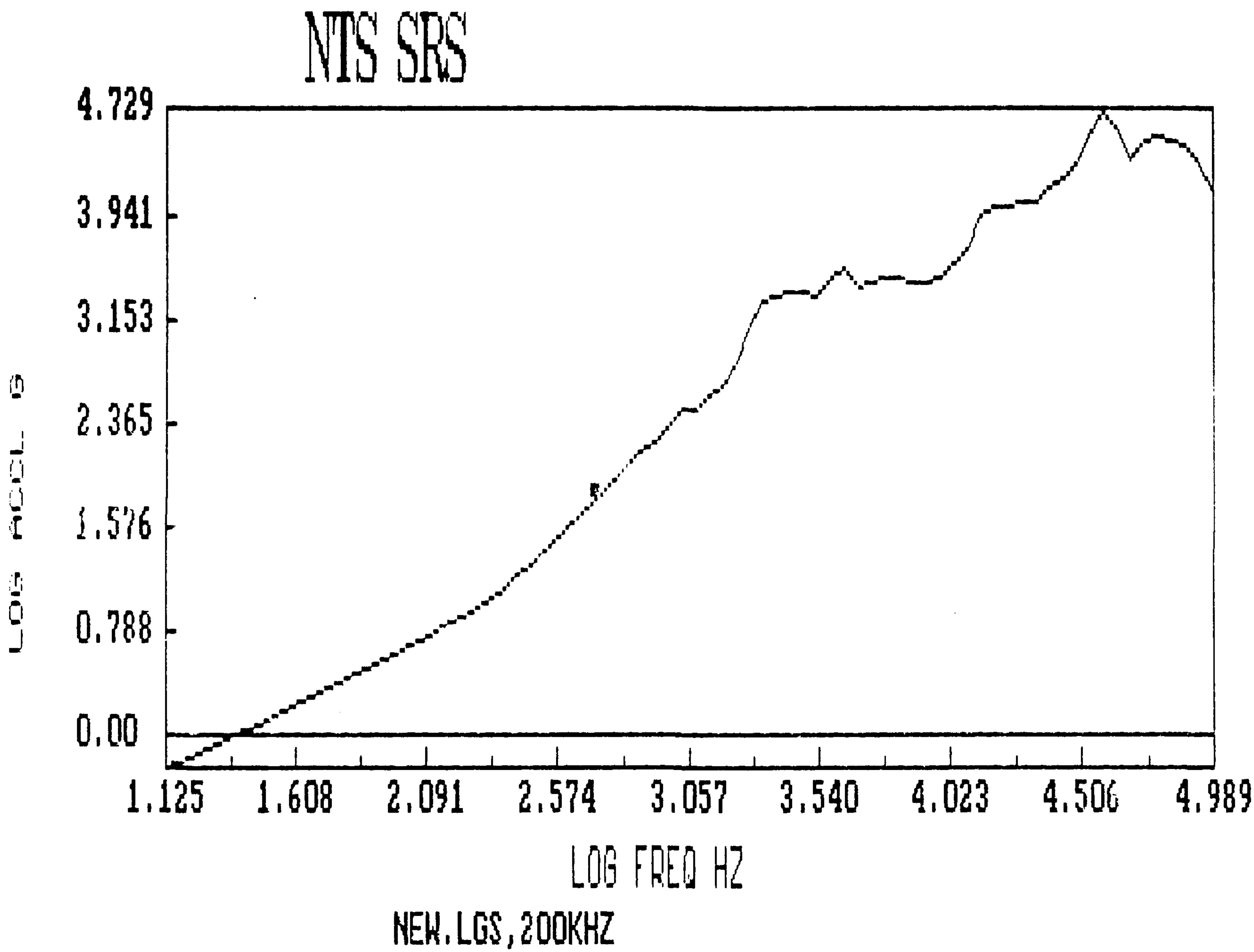
Monitoring transient or continuous mechanical vibrations
Compliment to LDV vibrometer
Mechanical "Oscilloscope"

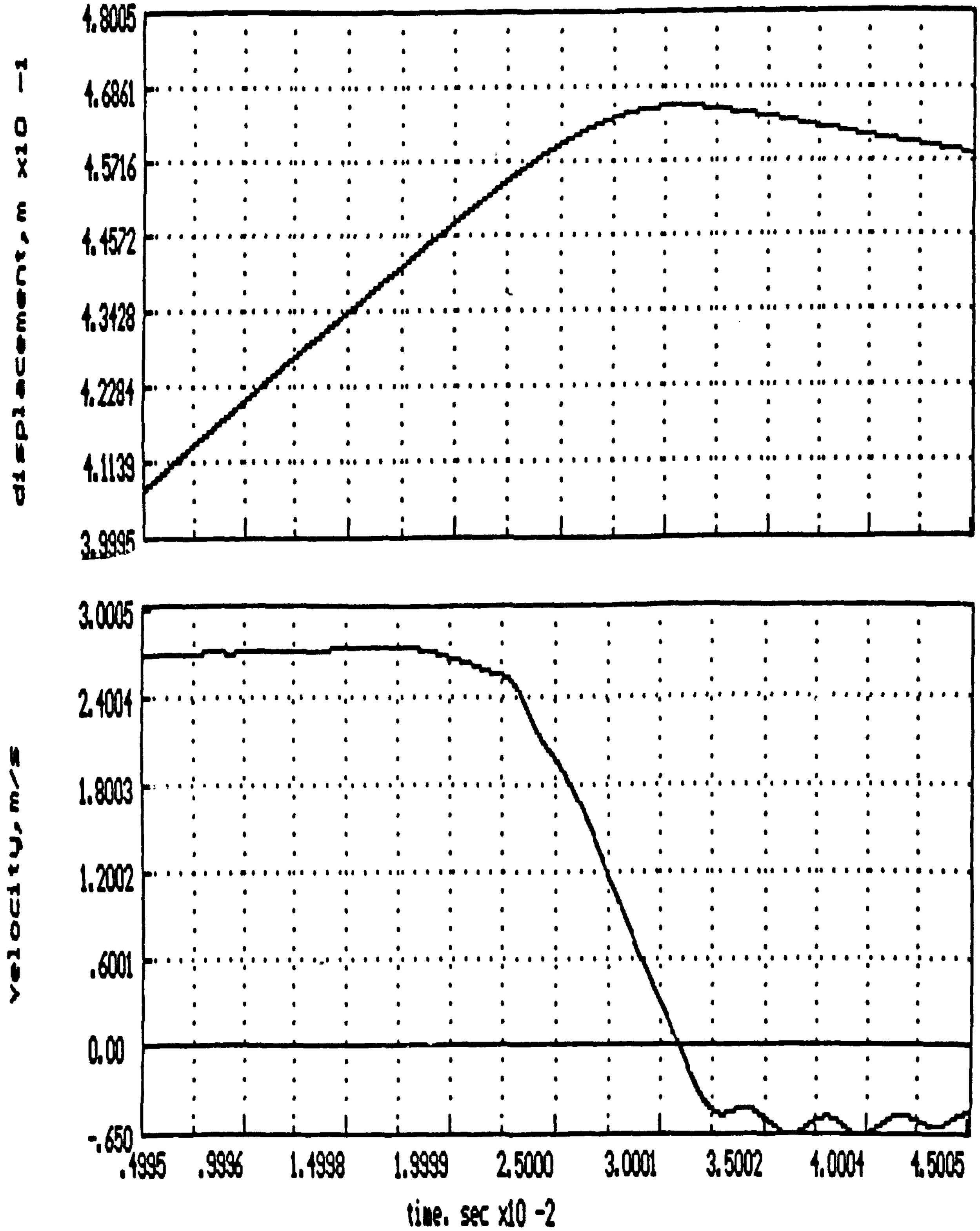


-- Displacement --
slide (5 point average)
0.0129
0.0128
0.0127
0.0126
0.0125
0.0124
0.0123
0.0122
0.0121
0.012
0.0119
0.0118
0.0117
0.0116
0.0115
0.0114
0.0113
0.0112
mm
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3
sec

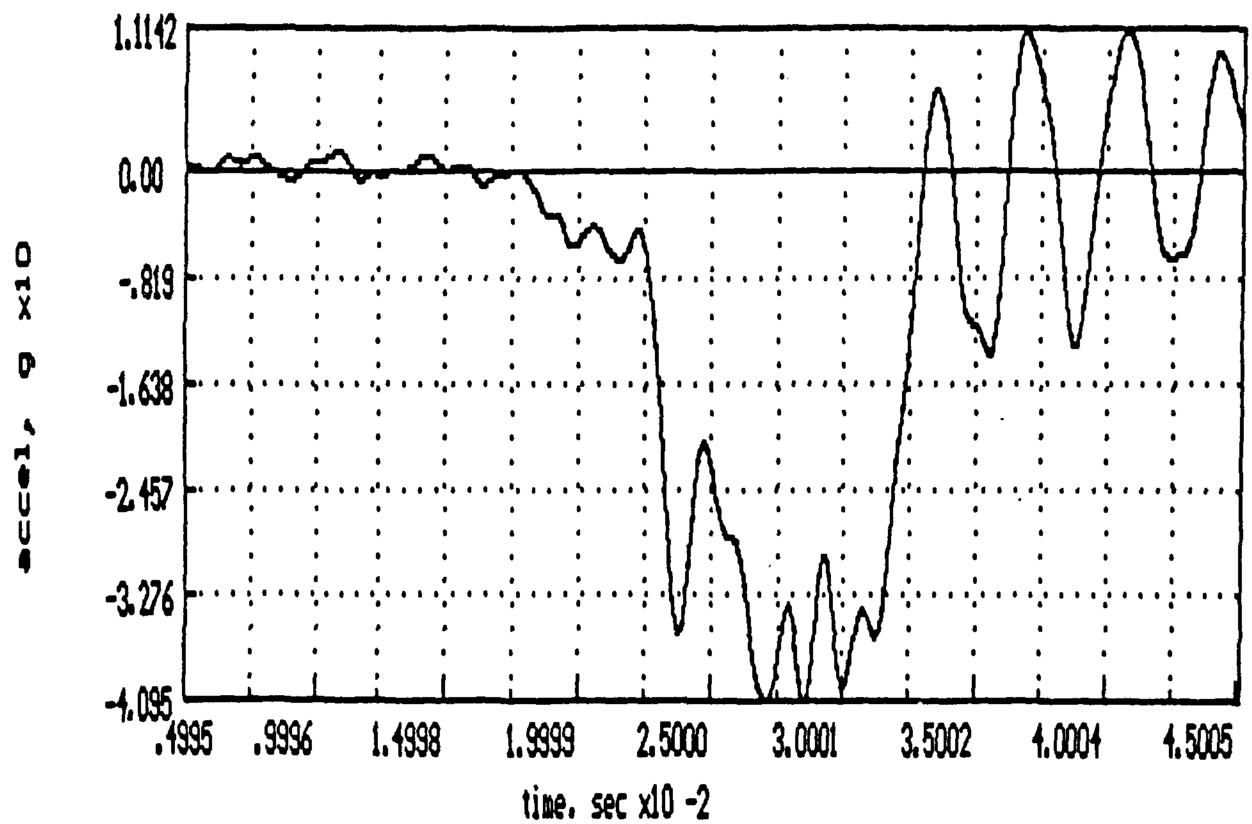

DISPLACEMENT
DEN7DF, 10,000HZ
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
(Times 1DE-7) m
0.1009
0.1011
0.1013
0.1015
0.1017
0.1019
0.1021
0.1023
0.1025
0.1027
0.1029
SEC


NTS, ACCELERATION
1.155
0.770
0.385
0.00
-0.317
-0.635
-0.952
ACCEL, G
x104
0.002
0.252
0.502
0.752
1.001
1.251
1.501
1.751
2.001
TIME,SEC
x10 -2
YES.DTA,200KHZ


NTS SRS
4.729
3.941
3.153
2.365
1.576
0.788
0.00
LOG ACCL G
1.125
1.608
2.091
2.574
3.057
3.540
4.023
4.506
4.989
LOG FREQ HZ
NEW.LGS,200KHZ



displacement, m x10 -1
4.8005
4.6861
4.5716
4.4572
4.3428
4.2284
4.1139
3.9995
velocity, m/s
3.0005
2.4004
1.8003
1.2002
.6001
0.00
-.650
.4995
.9996
1.4998
1.9999
2.5000
3.0001
3.5002
4.0004
4.5005
time, sec x10 -2


1.1142
0.00
-.819
-1.638
-2.457
-3.276
-4.095
accel, g x10
.4995
.9996
1.4998
1.9999
2.5000
3.0001
3.5002
4.0004
4.5005
time, sec x10 -2

MICOM LOGISTICS RESEARCH AND DEVELOPMENT WORKSHOP

EVALUATION OF A SINGLE-BEAM LASER TRACKING SYSTEM FOR LARGE-DIMENSIONAL METROLOGY

Presented By:
SHARON M. JOHNSON

U.S. ARMY TMDE ACTIVITY
SCIENCE AND ENGINEERING CENTER
REDSTONE ARSENAL, AL 35898-5400

Wednesday, 28 August 1991

TOM BEVIL CENTER
Huntsville, Alabama

EVALUATION OF A SINGLE-BEAM LASER TRACKING SYSTEM FOR LARGE-DIMENSIONAL METROLOGY

SHARON M. JOHNSON

U.S. Army TMDE Activity
Science and Engineering Center
Redstone Arsenal, Alabama 35898-5400

I. INTRODUCTION.

In this report, a Single-Beam Laser Tracking System is discussed. The Laser Tracking System is a precision metrology device which can track and measure the position of a moving target in 3 axes at a rate of 2 meters/second. The measuring accuracy of the system is ± .002 inch over a distance of 20 feet. The maximum measuring range is 70 feet with a sweep area of 360° horizontal and 90° vertical. Operation, testing, and proposed uses of the system will be addressed.[2]

II. PROPOSED USE.

A. <u>Need</u>. Corpus Christi Army Depot (CCAD) currently aligns and repairs helicopter, APACHE and BLACKHAWK, tail sections utilizing jig fixtures. The tail sections are removed from the helicopter body and are placed into the large (up to 40 feet long) steel jigs for repair. Once the repair is complete, the tail is reconnected to the body. To assure proper reassembly, the jig fixture is required to be aligned to ± .01 inch. Linear measurements are acquired between fixed points along the jig and then compared to known distances on master jigs. These measurements are obtained utilizing optical tooling employing autocollimators, 10' straight edge bars and elevation bars.

The current method is laborious, (>120 man-hours/jig, >10,000 pounds of equipment) and inaccurate (no thermal compensation). The jigs are at different sites around the world and are calibrated in open-air hangars. The temperature may vary 30^{o}F during measurements which would produce an expansion of .0936 inch (calculation at app. 1); therefore, the required ± .01 inch tolerance is not attainable using the present method.

B. Solution. A Laser Tracking System was purchased in Dec 90, to replace the current optical tooling method. The Laser System is a three-dimensional measuring device which can track and measure a moving target in three axes (fig. 1).

1. The detachable, portable system weighs less than 200 pounds and is comprised of three major components:

   a. 386/20 computer with 387/20 math co-processor.
   b. System controller
   c. Tracking unit

2. The computer is a high speed Intel 80386/20 based computer with Intel 80387/20 math co-processor. It has 1 Mbyte onboard memory, 40 Mbyte hard disk, 1.2 Mbyte 5.25" floppy and for control purposes a decoder card, 12 bit analog to digital, and 12 bit digital to analog cards. The menu driven software is written in Turbo C.

3. The system controller houses all electronic components necessary to control the tracker unit.

4. The Tracking unit is comprised of a single-beam, Class II (eyesafe), Helium-Neon laser, photo-sensing device, and dual axis servo controlled tracking mirror all housed in an Aluminum cylinder.[1]

III. SYSTEM OPERATION.

A. The Laser System is a single-beam laser Doppler displacement system. The system monitors the displacement of retro-reflector movements between any two points. This system utilizes an optical device which detects Doppler shift of laser frequency change. A phase detector compares the frequency of the outgoing beam to the frequency of the return beam. For each half wavelength of displacement, a counter is incremented; a microprocessor reads the counter and phase angle, and converts them to output units.

B. Simultaneously, as the beam is returned to the tracker, a portion of the beam's energy is diverted to a photo-sensing device which monitors the beam position. This enables the servo-action to maintain constant beam-target lock. A combination of encoder angles and laser distance is utilized to compute the XYZ coordinate position of the target (fig. 2).[1]

IV. SELF-CALIBRATION.

A. Since the Laser System is transportable, systematic errors such as misalignment, and beam offset can be incurred during shipping. In order to detect systematic errors and verify system accuracy, the system possesses a "ball-bar" calibration technique.

B. The ball-bar is a meter-long aluminum bar mounted on a rotating stage. At one end of the bar, the target is attached to a magnetic base. During calibration, the bar is manually rotated, 2 meters in front of the tracker, in a vertical plane. The system tracks, and stores this circular trajectory.

C. Since the tracker is a true spherical coordinate measuring system, and a circle is one of its basic geometric elements, the similarities of the two allow for precise and direct analysis of the system accuracy.

Simulation model and analysis software has been incorporated into the system to enable the user to view errors and choose either system realignment or error compensation (fig. 3 and 4).[2]

V. **TESTING.**

The Laser system utilizes new technology which enables it to automatically track a moving target compared to its predecessors which required painstakingly slow manual alignment. The unit under consideration is only the fourth of its kind, therefore, necessitating thorough verification and testing.

A. **Initial Calibration.**

1. The first step to achieve successful measurements is to maintain target lock-on. The laser beam is manually or automatically positioned to intercept the center of the retro-reflector (fig. 5).[1] Once lock-on has occurred, a slight grabbing motion is detected at the gimbal and the interferometer and intensity labels on the screen disappear. (Should beam interruption occur, the labels will reappear and the system must be re-calibrated). After the laser is properly locked on the target, the y-distance between the laser and target is entered; this assigns the gain for motor drives which maintains tracking control. Once these steps have been completed, the unit can track and measure on a relative scale.

2. Since the laser interferometer is a relative measuring device, an absolute distance procedure must be performed before actual measurements can be obtained. To achieve such measurements, the manufacturer provided a Standard Calibration Bar (fig. 6). The bar is aluminum with magnets at point 1 and point 2. The distance between the two points has been measured with a Hewlett Packard Laser Interferometer to be 32.99474" at 76 ^{o}F.[2]

3. The beam is locked on the target at point 1 of the bar and "entered." The system stores angular and distance information from point 1. Next, the target is moved from point 1 to point 2, and the known distance entered. From this information, the system calculates the absolute distance from the tracker to target.

4. After evaluating the calibration method, it was deemed satisfactory; however, this author has replaced the Aluminum Calibration Bar with a steel bar of the same dimensions. The steel bar was chosen because of thermal stability approximately twice that of aluminum ($6.5\times10^{-6}/^{o}F$, $13.1\times10^{-6}/^{o}F$) and the rigidity of the material. It was also determined that the calibration bar must be clamped firmly in place before accurate measurements can be realized.

B. **Controlled Environment Testing**.

1. **Software**. The first operational area to be considered was software functionality. The software package is divided into two main portions; index pulse routine and main menu.

a. Upon system boot, the gimbal searches for index pulses on both azimuth and elevation encoders. If both pulses are found, the screen indicates such and advances to the main menu. If one or both pulses are not found, the screen depicts such and the manufacturer must be contacted.

b. The main menu is compiled of 11 function-key commands. Capabilities include; selecting English or Metric, Spherical or Cartesian units, static or dynamic data acquisition and environmental compensation. All software functions were found to be user-friendly and self-explanatory.

2. **Hardware**. The laser, computer, and controller were inspected for workability and functionality. Upon completion of such, an intermittent problem between controller and laser unit was detected. The tracker could not maintain target lock. The unit was returned to the manufacturer where a broken connector pin and burned op-amp were discovered and replaced. Subsequently, the laser was returned to Redstone and retested. Upon completion of retest, the system passed and no further problems were noted in that area.

3. **Distance.** The Laser System was specified to track over a distance of 70 feet. Verification was accomplished by attaining laser-target lock, and manually moving the target in the y-direction until the laser intensity weakened enough to break contact. The distance acquired by the system was 97 feet; exceeding the specification.

4. **Speed**. The specification stated the laser should be capable of tracking a target moving 2 meters/second. The tracking rate was verified by mounting the retro-reflector on an air track glider (fig. 7); beam-target lock was achieved and the glider was manually pushed from one end of the track to the other. This process was timed for 2 seconds and the distance traveled was measured. The test comfirmed the 2 meter/second claim.

5. **Stability**. The stability was determined by initially calibrating the system and collecting data every minute while maintaining beam lock, on a stationary target. The sampling rate was adjusted from 5 to 20 seconds to determine greatest stability. (Sampling time is set by entering the number of averages and frequency per reading; i.e., 50 av/5 Hz = 10 seconds sampling time). It was determined that a 10-second sample time provided a stability

of ± .0005 inches at a y-distance of 8 feet (app. 2).

6. **Repeatability**. The repeatability of the system was specified at ±.001 inch at a distance of 10 feet. System repeatability was verified by initially calibrating the system and collecting data every minute. The data was collected by attaching the target to a fixed point while maintaining target lock on. The target was moved and replaced to the fixed point at one minute intervals. The sampling rate was 10 seconds. The repeatability was determined to be ±.0008 inches (app. 3).

7. **Relative Accuracy**. The accuracy of the system was specified to be ±.001 inch at a distance of 10 feet. Verification of such was achieved by comparing simultaneous measurements obtained from the Laser Tracking System and an HP Interferometer. (The HP Interferometer is the accepted standard for linear measurements with historical data verifying an accuracy of ±.0001".) The simultaneous measurements were attained by securing both the Laser Tracker and HP retroreflectors atop an air track glider (fig. 8). The Laser tracker was positioned perpendicularly to the airtrack at an initial distance of 8 feet. The HP Interferometer was stationed in line with the air track (fig. 9). The glider was placed at position 1, the lasers zeroed simultaneously and the glider, carrying the targets, pushed to position 2. Simultaneous data points were gathered and measurements were compared. This process was repeated over a 1 month period over distances between point 1 and 2 ranging from 11 inches to 12 feet. During the 1 month period, the position of the laser tracker was varied and the standard calibration bar placement varied during initial calibration.

The absolute difference between each standard (HP) value and the corresponding (API) value was calculated. The mean of the differences ($\bar{x}\Delta$) was calculated for each of the 13 data sets. The mean of the $\bar{x}\Delta$ was then calculated and the system accuracy over a range of 1-12 feet was determined to be ±.0012 inches, therefore meeting the specification (Data at app. 4).

C. **Environmental Compensation.**

1. The next inspection area was the refractive index correction. The system possesses the capability to compensate for air temperature, humidity, and pressure. The appropriate values are entered into the system, it automatically calculates the correction factors and adjusts the data accordingly. It is recommended that during rapidly changing environmental conditions, the factors be entered every half-hour.

2. Although the system corrects for the refractive index, it does not correct for the thermal expansion of the apparatus being measured. As was previously mentioned, this system will be used to measure large (> 35 feet) steel jig fixtures in an uncontrolled environment (50°F-100°F); therefore, thermal compensation is necessary. Manual calculations are time consuming; consequently, an automated digital temperature measurement system is being incorporated into the laser system. The temperature system is composed of 5 thermometers (accuracy ± .1 $^{\circ}$ C) which will be mounted directly on the item being measured. The average temperature will automatically be input into the system, the user will be prompted to enter the composition of the material being measured, triggering the appropriate

expansion coefficient thus completing the thermal expansion equation:

$$\delta T = \alpha (\Delta T) L$$

where α = expansion coefficient, $\Delta T = |\text{material temperature} - 68^{\circ}F|$, and L = length of span being measured. After calculating δT, the system will automatically display and output the corrected measurements.

D. **Uncontrolled Environment Testing**.

1. The previously mentioned tests and evaluations were conducted in a controlled laboratory environment (68 °F- 70 °F, and limited space). The unit as noted reacted favorably; however, since the utilization of the system will be in an uncontrolled environment, and over a 40 foot area, it was necessary to repeat the tests in such an environment. The system was stationed in an unair-conditioned warehouse (85 °F- 98 °F) and previously stated tests were conducted. When these tests were performed in the hot environment, the stability, repeatability and accuracy data failed to meet specifications (app. 5). The manufacturer was notified and stated that the laser was only specified for 60 °F ± 15 °F; therefore, explaining the noted thermal effects. The system was returned to the manufacturer on 22 Jul 91, to receive laser modifications. The laser will be modified and the range changed to $90^{\circ} \pm 15^{\circ}F$ (The aforementioned automated temperature system will be installed simultaneously.)

2. The system should be returned for testing no later than 30 Aug 91 and will undergo the uncontrolled environmental tests again. Subsequently, if the system meets specifications, this author will accompany the unit to Corpus Christi to conduct training classes and fielding; therefore, providing

Corpus Christi Army Depot the following improvements:

	OLD METHOD	NEW METHOD
WEIGHT	10,000 lbs	200 lbs
TIME	120 manhrs/jig	8 manhrs/jig
ACCURACY	± .09 inch	± .003-.005 inch

VI. **CONCLUSION.**

Conventional ways of utilizing large templates, coordinate measuring machines (CMMs) and theodolites for measuring large structures are laborious, time-consuming and expensive. The Laser Tracking System under consideration in this report was thoroughly tested and proved to be a user-friendly, portable, high-speed and accurate measuring system in a laboratory environment. Applications include large structural measurements, milling machine calibrations and robotic tracking.

Upon completion of retesting in the uncontrolled conditions, subsequent findings will be disclosed in a final report.

REFERENCES

1. Mr. Q. Ma and Mr. K. Lau, Operations Manual for the Single Beam Laser Tracking System (LTS-310), Automated Precision, Inc., Gaithersburg, MD (Sep 90).

2. Mr. Q. Ma, Mr. K. Lau, and Mr. P. Tan, Use of an Advanced Laser Tracking System for Large-Dimensional Measurements, Automated Precision, Inc., Gaithersburg, MD.

LTS-310 System Configuration

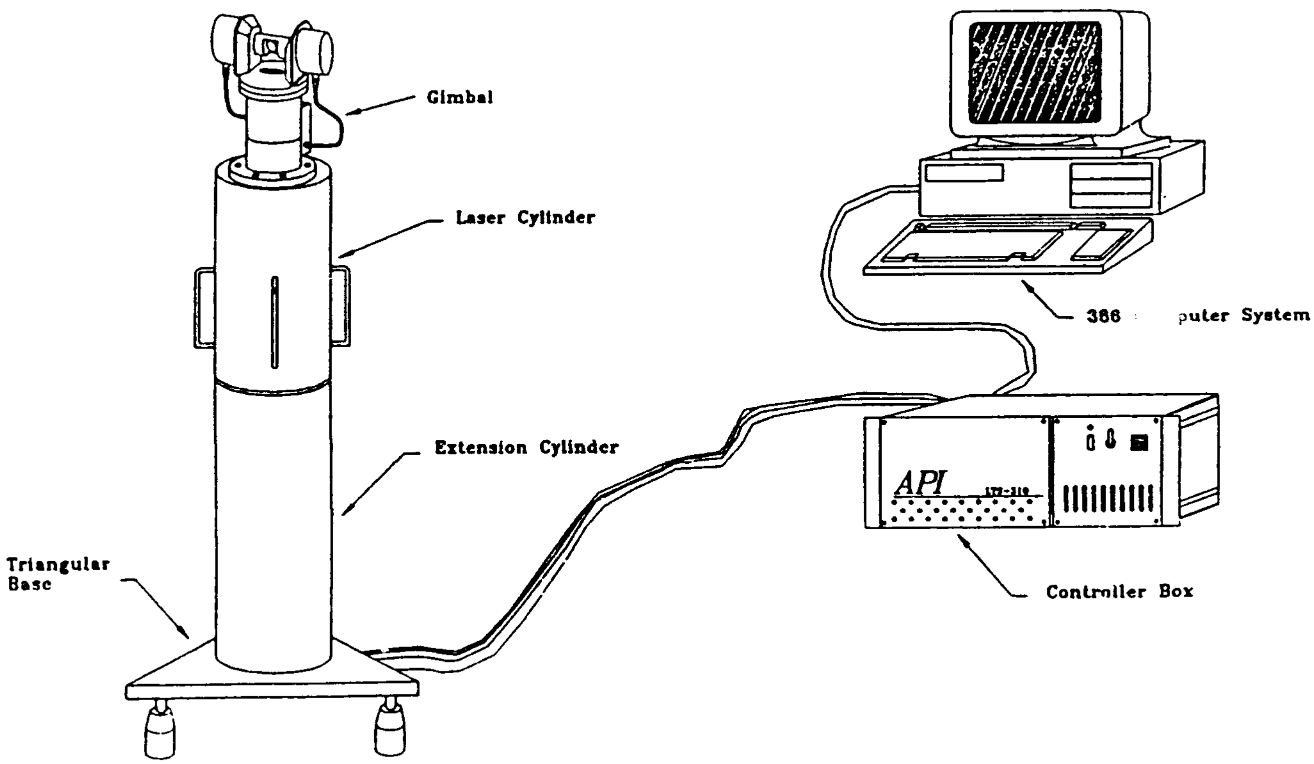


FIG. 1 - LTS-310 SYSTEM CONFIGURATION

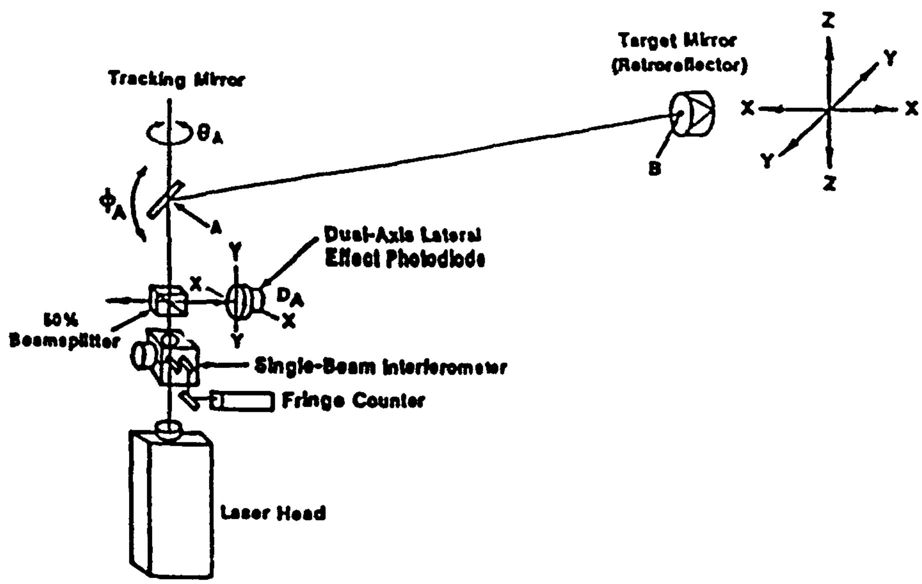


FIG. 2 - Basic Configuration of a Single-Beam Laser Tracking Interferometer System

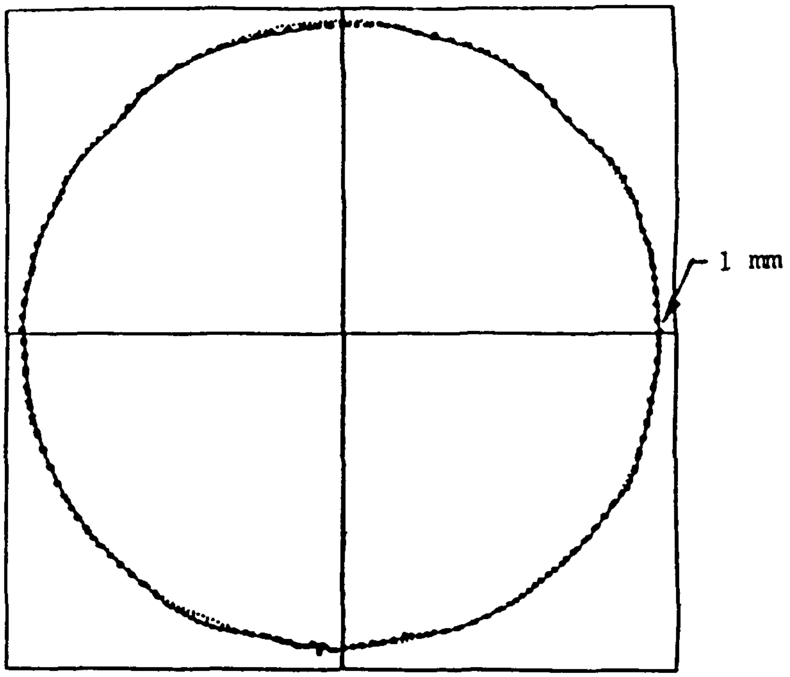


FIG. 3 - 2-D Error Pattern of a Well-Aligned System

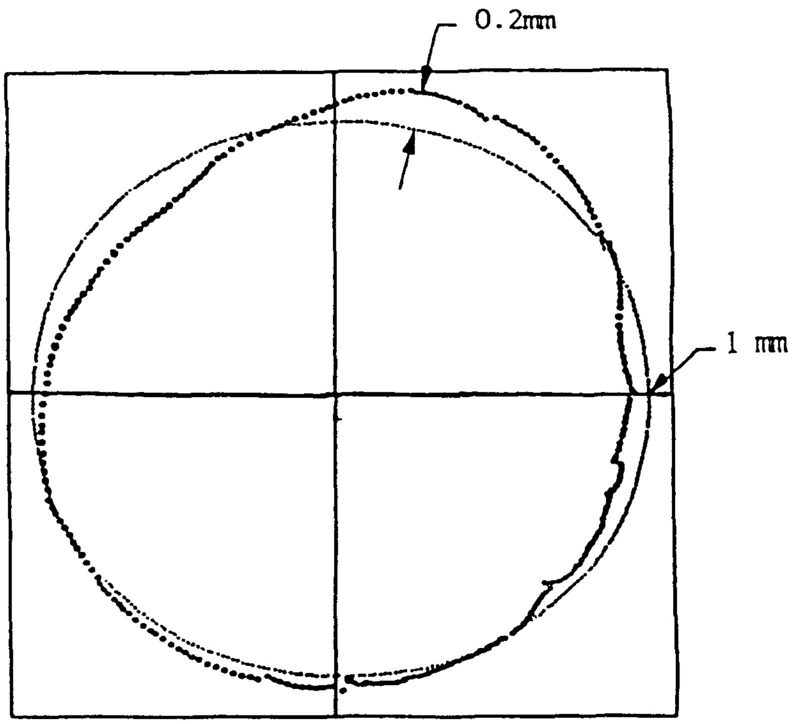
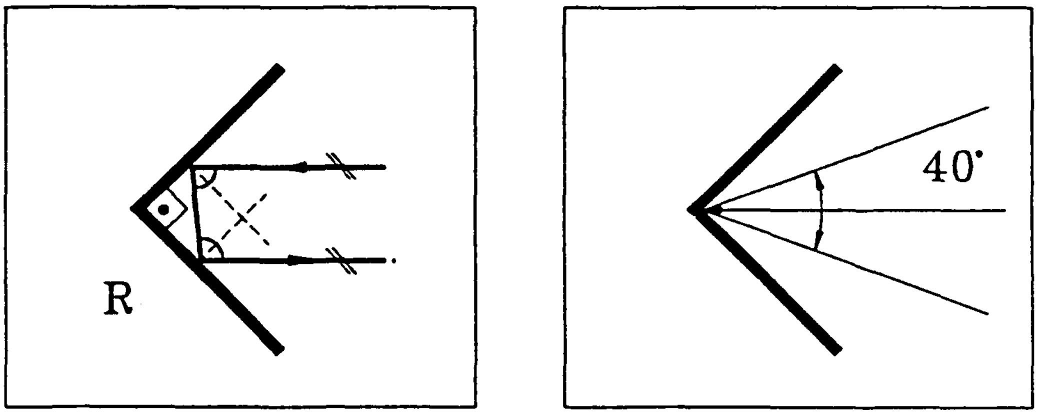


FIG. 4 - 2-D Error Pattern of a Misaligned System
Using the Ball-Bar Calibration

FIG. 5- RETRO REFLECTORS

CORNER CUBE



The corner cube consist of three plane mirrors. Each pair of mirrors includes a 90° angle. This allows a very small retro reflector with low weight but restricts the working range.

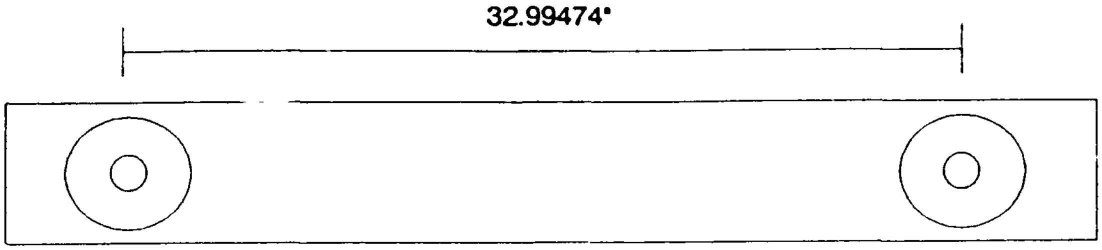


FIG. 6 - Al Standard Calibration Bar

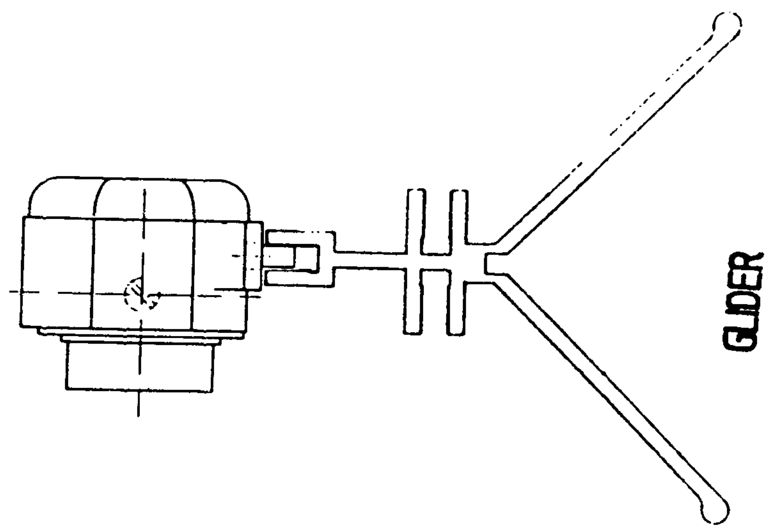


FIG. 7 - GLIDER

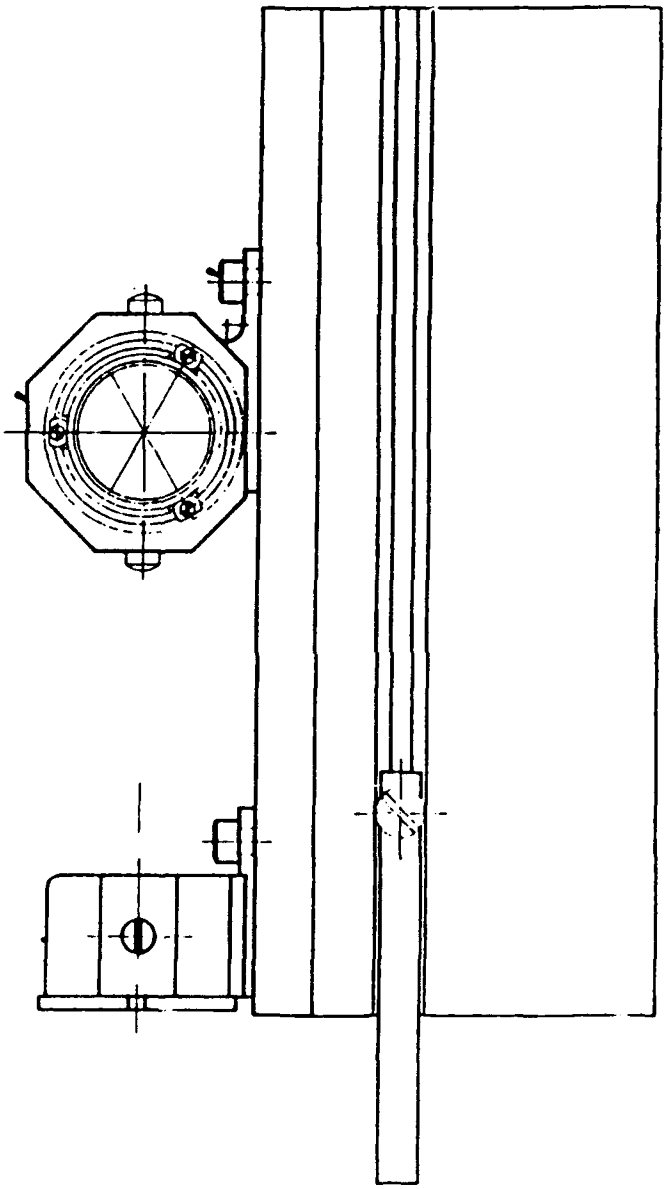


FIG. 8 - GLIDER ASSEMBLY

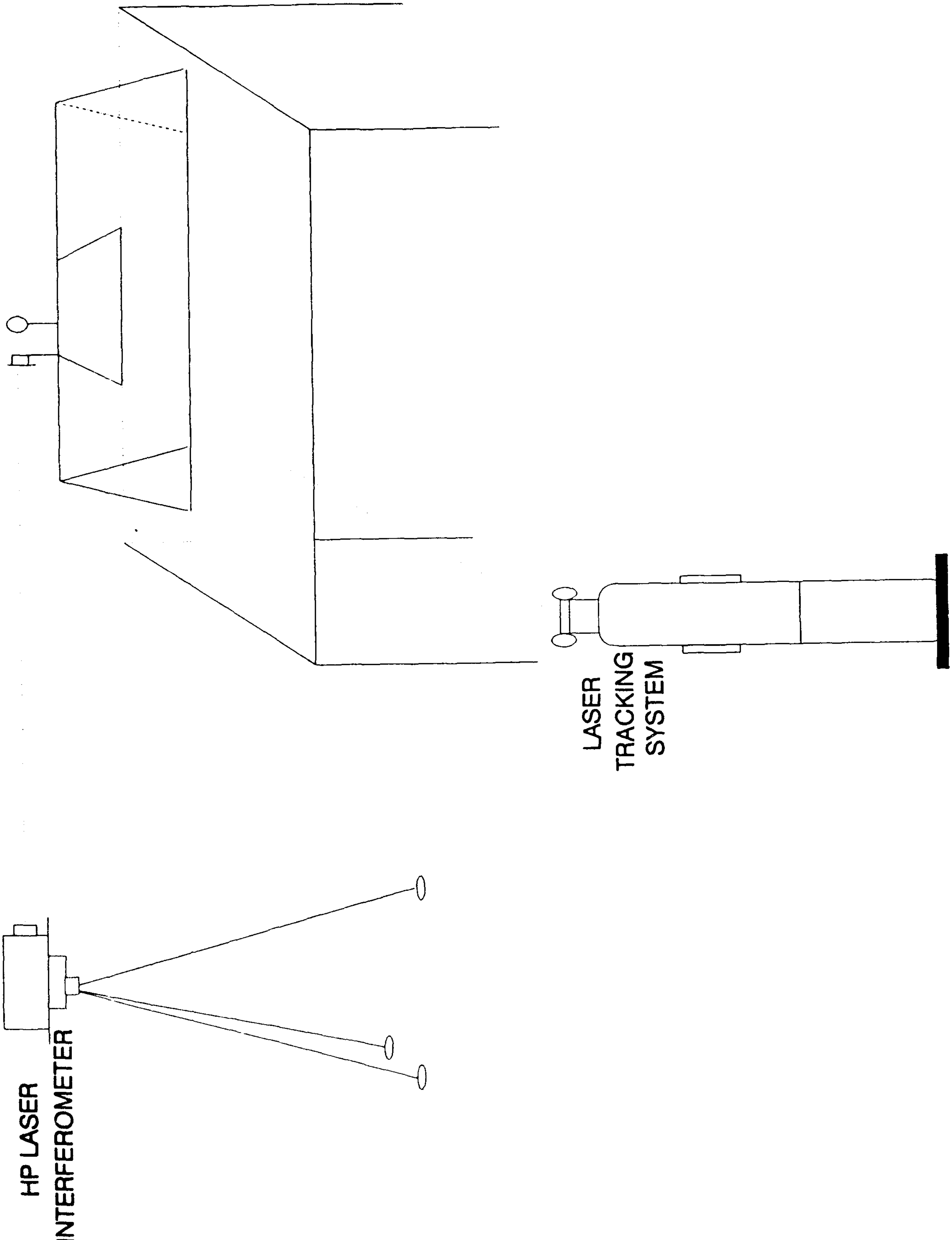


FIG. 9 - SIMULTANEOUS MEASUREMENTS

APPENDIX 1

EXPANSION CALCULATION

$$\delta T = \alpha (\Delta T) L$$

where α = coefficient of expansion for steel

ΔT = $|$mat. temp at time of measurement - 68 °F$|$

L = length being measured in inches

$\delta T = 6.5 \times 10^{-6}/°F (98°F - 68°F)\ 480$ in.

$= .0936$ in.

APPENDIX 2

STABILITY

SET 1

1	.0033"
2	.0032"
3	.0031"
4	.0034"
5	.0031"

s=.00013"
2s=.0004"

SET 2

1	.0048"
2	.0049"
3	.0052"
4	.0053"
5	.0049"

s=.00019"
2s=.0005"

SET 3

8:30 am	.003315"
2:30 pm	.003203"
	.000112"

To obtain the stability of the system, the ~~so~~ laser was locked onto a stationary target. Readings were taken every 1 min for set 1 + 2.* The standard deviation (s) was calculated for each set. The standard deviation (s) was multiplied by 2.869 to obtain 95% probability band. The largest 2s was selected as the system stability

* Set 3 depicts readings collected at 8:30am + 2:30pm.

APPENDIX 3

REPEATABILITY

SET 1

1	.0006"
2	.0006"
3	.0004"
4	.0002"
5	.0008"

s=±.00023"
2s=±.0007"

SET 2

1	.0002"
2	.0001"
3	.0007"
4	.0005"
5	.0006"

s = ±.00026"
2s =±.0007"

SET 3

1	60.5321"
2	60.5324"
3	50.5323"
4	60.5328"
5	60.5328"
6	60.5325"
7	60.5329"
8	60.5324"
9	60.5329"
10	60.5328"

s = ±.00028"
2s=±.0008"

Target was placed + replaced to same stationary point every 1 min for each set. The standard deviation (s) was calculated for each set. (s) was then multiplied by 2.869 to determine 95% probability repeatability was within range.

Set 3 was largest 2s ∴ ±.0008" was determined to be the repeatability of the system)

APPENDIX 4

RELATIVE ACCURACY

```
EADER DATA FOR: B:SET1     LABEL: 4/9/91 MEASURED IN mm
UMBER OF CASES: 10    NUMBER OF VARIABLES: 2


ARIABLE NUMBERS AND NAMES FOR: B:SET1
  1. HP           2. API
```

set 1 data   4/9/91


```
EADER DATA FOR: B:SET1     LABEL: 4/9/91 MEASURED IN mm
UMBER OF CASES: 10    NUMBER OF VARIABLES: 2
```


		HP		API	Δ
1	700	.0378mm	700	.0666mm	.028 mm
2	700	.0475mm	700	.0558 mm	.0083 mm
3	700	.0556mm	700	.0543 mm	.0013 mm
4	700	.0548mm	700	.0344 mm	.0204 mm
5	700	.0726mm	700	.0498 mm	.0228 mm
6	700	.0897mm	700	.0436mm	.0461 mm
7	700	.0686mm	700	.0556mm	.013 mm
8	700	.0574mm	700	.0450mm	.0124 mm
9	700	.0662mm	700	.0486mm	.0136 mm
10	700	.0569mm	700	.0533mm	.0036 mm

$\bar{x}\Delta$ = .01695mm = .0006"

S = .01318"

Laser y-distance from Bar = 2.5m
Calibrated with Al Bar

To obtain the accuracy of the system, simultaneous readings were taken between 2 points @ .7meter ≈ 700mm. Variable 1 (HP) + Variable 2 (API) data was compared. The delta Δ was calculated between each (HP + API) of the 10 reading, then the mean $\bar{x}$ was calculated of the Δs to obtain the $\bar{x}\Delta$. This was determined to be the system accuracy of the set.

set 2

HEADER DATA FOR: B:SET2   LABEL: MEASUREMENT = mm Y-DIS = 2.5M
NUMBER OF CASES: 10   NUMBER OF VARIABLES: 2

4/9/91

	HP	API	Δ
1	700.5148	700.5119	.0029 mm
2	700.5183	700.5145	.0038 mm
3	700.5158	700.5137	.0021 mm
4	700.5189	700.5184	.0005 mm
5	700.5056	700.5134	.0078 mm
6	700.4732	700.5235	.0503 mm
7	700.5198	700.5077	.0121 mm
8	700.5216	700.5090	.0126 mm
9	700.5210	700.5079	.0131 mm
10	700.4896	700.5251	.0355 mm

$\bar{x}\Delta$ = .01407 mm = .0005"

s = .01624 mm

y-distance = 2.5m

Set up + calculations same as set 1

set 3

HEADER DATA FOR: B:SET3   LABEL: SET3 mm
NUMBER OF CASES: 10   NUMBER OF VARIABLES: 2

4/9/91

	HP	API	Δ
1	700.0460	700.1090	.063 mm
2	700.3072	700.1142	.077 mm
3	700.0846	700.1108	.026 mm
4	700.0487	700.1051	.0564 mm
5	700.0455	700.0982	.0527 mm
6	700.0861	700.1072	.0211 mm
7	700.0707	700.1163	.0456 mm
8	700.0821	700.1131	.031 mm
9	700.0640	700.1105	.0465 mm
10	700.0810	700.1000	.0190 mm

$\bar{X}\Delta$ = .043 mm = .0016"

S = .019 mm

Setup & calculation same as set 1

set 4

HEADER DATA FOR: B:SET4 LABEL: SET4 mm
NUMBER OF CASES: 10 NUMBER OF VARIABLES: 2

4/9/91

	HP	API	Δ
1	700.0954	700.0887	.0067 mm
2	700.1040	700.0943	.0097 mm
3	700.0985	700.0990	.0005 mm
4	700.0749	700.0999	.025 mm
5	700.0980	700.0890	.009 mm
6	700.0959	700.0891	.0068 mm
7	700.0850	700.0898	.0048 mm
8	700.0754	700.0965	.0211 mm
9	700.0749	700.1047	.0298 mm
10	700.0819	700.0930	.0111 mm

$\bar{x}\Delta$ = .0124 mm = .00049"

s = .0096 mm

y-distance 2.5m

Set up & calculation same as set 1

set 5

HEADER DATA FOR: B:SET5 LABEL: SET5 MM
NUMBER OF CASES: 10 NUMBER OF VARIABLES: 2 4/11/91

	HP	API	Δ
1	1394.9209	1395.0028	.0819
2	1394.9221	1395.0234	.1013
3	1394.9369	1395.0153	.0784
4	1394.9795	1395.0136	.0565
5	1394.9767	1395.0136	.0369
6	1394.9600	1395.0121	.0521
7	1394.9900	1395.0115	.0215
8	1394.9427	1395.0190	.076
9	1394.9753	1395.0229	.0476
10	1394.9613	1395.0230	.0617

$\bar{X}\Delta = .06139\text{mm} = .0024''$

$s = .02358$

Set up same as set 4 except distance measured is @ 1300 mm.

Calculations same as set 1

set 6

HEADER DATA FOR: B:SET6 LABEL: SET6 MM
NUMBER OF CASES: 10 NUMBER OF VARIABLES: 2

4/11/91

	HP	API	Δ
1	1394.9872	1394.9592	.028 mm
2	1394.9730	1394.9680	.005 mm
3	1394.9747	1394.9603	.014 mm
4	1394.9822	1394.9670	.0152 mm
5	1395.0033	1394.9509	.0524 mm
6	1395.0073	1394.9619	.0454 mm
7	1394.9840	1394.9778	.0062 mm
8	1394.9678	1394.9672	.0006 mm
9	1395.0014	1394.9688	.0326 mm
10	1394.9760	1394.9711	.0049 mm

$\bar{X}\Delta$ = .0204 mm = .0008"

Same setup as set 5

Calculations same as set 1

set 7

HEADER DATA FOR: B:SEET7   LABEL: SET7 mm
NUMBER OF CASES: 10   NUMBER OF VARIABLES: 2

4/11/91

	HP	API	Δ
1	1395.0200	1394.9875	.0423 mm
2	1394.9626	1394.9875	.0249 mm
3	1394.9669	1394.9909	.024 mm
4	1394.9802	1394.9838	.0036 mm
5	1395.0148	1394.9923	.0225 mm
6	1394.9943	1394.9852	.0091 mm
7	1395.0264	1394.9860	.0404 mm
8	1394.9800	1395.0013	.021 mm
9	1394.9768	1394.9832	.0064 mm
10	1394.9885	1394.9836	.0049

$\bar{X}\Delta$ = .0199 mm = .00078"

.01399

Set up as set 5

Cal. as set 1

set 8

HEADER DATA FOR: B:SET8 LABEL: SET8 4/12/91 INCH
NUMBER OF CASES: 10 NUMBER OF VARIABLES: 2

4/12/91

	HP	API	Δ
1	54.9198	54.9195"	.0003"
2	54.9195"	54.9201"	.0006"
3	54.9219"	54.9198"	.0021"
4	54.9213"	54.9205"	.0008"
5	54.9194"	54.9203"	.0009"
6	54.9223"	54.9210"	.0013"
7	54.9231"	54.9210"	.0021"
8	54.9205"	54.9208"	.0003"
9	54.9224"	54.9207"	.0017"
10	54.9205"	54.9205"	.0000"

$\bar{x}\Delta$ = .0010"

s = .00076"

y-distance 92 inches

Same set up as set 1 except measuring @ 55"

Cal. same as set 1

set 9

EADER DATA FOR: B:SET9   LABEL: SET9 INCH
UMBER OF CASES: 10   NUMBER OF VARIABLES: 2

4/20/91

	HP"	API"	Δ
1	54.9143"	54.9203"	.006
2	54.9145"	54.9203"	.0058"
3	54.9148"	54.9212"	.0064"
4	54.9235	54.9212	.002"
5	54.9199	54.9207	.0008"
6	54.9203	54.9214	.0011"
7	54.9212	54.9208	.0004"
8	54.9235	54.9208	.0027"
9	54.9206	54.9213	.0007"
10	54.9224	54.9206	.0018"

$\bar{X}\Delta = .0027''$

$S = .0024''$

Setup + cal. same as set 8

set 10

HEADER DATA FOR: B:SET10 LABEL: SET10 4/30/91 IN. MEAS @ 45o 92" - TARGE
NUMBER OF CASES: 9 NUMBER OF VARIABLES: 2

	HP	API	Δ
1	11.9947"	11.9953	.0006
2	11.9947"	11.9972	.0025
3	11.9947"	11.9956	.0009"
4	11.9947"	11.9928	.0019"
5	11.9947	11.9939	.0008"
6	11.9947	11.9979	.0032"
7	11.9947	11.9952	.0005
8	11.9947	11.9978	.0031
9	11.9947	11.9977	.0029
			.0034

$\bar{X}\Delta$ = .0019"

s = .0012"

Calibrated using steel Bar at 45° to laser.

y - distance from laser to target 92"

Measured @ 12"

Cal. same as set 1

SET 11

5/30/91

	HP	API	Δ
1	698.1895	698.1748	.0147 mm
2	698.1856	698.1613	.0243 mm
3	698.1888	698.1439	.0449 mm
4	698.1859	698.1677	.0192 mm
5	698.1867	698.1590	.0277 mm
6	698.1484	698.1877	.0393 mm
7	698.1839	698.1681	.0158 mm
8	698.1758	698.1759	.0001 mm
9	698.1830	698.1687	.0143 mm
10	698.1762	698.1741	.0021 mm

$\bar{x}\Delta$ = .0204 mm = .0008"

σ = .0144

Measured @ 698 mm

Cal. same as set 1

set 12

HEADER DATA FOR: B:SET12   LABEL: SET12 5/14/91 INCH
NUMBER OF CASES: 10   NUMBER OF VARIABLES: 2

5/14/91

	HP	API	Δ
1	142.2575	142.2563	.0012"
2	142.2563	142.2557	.0006"
3	142.2579	142.2574	.0005"
4	142.2573	142.2572	.0001"
5	142.2577	142.2578	.0011"
6	142.2575	142.2564	.0011"
7	142.2576	142.2566	.0015"
8	142.2575	142.2583	.0008"
9	142.2576	142.2575	[illegible]"
10	142.2575	142.2550	.0025"

$\bar{X}\Delta$ = .0008

S : .0007

Measured @ 142"

Cal. as set 1

SET 13

	HP	API	Δ |HP-API|
1	142.2574"	142.2577^{+}	.0003
2	.	142.2579^{+}	.0005
3	.	142.2565^{-}	.0009
4	.	142.2575^{+}	.0001
5	.	142.2569^{-}	.0005
6	.	142.2582^{+}	.0008
7	.	142.2562^{-}	.0012
8	.	142.2577^{+}	.0003
9	.	142.2581^{+}	.0007
10	↓	142.2570^{-}	.0004

$\bar{X}\Delta$ = .00057 inches

σ : .0003

y - distance = 92 inch

Averaged 10 readings of HP Laser to obtain 142.2574". Subtracted each API # from such to obtain 10 Δs. Took mean of Δs = [illegible] relative accuracy.

LISTING OF 13 MEANS

1	.0006"
2	.0005"
3	.0016"
4	.0005"
5	.0024"
6	.0008
7	.0008'
8	.0010"
9	.0027"
10	.0019
11	.0008
12	.0008
13	.0006

$\bar{X}$ = .0012"

Listed $\bar{x}\Delta$s (in inches) from all 13 sets of data, Calculate $\bar{x}$ from these 13 #s & determine that to be the relative accuracy of the New Laser system when compared to the "standard" HP Laser. acc. of new laser = .0012" from 0 - 12 feet.

APPENDIX 5

THERMAL EFFECTED DATA

11 Jul 91

Set 1 (Repeatability)

Beg Mat. temp 82.01°F

End Mat. temp 82.50°F

Air temp 84.5°F 85.41

Compensated AL Bar length 32.9973179"

Cal on AL Bar - placed/replace per 1 min

Sample time 10 sec.

Thermal expansion of Bar .00021"

11 jul set 1

527.902512	-5.639441	92.707587	--	0.000465
527.902301	-5.639027	92.707581	--	0.000472
527.902077	-5.639298	92.707701	--	0.000608
527.902023	-5.639107	92.707724	--	0.000531
527.902037	-5.639205	92.707599	--	0.253397
527.649115	-5.639278	92.707482	--	0.253287
527.649225	-5.639163	92.707831	--	0.253761
527.648752	-5.638752	92.708024	--	0.253548
527.648964	-5.639249	92.707845	--	0.253731
527.648782	-5.639042	92.707984	--	0.254419
527.648094	-5.638832	92.708024	--	0.316546
527.585967	-5.638870	92.708075	--	0.328367
527.574146	-5.638821	92.708095	--	0.371519
527.530994	-5.639025	92.708104	--	0.419159
527.483354	-5.638853	92.708192	--	0.429096
527.473417	-5.638814	92.708194	--	0.428967
527.473547	-5.638683	92.708445	--	0.429000
527.473513	-5.638776	92.708414	--	0.446515
527.455999	-5.638718	92.708640	--	0.446441
527.456073	-5.638671	92.708602		

Set 2 (Stability)

Beg. Mat. temp 83.50

End Mat temp 83.62

Air temp 86.51

Compensated Bar length 32.9979570

Cal on AL Bar – target remained stationary

measured/1min sample time 10 sec.

11 jul set 2

529.606154	-2.062951	92.714072	--	0.000020
529.606174	-2.062954	92.714072	--	0.000190
529.606157	-2.063024	92.713897	--	0.000046
529.606155	-2.062996	92.714055	--	0.000025
529.606152	-2.062972	92.714059	--	0.000074
529.606156	-2.063024	92.714083	--	0.000200
529.606141	-2.062957	92.714271	--	0.000186
529.606165	-2.062975	92.714256	--	0.000048
529.606153	-2.062979	92.714111	--	0.000118
529.606138	-2.062916	92.714184		

12 Jul 91

Air temp 92.53°F
Beg Mat temp 89.42°F
End Mat temp 89.75°F
Laser case temp 21°C
Measurement taken in XYZ
Sample time 10 sec

143.858872	507.774006	-25.261772	--	0.006523
143.855930	507.768536	-25.263764	--	0.006704
143.854662	507.769130	-25.263627	--	0.004224
143.854902	507.772596	-25.262080	--	0.005757
143.854713	507.770818	-25.264155	--	0.006259
143.853410	507.771263	-25.263119	--	0.008214
143.852062	507.769498	-25.262648	--	0.007838
143.852206	507.770200	-25.263357	--	0.005144
143.854893	507.776766	-25.263508	--	0.019854
143.858225	507.793283	-25.266478	--	0.024632
143.860370	507.798431	-25.264583	--	0.025007
143.859121	507.798743	-25.265429	--	0.025489
143.858999	507.798678	-25.268172	--	0.026428
143.858415	507.799665	-25.268085	--	0.025751
143.860912	507.798793	-25.268449	--	0.025481
143.859670	507.799169	-25.265704	--	0.026350
143.858796	507.799335	-25.269036	--	0.026747
143.859701	507.798900	-25.271518	--	0.026876
143.859423	507.799646	-25.269811	--	0.026711
143.861251	507.799187	-25.270358		

APPENDIX 2

STABILITY

SET 1

1	.0033"
2	.0032"
3	.0031"
4	.0034"
5	.0031"

s=.00013"
2s=.0004"

SET 2

1	.0048"
2	.0049"
3	.0052"
4	.0053"
5	.0049"

s=.00019"
2s=.0005"

SET 3

8:30 am	.003315"
2:30 pm	.003203"
	.000112"

To obtain the stability of the system, the ~~so~~ laser was locked onto a stationary target. Readings were taken every 1 min for set 1 + 2.* The standard deviation (s) was calculated for each set. The standard deviation (s) was multiplied by 2.869 to obtain 95% probability band. The largest 2s was selected as the system stability

* Set 3 depicts readings collected at 8:30am + 2:30pm.

APPENDIX 3

REPEATABILITY

SET 1

1	.0006"
2	.0006"
3	.0004"
4	.0002"
5	.0008"

s=±.00023"
2s=±.0007"

SET 2

1	.0002"
2	.0001"
3	.0007"
4	.0005"
5	.0006"

s = ±.00026"
2s =±.0007"

SET 3

1	60.5321"
2	60.5324"
3	60.5323"
4	60.5328"
5	60.5328"
6	60.5325"
7	60.5329"
8	60.5324"
9	60.5329"
10	60.5328"

s = ±.00028"
2s=±.0008"

Target was placed + replaced to same stationary point every 1 min for each set. The standard deviation (s) was calculated for each set. (s) was then multiplied by 2.869 to determine 95% probability repeatability was within range.

Set 3 was largest 2s ∴ ±.0008" was determined [illegible] repeatability of the system)

APPENDIX 4

RELATIVE ACCURACY

HEADER DATA FOR: B:SET1 LABEL: 4/9/91 MEASURED IN mm
NUMBER OF CASES: 10 NUMBER OF VARIABLES: 2

VARIABLE NUMBERS AND NAMES FOR: B:SET1
1. HP 2. API

set 1 data

4/9/91

HEADER DATA FOR: B:SET1 LABEL: 4/9/91 MEASURED IN mm
NUMBER OF CASES: 10 NUMBER OF VARIABLES: 2

		HP		API	Δ
1	700	.0378mm	700	.0666mm	.028 mm
2	700	.0475mm	700	.0558 mm	.0083 mm
3	700	.0556mm	700	.0543 mm	.0013 mm
4	700	.0548mm	700	.0344 mm	.0204 mm
5	700	.0726mm	700	.0498 mm	.0228 mm
6	700	.0897mm	700	.0436mm	.0461 mm
7	700	.0686mm	700	.0556mm	.013 mm
8	700	.0574mm	700	.0450mm	.0124 mm
9	700	.0662mm	700	.0486mm	.0136 mm
10	700	.0569mm	700	.0533mm	.0036 mm

$\bar{X}\Delta$ = .01695mm = .0006"
S = .01318"

Laser y-distance from Bar = 2.5m
Calibrated with Al Bar

To obtain the accuracy of the system, simultaneous readings were taken between 2 points @ .7meter ≈ 700mm. Variable 1 (HP) + Variable 2 (API) data was compared. The delta Δ was calculated between each (HP + API) of the 10 reading, then the mean $\bar{X}$ was calculated of the Δs to obtain the $\bar{X}\Delta$. This was determined to be the system accuracy of the set.

set 2

HEADER DATA FOR: B:SET2   LABEL: MEASUREMENT = mm   Y-DIS = 2.5M
NUMBER OF CASES: 10   NUMBER OF VARIABLES: 2

4/9/91

	HP	API	Δ
1	700.5148	700.5119	.0029 mm
2	700.5183	700.5145	.0038 mm
3	700.5158	700.5137	.0021 mm
4	700.5189	700.5184	.0005 mm
5	700.5056	700.5134	.0078 mm
6	700.4732	700.5235	.0503 mm
7	700.5198	700.5077	.0121 mm
8	700.5216	700.5090	.0126 mm
9	700.5210	700.5079	.0131 mm
10	700.4896	700.5251	.0355 mm

$\bar{x}\Delta$ = .01407 mm = .0005"

s = .01624 mm

y-distance = 2.5m

Setup + calculations same as set 1

set 3

HEADER DATA FOR: B:SET3   LABEL: SET3 mm
NUMBER OF CASES: 10   NUMBER OF VARIABLES: 2

4/9/91

	HP	API	Δ
1	700.0460	700.1090	.063 mm
2	700.3072	700.1142	.077 mm
3	700.0846	700.1108	.026 mm
4	700.0487	700.1051	.0564 mm
5	700.0455	700.0982	.0527 mm
6	700.0861	700.1072	.0211 mm
7	700.0707	700.1163	.0456 mm
8	700.0821	700.1131	.031 mm
9	700.0640	700.1105	.0465 mm
10	700.0810	700.1000	.0190 mm

$\bar{x}\Delta$ = .043 mm = .0016"

s = .019 mm

Setup & calculation same as set 1

set 4

HEADER DATA FOR: B:SET4   LABEL: SET4 mm
NUMBER OF CASES: 10   NUMBER OF VARIABLES: 2

4/9/91

	HP	API	Δ
1	700.0954	700.0887	.0067 mm
2	700.1040	700.0943	.0097 mm
3	700.0985	700.0990	.0005 mm
4	700.0749	700.0999	.025 mm
5	700.0980	700.0890	.009 mm
6	700.0959	700.0891	.0068 mm
7	700.0850	700.0898	.0048 mm
8	700.0754	700.0965	.0211 mm
9	700.0749	700.1047	.0298 mm
10	700.0819	700.0930	.0111 mm

$\bar{X}\Delta$ = .0124 mm = .00049"

s = .0096 mm

y-distance 2.5m

Set up & calculation same as set 1

set 5

HEADER DATA FOR: B:SET5 LABEL: SET5 MM
NUMBER OF CASES: 10 NUMBER OF VARIABLES: 2 4/11/91

	HP	API	Δ
1	1394.9209	1395.0028	.0819
2	1394.9221	1395.0234	.1013
3	1394.9369	1395.0153	.0784
4	1394.9795	1395.0136	.0565
5	1394.9767	1395.0136	.0369
6	1394.9600	1395.0121	.0521
7	1394.9900	1395.0115	.0215
8	1394.9427	1395.0190	.076
9	1394.9753	1395.0229	.0476
10	1394.9613	1395.0230	.0617

$\bar{X}\Delta = .06139$ mm $= .0024''$

$s = .02358$

Set up same as set 4 except distance measured is @ 1300 mm.

Calculations same as set 1

set 6

HEADER DATA FOR: B:SET6 LABEL: SET6 MM
NUMBER OF CASES: 10 NUMBER OF VARIABLES: 2

4/11/91

	HP	API	Δ
1	1394.9872	1394.9592	.028 mm
2	1394.9730	1394.9680	.005 mm
3	1394.9747	1394.9603	.014 mm
4	1394.9822	1394.9670	.0152 mm
5	1395.0033	1394.9509	.0524 mm
6	1395.0073	1394.9619	.0454 mm
7	1394.9840	1394.9778	.0062 mm
8	1394.9678	1394.9672	.0006 mm
9	1395.0014	1394.9688	.0326 mm
10	1394.9760	1394.9711	.0049 mm

$\bar{X}\Delta$ = .0204 mm = .0008"

Same setup as set 5

Calculations same as set 1

set 7

HEADER DATA FOR: B:SEET7   LABEL: SET7 mm
NUMBER OF CASES: 10   NUMBER OF VARIABLES: 2

4/11/91

	HP	API	Δ
1	1395.0200	1394.9875	.0423 mm
2	1394.9626	1394.9875	.0249 mm
3	1394.9669	1394.9909	.024 mm
4	1394.9802	1394.9838	.0036 mm
5	1395.0148	1394.9923	.0225 mm
6	1394.9943	1394.9852	.0091 mm
7	1395.0264	1394.9860	.0404 mm
8	1394.9800	1395.0013	.021 mm
9	1394.9768	1394.9832	.0064 mm
10	1394.9885	1394.9836	.0049

$\bar{X}\Delta$ = .0199 mm = .00078"

.01399

Set up as set 5

Cal. as set 1

set 8

HEADER DATA FOR: B:SET8   LABEL: SET8 4/12/91 INCH
NUMBER OF CASES: 10   NUMBER OF VARIABLES: 2

4/12/91

	HP	API	Δ
1	54.9198"	54.9195"	.0003"
2	54.9195"	54.9201"	.0006"
3	54.9219"	54.9198"	.0021"
4	54.9213"	54.9205"	.0008"
5	54.9194"	54.9203"	.0009"
6	54.9223"	54.9210"	.0013"
7	54.9231"	54.9210"	.0021"
8	54.9205"	54.9208"	.0003"
9	54.9224"	54.9207"	.0017"
10	54.9205"	54.9205"	.0000"

$\bar{x}\Delta = .0010''$

$s = .00076''$

y-distance 92 inches

Same set up as set 1 except measuring @ 55"

Cal. same as set 1

set 9

HEADER DATA FOR: B:SET9 LABEL: SET9 INCH
NUMBER OF CASES: 10 NUMBER OF VARIABLES: 2

4/20/91

	HP"	API"	Δ
1	54.9143"	54.9203"	.006
2	54.9145"	54.9203"	.0058"
3	54.9148"	54.9212"	.0064"
4	54.9235	54.9212	.002"
5	54.9199	54.9207	.0008"
6	54.9203	54.9214	.0011"
7	54.9212	54.9208	.0004"
8	54.9235	54.9208	.0027"
9	54.9206	54.9213	.0007"
10	54.9224	54.9206	.0018"

$\bar{x}\Delta = .0027''$

$s = .0024''$

Setup + cal. same as set 8

set 10

HEADER DATA FOR: B:SET10 LABEL: SET10 4/30/91 IN. MEAS @ 45o 92" - TARGE
NUMBER OF CASES: 9 NUMBER OF VARIABLES: 2

	HP	API	Δ
1	11.9947"	11.9953	.0006
2	11.9947"	11.9972	.0025
3	11.9947"	11.9956	.0009"
4	11.9947"	11.9928	.0019"
5	11.9947	11.9939	.0008"
6	11.9947	11.9979	.0032"
7	11.9947	11.9952	.0005
8	11.9947	11.9978	.0031
9	11.9947	11.9977	.0029
			.0034

$\bar{X}\Delta$ = .0019"

s = .0012"

Calibrated using Steel Bar at 45° to laser.
y - distance from laser to target 92"

Measured @ 12"

Cal. same as set 1

SET 11

5/30/91

	HP	API	Δ
1	698.1895	698.1748	.0147 mm
2	698.1856	698.1613	.0243 mm
3	698.1888	698.1439	.0449 mm
4	698.1859	698.1677	.0192 mm
5	698.1867	698.1590	.0277 mm
6	698.1484	698.1877	.0393 mm
7	698.1839	698.1681	.0158 mm
8	698.1758	698.1759	.0001 mm
9	698.1830	698.1687	.0143 mm
10	698.1762	698.1741	.0021 mm

$\bar{x}\Delta = .0204\,mm = .0008''$

$\sigma = .0144$

Measured @ 698 mm

Cal. same as set 1

set 12

HEADER DATA FOR: B:SET12   LABEL: SET12 5/14/91 INCH
NUMBER OF CASES: 10   NUMBER OF VARIABLES: 2

5/14/91

	HP	API	Δ
1	142.2575	142.2563	.0012"
2	142.2563	142.2557	.0006"
3	142.2579	142.2574	.0005"
4	142.2573	142.2572	.0001"
5	142.2577	142.2578	.0001"
6	142.2575	142.2564	.0011"
7	142.2576	142.2566	.0010"
8	142.2575	142.2583	.0008"
9	142.2576	142.2575	[illegible]
10	142.2575	142.2550	.0025"

$\bar{X}\Delta$ = .0008

S : .0007

Measured @ 142"

Cal. as set 1

SET 13

	HP	API	Δ |HP-API|
1	142.2574"	142.2577+	.0003
2	.	142.2579+	.0005
3	.	142.2565-	.0009
4	.	142.2575+	.0001
5	.	142.2569-	.0005
6	.	142.2582+	.0008
7	.	142.2562-	.0012
8	.	142.2577+	.0003
9	.	142.2581+	.0007
10	↓	142.2570-	.0004

$\bar{X}\Delta = .00057$ inches

$s = .0003$

y - distance = 92 inch

Averaged 10 readings of HP Laser to obtain 142.2574". Subtracted each API # from such to obtain 10 Δs. Took mean of Δs [illegible] relative accuracy.

LISTING OF 13 MEANS

1	.0006"
2	.0005"
3	.0016"
4	.0005"
5	.0024"
6	.0008
7	.0008
8	.0010"
9	.0027"
10	.0019
11	.0008
12	.0008
13	.0006

$\overline{X}$ = .0012"

Listed $\bar{x}\Delta$s (in inches) from all 13 sets of data, Calculate $\bar{x}$ from these 13 #s & determine that to be the relative accuracy of the New Laser system when compared to the "standard" HP Laser. acc. of New laser = .0012" from 0 - 12 feet.

APPENDIX 5

THERMAL EFFECTED DATA

11 Jul 91

Set 1 (Repeatability)

Beg Mat. temp 82.01°F

End Mat. temp 82.50°F

Air temp 84.5°F 85.41

Compensated AL Bar length 32.9973179"

Cal on AL Bar - placed/replace per 1 min

Sample time 10 sec.

Thermal expansion of Bar .00021"

11 jul set 1

527.902512	-5.639441	92.707587	--	0.000465
527.902301	-5.639027	92.707581	—	0.000472
527.902077	-5.639298	92.707701	—	0.000608
527.902023	-5.639107	92.707724	--	0.000531
527.902037	-5.639205	92.707599	—	0.253397
527.649115	-5.639278	92.707482	—	0.253287
527.649225	-5.639163	92.707831	—	0.253761
527.648752	-5.638752	92.708024	—	0.253548
527.648964	-5.639249	92.707845	—	0.253731
527.648782	-5.639042	92.707984	—	0.254419
527.648094	-5.638832	92.708024	—	0.316546
527.585967	-5.638870	92.708075	—	0.328367
527.574146	-5.638821	92.708095	—	0.371519
527.530994	-5.639025	92.708104	—	0.419159
527.483354	-5.638853	92.708192	—	0.429096
527.473417	-5.638814	92.708194	—	0.428967
527.473547	-5.636683	92.708445	—	0.429000
527.473513	-5.638776	92.708414	—	0.446515
527.455999	-5.638718	92.708640	--	0.446441
527.456073	-5.638671	92.708602		

Set 2 (Stability)

Beg. Mat. temp 83.50

End Mat temp 83.62

Air temp 86.51

Compensated Bar length 32.9979570

Cal on AL Bar - target remained stationary measured/1 min sample time 10 sec.

11 jul set 2

529.606154	-2.062951	92.714072	—	0.000020
529.606174	-2.062954	92.714072	—	0.000190
529.606157	-2.063024	92.713897	—	0.000048
529.606155	-2.062996	92.714055	—	0.000025
529.606152	-2.062972	92.714059	—	0.000074
529.606156	-2.063024	92.714083	—	0.000200
529.606141	-2.062957	92.714271	—	0.000186
529.606165	-2.062975	92.714256	—	0.000048
529.606153	-2.062979	92.714111	—	0.000118
529.606138	-2.062916	92.714184		

12 Jul 91

Air temp 92.53°F
Beg Mat temp 89.42°F
End Mat temp 89.75°F
Laser case temp 21°C
Measurement taken in XYZ
Sample time 10 sec

143.858672	507.774006	-25.261772	—	0.006523
143.855930	507.768536	-25.263764	--	0.006704
143.854662	507.769130	-25.263627	—	0.004224
143.854902	507.772596	-25.262080	—	0.005757
143.854713	507.770818	-25.264155	--	0.006259
143.853410	507.771263	-25.263119	--	0.008214
143.852062	507.769498	-25.262648	--	0.007836
143.852206	507.770200	-25.263357	—	0.005144
143.854893	507.776766	-25.263508	—	0.019654
143.858225	507.793283	-25.266478	—	0.024632
143.860370	507.798431	-25.264583	—	0.025007
143.859121	507.798743	-25.265429	—	0.025489
143.858999	507.798678	-25.268172	—	0.026428
143.858415	507.799665	-25.268085	—	0.025751
143.860912	507.798793	-25.268449	--	0.025481
143.859670	507.799169	-25.265704	—	0.026350
143.858796	507.799335	-25.269036	--	0.026747
143.859701	507.798900	-25.271518	—	0.026876
143.859423	507.799646	-25.269811	--	0.026711
143.861251	507.799187	-25.270358		

CALIBRATOR PERFORMANCE PROGNOSTICATION

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INTRODUCTION

An instruments performance specification provides us with the instruments uncertainty between specific calibration intervals. This is the manufacturers guaranteed worst case performance between these set calibration interval. Manufacturers determine uncertainty specifications using an error analysis based on expected component performance and then, using some factor of confidence, assign specific uncertainty specification for each calibration interval. These performance specifications provide us with a maximum limit of error and help us set calibration intervals but tell us nothing about the instruments actual performance. Depending on how these specification are derived they can be conservative or liberal when compared to the instruments actual performance.

Using statistical process control (SPC) [1] has long been a method of determining calibration intervals. This is done by measuring and monitoring an instruments performance and then using the data to determine the actual performance of the instrument. Typically the data collection process to incorporate SPC is a difficult and time consuming task. Modern calibration equipment, which have internal measurement and calibration capabilities, simplifies this data collecting process. Once the data is collected over some period of time it must be analyzed in order to make some performance predictions. This paper describes a software package which is used to collect, analyze, and graph the performance of the Fluke 5700A calibrator.

DATA COLLECTION

The Fluke 5700A Calibrator lends itself to a SPC application because of its Artifact Calibration[2] capability. At the completion of Artifact Calibration the 5700A calibrator internally generates a calibration shift report which provides data on 184 various parameters of the 5700A. This data shows the change relative to the last stored Artifact Calibration. It is this data that can be accumulated and analyzed, using statistical process techniques, to make predictions on the calibrators performance.

The following data is an example of an artifact calibration shift report showing the results of the DCV 11V range.

RANGE	Point	Zero Shift	Full Scale Shift		Spec (+/-)	Shift (% spec)
11V	+FS	0.000000 V	0.000006 V	0.54 ppm	7.36 ppm	7.35
11V	-FS	0.000000 V	0.000004 V	0.39 ppm	7.36 ppm	5.31

In the previous example the DCV +11V range has a full scale shift of +0.54 ppm relative to the presently stored calibration constants. If the presently used calibration constants were stored 30 days ago the calibrator has shifted +0.54ppm in 30 days. The Fluke developed software imports this data from the 5700A and makes performance predictions on all 184 parameter of the 5700A calibrator.

PERFORMANCE PREDICTION

The Fluke developed software package uses the Full Scale Shift data and the time since the last stored artifact calibration from "n" number of artifact calibrations to calculate the 5700A's performance. The drift rate per unit of time and the instruments performance at the present time (time = 0) is first calculated. The drift rate (m) is determined by first determining the following quantities:

$$\Sigma x = \sum_{i=1}^{n} x_i \qquad \Sigma y = \sum_{i=1}^{n} y_i \qquad \Sigma x2 = \sum_{i=1}^{n} x_i^2 \qquad \Sigma xy = \sum_{i=1}^{n} x_i\, y_i$$

y = full scale shift (y axis)
x = time relative to the last stored artifact calibration

Then "m" and "b" are determined using the following formulas.

$$m = \frac{(n\ \Sigma xy) - (\Sigma x\ \Sigma y)}{(n\ \Sigma x2) - \Sigma x^2} \qquad b = \frac{(\Sigma x2\ \Sigma y) - (\Sigma xy\ \Sigma x)}{(n\ \Sigma x2) - \Sigma x^2}$$

m = drift rate per unit time
b = is the constant y at the time x = 0

The assumed behavior of any output constant is a linear drift [3]. Using the following formula the expected deviation in the output (y_i) at any time (x_i) can be determined.

$$y_i = m * x_i + b$$

y_i = is the output deviation at time $x=x_i$
x = time

EXAMPLE

The following example shows how we use the previous formulas, on data collected by the 5700A calibrator, to determine the calibrators drift rate and plot the linear regression. The following is the data collected from the 5700A's +11VDC range. This 5700A was artifact calibrated 33 days ago and the corrections stored in the 5700A. Then over the next 32 days 7 "artifact cal check's" were performed. An "artifact cal chk" is and artifact calibration but instead of storing the correction to the calibrator, and adjusting the output to nominal, it is stored into a history file in the software package.

Example:

	x coord	y coord
5-03-91 Artifact cal store	-33	0
5-09-91 Artifact cal chk	-27	0.23ppm
5-14-91 Artifact cal chk	-22	0.30ppm
5-20-91 Artifact cal chk	-16	0.31ppm
5-24-91 Artifact cal chk	-12	0.34ppm
5-28-91 Artifact cal chk	-9	0.47ppm
5-31-91 Artifact cal chk	-5	0.42ppm
6-04-91 Artifact cal chk	-1	0.54ppm

Using the above data the calculated drift rate "m" = +0.0141ppm / day and the calculated output at time x=0 "b" = +0.55ppm. The following figure plots these full scale shifts on the y axis and the relative time on the x axis, then plots the linear regression of this range.

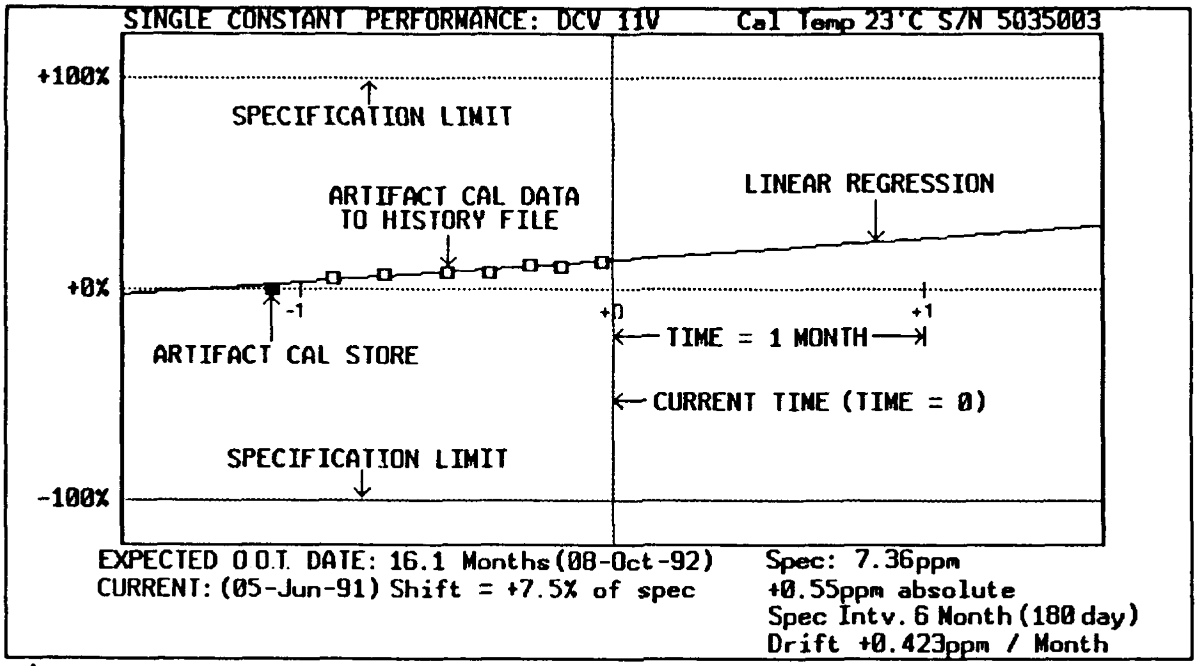

Figure 1

CONFIDENCE OF PREDICTION

Once the linear regression is plotted it is necessary to apply some confidence to this performance determination. Using the following formula the confidence is determined.

$$V_{conf} = T * S * \sqrt{\left[1 + 1/n + \{(x_j - x_{avg})^2\} / \{\sum_{i=1}^{n} (x_i - x_{avg})^2\}\right]}$$

T = the student-T number for a selected level of confidence with n-2 degrees of freedom.

$$S = \sqrt{\left[\{ \sum_{i=1}^{n} (y_i - b - m*x_i)^2 \} / (n-2) \right.}$$

n = total number of data points

x_j = time where the tolerance is to be computed

x_{avg} = average time of data points = $1/n * \sum_{i=1}^{n} x_i$

b = is the (constant) voltage at the time x=0

The following figure shows the confidence bands around the determined linear regression of the 11V DC range. These confidence bands are based on the student T number for a 99.00% or $\pm 2.58\sigma$ confidence factor. The tolerance of these confidence bands, as computed above, is affected by the desired confidence level (T) and the variance of the datapoints from the linear regression line.[4]

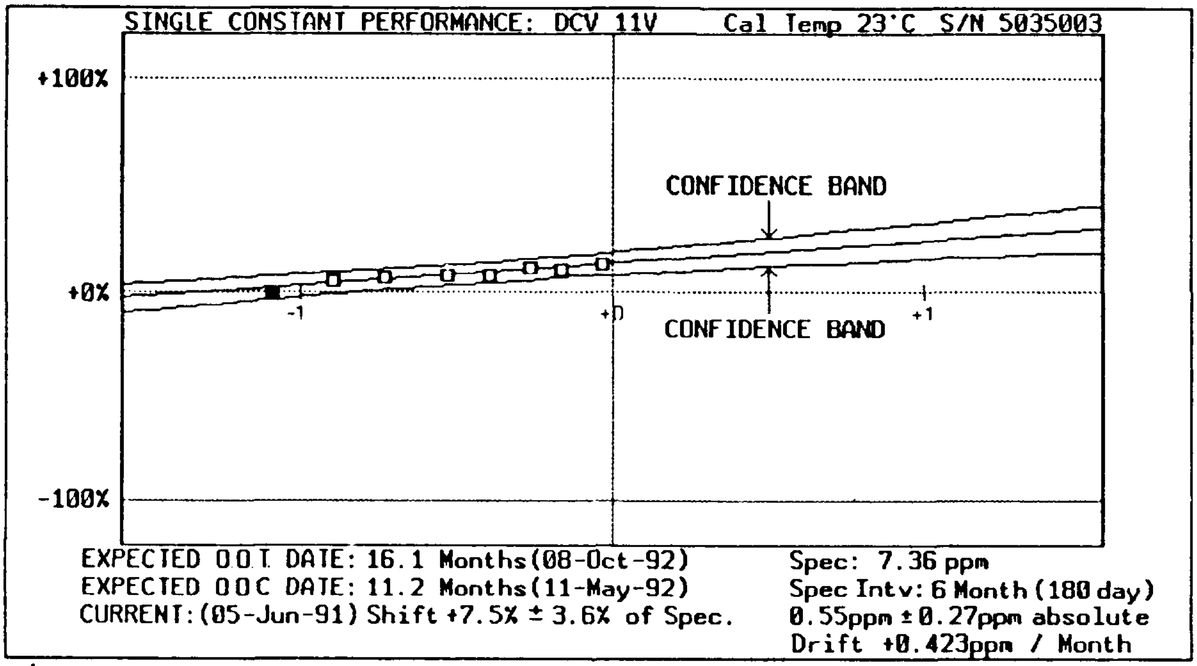

Figure 2

PERFORMANCE SUMMARY

A plotted linear regression with confidence bands would tell us the performance of a specific parameter but it's difficult to review 184 parameters to determine the instruments overall performance. To simplify this a summary graph is created depicting the performance of all 184 parameters being charted. This provides a way to quickly scan the overall performance of the calibrator. The following figure 3 is an example of this performance summary.

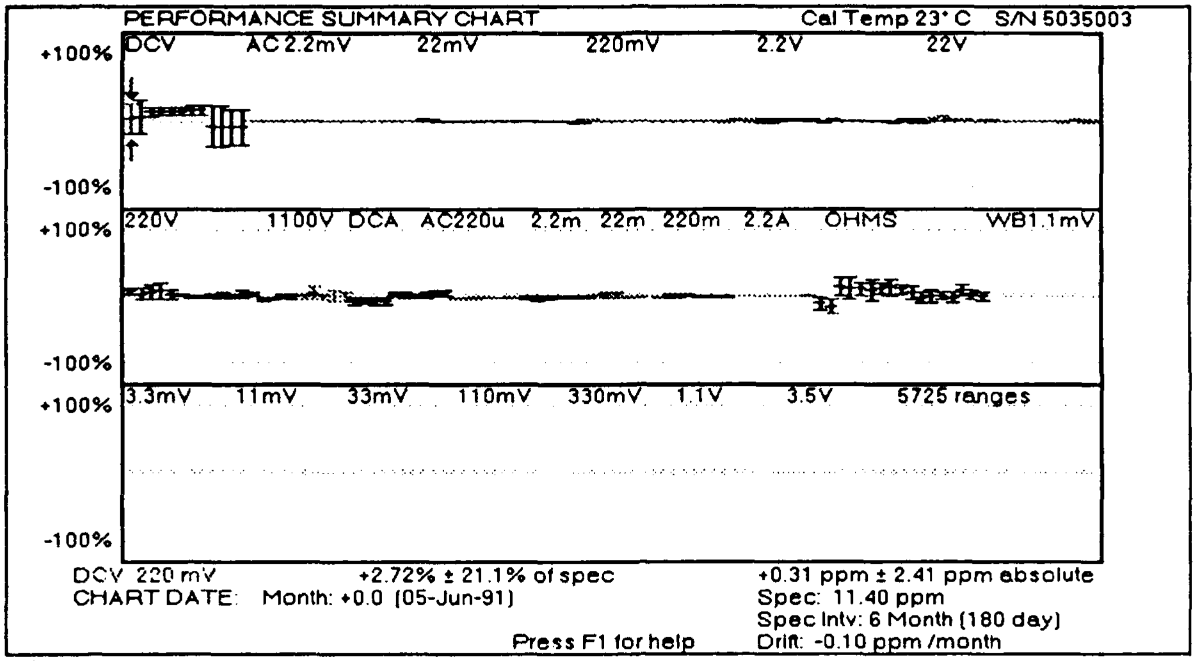

Figure 3

To better understand the previous performance summary the following figure 4 is a "blow up" of the OHMS portion.

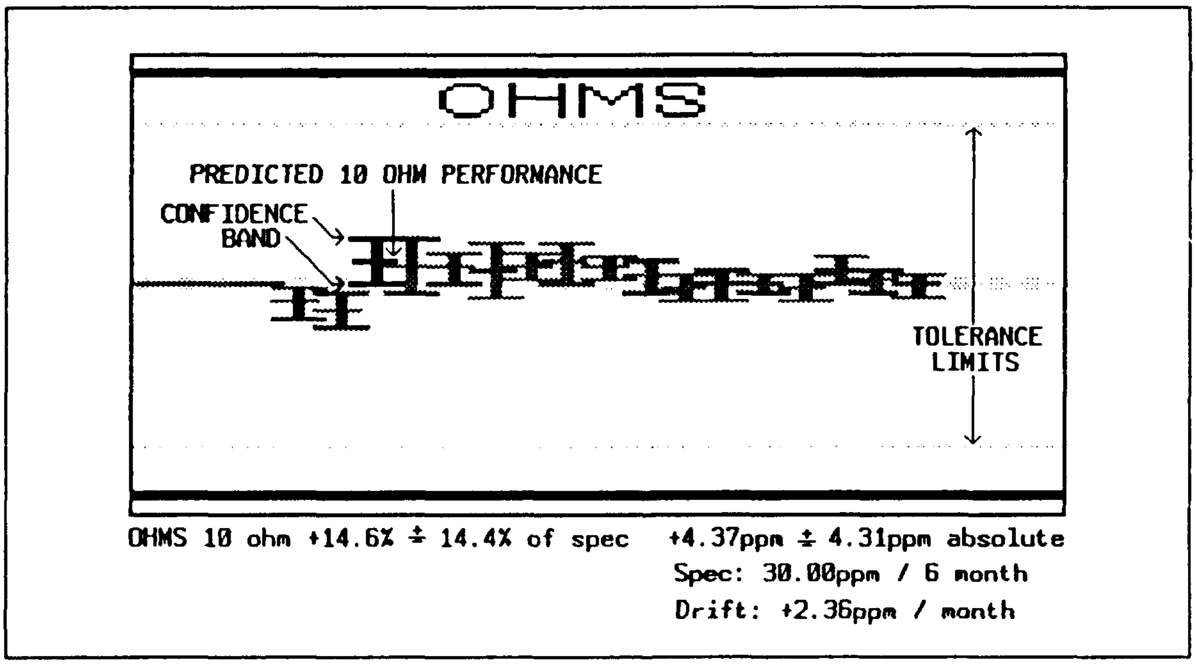

Figure 4

Each calibrator resistor is shown in this summary. The center line of each bar is the predicted resistor deviation from nominal based on the calculated linear regression. The top and bottom end of each bar represents the calculated confidence band of this prediction. Both are determined for the present time and the tolerance limits are equal to the calibrators 6 month uncertainty specifications.

PERFORMANCE HISTOGRAMS

The following figure 5 is a histogram showing a summary of the instruments out of tolerance (OOT) expectations.

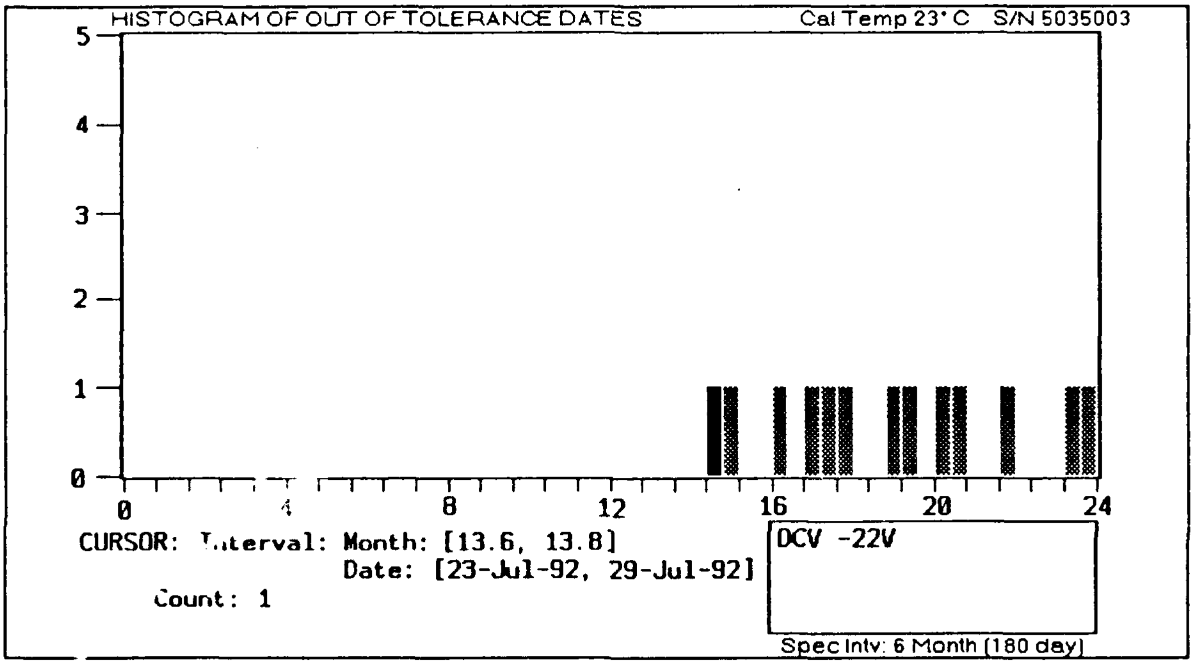

Figure 5

The Y coordinate is the number of parameters and the x coordinate is time defined in months. The highlighted bar is the first expected out of tolerance condition which will occur in approximately 13.6-13.8 months from today (day 0) with the DCV - 22V range becoming out of tolerance.

The following figure 6 is a histogram showing a summary of the instruments out of confidence (OOC) expectations.

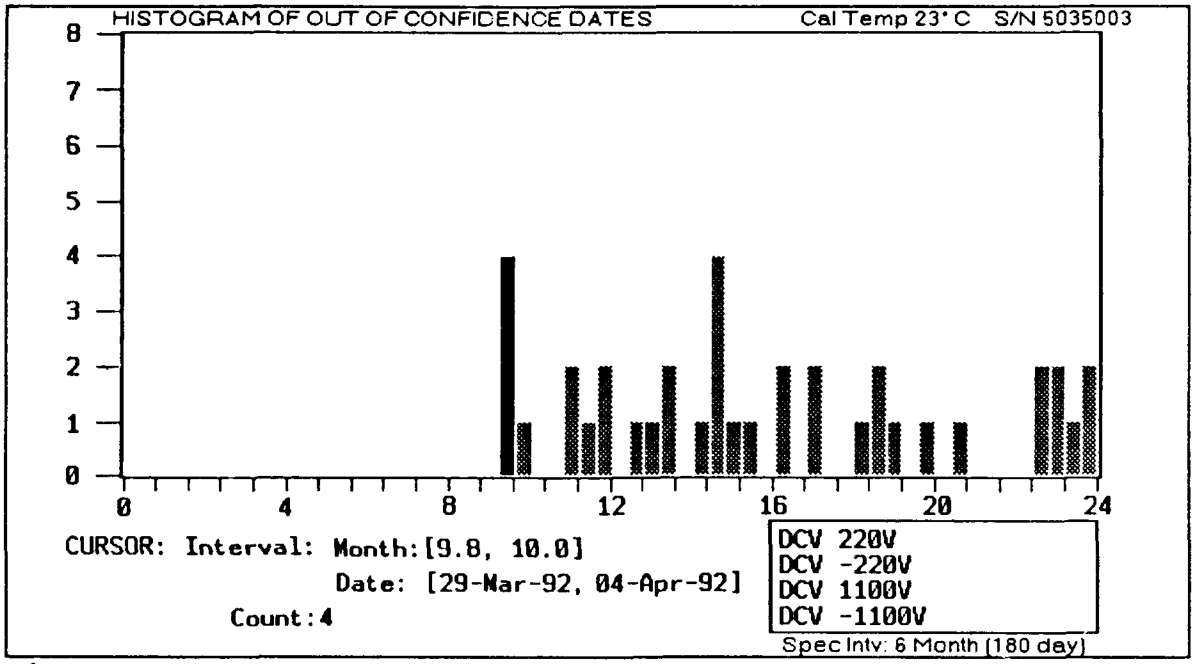

Figure 6

Again, the Y coordinate is the number of parameters and the x coordinate is the time defined in months. In this example the first expected out of confidence conditions will occur in approximately 9.8-10.0 months from today (day 0) with the DCV ±220V and ±1100V ranges becoming out of confidence.

CONCLUSION

There are two main benefits from SPC on the 5700A calibrator. The first is to set calibration intervals per actual instrument performance. The second benefit is enhancing the calibrators accuracy to its actual performance thus achieving a high test uncertainty ratio between the calibrator and UUT.

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(1) Capell, Frank. <u>From 4:1 to SPC.</u> ISA Transactions 1991. Vol 29 Number 4. (Revised from NCSL 1988)

(2) Baldock, Paul. <u>Artifact Calibration.</u> Measurement Science Conference 1991.

(3) Capell, Frank. <u>Performance Proofing a Self-Adjusting Calibrator.</u> ASQC Annual Quality Congress Transactions, May 1991.

(4) Miller, J. R. <u>Modification of Calibration Intervals Using Measurement Data.</u> Measurement Science Conference 1983.

SLIDE #	NAME	DESCRIPTION
1	SLIDE01 .CHT	MICOM Logistics R&D Workshop

This briefing will provide an overview of the Direct Support Diagnostic (DSD) program. This is an initiative proposed by Textron Lycoming to improve the effectiveness of AGT 1500 field maintenance.

By J. Scott Shurtleff

AGT 1500
Direct Support Diagnostic
(DSD)

Briefing for

Second MICOM Logistics
R&D Workshop

28 August 1991

SLIDE #	NAME	DESCRIPTION
2	SLIDE02 .CHT	Logistics Workshop Briefing Agenda

The briefing will present background concerning the AGT 1500 engine, the problem being addressed and our proposed solution. Finally, I will discuss the proposed diagnostic expert system.

AGT 1500 DSD Briefing

Agenda

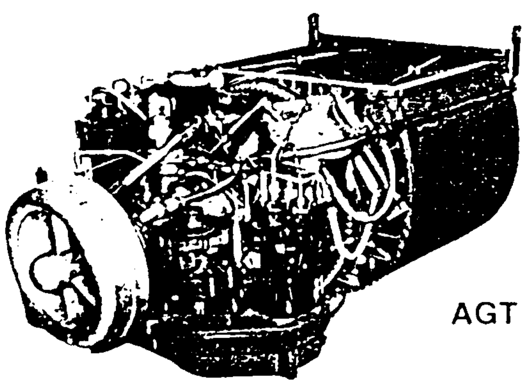
- Background
- The Opportunity
- The DSD Solution
- Diagnostic Expert System
- Summary

SLIDE #	NAME	DESCRIPTION
3	TANK .CHT	AGT Application

The AGT 1500 engine is the powerplant for the Army's M1-series main battle tank. This vehicle has been deployed in Europe, Korea, and, most notably, in Operation Desert Storm. The engine is a 1500 horsepower turbine engine and represents a significant advance in heavy vehicle propulsion.

TEXTRON LYCOMING STRATFORD DIVISION

TEXTRON LYCOMING AGT 1500 ENGINE



AGT 1500

MAJOR M1 TANK ADVANTAGES

- Special Armor Protection
- Improved Ammunition
- Cross Country Mobility and Speed
- All Weather Fighting Capability
- Ammunition Compartments
- Full Turret Stabilization

PRODUCTION STATUS

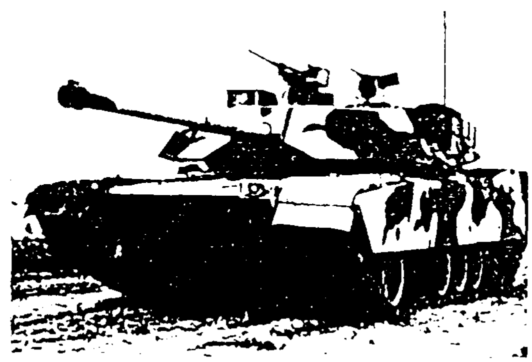
- Requirement: 7,467 Tanks by 1991
- Deliveries: 7,280 (31 May 1991)

MAJOR TURBINE ADVANTAGES

- Weight and Size
- Engine Starting
- Usable Horsepower and Torque
- Acceleration
- Multi-Fuel Capability
- Quiet Operation
- Growth Potential

PRODUCTION STATUS

- New Rqmt.: 11,973 Eng. Equiv. by Dec. 1994
- Deliveries: 9,874 (31 May 1991)



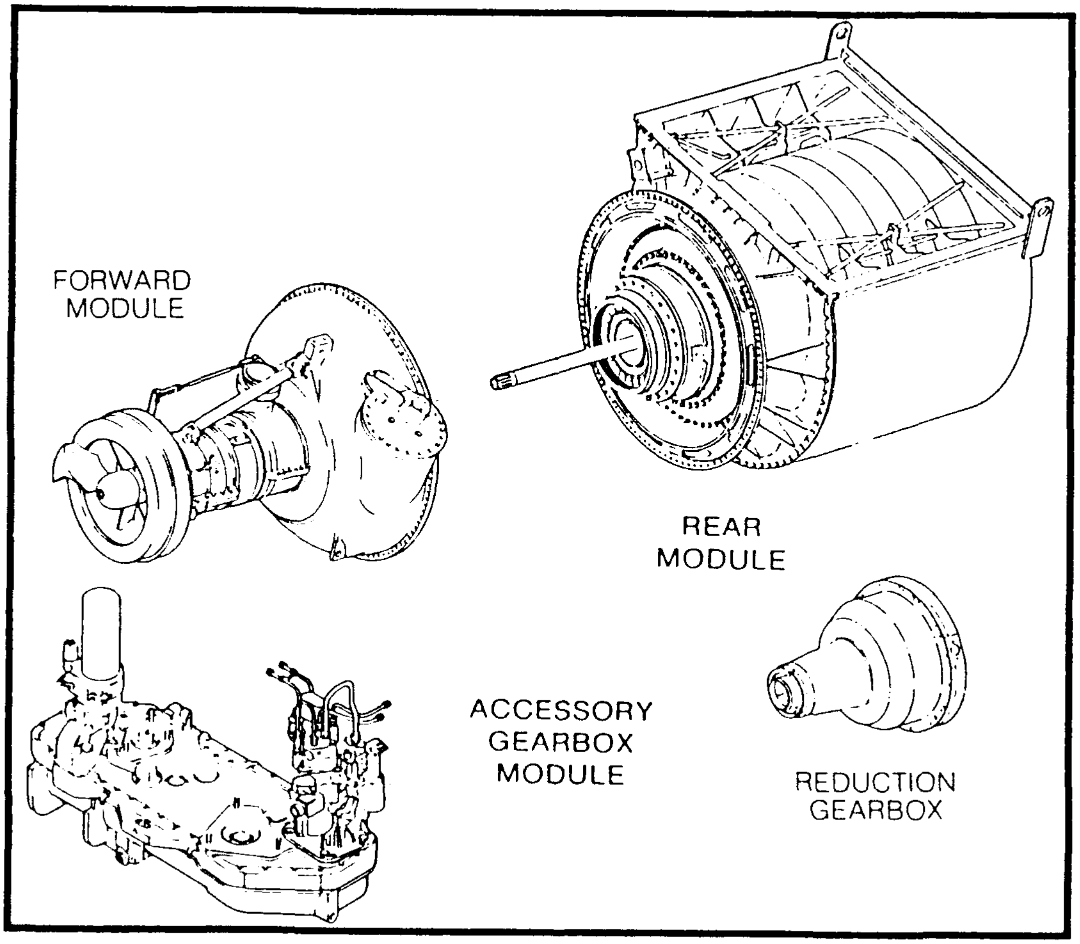
M1 ABRAMS TANK

AE1710-10

SLIDE #	NAME	DESCRIPTION
4	MODULES .CHT	AGT Modularity

A key feature of the AGT 1500 is that it is designed for maintenance. The engine separates into four field-replaceable modules. Faulty modules are returned to the Depot for overhaul and the reconfigured engine is returned to service. This is a difference from diesel engine field maintenance that has significantly changed the role of the Direct Support mechanic: they must diagnose faults to the modular level to identify the faulty ones. As a result, the DS maintenance level is key to maximizing Operational Readiness and minimizing NEOFs.

AGT 1500 MODULAR DESIGN



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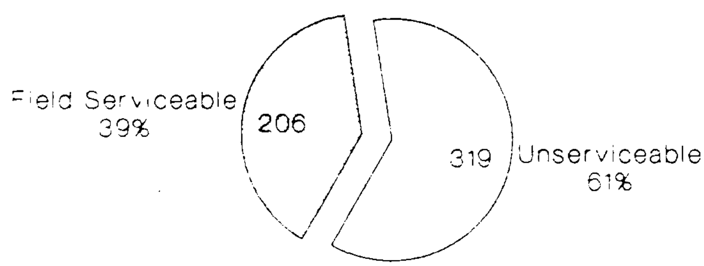
SLIDE #	NAME	DESCRIPTION
5	SLIDE05 .CHT	AGT 1500 Field Data from Germany

Textron Lycoming has gathered significant data from Germany. This data is based on field reports and Depot inspections during 1989. We have identified that field-serviceable modules represented nearly 40% of the modules returned to Mainz Army Depot. This translates into excess overhaul cost, spares requirements and material movement. The bottom line is increased O&S cost and reduced readiness.

The DSD Opportunity

Modules returned to Depot unnecessarily



Four Divisions in Germany
February to December 1989

SLIDE #	NAME	DESCRIPTION
6	SLIDE06 .CHT	DSD and the "Knowledge Gap"

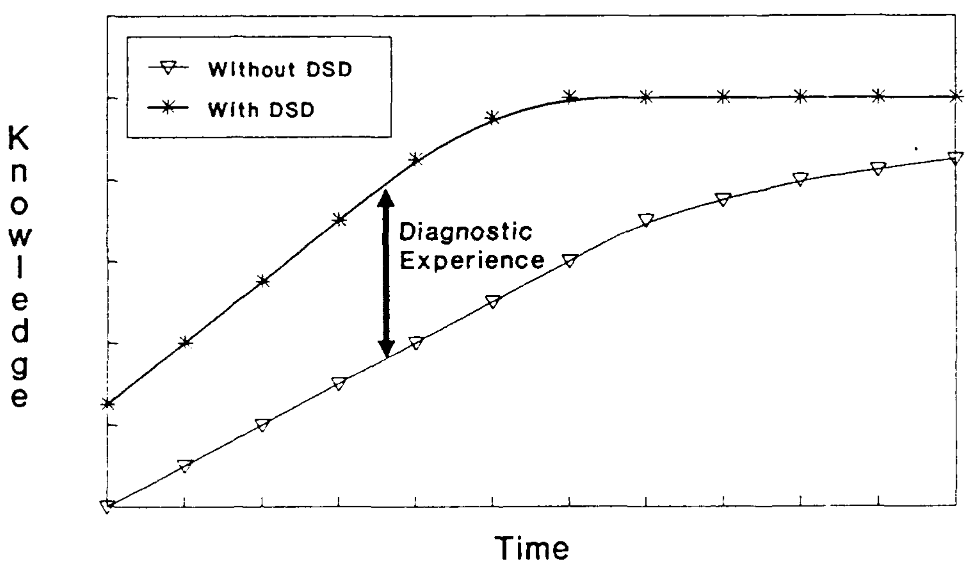
This situation occurs because Army DS mechanics do not have sufficient diagnostic experience:

- o tours of duty are short,
- o they are responsible for many different systems,
- o schoolhouse training covers a lot very quickly, and
- o diagnostic experience is very difficult to teach.

DSD will close this "knowledge gap" by providing diagnostic experience in the form of an expert system.

Supporting the DS Mechanic

DSD provides diagnostic experience

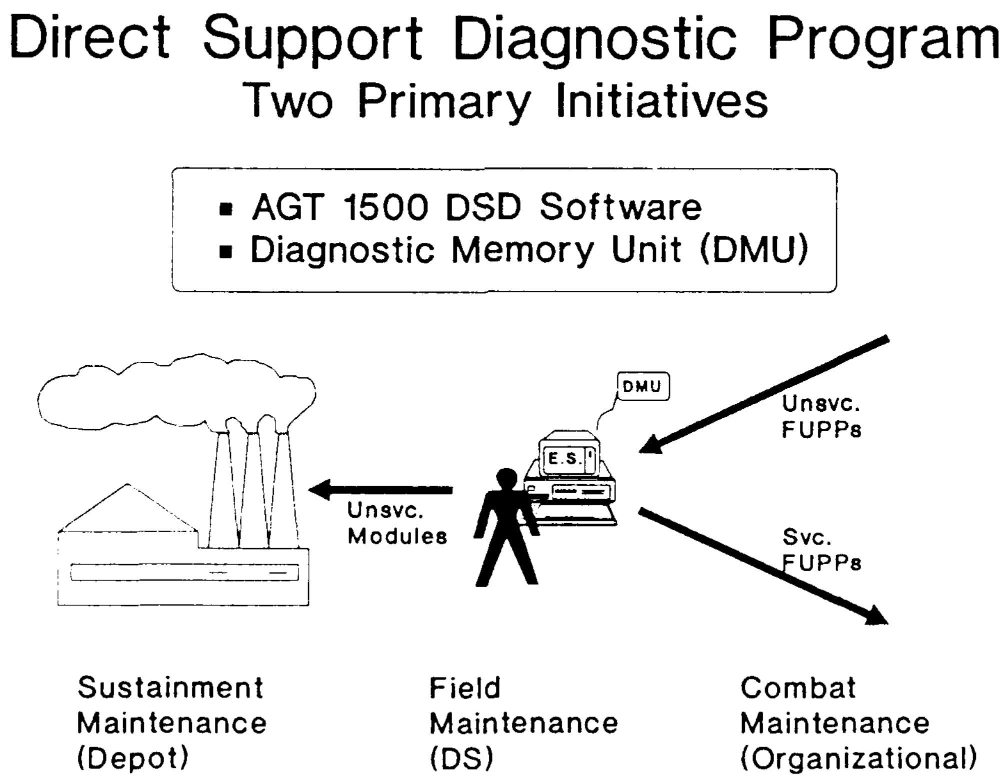


SLIDE #	NAME	DESCRIPTION
7	SLIDE07 .CHT	Two Major Parts of DSD

Textron Lycoming's DSD program will assist the DS mechanic by providing diagnostic expertise and engine data. Our focus is on the soldier, because the mechanic's effectiveness is the key to a successful maintenance program.

DSD is composed of two complementary, yet independent, initiatives:

1. Diagnostic software to assist the soldier with fault isolation and corrective action to the module level.
2. An engine-mounted electronic box (the DMU) that provides historical data concerning engine operation.

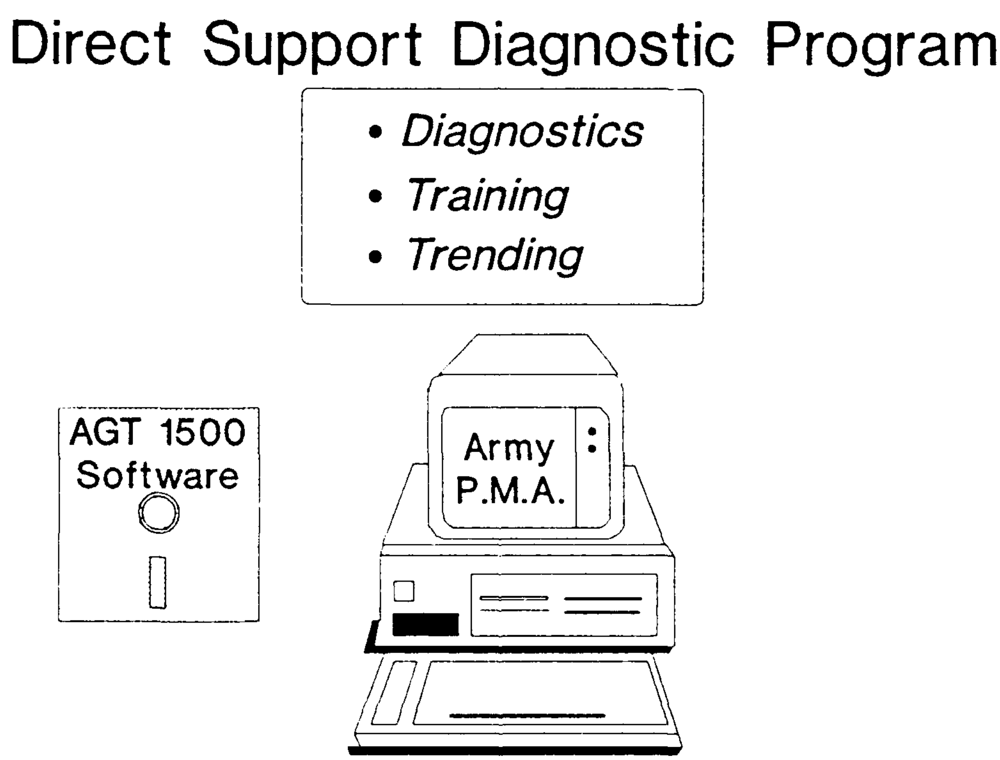


SLIDE #	NAME	DESCRIPTION
8	SLIDE08 .CHT	DSD Software Functionality

The DSD software will be deployed on a Portable Maintenance Aid (PMA) specified and supplied by the Army. We expect that the PMA will be a laptop computer, running MS-DOS or UNIX.

The DSD software will provide three major functions:

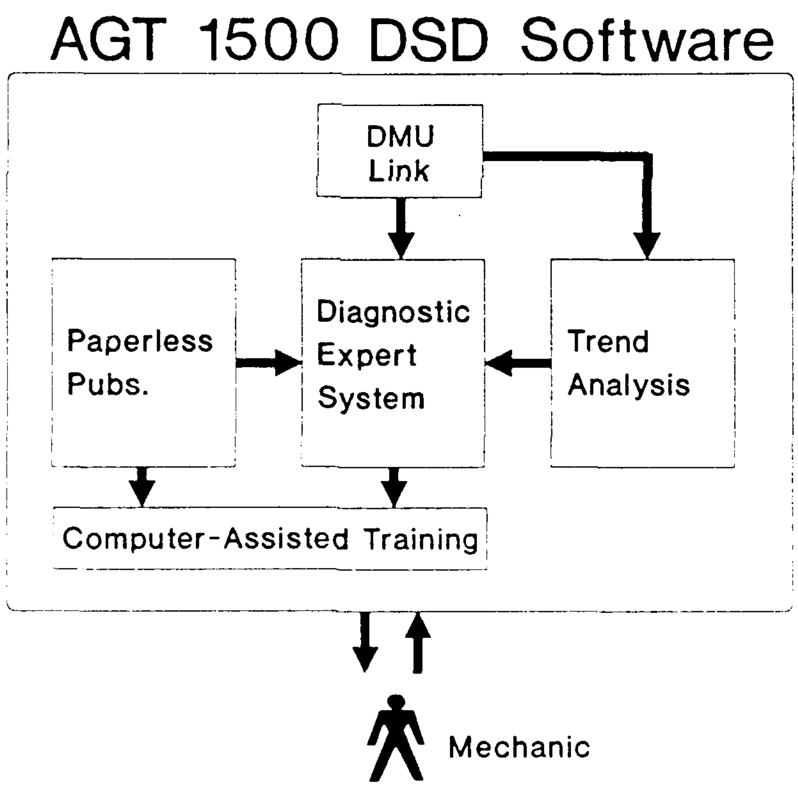
1. Diagnostics that include maintenance documentation,
2. training for the mechanic, intended for use on-the-job, and
3. engine performance trending to enable prognostics.



SLIDE #	NAME	DESCRIPTION
9	SLIDE09 .CHT	DSD Software Architecture

The long-term vision for DSD is represented by five integrated functions:

1. The diagnostic expert system is the key module: it contains the troubleshooting expertise. When available, data from the DMU will be used to enhance diagnosis.
2. Paperless pubs are maintenance documents in electronic form, accessible directly from the expert system.
3. The training module will provide a learning opportunity with self-paced instruction and diagnostic exercises.
4. A data download function is provided by the DMU link.
5. Trending contains engine historical data for prognosis.



SLIDE #	NAME	DESCRIPTION
10	SLIDE10 .CHT	Features of an Expert System

An expert system is a computer program that mimics an expert's thought process to solve a difficult problem. The power of an expert system comes from the knowledge that it contains, provided by the expert. An expert system can be easily distributed to make the problem-solving expertise more accessible than scarce human experts.

Typical interaction with an expert system is through a rigid question-and-answer dialogue. New methods are providing greater flexibility, allowing the user to select from a set of promising alternatives.

What are expert systems?

- Assist people with complex problems
- Capture expert knowledge
- Deliver experience when & where needed
- Conduct dialogues with decision makers
- Provide alternative courses of action

SLIDE #	NAME	DESCRIPTION
11	SLIDE11 .CHT	Alternative Expert System Technologies

The two approaches for diagnostic expert systems are symptom-based and model-based:

The common symptom-based technologies are fault trees and rules. These have a rigid question-and-answer style. A less mature technology, cases, offers more flexibility. The model-based approach is also less mature in terms of off-the-shelf products. Interaction with a model-based system is usually highly user-directed, but this depends on the delivery mechanism. Model-based systems are often limited to certain types of equipment (e.g. electronics).

Which Expert System?

Alternative Approaches

- Symptom-based
  - Fault tree
  - Rules
  - Cases

- Model-based
  - Device-independence
  - Delivery mechanism
  - Hybrids

SLIDE #	NAME	DESCRIPTION
12	SLIDE12 .CHT	Requirements for the DSD Expert System

We have specified key features of the DSD expert system:

1. It will provide both system- and user-guided interaction styles.
2. In user-guided mode, it will provide a ranked list of alternative tests. The mechanic makes the choice.
3. A ranked list of faults will always be available. This allows the mechanic to decide between replacing now or testing more.
4. There will be direct access to relevant sections of the maintenance manuals.

The DSD Expert System

Key Features

- Step-by-step or user-selected troubleshooting
- Provides test selection alternatives
- Adapts to unknowns
- Likely faults always available
- Quick access to relevant documentation

SLIDE #	NAME	DESCRIPTION
13	SLIDE13 .CHT	Logistics Conference Briefing Summary

There is a need for diagnostic support at the DS level for the AGT 1500 engine. Accurate fault isolation at DS is critical to successful field maintenance of the engine. DSD will provide the experience required to perform modular maintenance in an expert system.

Textron Lycoming is paying particular attention to meeting the needs of the DS mechanic. Our proposed system is feasible with today's technology and has significant future growth potential.

Summary

- Turbine engine changed DS role
- Diagnostics key to DS effectiveness
- Mechanics need diagnostic tool
- Focus is on the soldier/mechanic
- DSD is technically feasible today

DSD will close the experience gap

BUILT-IN TREND ANALYSIS

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I. **INTRODUCTION.**

Prognosis, a prediction or diagnosis, which is it to be? Most of us would choose to know the future. Can we predict the future? Yes!, as will be explained in this paper; furthermore, the prediction will be in realtime and simply accomplished.

We all use machinery of some sort--cars, refrigerators, air-conditioners, generators, televisions, missiles, tanks, electronic/mechanical test equipment, measurement standards, etc. As has been described in the technical[1,2,3,4,5] literature, it is possible to predict future behavior based on data taken over time for all manner of equipment and physical phenomena. This is known as trend analysis. Figure 1 gives a simple picture of this idea.

This linear time trend, and the mathematical formulation involved (given in the appendix), predicts future values and error bounds around that value.

Another possible data set[5] looks like that shown in figure 2. This data does not exhibit a trend, it is a random function of time.

Can one predict future values based on this data, with error bound similar to the linear trend of figure 1? Yes, using the Brownian Motion or Drunkard Walk concepts (math given in appendix), the predictions given in figure 3 can be made.

Given data that fits one of these two models, there are means to predict the future.

II. POSSIBLE APPLICATIONS/USES.

(1) The future value of a measurement standard, with the required input data, is predictable (see figure 4). Not only is the value determinate, but of equal importance, the error limits are also found.

(2) Time to recalibrate to maintain a specified tolerance (calibration interval). Note in figure 4 that the error bounds expand as a function of time so that if this is undesirable, one can find the time to wait before recalibrating the device to maintain a fixed tolerance (see figure 5).

(3) Adjustment of value to eliminate drift; one can use the slope (m) of the line to eliminate the drift rate, for awhile; however, this should not be continued indefinitely (m * t = correction), see Figure 6.

(4) Monitor trend for abnormal shifts, damage to item, etc., - a marked change in trend is watched for, if it is detected then one changes the sampling rate, verifies the abnormality and takes the appropriate action (see figure 7).

(5) Attempt a correlation between observed faults and recorded data in realtime, this is ambitious but suppose failures or faults of the machine are stored as environmental measurements (temperature, shock, humidity, etc.) are made using the same time base. The data can then be analyzed for correlations, in realtime, by math routines stored in the module. I will return to this subject later.

Problem Areas

In the past[4] for laboratory applications of the trend analysis, it was required that data be entered into the computer manually after it was gathered.

This is solved by interfacing computer directly to measurement equipment, see figure 8.

Using this arrangement, data is then taken as a function of time, stored and when appropriate, it is analyzed. This is useful for laboratory or industrial applications.

Another problem has to do with excessive data; hence, there is the need for simple figures of merit. Some items produce many values. It's often not practical to use all the points to produce trends; so recently,[5] we selected a single quantity to serve as an indicator. This figure of merit is the sum of the deviations from nominal. It has worked well for some types of data. This trend analysis is number intensive and has only been made practical by use of the computer; but now that inexpensive computers are available, it can save money by preventing over calibration, and allowing maintenance of machinery at convenient times, before damage occurs, etc.

Recently, a few instrument makers have become interested in these techniques to enhance the performance of their products. One innovation to solve the problem of excessive data has been to calculate many trends, obtain a large number of calibration intervals, and then plot a distribution of these intervals. What to do with this distribution is unclear as of now.

III. BUILT-IN TREND ANALYSIS

What is really needed is a small module, the size of a large IC chip, battery powered, containing measurement sensors, clock, storage and math routines so after an appropriate amount of data is gathered, it can automatically analyze it and produce the prediction.

The predication would be one of the four given in the application discussion. Other uses may be imagined.

Does such an item exist today? No, however, considerable progress has been made on parts of this idea by workers[6] the AF Rome Development Center in New York.

A so-called Time-Stress Measurement Device (TSMD) has been designed and tested (see figure 9). It measures and records temperature, vibration, humidity, shock, corrosion, and voltage/current transients. Currently they are making the device smaller, 1" x 2" hybrid flat pack which they call a MICRO TSMD. This device can be directly mounted on a printed circuit board. They plan on exploring the idea of mating the device to the systems Built-in Self Test to enhance diagnostics.

A problem these authors wish to attack is the large number of Retest OK (RTOK) and can not duplicate (CND) which are similar to the Army's No Evidence of Failure (NEOF) category. These categories account for 35 to 65 percent of the indicated faults in Air Force avionics. Many of these RTOK and CND events are thought to be environmentally related, and a record of the environmental conditions at the time of occurrence should greatly aid in the resolution of these events.

Development began in FY 86. Their first effort used off the shelf components located in a module 6" X 3" X 1-1/4", and was flown in A-10 and A-7 aircraft. They measured temperature, vibration, humidity, shock, corrosion, and power transients. The sensors were a thermocouple, humidity sensor, corrodible resistor, single axis accelerometer, and voltage transient recorder. Evidently, these sensors were not inside the module and a sample rate of 1/10 second was used. Figure 10 presents some of their data. This data is stored in the module and down loaded for analysis/display at some later time (not realtime).

This was the first time that this type of device was used to collect data on operational aircraft during normal sorties.

Next (FY88) they began to downsize it and build in the sensors. The TSMD was designed to be mounted on circuit cards on an electronic warfare system, *located at Warner Robbins Air Force Base.* In addition to the data mentioned above, the board serial number, maintenance history, warranty data, etc., will be stored.

Power required is 250 milliwatts; a battery (button-cell) is used to maintain the clock and record mechanical shocks. Plans are to fly 17 of them this summer (1991) at Warner Robbins.

Future of TSMD

Additional parameters such as acoustical energy, nuclear radiation and chemical contaminants are to be measured. This data will then be analyzed for correlations between fault occurrences and environmental stress (but not in realtime by the TSMD).

IV. LIMITATIONS.

It may be thought that the main problem to be solved is putting all the electronics together; i.e., math routines, measurement sensors, clock, and data storage all on a chip. However, a review of work by others using data to establish trends discloses otherwise:

(a) "Selecting the proper variable to measure...has led to a great deal of difficulty. Whether we have selected the proper parameter to measure as a performance indicator...involves a matter of time and experience...and cannot be determined overnight."[7]

(b) "Selecting the attributes to be measured is probably the most critical step...the attribute must be a valid measure...."[8]

(c) In FY 89, a Laser Engine Analyzer (LEA) System was set up to detect impending failures or faults of internal components of engines. A test effort was begun to determine whether frequency or amplitude shifts would indicate impending failures or faults of internal components of engines. (Were they looking at frequency and amplitude of pressure waveforms or vibration waveforms?) Whichever, they then would tear down several engines returned from the field for overhaul. The condition of the internal components would then be noted for correlation with the various waveforms. Thirty engines a month were to be tested, up to a total of 500 engines. The LEA was to be used to verify the PWA results.

Two types of engines were involved: Code A and Code F. Code A engines being acceptable, and Code F not being accepted. Both were disassembled and components inspected. The data from one type engine was compared to the other type to find possible correlation; none was found! It appears not all the intended engines were inspected, but it is clear that early results are inconclusive.[9]

These histories point up one of the main problems, if not the main problem and that is to know what to measure. To know what attribute(s) are the indicators of impending failure.

V. FUTURE WORK

We propose to combine the routines already tested[3,4,5] with sensors and IC technology into a stand alone device capable of realtime prognosis. The initial development would be kept as modest as possible; for example, a single parameter measured such as temperature or pressure, to prove out the concept.

Any interested parties are welcome to contact us.

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MATHEMATICAL APPENDIX

Linear time trend

$y_j = mx_j + b$

where y_j is the predicted measurement at the j^{th} time period, m is the slope and b is the intercept.

Significance test

if $\frac{|b|}{\sigma_b} \geq t$ then one has

a significant trend, where σ_b is the standard error of the estimated slope and t is the students t number at some desired confidence level.* The prediction tolerances are given by

$$\pm\, t\, s \sqrt{1 + \frac{1}{n} + \frac{(x_j - \overline{X})^2}{\sum_{i=1}^{n} (X_i - \overline{X})^2}}$$

$$\text{where } s = \sqrt{\sum_{i=1}^{n} \frac{(X_i - y_{ic})}{n-2}}$$

* degrees of freedom = n-2

where

$\bar{X}$ = average time

X_j = time where one wishes to know y.

<u>Random</u> <u>trend</u>

Error in the prediction D is

$$D = \sqrt{\tau}\left(1 + \frac{\tau}{(x_m - x_o}\right)^{1/2}$$

where σ is the std dev per $(\text{time})^{1/2}$

τ time to the next calibration

$x_m - x_o$ is the total time from first to last measurement.

T is the student T number

$$\tau = \frac{(x_m\ x_o)\left[\sqrt{1 + \dfrac{4R^2}{T^2\sigma^2(X_m - x_o)}} - 1\right]}{2}$$

FIGURE 1 - LINEAR TIME TREND

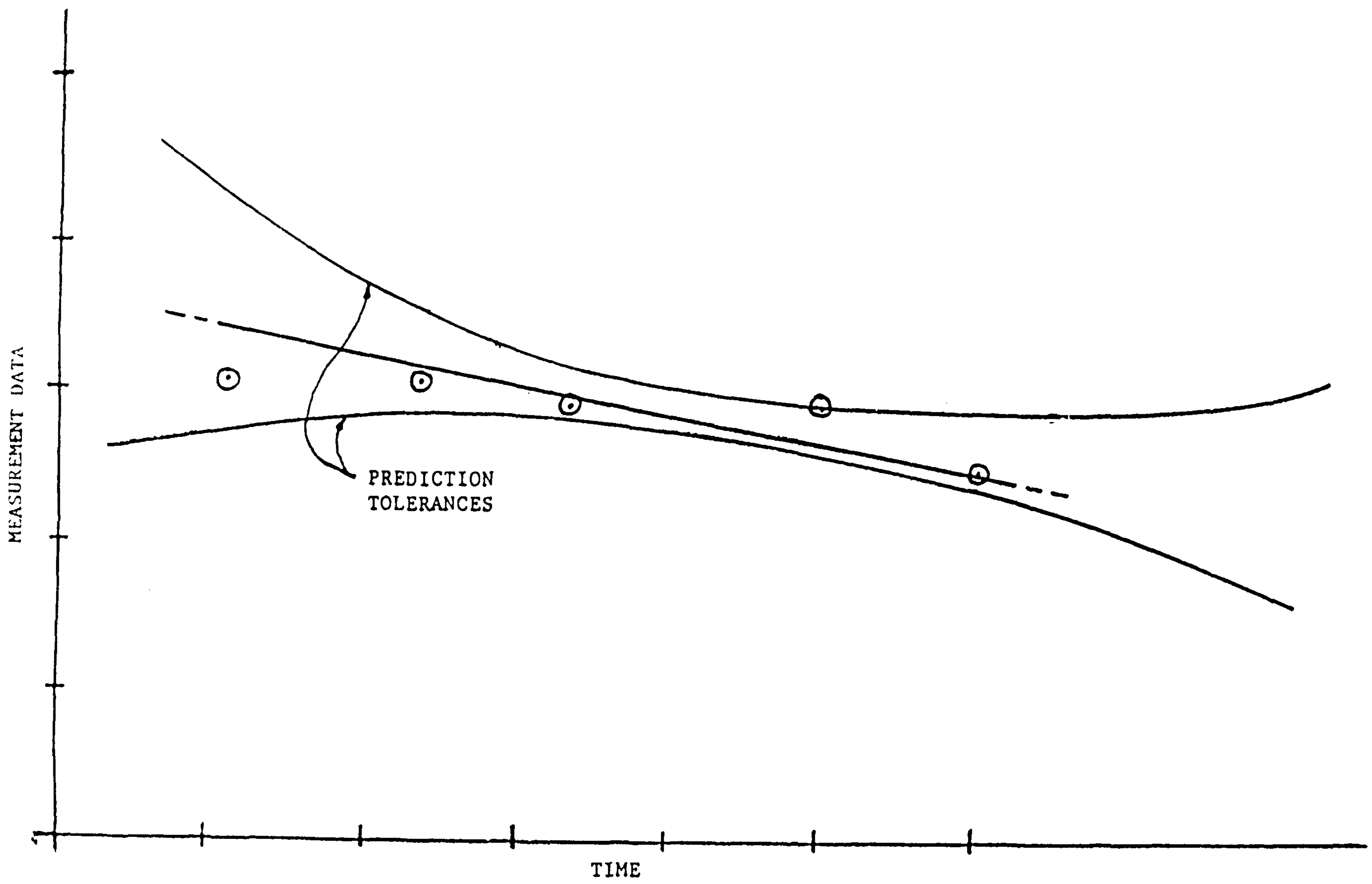


FIGURE 2
OPTICAL POLYGON 72SIDED SN 202

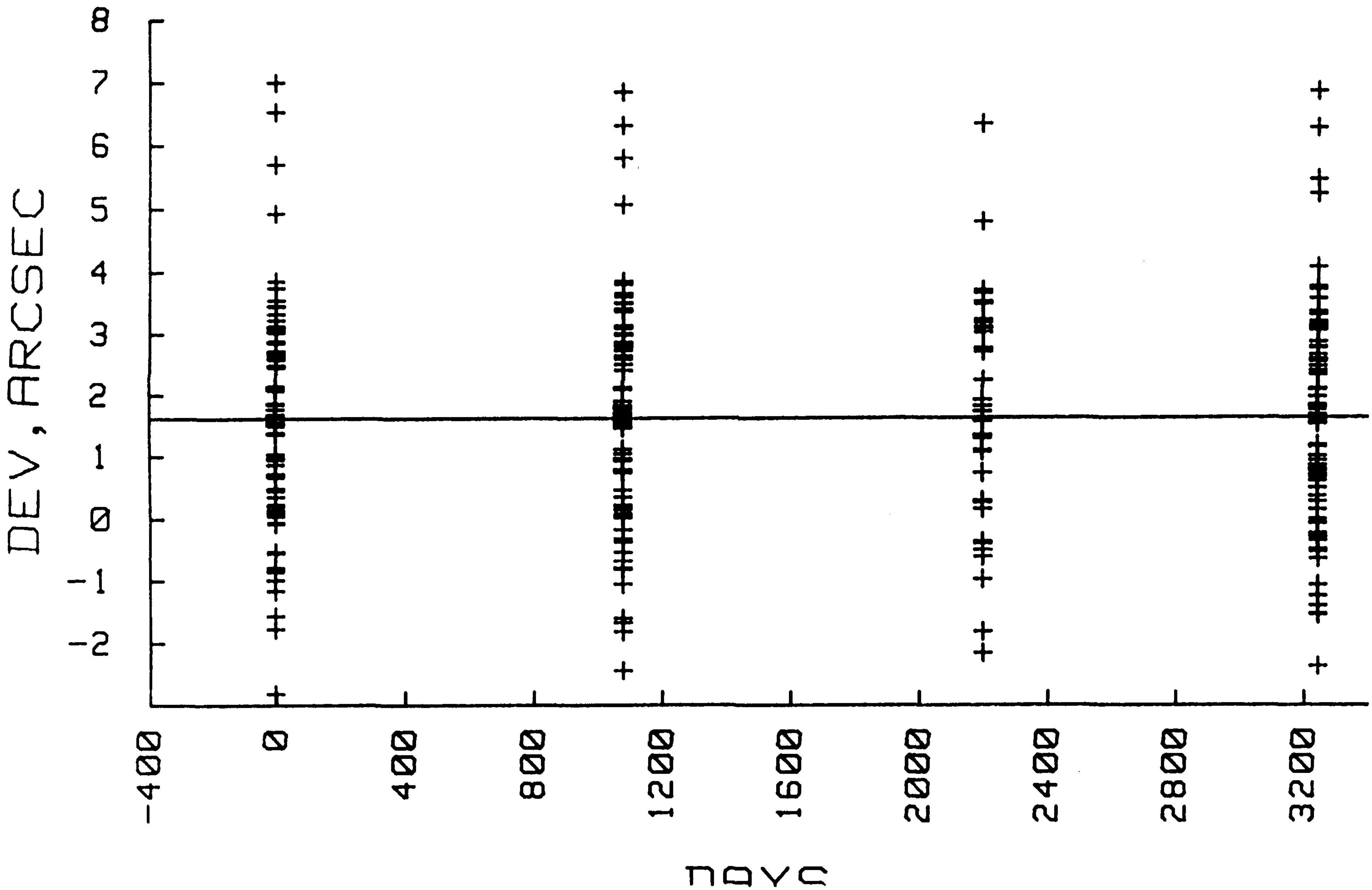


FIGURE 3

RANDOM DATA TREND FORECAST ERROR VERSUS TIME

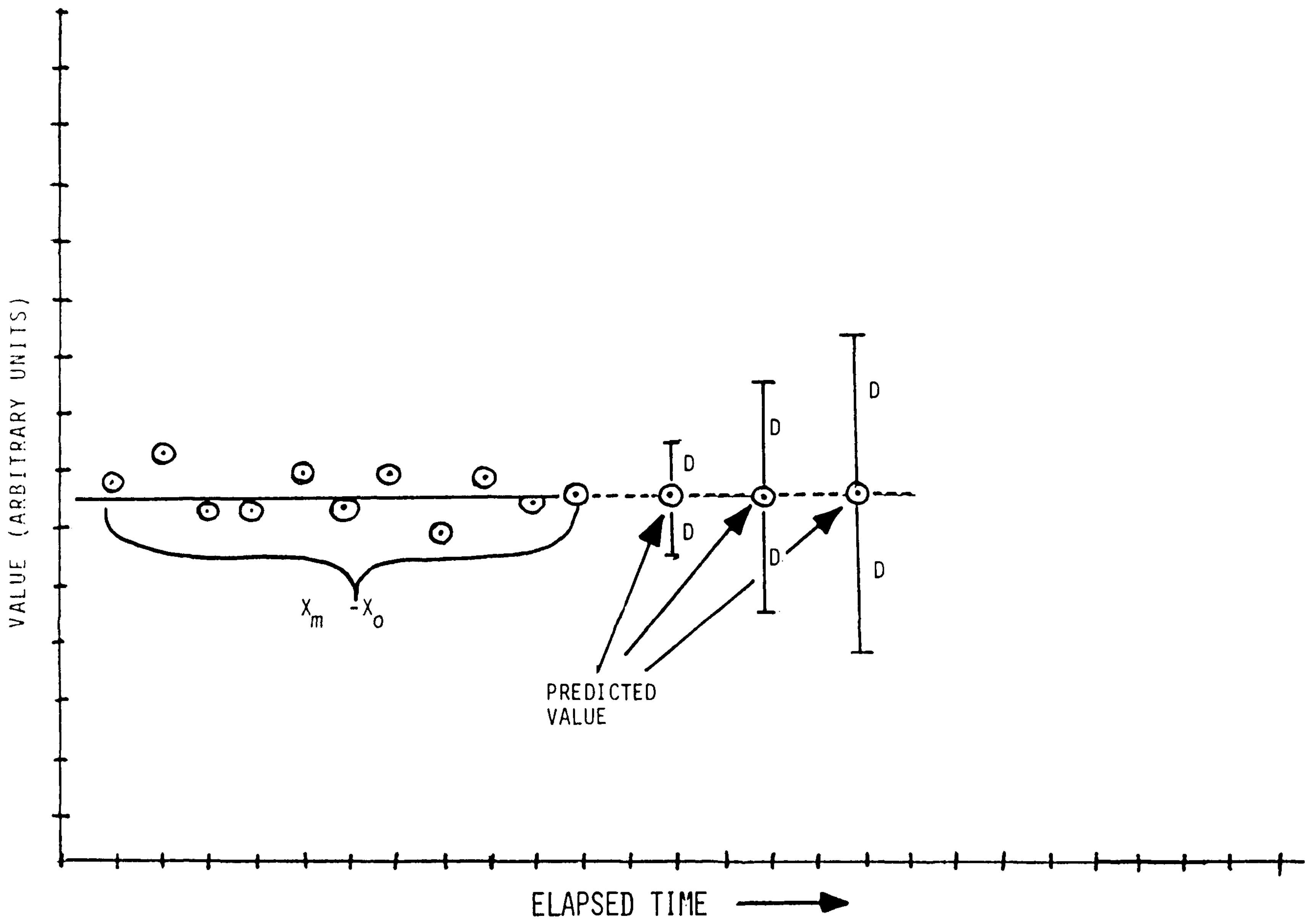
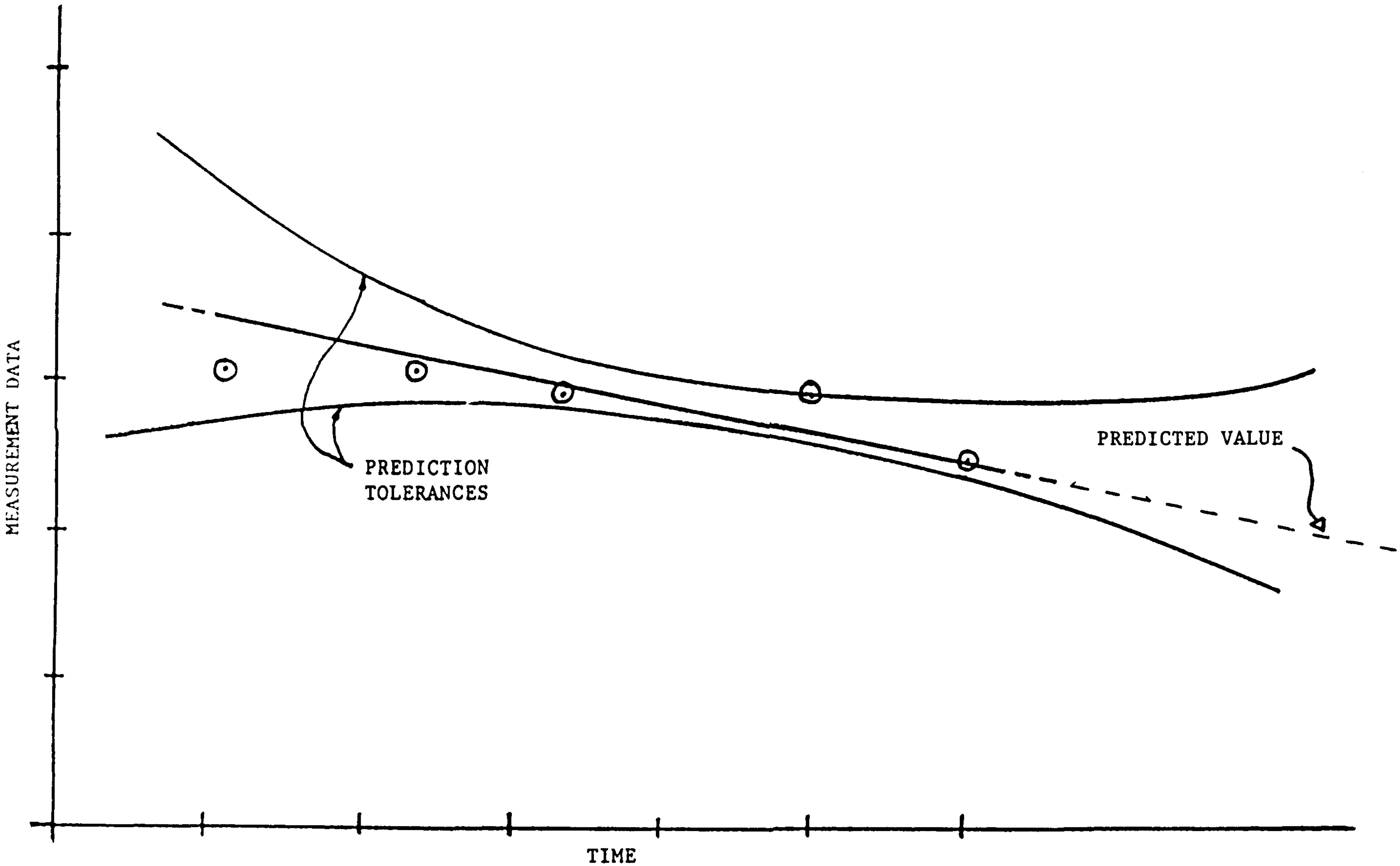
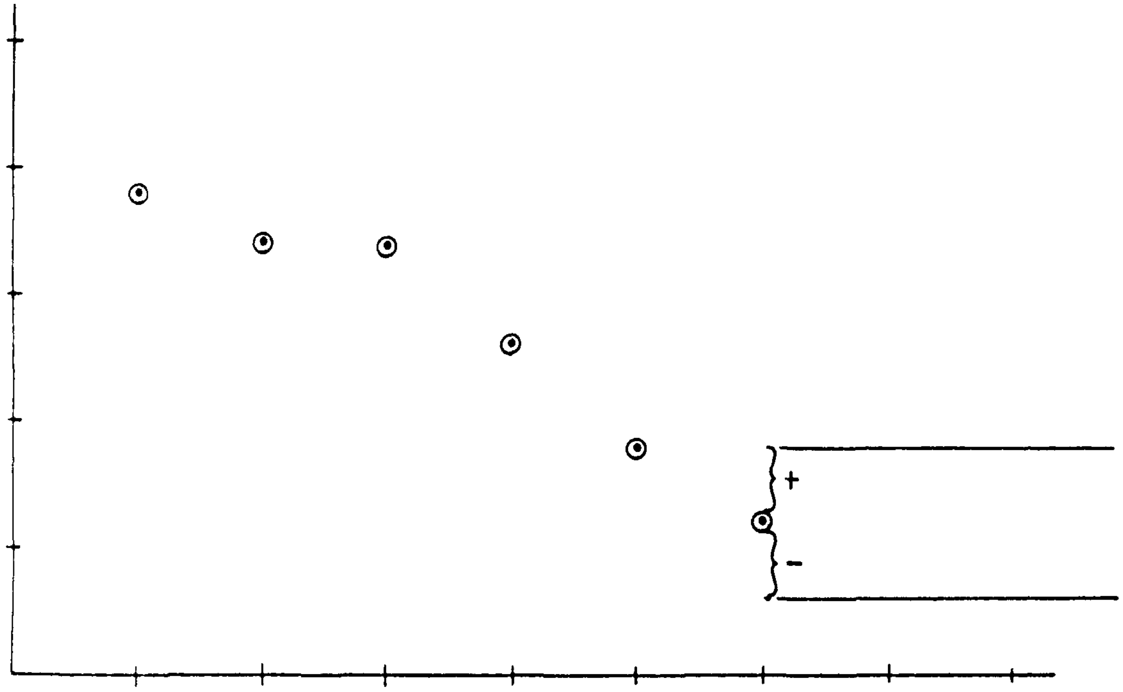


FIGURE 4 - PREDICTED VALUE





REQUIREMENT LIMITS AROUND CURRENT VALUE

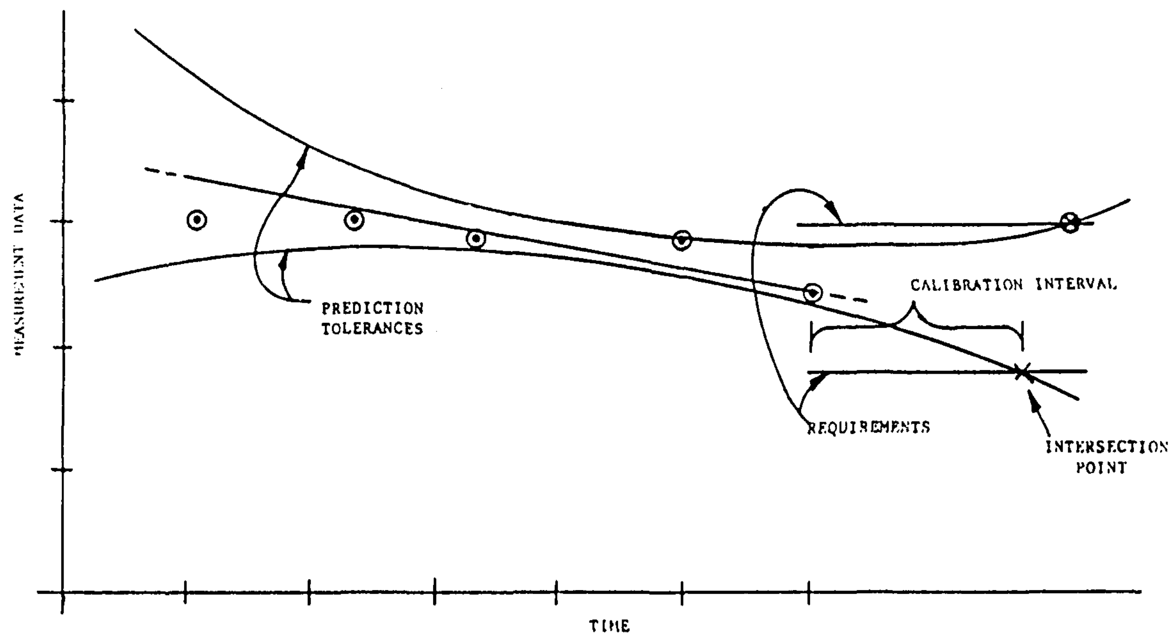


FIGURE 6 - MATHEMATICALLY ELIMINATING DRIFT

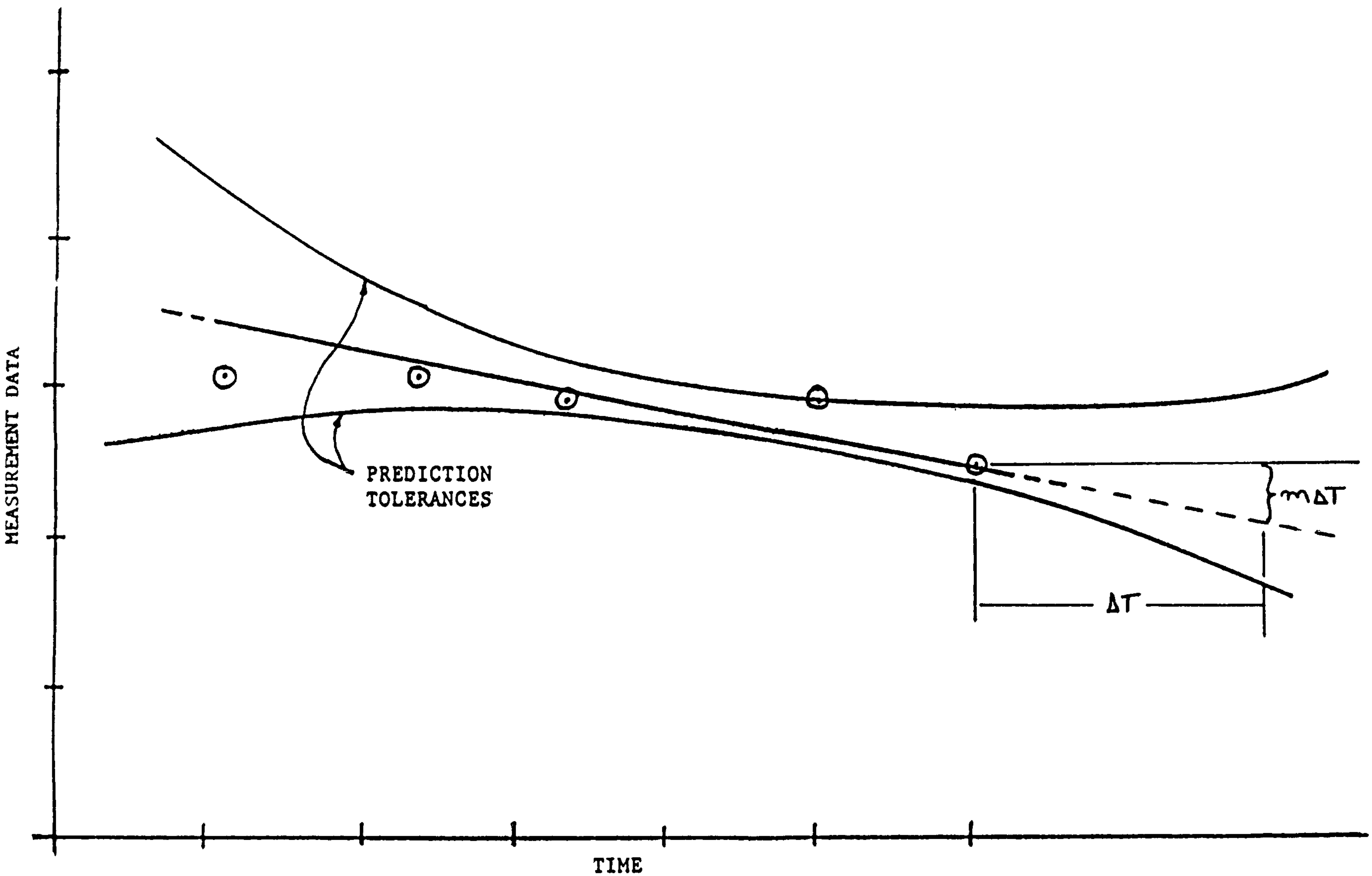


FIGURE 7 - TREND WITH ABNORMAL SHIFT

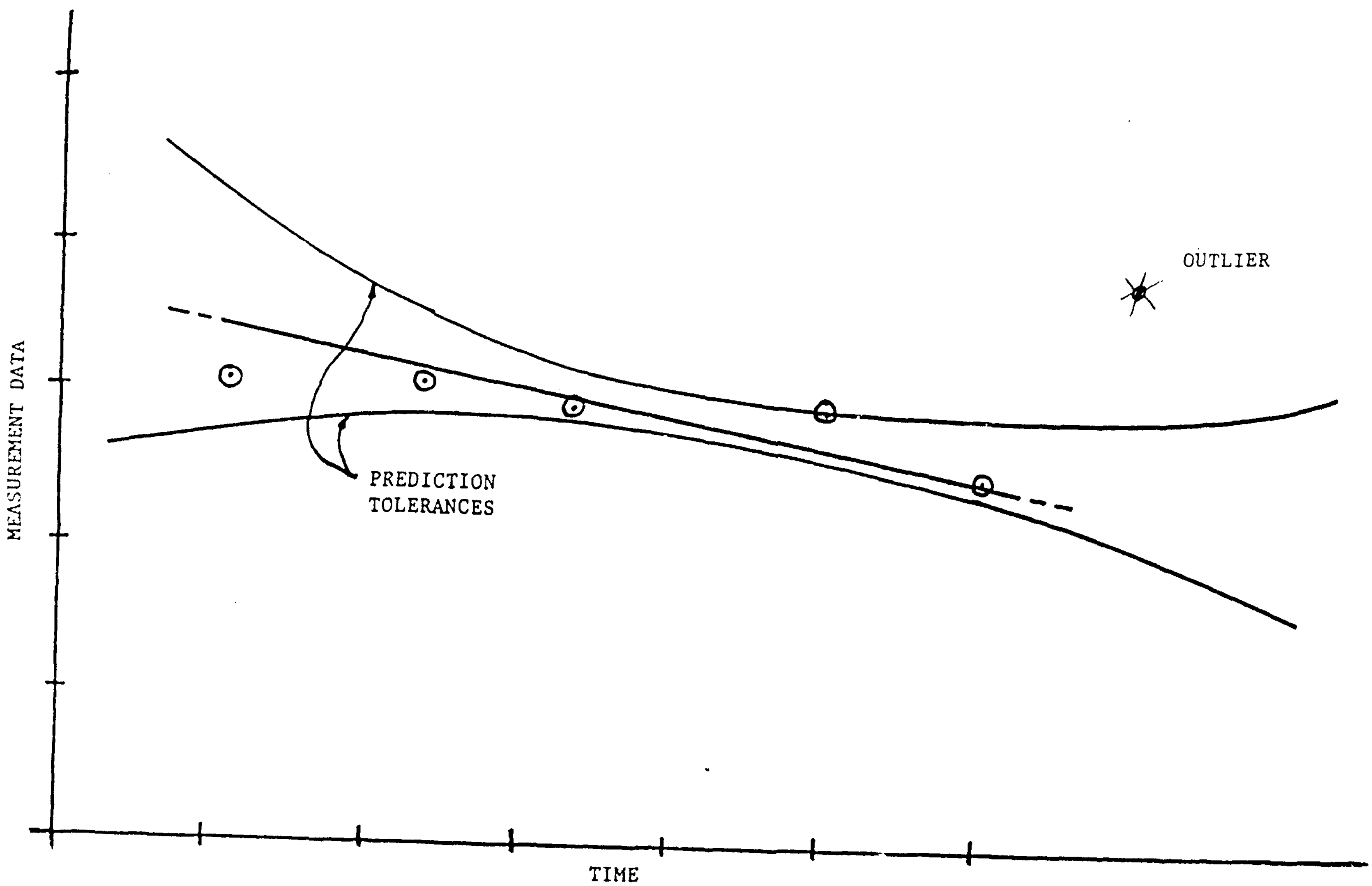


FIGURE 8 - ON LINE DATA TAKING WITH COMPUTER

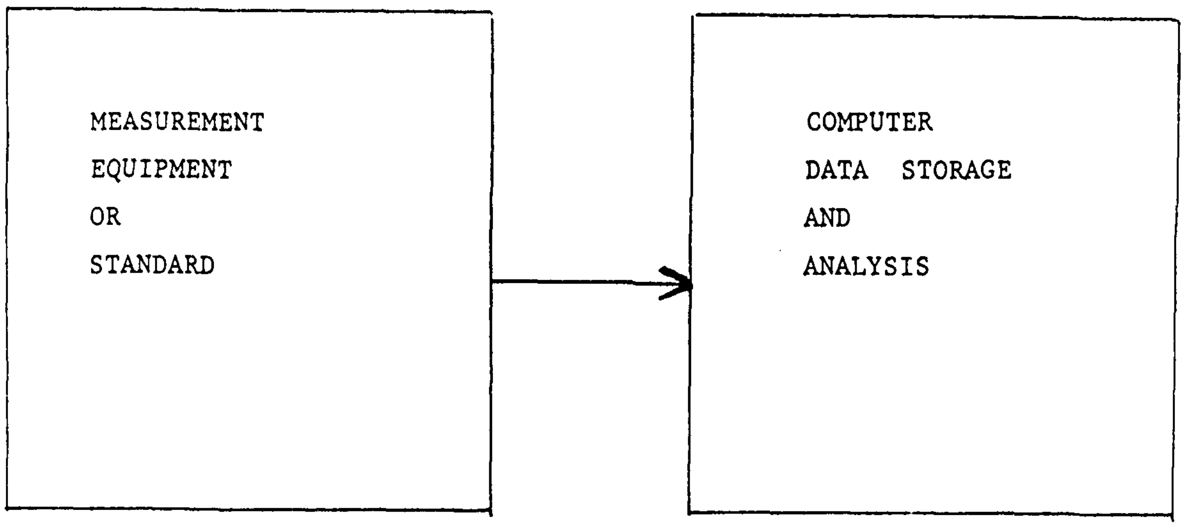
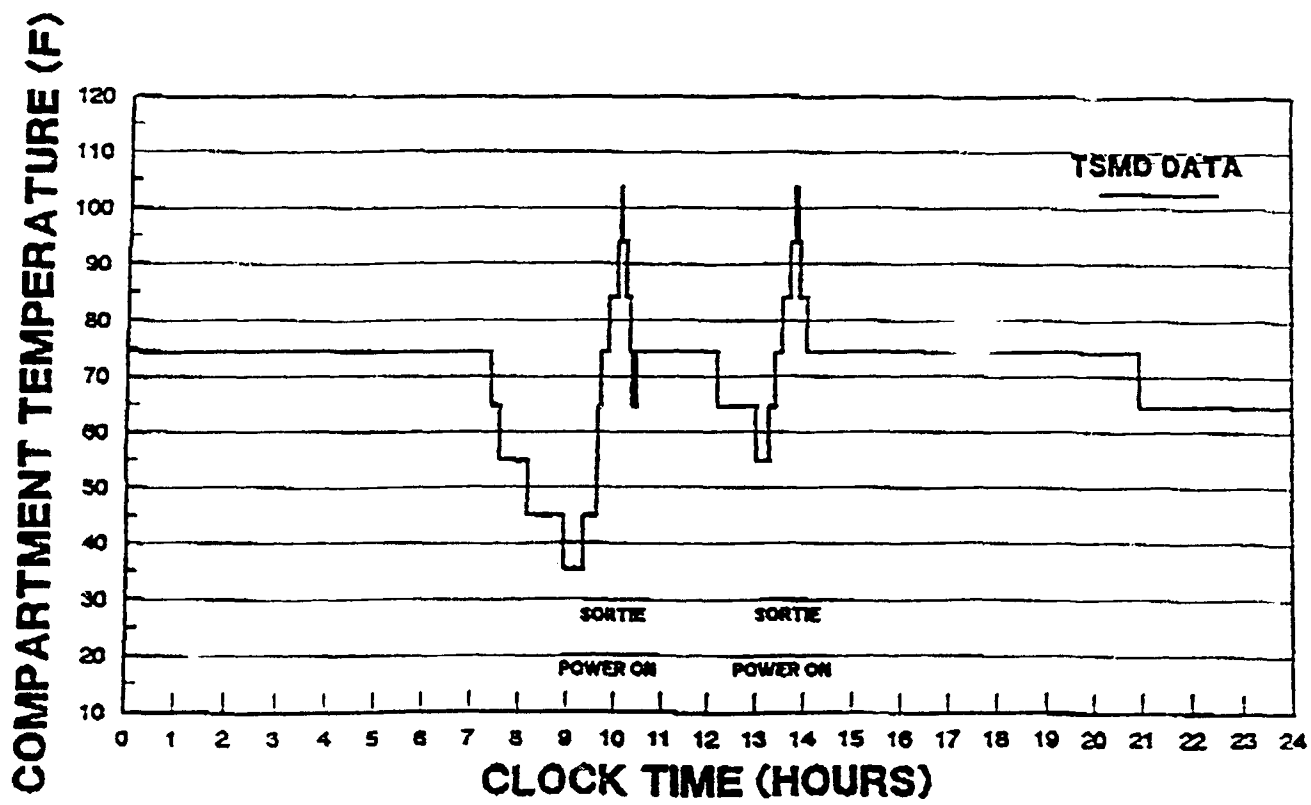


TABLE 1. Micro TSMD RECORDING CAPABILITY

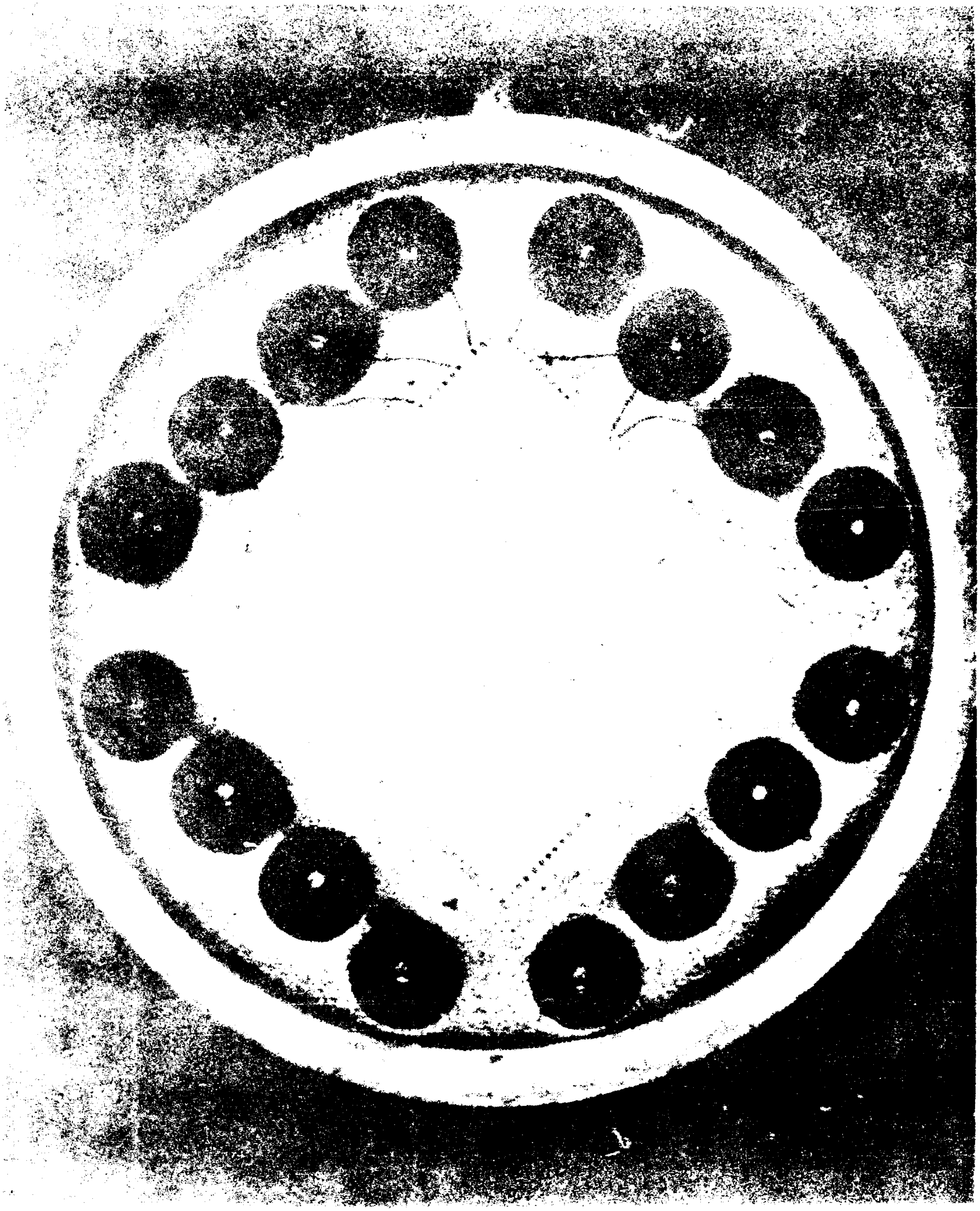
	RANGE	RESOLUTION
TIME	99 yrs	0.1 sec
SHOCK	±25g	0.2g
VIBRATION		
AMPLITUDE	0-0.2 g^2/Hz	0.001 g^2/Hz
FREQUENCY	20-2000 Hz	32 Freq. Bins
VOLTAGE	2V-10V	10 mV
TEMPERATURE	-55°C to 125°C	1°C
VOLTAGE TRANSIENTS	2V to 100V	3 Thresholds



TSMD STRESS PROFILE FOR A-7

FIGURE 9 - SOME TSMD DATA

(Reference 6)



ARMY DYNAMIC PRESSURE MEASUREMENTS

By John M. Ball
U.S. Army TMDE Activity
Redstone Arsenal, AL

ABSTRACT: This paper briefly describes dynamic pressure measurements in the Army, tests performed, ranges of interest, and transducers. Army calibration program and traceability requirements are outlined along with measurement concerns. Several actual calibration systems are described. The need for a national calibration service and measurement program in this parameter is emphasized.

I. INTRODUCTION.

A national survey of Army dynamic pressure measurement activities was conducted in 1986 [1]. This census, while not all inclusive, identified quantities of transducers, ranges of interest, and locations at which dynamic pressure measurements were conducted. Test ranges, proving grounds, and development centers constituted the principal users of dynamic pressure transducers. While ranges of interest varied with the application, measurements from thousands of atmospheres to tens of thousands of atmospheres were then common and are currently being performed on a routine basis in a number of locations. Higher range measurements usually involve combustion generated pressures: chamber pressures, blast pressures, and so on. Lower range measurements are applied to such things as engine pressures. Products from most major manufacturers of dynamic pressure transducers and unique, Army designed and manufactured transducers are represented. Hundreds of these transducers are formally supported through the Army calibration process. The typical transducer had a range of about 6800 Atm (100,000 PSI), with an expected error of 1% to 2%.

A study conducted in 1990 demonstrated that certain of these dynamic pressure machines generated pressures which agreed with precision static measurements to about one percent.[5] It was not possible, however, to directly validate the performance of these devices in their dynamic mode.

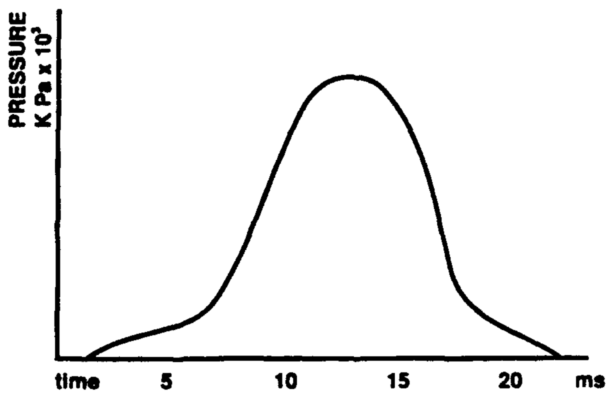
II. ARMY CALIBRATION PROGRAM

By regulation [2], the U. S. Army operates a calibration program designed to ensure the accuracy of measurements in all parameters and to guarantee the correct performance of Army test, measurement, and diagnostic equipment. The test ranges, proving grounds, RD&E Centers, and laboratories which perform dynamic pressure measurements are supported by calibration and repair services from mobile calibration vans and sophisticated, fully equipped measurement laboratories. These activities are controlled, operated, and supported through a hierarchy of calibration laboratories, including the Army Primary Standards Laboratory, which functions as the "bureau of standards" for the Army.

Program management, engineering, and logistics for these calibration functions and for general purpose Army test instrumentation and automated test equipment are centralized in the U. S. Army TMDE Activity headquartered at Redstone Arsenal, AL.

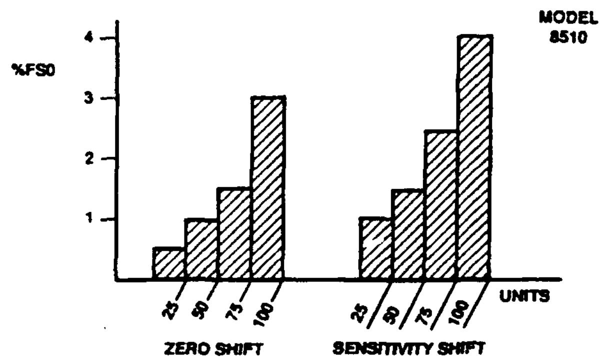
III. TRACEABILITY

Calibration generally requires a measurement system with known accuracy and a test unit which is certified against this system. Regulations govern accuracy relationships between measurement systems and items to be calibrated [3]. In many cases, a transducer which has been calibrated is used as an "artifact standard" to transfer accuracy to other items.



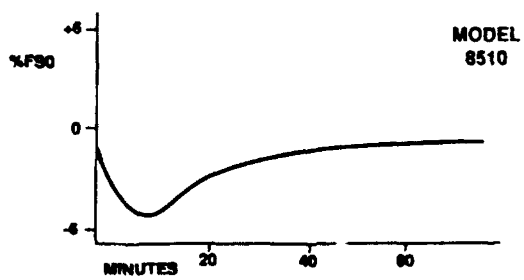
TYPICAL CHAMBER PRESSURE PULSE

Figure 1



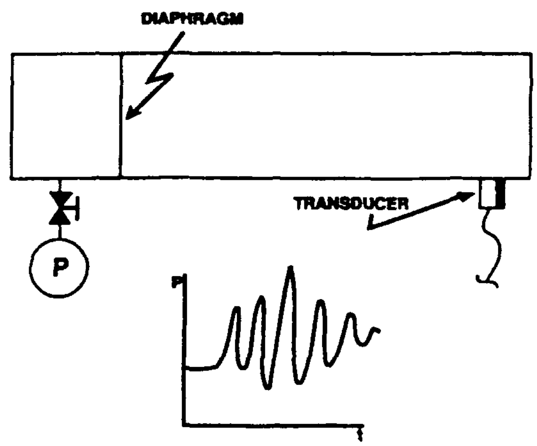
TEMPERATURE INDUCED PERFORMANCE CHANGES WITHIN COMPENSATED RANGE -20 to 93°C

Figure 2



70°C WATER STEP

Figure 3



SHOCK TUBE CALIBRATOR

Figure 5

Periodic calibration detects changes in performance and permits correction or adjustment. The accuracy of a calibration is dependent upon a reference which may be another piece of hardware, a physical phenomena, or a process. The National Institute of Standards and Technology (NIST), is the organization in this country to which all measurements except time are legally referenced. "Traceability" is the process by which the relationship of field measurements to NIST is documented.

Dynamic pressure measurements, however, are not directly traceable to NIST. This is the most significant issue in this parameter today. Neither does the NIST provide dynamic pressure measurement services. Without traceability, the accuracy of such measurements cannot be directly validated at any level in the calibration hierarchy, calibration support is reduced to the certification of repeatability at some inexactly known value, and the Army's testing program is seriously compromised.

Army users and calibration operations have applied several different calibration approaches in an attempt to provide measurement services and some degree of traceability. Several will be described briefly later in this paper.

IV. THE PHENOMENA

Dynamic pressure measurements are almost always measurements of rapid pulses. In many applications, the pressure pulse is accompanied by a dynamic temperature pulse, the fluid being measured is a combusting gas, and powerful mechanical shocks and vibrations exist in the test item. Consider as an illustration a piezoelectric transducer mounted to measure chamber pressure in a cannon, the nature of the fluid, the simultaneous mechanical shock pulses, vibrations, environmental effects, mounting conditions, and the construction of transducers commonly applied. Transducers in such an installation experience mechanical stresses, electromagnetic pulses, and temperature shocks in addition to the parameter of interest. To physically protect the transducer from the process, grease, modeling clay, or some other material is often packed into the mounting hole.

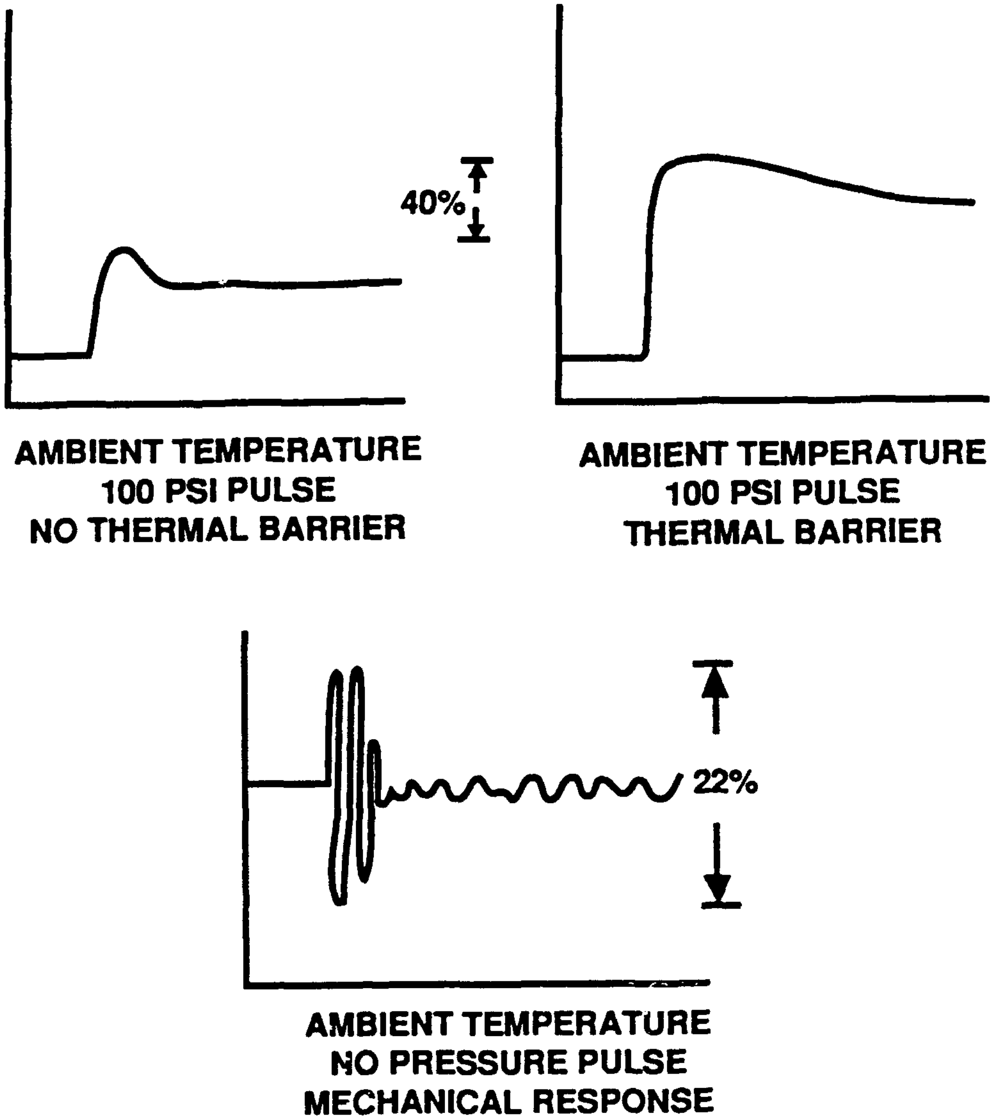
The user is generally interested not only in the amplitude of the pressure pulse but in capturing the pulse for analysis (Figure 1).

V. TRANSDUCER

Because the process being measured is such a strain upon the transducer, it has become a common practice to "calibrate" these devices prior to and just after a test to detect drastic performance changes which may have occurred during the measurement process.

Dynamic pressure transducers exhibit hysteresis, nonlinearity, nonrepeatability, zero shift, resonances, and sudden, catastrophic failure. Their output is affected by strain on the cables, thermal transients and shocks, mechanical vibrations, electrical effects (ground loops, lead resistances, etc.), ambient conditions, photo flash, over pressure, and warm up time.

Transducers are often specified in terms of the root mean square (RMS) of linearity to a "best straight line fit" of pressure data to transducer response based upon static pressure values, repeatability, and hysteresis. Frequency response is generally indicated by specifying the resonant frequency of the device. Other sources of potential error (see Table), are well documented by manufacturers and researchers [4].



(AFTER WILLIS)

RESPONSE OF MINIATURE DYNAMIC PRESSURE TRANSDUCERS

Figure 4

Figures 2 and 3 illustrate typical temperature related effects for one type transducer. Even though these effects are relatively large compared to the accuracy of the measurement desired, the effect of transient temperatures can be much greater and is not so predictable. Figure 4 is based upon illustrations from a study of the performance of miniature pressure transducers. When used without a specially constructed thermal damper, 40% performance shifts were observed. The same study found the effects of mechanical vibrations to be as much as 25% of full scale transducer output [6].

The grease or modeling clay which protect the sensor, the orifice snubber, protective shield, diaphragm, liquid cell, and mechanical construction of the device itself all act as low pass filtering elements, guaranteeing that the signal from the transducer is not identical to the actual process pulse of interest. An accurate characterization of the relationship between the process and the senor response is required to reproduce process information from transducer signal. Not only pressure information but also frequency response and repeatability data are essential to the utilization of dynamic test results. The validity of such a characterization is a direct function of the calibration process.

VI. MEASUREMENT SUPPORT

Whether NIST support exists or not, Army dynamic pressure transducers must be certified and their performance verified. A variety of Army systems and commercial approaches to providing this measurement support are in common use. Because direct NIST traceability does not exist, each approach depends upon indirect means and calculations for estimating system accuracy. Of course, stated accuracies can often be neither independently verified nor disproved.

Direct calibration traceability to NIST through an artifact is not necessary for a measurement to be traceable to NIST. If a particular measurement depends in a well understood manner upon other parameters which are directly NIST traceable, it is theoretically possible to determine the accuracy of the measurement of interest through an error analysis calculation. Such is the justification for the systems below being identified as calibrators rather than testers.

VII. SAMPLE SYSTEMS

Several actual, Army calibration systems are described below. None of these devices claims to adequately simulate actual usage conditions.

Shock tubes have been in use for years to produce known pressure pulses in gas (Figure 5). The chamber on the left is pressurized behind the diaphragm, which is burst when a predetermined pressure level has been reached. A pressure wave travels down the tube, stimulating the transducer. Calculations from gas theory are a possible basis; however, pressure data is generally obtained through comparison of the transducer under test to another transducer, a calibration standard. Shock tubes yield good frequency data. Weaknesses in the method include difficulty in reproducing the same pulse at the transducer, very slow repetition rate, and a generally low maximum pressure (hundreds rather than thousands of atmospheres). Also, at high pressures, such devices are somewhat dangerous.

In contrast to the situation in dynamic pressure, static pressure measurement services, calibration, and NIST traceability are readily available. The accuracy of such measurements is parts per million up to about 7,000 Atm for liquid pressure. The device illustrated in Figure 6 takes advantage of the extreme accuracy and repeatability of the dead weight piston gage to produce calibrations. A precise pressure head is generated upon the transducer under test and then the valve is thrown, rapidly releasing the pressure. Transducer response is measured for a series of pressure levels. This device is ideally suited for performing repeated tests at very well defined pressure levels, for example, before and after test range shots. Concerns include the use of constant temperature oil to simulate the exploding gas actually present under use conditions, and the assumption that the transducer under test responds in the same manner to a static pressure suddenly bled off as to a positive step pressure. Such a system has excellent repeatability.

Another design, also using a piston in cylinder, generates an impulse in the fluid by dropping an anvil on the piston (Figure 7). Force applied is calculated from anvil weight and height dropped, pressure from force divided by cross sectional area. While the pressure generated is less well known than in the previous system, a true pulse is produced.

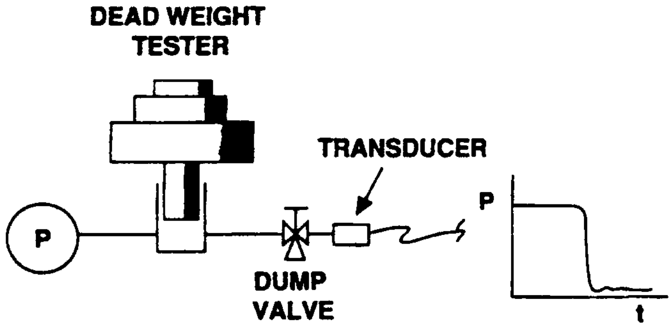
A third liquid based design is built around a very fast acting valve (Figure 8.) The chamber is pressurized and the static pressure measured by a pressure sensor which need not be fast, but should be accurate. The valve fires, exposing the transducer to a sudden, positive pressure step. The pressure gage records the new, slightly reduced pressure to which the transducer was exposed. It should be noted that the pressure gage is never exposed to significant stresses. This design shares the weaknesses of the other liquid calibrators, also assumes symmetry of response, and has the additional problem of the fast acting valve which experiences terrific stresses and must be rebuilt after every few dozen uses. It does, however, repeatably generate very high pressure calibration steps and correlates well with other measurement methods.

A final example is the pneumatic step function generator illustrated in Figure 9. This device uses a uniquely actuated, very fast poppet valve to generate step pressure pulse on a static pressure. It has proven useful for generating accurately known, repeatable performance data with either positive or negative steps. This calibrator, however, is limited to about 2,000 PSI.

VII. SUMMARY AND CONCLUSIONS

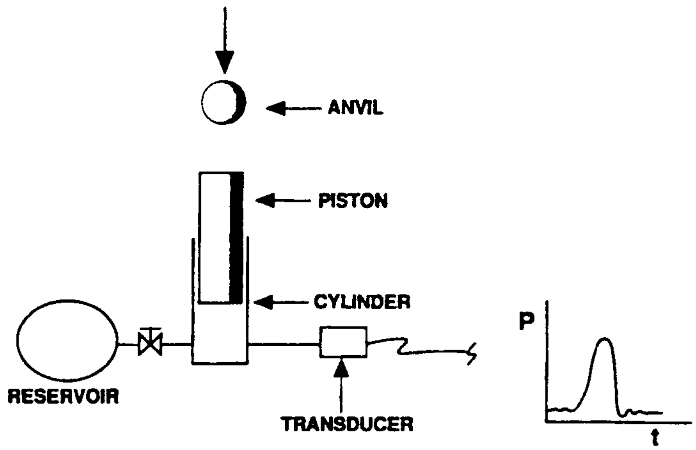
Requirements currently exist in the Army for dynamic pressure measurements and calibration support. Future requirements will probably far exceed those of today [6]. Calibrators which are in use do not very well simulate actual use conditions and accuracies stated are based upon estimations, comparisons, repeatability, and experience, rather than direct traceability to national standards. On the other hand, commercial and custom made calibrators probably perform sufficiently well to be practical in most applications, and could be made much more accurate if transfer standards existed which could certify and characterize their performance.

A national measurement service with a solid, scientific basis is sorely needed and an associated calibration service for transducers. The national measurement system should measure dynamic pressure and dynamic temperature in gas. The system should be capable of generating a variety of pulse and step widths. There are numeous legal and practical, operational requirements for this service. Transducers which currently exist might well prove adequate as transfer artifact standards which could be used to calibrate many of the calibration systems now in use, providing real NIST traceability.



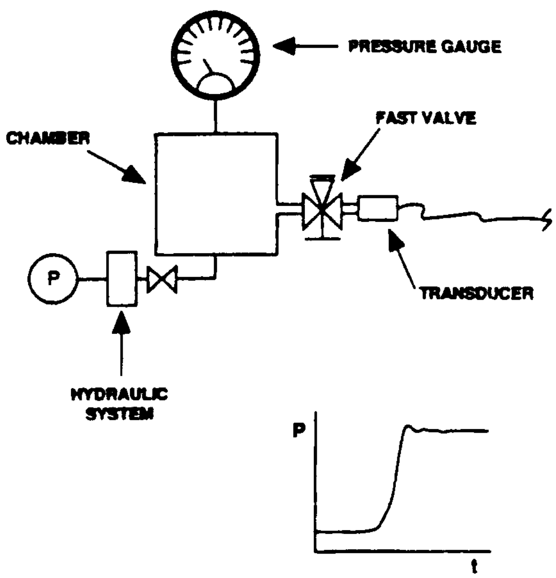
HYDRAULIC DEAD WEIGHT CALIBRATOR

Figure 6



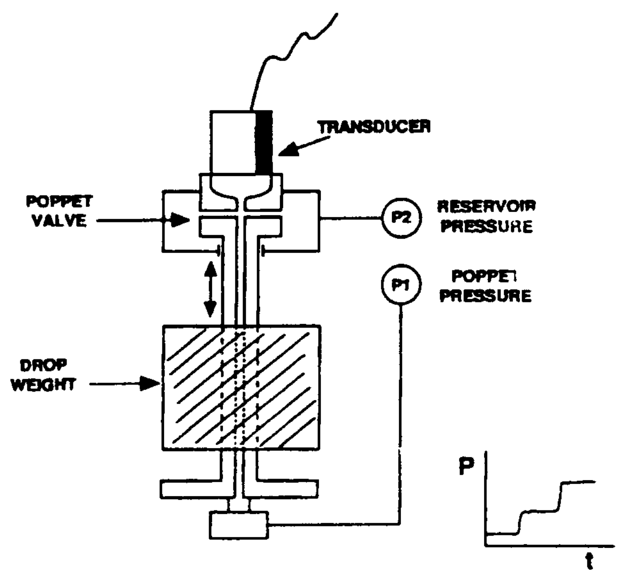
DROP BALL IMPULSE CALIBRATOR

Figure 7



HIGH PRESSURE HYDRAULIC
STEP FUNCTION CALIBRATOR

Figure 8



PNEUMATIC STEP GENERATOR

Figure 9

Measurement accuracy could well be improved an order of magnitude or more without significant changes to the current hardware base in the Army with true traceability.

Development of a service for calibrating dynamic pressure transducers will not only improve Armysupport in this parameter, but provide a significant national resource for military and civilian industries.

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7. Juhasz, Arpad A., et. al., A 150,000 Pounds Per Square Inch Dynamic Pressure Calibrator, Technical Report BRL-TR-2856, U. S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1987. Mentions performance and shows chart.

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MINIATURE PRESSURE TRANSDUCERS

PARAMETER	UNIT	AVERAGE VALUE	MAXIMUM VALUE
Full Scale Output at 10 Volts (FSO)	mV	357.5	392.1
Zero Offset	% FSO	.50	1.40
Nonlinearity	% FSO	.06	.15
Hysteresis	% FSO	.017	.03
Nonrepeatability	% FSO	.017	.03
Combined Effect of Linearity, Repeatability and Hysteresis	% FSO, RSS	.07	.15
Zero Shift after 2.5X Overpressure	% FSO	.015	.025
Input Resistance	Ohm	1603	2331
Output Resistance	Ohm	738	1030
Zero Error Due to Temperature			
-18 ° to 65 °C	% FSO	.31	.99
-54 ° to 74 °C	% FSO	.62	1.96
Sensitivity Error Due to Temperature			
-18 ° to 65 °C	%	.25	.53
-54 ° to 74 °C	%	.63	1.39
Diaphragm Resonant Frequency			
15 psia	Hz	140,000	
50 psia	Hz	240,000	
100 psia	Hz	280,000	
200 psia	Hz	400,000	
Flat Frequency Response of Transducer	Hz	250	
Warmup Time (1% Accuracy)	mS	1	
Acceleration Sensitivity	% FSO/g	1.5x10-4%/g	
Zero Shift with Mounting Torque	% FSO	.1	
Nonlinearity at 2X Range	% 2X FSO	.2	
Insulation Resistance at 50 Vdc	Megohm	1,000	
Noise (DC to 50,000 Hz)	μV rms	5	

(After Poff)

Figure 1. Typical Chamber Pressure Pulse.

Figure 2. Temperature Induced Performance Changes.

Figure 3. Response to 70 °C Water Step.

Figure 4. Response of Miniature Dynamic Pressure Transducers.

Figure 5. Shock Tube Calibrator.

Figure 6. Hydraulic Dead Weight Calibrator.

Figure 7. Drop Ball Impuse Calibrator.

Figure 8. High Pressure Hydraulic Step Function Calibrator.

Figure 9. Pneumatic Step Generator.

MICOM LOG R&D CONFERENCE

ARMY DYNAMIC MEASUREMENTS

BY
JOHN M. BALL

U.S. ARMY TMDE ACTIVITY
REDSTONE ARSENAL, ALABAMA

AUGUST 1991

G1-91-1242-1

OUTLINE

DYNAMIC PRESSURE APPLICATIONS
- THE NEED

CALIBRATION & TRACEABILITY
- THE ISSUES

PHENOMENA & TRANSDUCERS

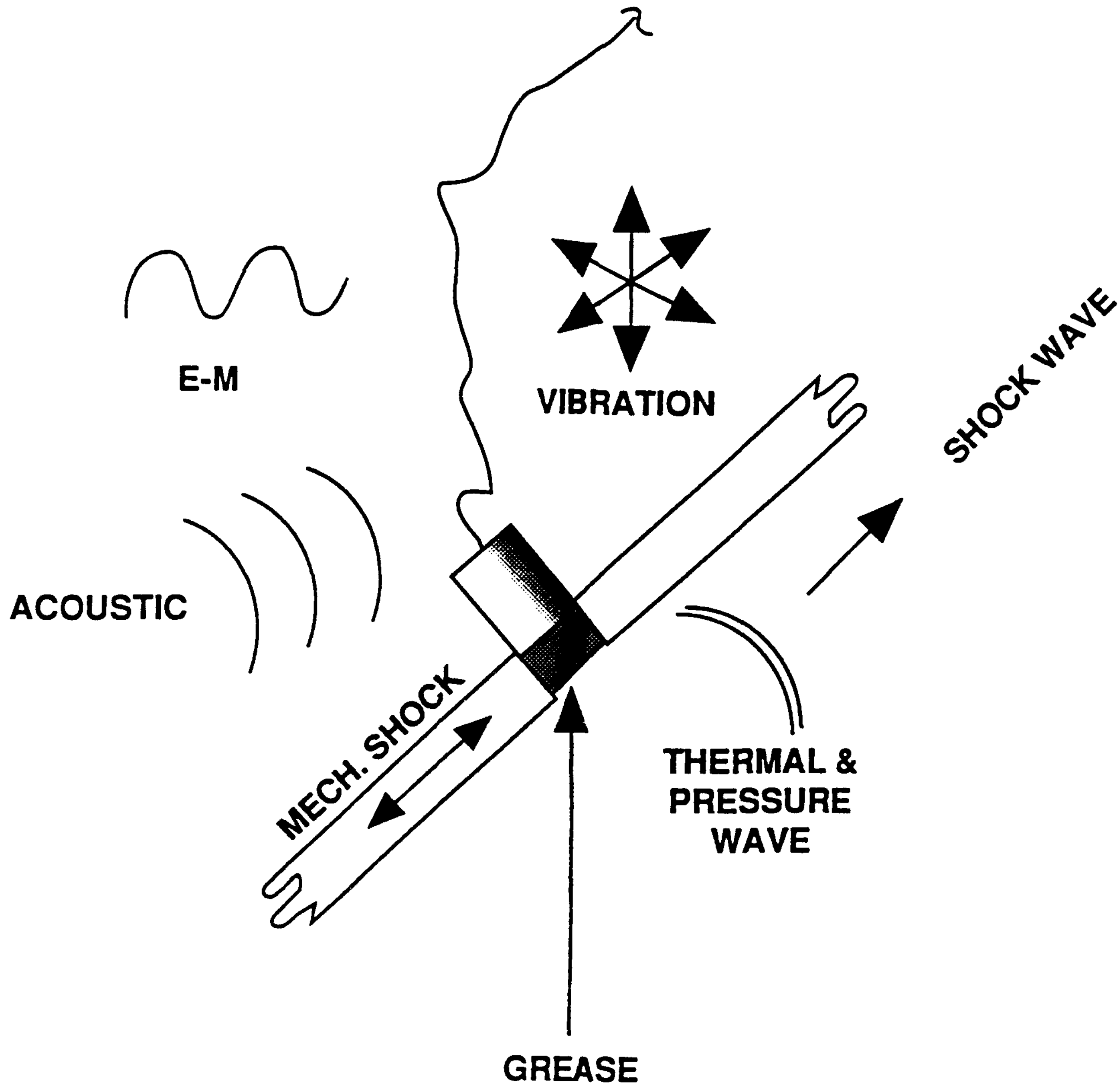
ARMY MEASUREMENT TECHNIQUES
- SAMPLES OF REAL SYSTEMS

CURRENT SITUATION

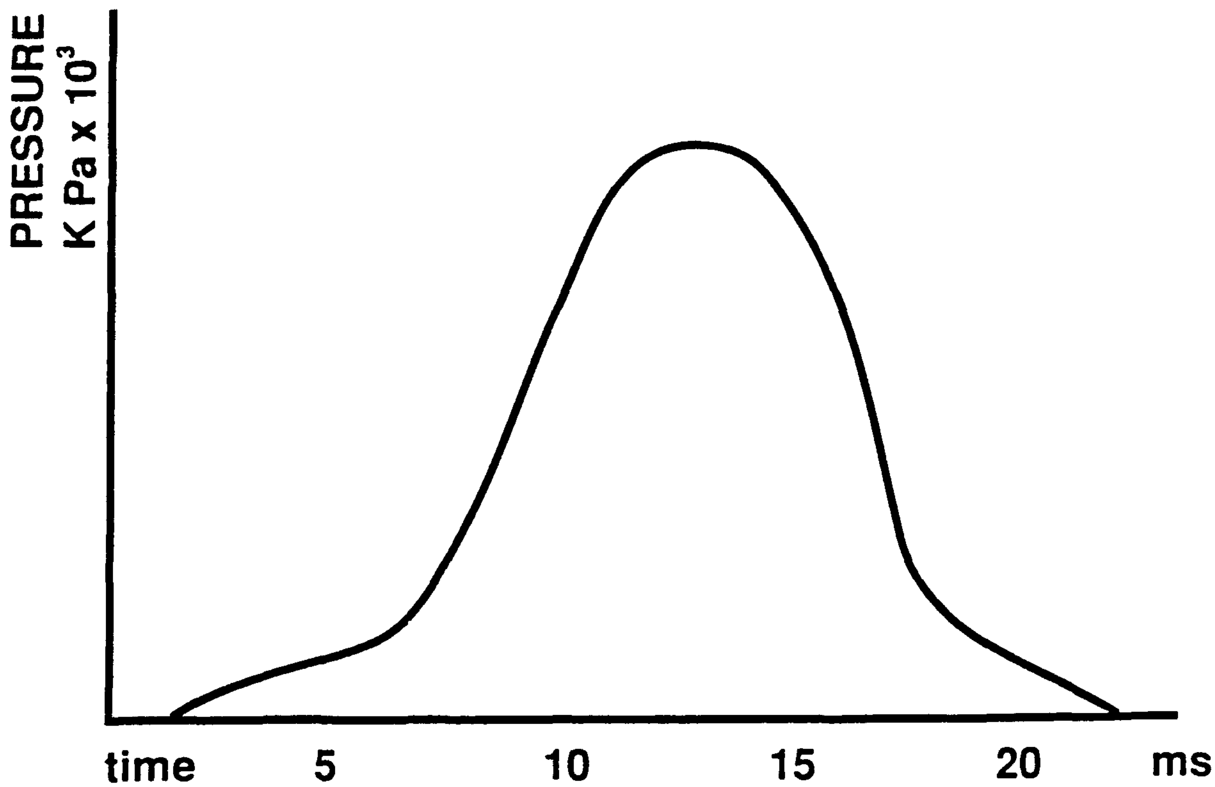
LOG R&D PROJECT

CONCLUSION
- TECHNOLOGY DEVELOPED
- MEASUREMENT SUPPORT TO U.S.
- SIGNIFICANT SCIENTIFIC ADVANCE

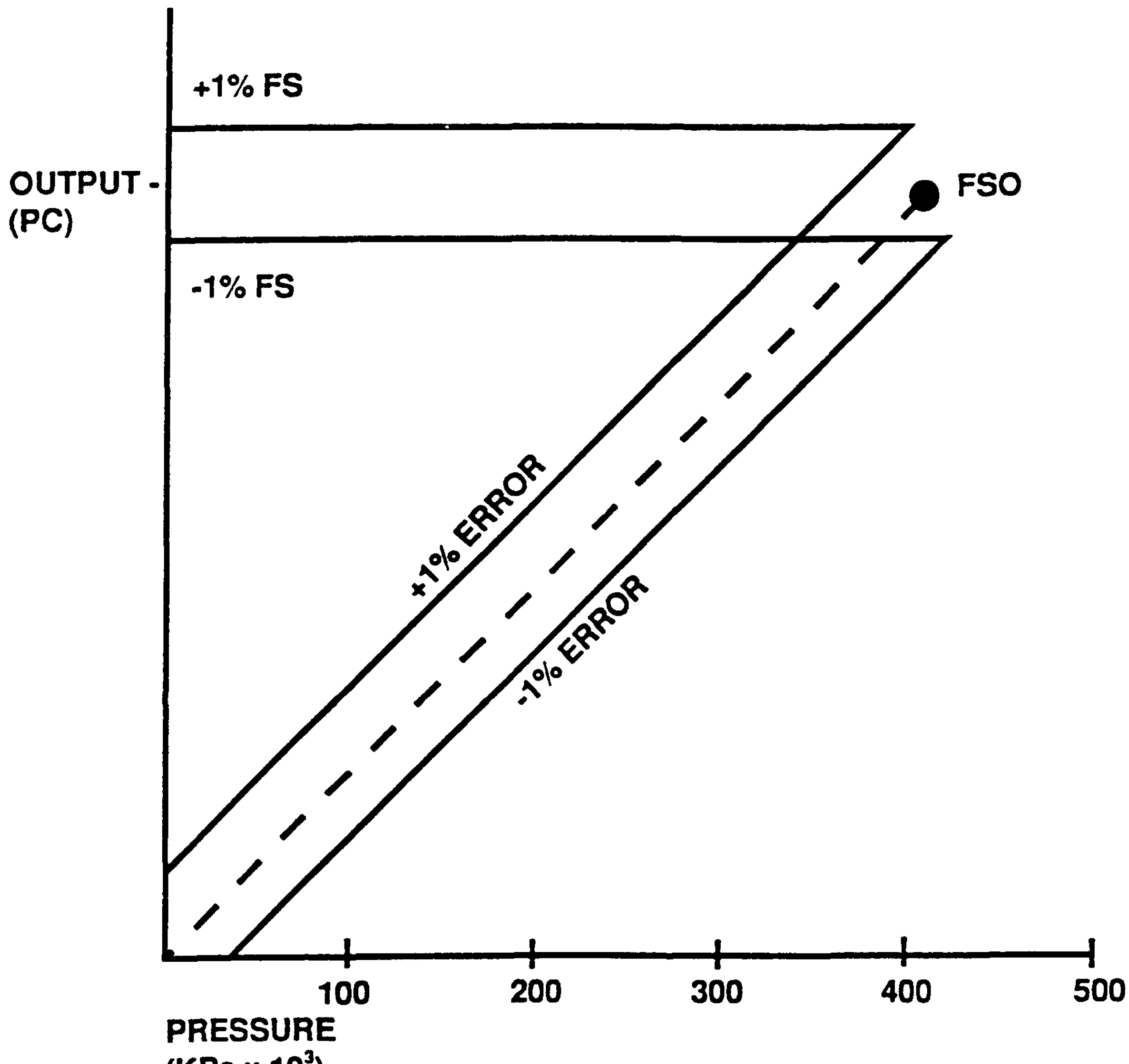
G1 91-1242-4



DYNAMIC PRESSURE TRANSDUCER
MOUNTED IN CANNON

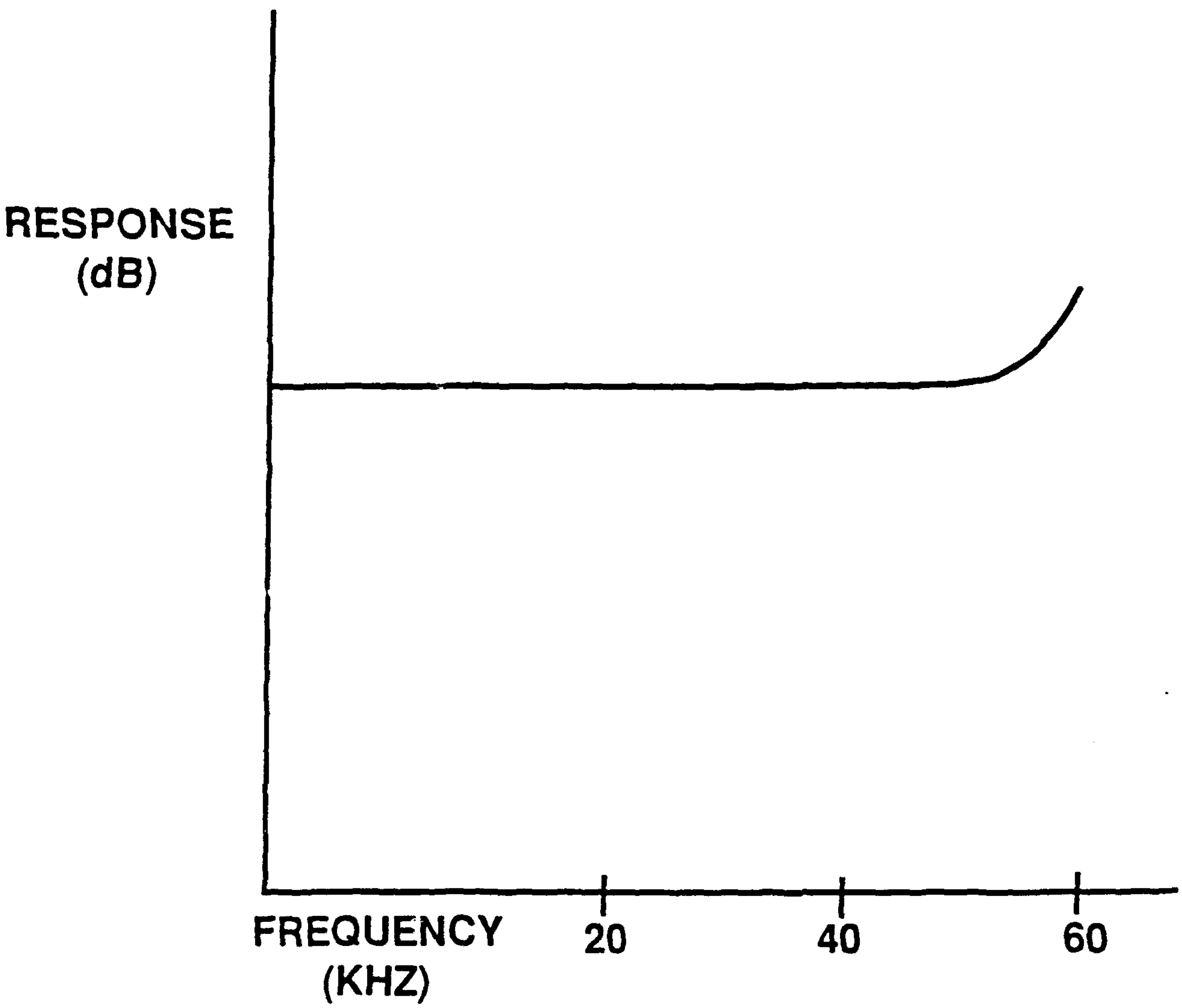


TYPICAL CHAMBER PRESSURE PULSE

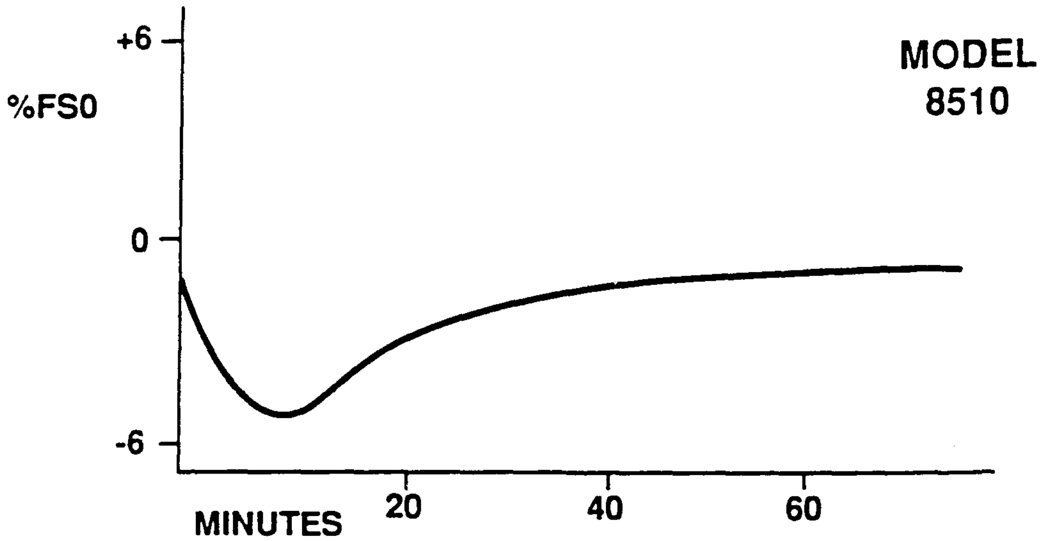


CALIBRATION CURVE
LINEARITY

(AFTER ITOP 3-2-810)

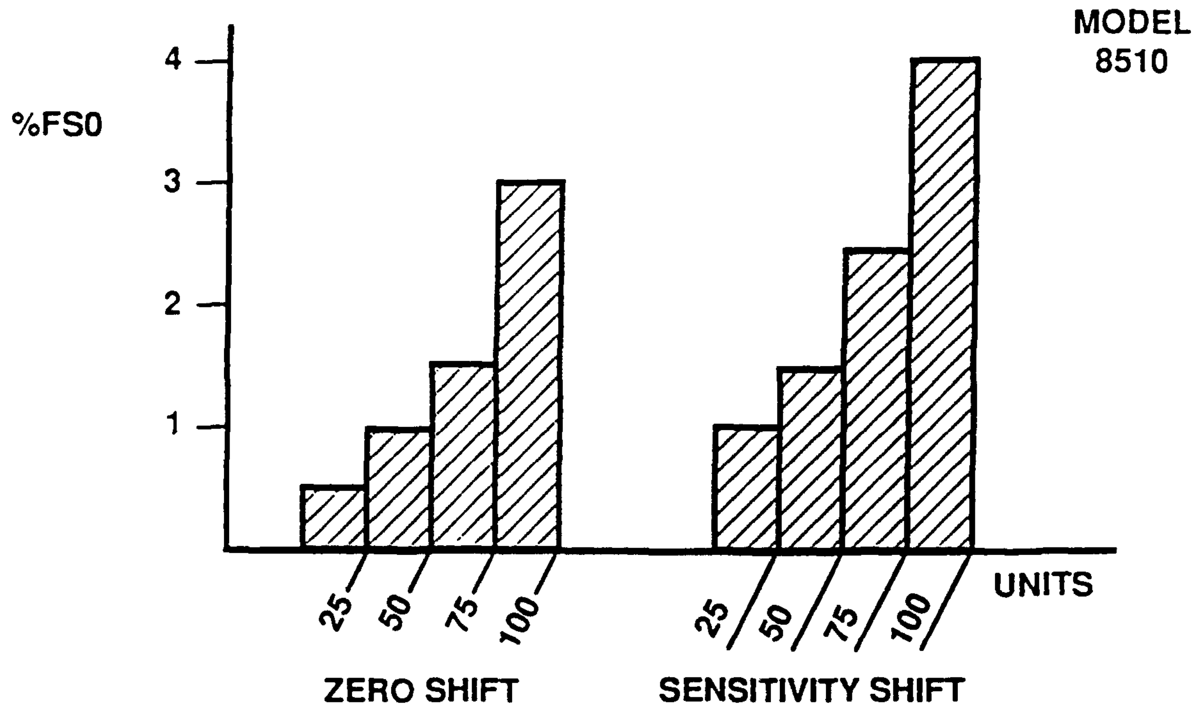


CALIBRATION CURVE
FREQUENCY



70°C WATER STEP

(TP279)



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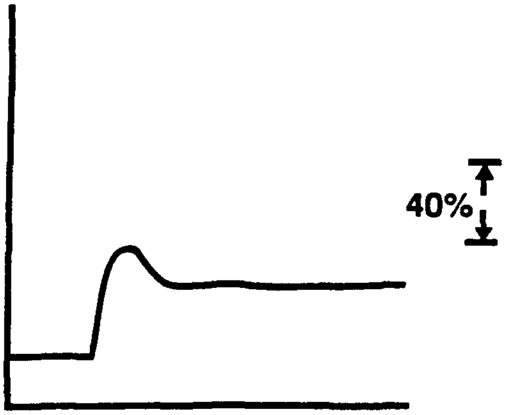
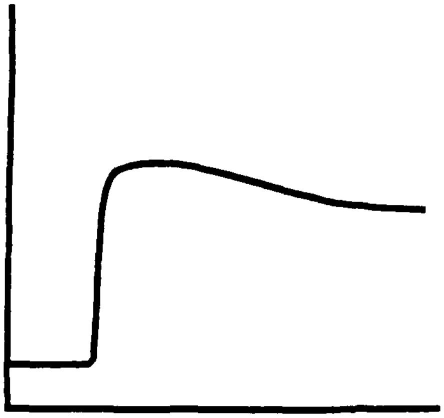
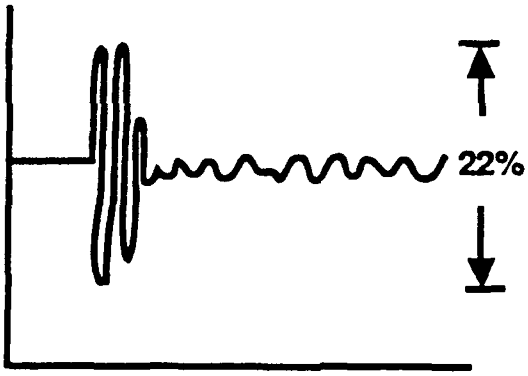
TEMPERATURE INDUCED PERFORMANCE CHANGES WITHIN COMPENSATED RANGE -20 to 93°C



AMBIENT TEMPERATURE
100 PSI PULSE
NO THERMAL BARRIER



AMBIENT TEMPERATURE
100 PSI PULSE
THERMAL BARRIER



AMBIENT TEMPERATURE
NO PRESSURE PULSE
MECHANICAL RESPONSE

(AFTER WILLIS)

RESPONSE OF MINIATURE DYNAMIC
PRESSURE TRANSDUCERS

MINIATURE PRESSURE TRANSDUCERS

PARAMETER	UNIT	AVERAGE VALUE	MAXIMUM VALUE
Full Scale Output at 10 Volts (FSO)	mV	357.5	392.1
Zero Offset	% FSO	.50	1.40
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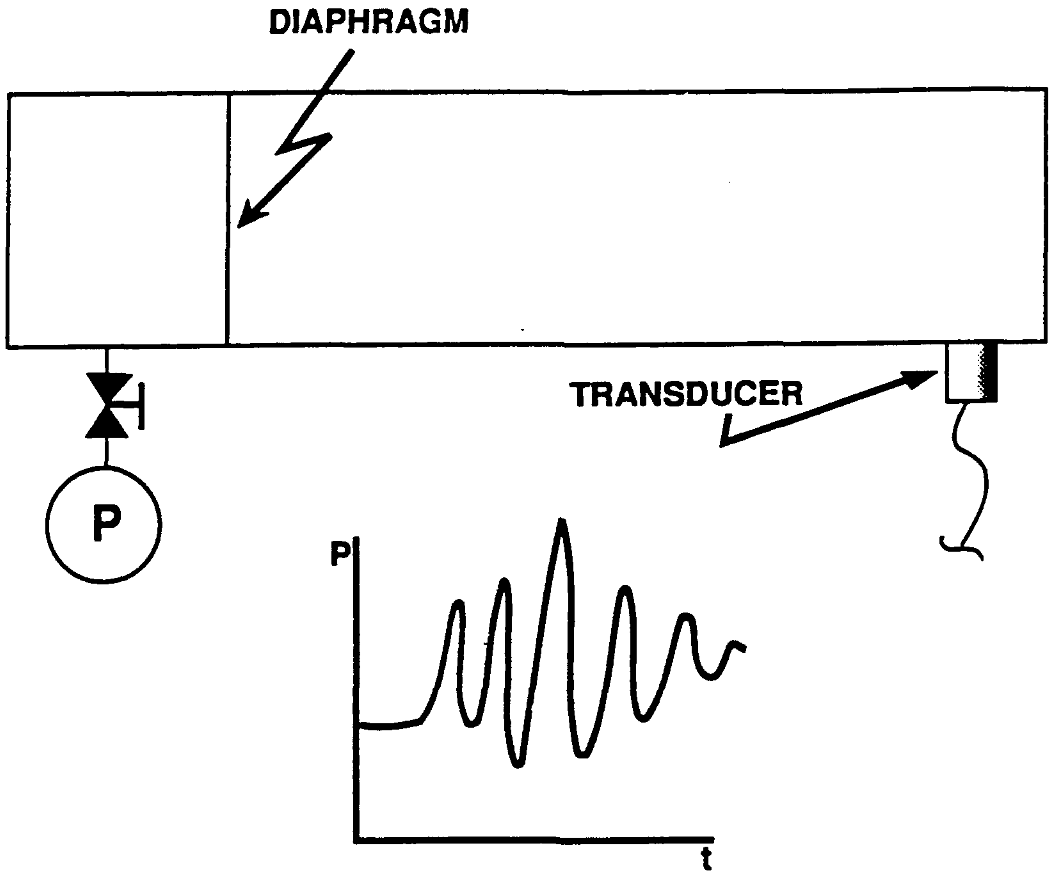
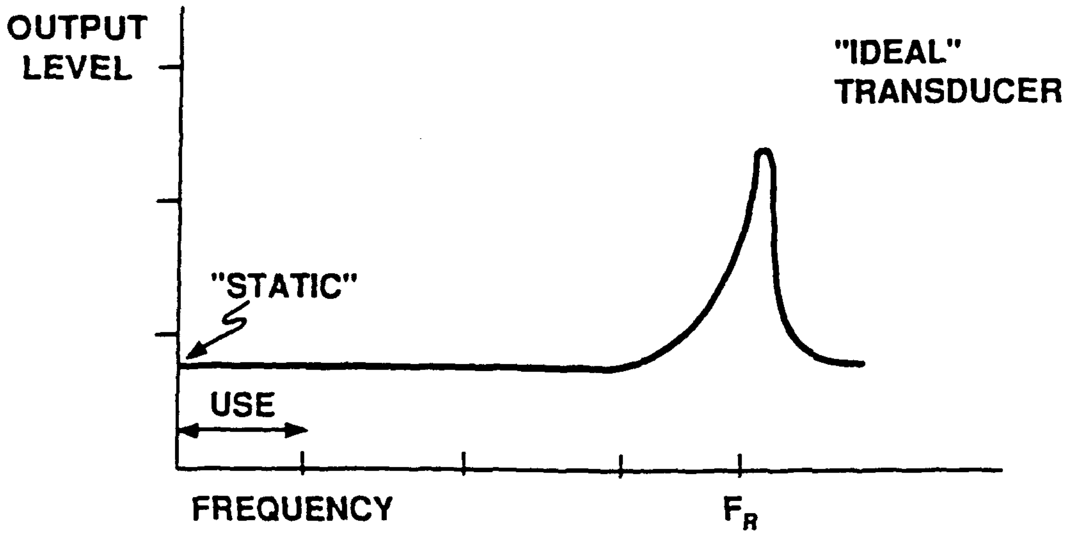
Warmup Time (1% Accuracy)	mS	1	
Acceleration Sensitivity	% FSO/g	1.5x10-4%/g	
Zero Shift with Mounting Torque	% FSO	.1	
Nonlinearity at 2X Range	% 2X FSO	.2	
Insulation Resistance at 50 Vdc	Megohm	1,000	
Noise (DC to 50,000 Hz)	μV rms	5	

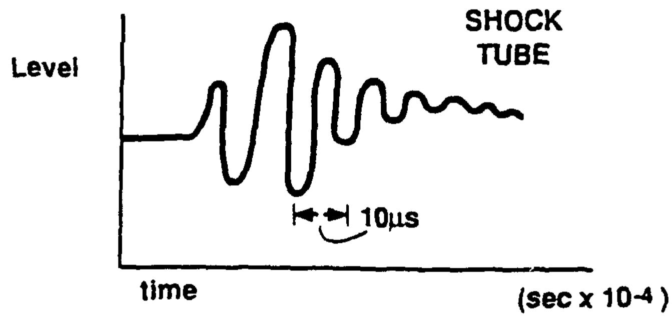
(After Poff)



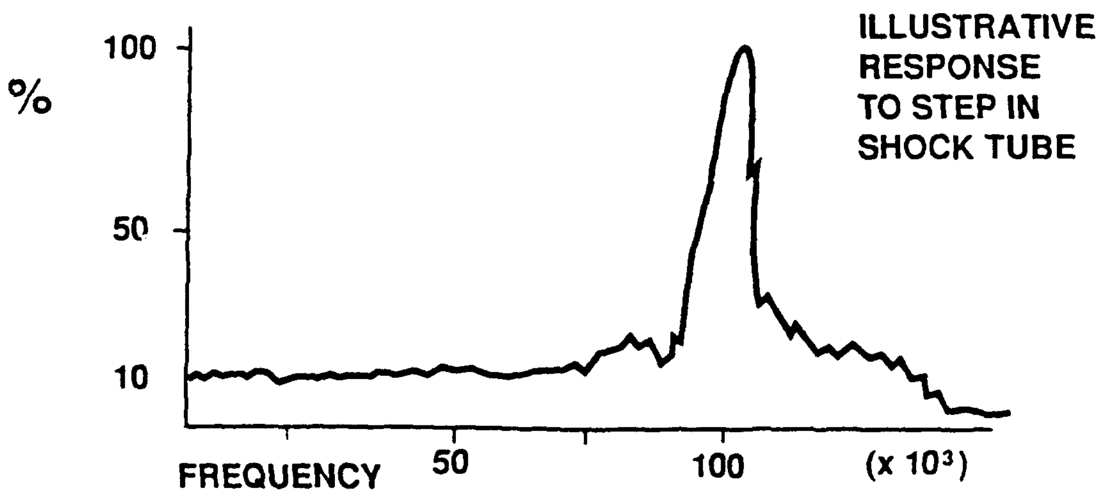
SHOCK TUBE CALIBRATOR



OUTPUT LEVEL
"IDEAL" TRANSDUCER
"STATIC"
USE
FREQUENCY
F_R



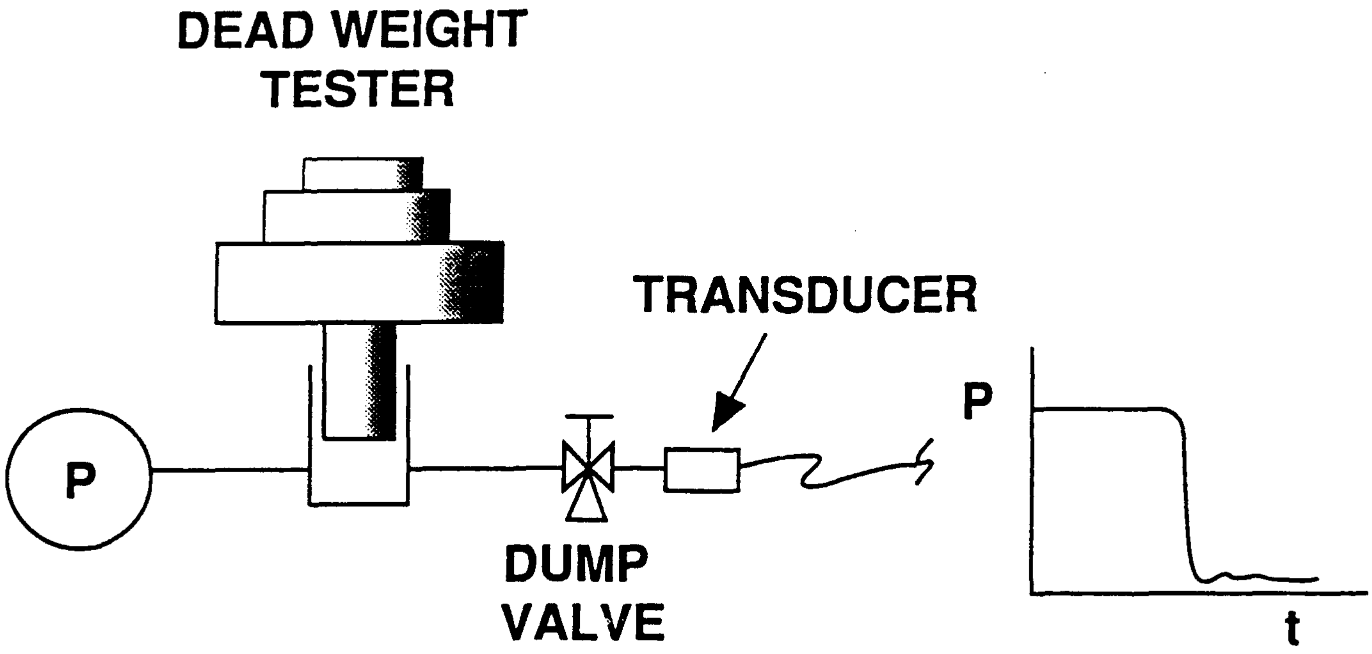
SHOCK TUBE
Level
10µs
time
(sec x 10-4)



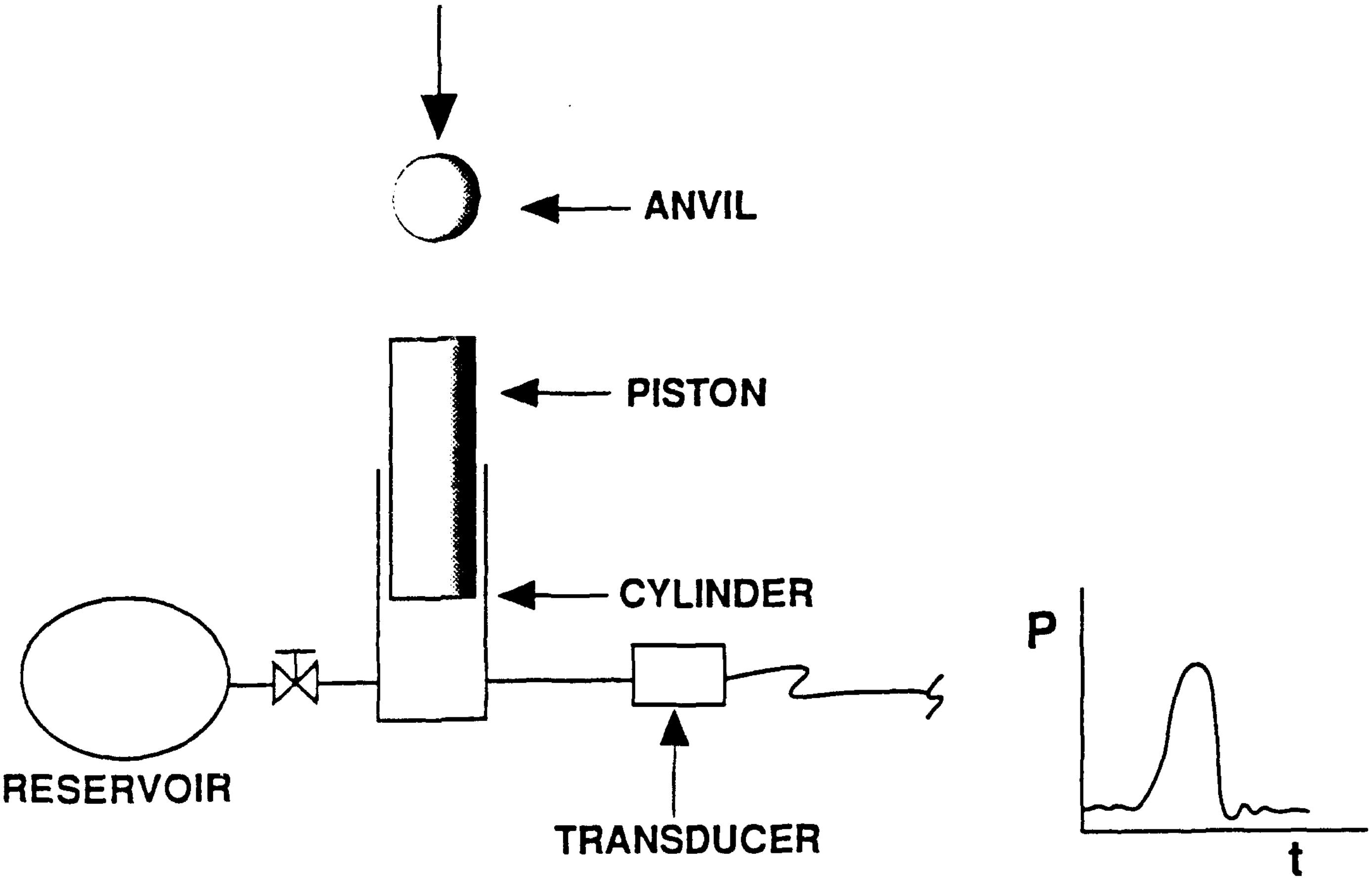
100
%
50
10
FREQUENCY
50
100
(x 10³)
ILLUSTRATIVE RESPONSE TO STEP IN SHOCK TUBE

(TP268)

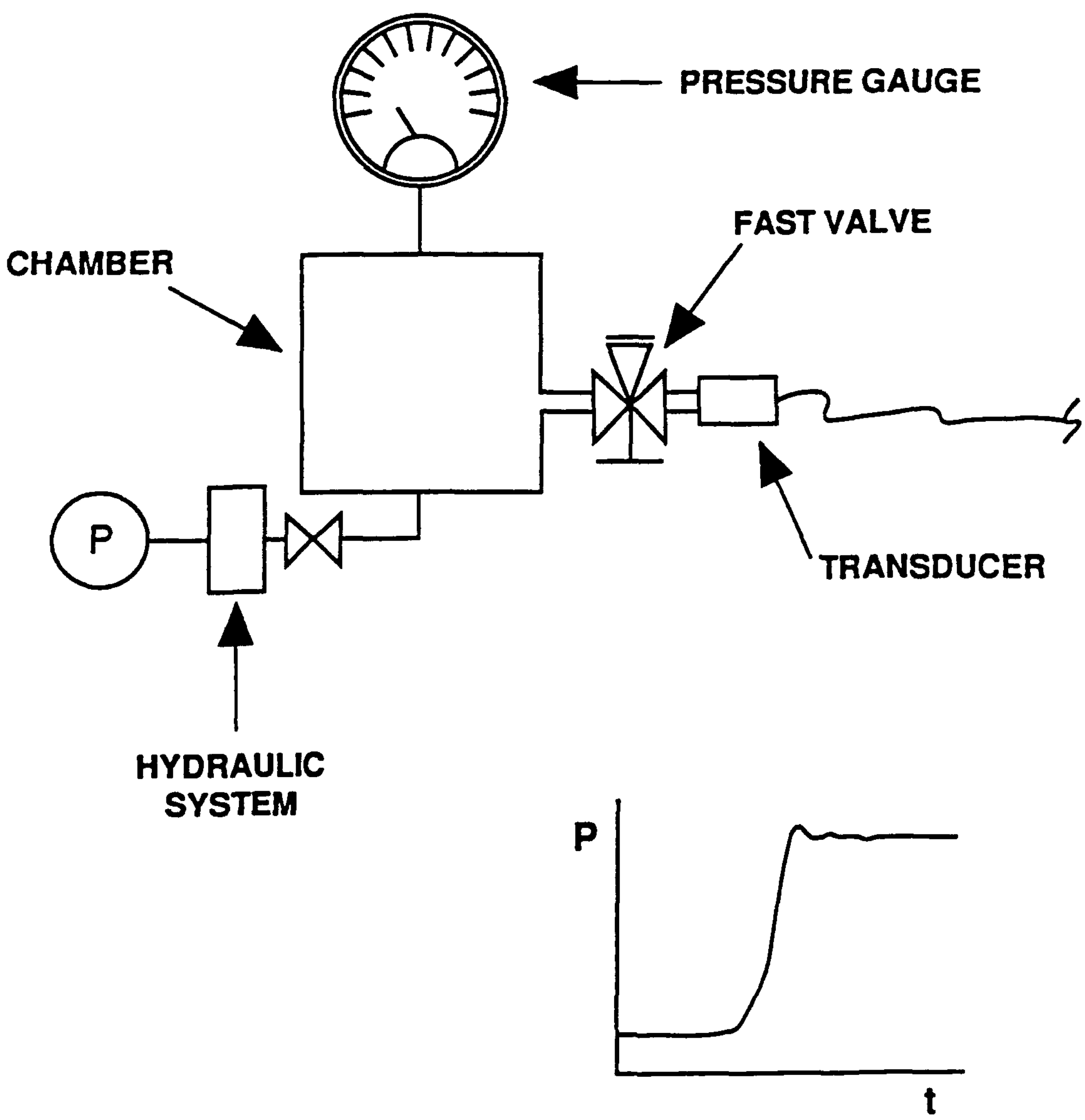
.4.1



HYDRAULIC DEAD WEIGHT CALIBRATOR



DROP BALL IMPULSE CALIBRATOR



HIGH PRESSURE HYDRAULIC STEP FUNCTION CALIBRATOR

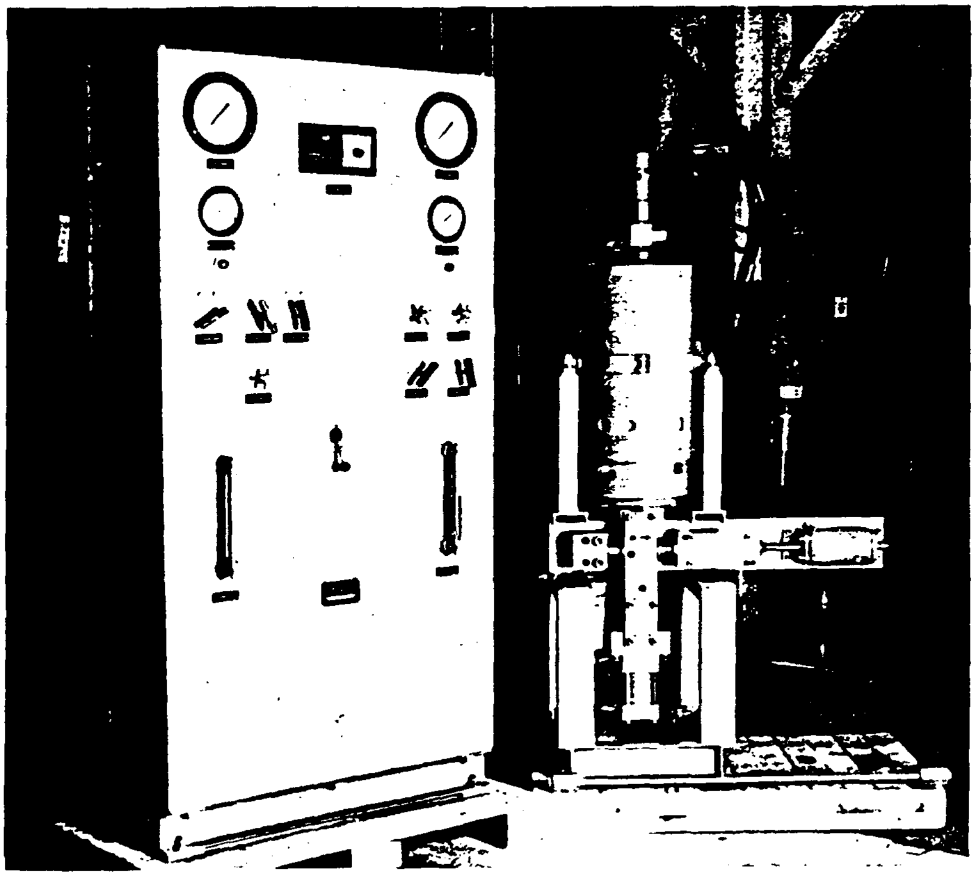
HARWOOD ENGINEERING COMPANY, Inc.

LABORATORY AND INDUSTRIAL
HIGH PRESSURE EQUIPMENT

455 SOUTH STREET
WALPOLE, MA. 02081-2799
TEL. 617-668-3600
TELEX 279990
HARWOOD WPOLUR

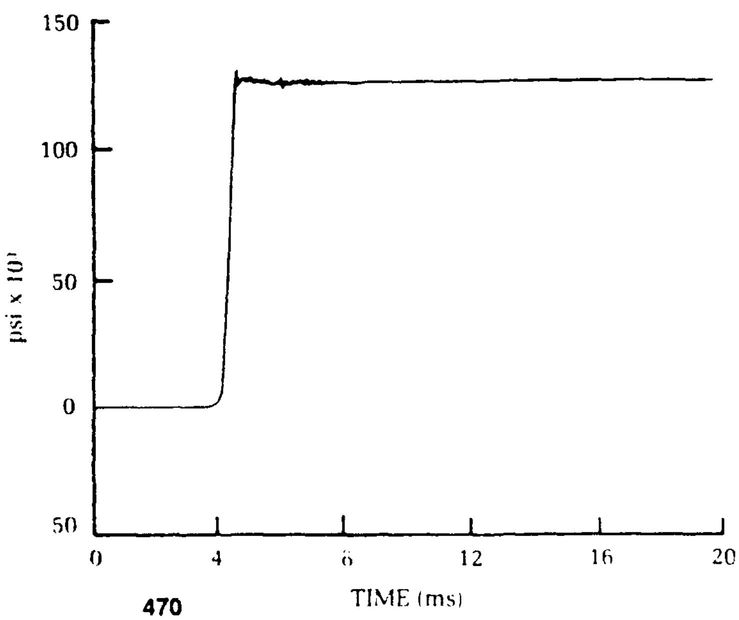
DYNAMIC POSITIVE STEP PRESSURE GENERATOR

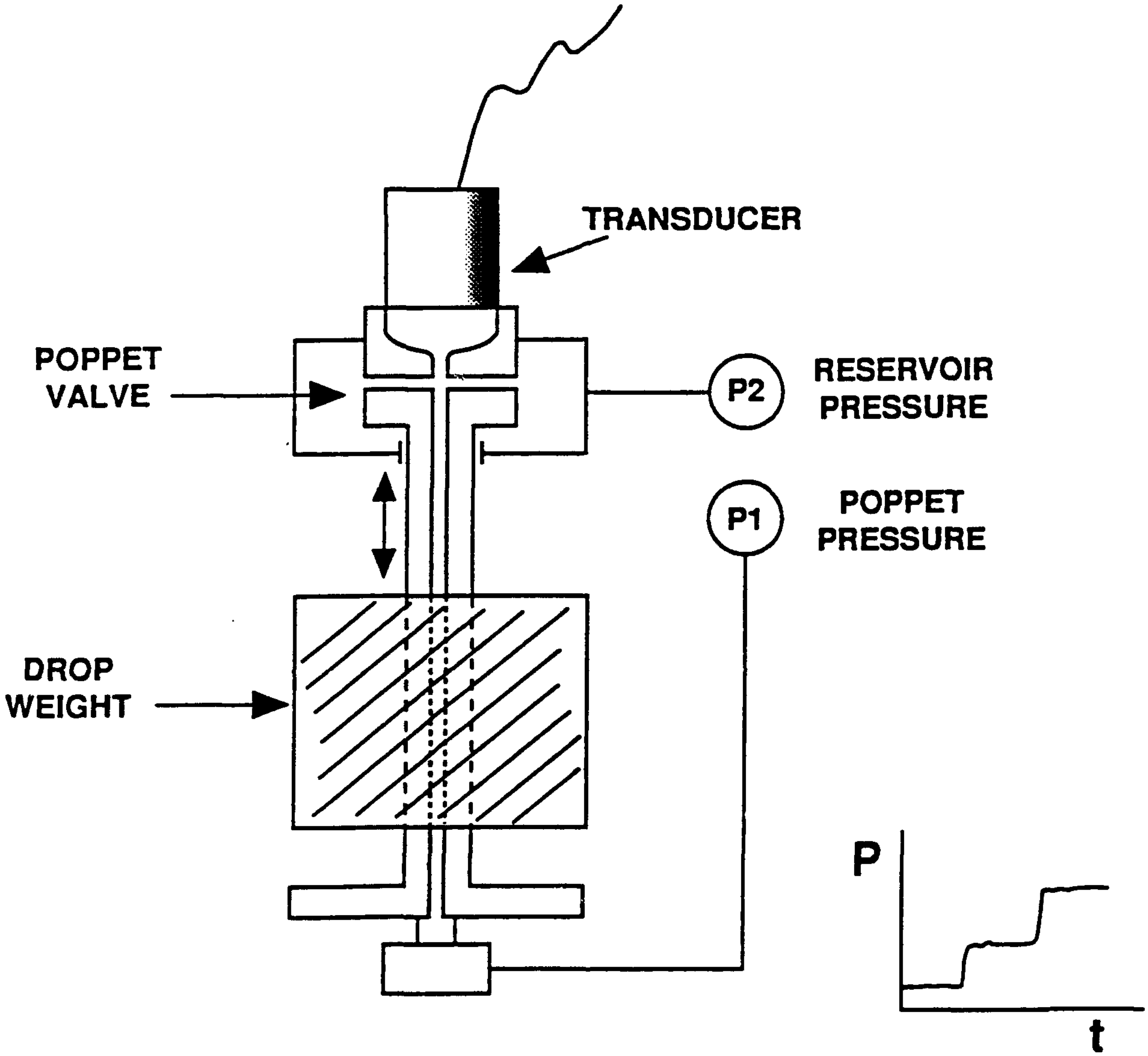
Dynamic Pressure Range 5000 to 150,000 psi
Traceable to National Bureau of Standards



Control Panel
&
Pressure Vessel

Typical Response
of Transducer
to 125,000 psi Step





PNEUMATIC STEP GENERATOR

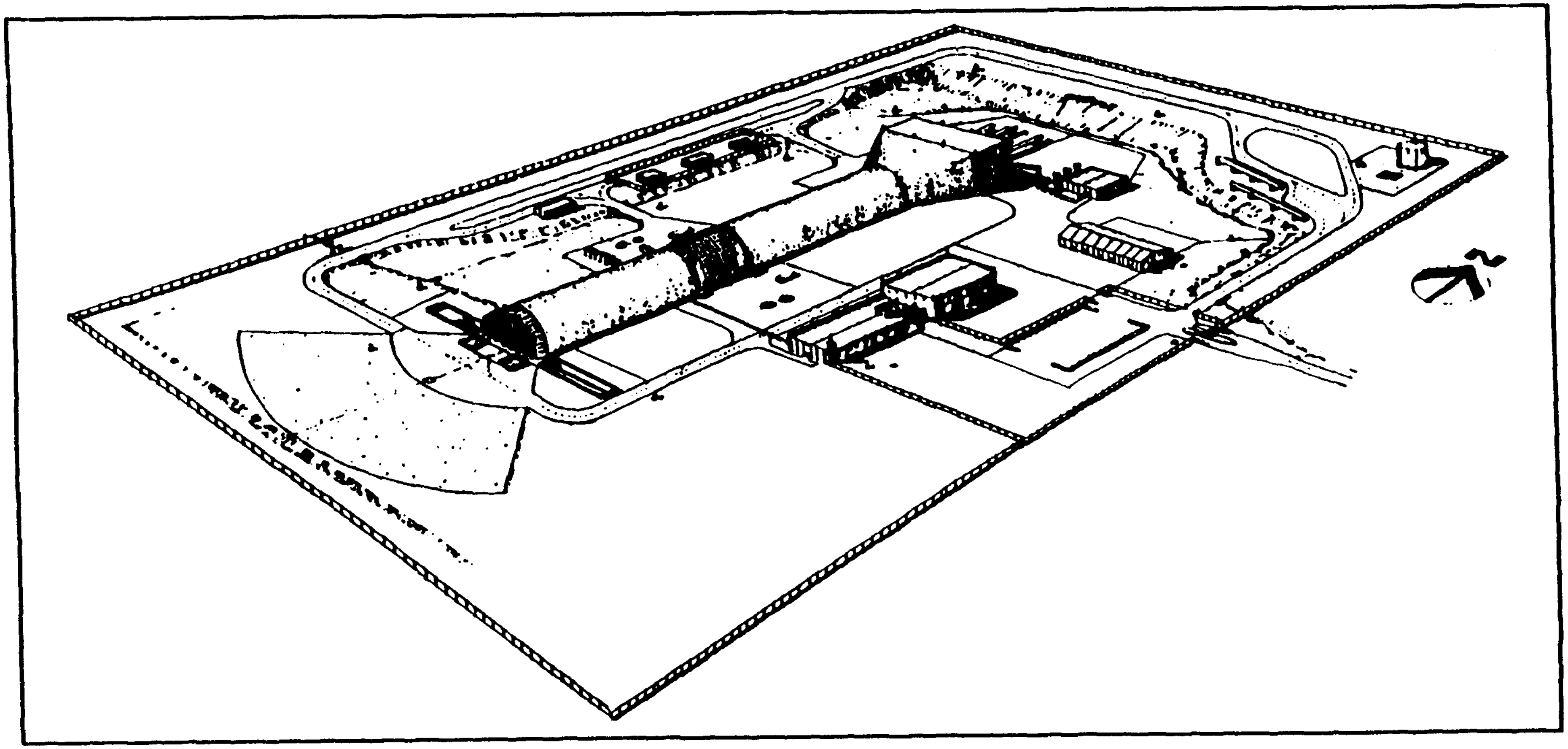


Figure VI-13. Large Blast/Thermal Simulator

CURRENT CALIBRATION TECHNOLOGY

- WEAK TRACEABILITY
- NEAR UPPER RANGE LIMIT
- DOES NOT SIMULATE USE CONDITIONS

G1-91-1242-2

NATIONAL MEASUREMENT TECH BASE

- CURRENTLY INADEQUATE
- NO NATIONAL MEASUREMENT SERVICES
- DYNAMIC GAS PRESSURE & TEMPERATURE TRACEABILITY NEEDED
- MUST SUPPORT HIGH DYNAMIC PRESSURE
- MUST INCLUDE TRANSFER STANDARD CALIBRATION SERVICE

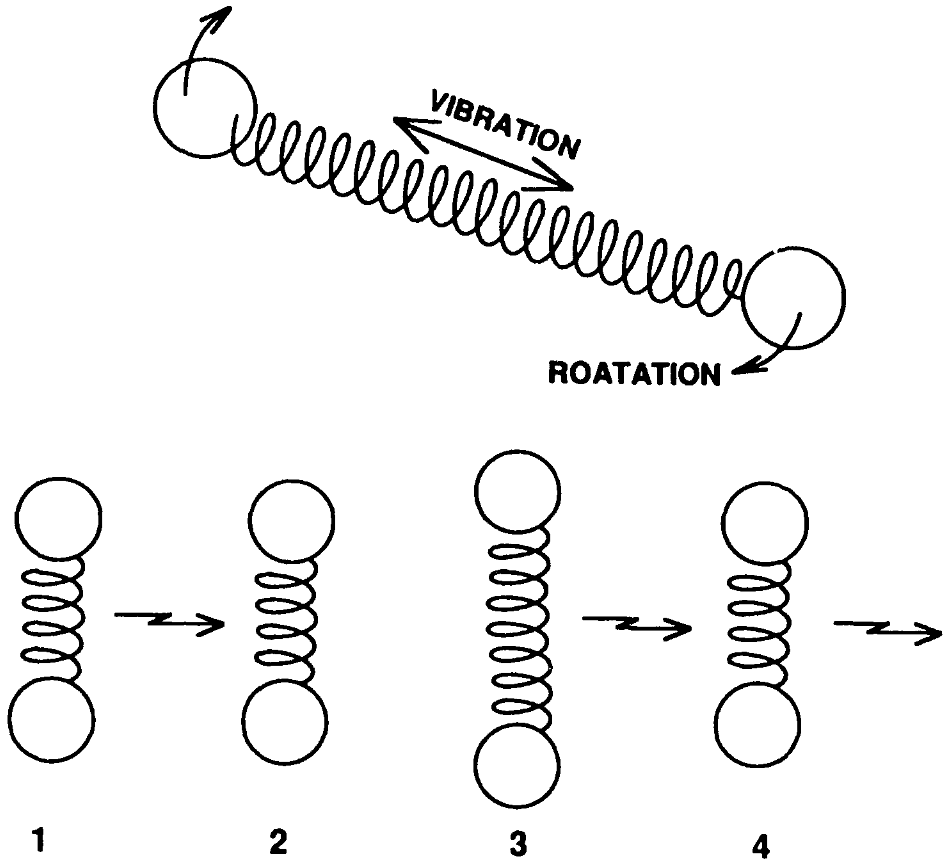
G1 91-1242-3

ARMY METROLOGY R&D PROJECT

- NIST INVESTIGATION OF POTENTIAL DYNAMIC PRESSURE/ TEMPERATURE MEASUREMENT METHOD
- TWO NIST RESEARCHERS
- TWO LABORATORIES FULL OF HIGH POWER LASER SYSTEMS
- NIST COMPUTER SUPPORT
- ARMY COST $55K/YEAR
- NIST INVESTMENT AT LEAST $500K/YEAR
- INITIATED 1987

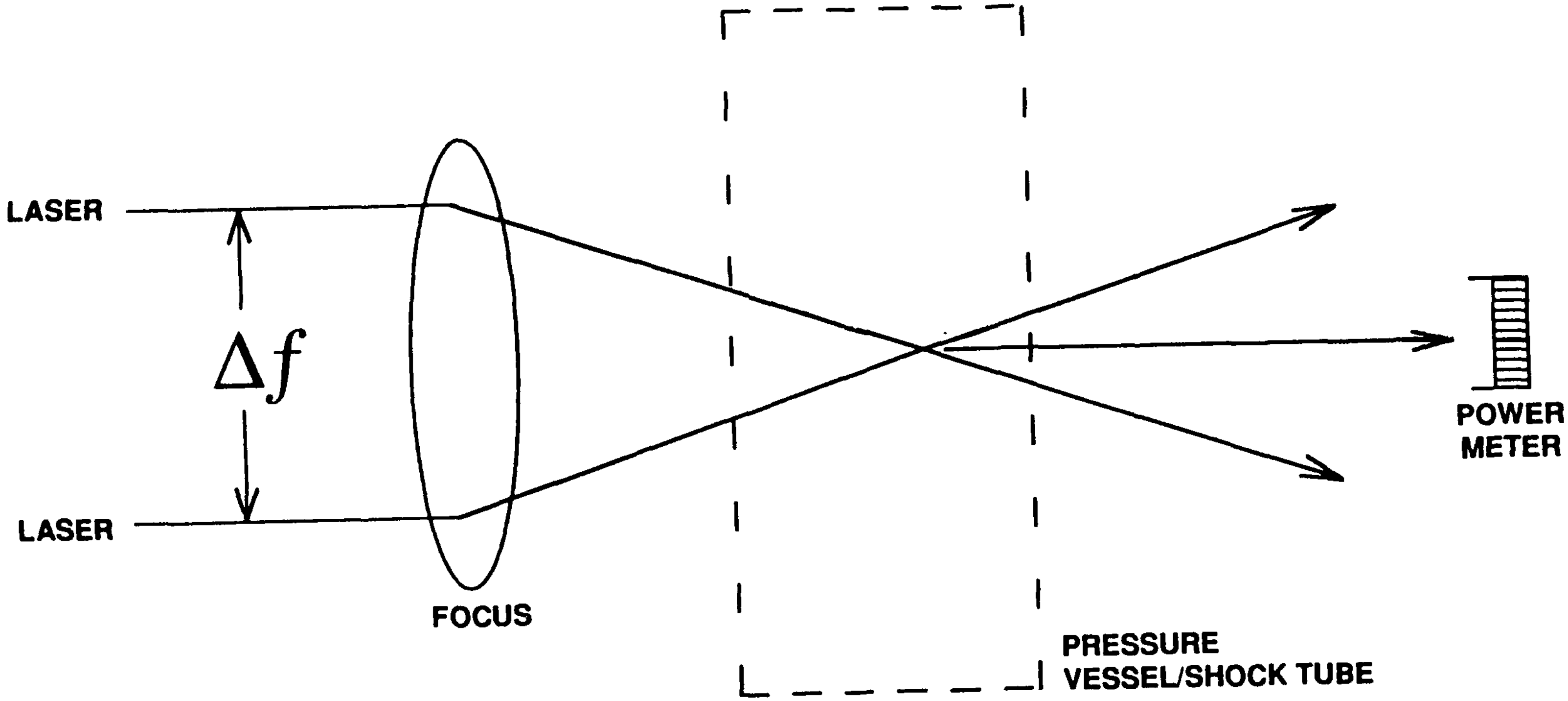
G1-91-1242-7

THE CONCEPT



G1-91-1242-6

LABORATORY SYSTEM
- SIMPLIFIED -



G1-91-1242-5

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Journal of Research of the National Institute of Standards and Technology

[J. Res. Natl. Inst. Stand. Technol. 95, 33 (1990)]

A Proposed Dynamic Pressure and Temperature Primary Standard

Volume 95 Number 1 January–February 1990

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Diatomic gas molecules have a fundamental vibrational motion whose frequency is affected by pressure in a simple way. In addition, these molecules have well defined rotational energy levels whose populations provide a reliable measure of the thermodynamic temperature. Since information concerning the frequency of vibration and the relative populations can be determined by laser spectroscopy, the gas molecules themselves can serve as sensors of pressure and temperature. Through measurements under static conditions, the pressure and temperature dependence of the spectra of selected molecules is now understood. As the time required for the spectroscopic measurement can be reduced to nanoseconds, the diatomic gas molecule is an excellent candidate for a dynamic pressure/temperature primary standard. The temporal response in this case will be limited by the equilibration time for the molecules to respond to changes in local thermodynamic variables. Preliminary feasibility studies suggest that by using coherent anti-Stokes Raman spectroscopy we will be able to measure dynamic pressure up to 10^8 Pa and dynamic temperature up to 1500 K with an uncertainty of 5%.

Key words: dynamic calibrations; dynamic sources; molecular transducer; nonlinear optical spectroscopy; pressure; primary standard; Raman spectrum; temperature; transducers.

Accepted: October 13, 1989

1. Introduction

With modern laser diagnostic techniques, it is possible to characterize the pressure (P) and temperature (T) of a gas at the molecular level. The measurement times for these techniques are such that the response to changes in T and P is limited only by the fundamental relaxation and transport processes of the molecular system. This provides the basis for a new approach to the calibration of transducers used in the measurement of dynamical P and T. The essence of dynamic calibrations is the determination of the time dependent response of the transducer, which requires, at a minimum, the application of a stimulus with known time dependence, i.e., a "standard" dynamic source.

If one were to rely on conventional sensors (whose response functions are *not a priori* known) to characterize the dynamic source, an inescapable circularity emerges from the preceding paragraph. Approaches to solution of this problem have traditionally [1] relied on some form of calculable source. In essence, this is a source some properties of which can be determined from accurate measurements, for example of quasi-static values of P and T and time rate of change of position, and whose time dependent P and T is then derived from an appropriate theoretical prescription, e.g., from hydrodynamics for sound propagation or fluid mechanics for shock waves (with appropriate equa-

PROJECT HISTORY

● LABORATORY CONSTRUCTED	1987
● STATIC P & T MEASUREMENTS	1988
● PRINCIPAL VALIDATED	1989
● DESIGN/CONSTRUCTION OF HIGH PRESSURE SHOCK TUBE BEGUN	1989
● SIGNIFICANT PUBLICATION	1990
● INTERNATIONAL WORKSHOP	1991

- INTERIM SHOCK TUBE CALIBRATION NEEDED
- STRONG ARMY/DOD PARTICIPATION
- STRONG U.S. NEED
- FOREIGN INTEREST/PARTICIPATION

● PRODUCTS

- 1992 NIST CAL SUPPORT (SHOCK TUBE)
- 1995 INTRINSIC SYSTEM ON LINE

G1-91-1242-9

CONCLUSIONS

- SIGNIFICANT ARMY LOG ISSUE EXISTS

- MODEST ARMY LOG R & D STIMULATED & LEVERAGED MAJOR SCIENTIFIC ADVANCE

- PRODUCTS
  - ARMY MEASUREMENT SUPPORT SERVICES
  - U.S./DOD/INTERNATIONAL SUPPORT
  - MOST SIGNIFICANT DYNAMIC PHYSICAL MEASUREMENT ADVANCE IN A GENERATION
  - ARMY PROBLEM SOLVED WITHOUT NEW TRANSDUCERS OR TESTERS

G1-91-1242-8

A 10ppm ACCURATE DIGITAL AC MEASUREMENT ALGORITHM

August 09, 1991

Ronald L. Swerlein
Hewlett Packard Co.

ABSTRACT

Digital sampling has been used for a number of years to make specialized and general purpose RMS AC voltage measurements. An algorithm is described that can be implemented using commercially available equipment to achieve a 1 year absolute accuracy approaching 10ppm. The implementation is usable for up to 1% distorted sinewaves with frequencies below 0.01 Hz and up to 1kHz with voltages from 10mV to 700V. Also, the error analysis serves as a tutorial on the limitations of integrating voltmeters used in a digitizing application.

INTRODUCTION

A digital sampling algorithm was developed and optimized for precision low frequency AC RMS measurement using the Hewlett Packard model HP3458A voltmeter. It's accuracy at high speed, precision time base, level triggering, and frequency measurement function made it ideal for this application. While optimized for this specific voltmeter, the principles discussed herein should be transportable to other digitizing equipment.

A program written in HP BASIC implementing this algorithm is listed in the paper's appendix. Operating instructions and an address for obtaining more information and program copies are also included.

Voltmeters have been used as samplers to digitally measure low frequency AC for many years (albeit in a somewhat handicapped fashion). By definition, an RMS (Root <u>MEAN</u> Squared) measurement involves averaging, which for low frequencies requires large amounts of time. For periodic waveforms, this can be substantially reduced if the sampling interval is exactly one or more periods. But due to the voltmeter's timebase quantization, this can normally be done only for specific frequencies. For example, if the voltmeter can space samples at multiples of 0.1s, it's pretty easy to see that 100 samples can exactly sample 10 periods of a 1 Hz waveform. If the waveform had a frequency of 1.3Hz, however, things wouldn't be quite so simple. In general, sampling over integral number of periods can only be achieved to a precision of 1/2 the voltmeter's time quantization. This imprecision can be a source of significant measurement error.

Another source of measurement error is aliasing. A pure sinewave can be perfectly reproduced (and measured) if the sample rate is greater than twice it's frequency (Nyquist theorem). For RMS measurement, a looser restriction that allows undersampling applies. An undersampled sinewave still appears as a sampled sinewave - but at a lower frequency. The RMS operation involves squaring this aliased sinewave which generates higher frequencies that may themselves alias down to some lower frequency. Errors will manifest if the lowest aliased frequency component is inside the passband of the RMS averaging filter. With care and a pure sinewave, it's usually possible to avoid this. But what about a distorted sinewave? Distortion appears in the frequency domain as higher freauency harmonics that can each contribute alias errors when undersampled. To complicate matters further, the desire to sample over integral number of periods tends to force a sample rate that is an exact multiple of the distorted sinewave's frequency and practically guaranteeing aliasing problems with it's harmonics.

This sampling algorithm uses the DCV (DC voltage) function of the HP3458A to digitize a low frequency waveform (from less than 0.1Hz up to 1kHz) and compute it's ACV and ACDCV RMS voltage. Errors due to sampling over inexact integral multiples of the waveform's period are eliminated with an algorithm involving the HP3458A's level trigger. Sample timing is selected to reduce aliasing of higher frequency harmonics. In addition, a number of errors introduced by the voltmeter (most notably that due to time integration) are backed out.

When the program in the appendix is run, an estimate of the total measurement uncertainty is displayed. Also displayed are measurement bandwidth, the sampling parameters, and the fundamental frequency of the input signal. Next, several intermediate results are displayed and then the final answer is computed. An example is shown in figure 1.

```
SIGNAL FREQUENCY(Hz)= 99.9991047572
Number of samples in each of 6 bursts= 1070
Sample Spacing(sec)=  .0008411
A/D Aperture(sec)= .0008111
Measurement bandwidth(Hz)=  616.4
SINEWAVE MEASUREMENT UNCERTAINTY(ppm)= 13
ADDITIONAL ERROR FOR 1% DISTORTION(ppm)= 8

The 6 intermediate results:
     1
      .999975
      .999979
      .999996
      .999976
      .999978

AC RMS VOLTAGE=     .999984
ACDC RMS VOLTAGE=   .999984
```

Figure 1 - Typical program output (see appendix)

THEORY of OPERATION

The RMS equation is:

IN GENERAL: $T \longrightarrow \infty$

$$\sqrt{\int_{t-T}^{t} \frac{V^2(t)}{T}\, dt} \qquad (1)$$

This is usually done in less than the infinite time shown above. The shortened equation is shown below where the averaging interval is T. If s(t) is periodic of period T then the result is exactly the same as T=infinity above.

IF PERIODIC:

$$\sqrt{\int_{t-NT}^{t} \frac{V^2(t)}{NT}\, dt} \qquad (2)$$

T= PERIOD, N INTEGER

If s(t) is a sinewave (sin(wt)), the above equation reduces to:

$$\sqrt{\int_{t-T}^{t} \frac{\sin^2(2\pi Ft)}{T}\, dt} \qquad (3)$$

Expressed as an error from the ideal result of 1/SQR(2), the above is approximately:

```
       !--scale factor--!   !--time varying ripple--!
   Err= sin(wT)/(2wT)     *      sin(2wt)                    (4)
```

This equation is bounded by the scaling factor 1/(4*PI*n) where n is the number of periods that are averaged over.

If T was exactly an integral number of periods of the input signal the above Err would be exactly zero. In practice, this can only be done with some uncertainty. Call this uncertainty dt. Then the scaling factor in the above equation reduces to:

Err= sin(w*Tperfect+wdt)/(2wT)= approx.= dt/(2wT)= dt/(2T) (5)

The algorithm uses the HP3458A to attempt to take a burst of Num samples spaced Tsamp apart where Num*Tsamp is an integral multiple of periods. The sample spacing of the HP3458A is quantized at 100ns. Therefore the sample spacing Tsamp can deviate from the ideal value needed by as much as 50ns. dt above then accumulates as the number of samples increases. T also increases as Num increases so the error term becomes:

Err= dt/(2T)= 50ns*Num/(2*Tsamp*Num)= 50ns/(2*Tsamp) (6)

This error is reduced still further if Num is large. The timing error (50ns*Num) can not increase forever. Num is selected so that whatever the timing error of Tsamp, the worst case deviation from the ideal of Tsamp*Num= integral periods is Tsamp/2. Therefore the error is bounded by:

Err= dt/(2T)= (Tsamp/2)/(2*Tsamp*Num)= 1/(4*Num) (7)

The actual error term is therefore bounded by the smaller of:

Err= smaller of [50ns/(2*Tsamp) or 1/(4*Num)] (8)

The algorithm first reduces ripple by reducing the scale factor of equation 4. This is achieved by selecting Num*Tsamp as close to ideal as possible so that the resultant error is that expressed by equation 8. The next level of reduction is done by synchronizing the burst of Num samples off of the zero crossing of the input waveform. The internal level trigger in the HP3458A is used to start the burst an amount of time equal to Delay from the zero crossing of the input signal. Multiple measurements will be identical without a time varying "ripple". The ripple component is "frozen" in time at a value of:

$$\text{Ripple} = \sin(wT)/(2wT) * \underbrace{\sin(2*w*\text{Delay})}_{\text{Frozen in time}} \qquad \text{Note: } w = 2*\text{PI}*\text{Freq} \qquad (9)$$

Now, these level triggered bursts are repeatably stable, but they still have an error equal to the "frozen" ripple. If multiple bursts of Num samples are taken with different values of Delay, it can be seen in equation 9 that differing values of ripple will be created. It can be conceptualized that the ripple term is being sampled in equivalent time at the difference of the different Delay values. If one ripple period is sampled at two or more equally spaced points, it is possible to average out the frozen ripple. For example, if 4 bursts are taken with each burst delayed relative to the previous by 1/(4*Freq), the resulting errors will cancel when the measurements are averaged. Figure 2 illustrates this technique.

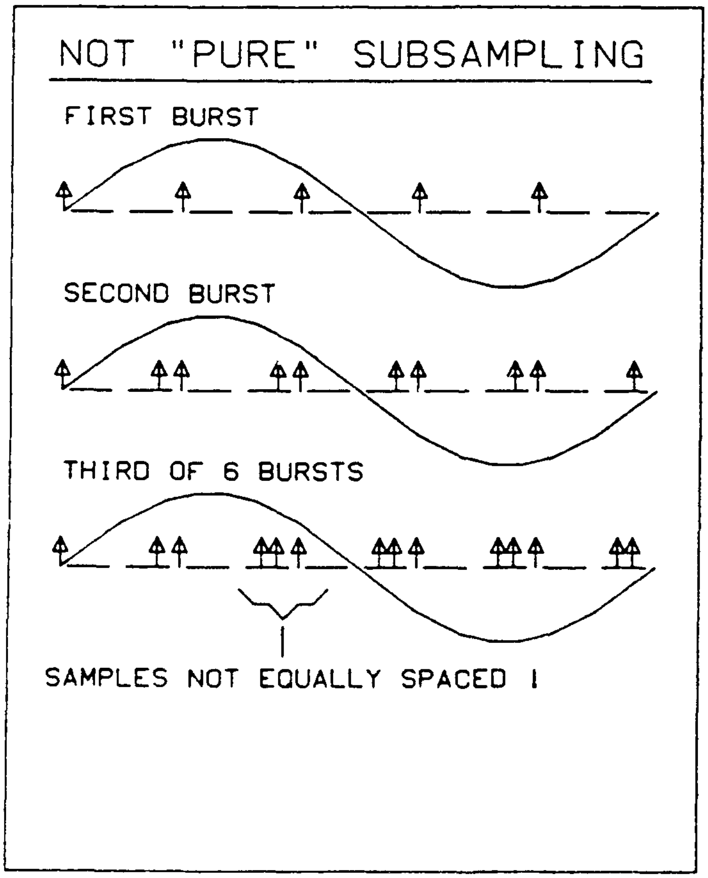

Figure 2 - Multiple bursts to average "frozen" ripple

The main ripple frequency in equation 9 is 2*Freq. Nyquist theory requires that at least 2 samples per period are needed for full characterization. Therefore the maximum value of Delay is 1/(4*Freq) and the minimum value for the number of bursts is 4 if the ripple waveform is to be sampled over one period (1/Freq). If the input signal isn't a pure sinewave, then the ripple will have higher frequency components which require smaller delays and larger number of bursts if aliasing is to be avoided. It can be shown that 6 bursts will average out 2nd harmonic distortion and that 8 bursts will average up to the 3rd harmonic. Since the algorithm is restricted to sinewaves of less than 1% distortion, the ripple due to harmonics is small relative to the main ripple defined in equation 8. And because for many waveforms energy decreases at higher frequencies, it may be appropriate to ignore these errors. Under this situation, 6 or 8 bursts are adequate. The following derivation illustrates this point. If the input signal is a sinewave with 1% distortion at the 3rd harmonic (D=.01), the RMS equation (3) becomes:

$$\sqrt{\int_{t-T}^{t} \frac{(\sin(2\pi Ft) + D\sin(6\pi Ft))^2}{T} dt} \qquad (10)$$

It reduces (sin(w1t)sin(w2)= cos((w1-w2)t)/2 - cos((w1+w2)t)/2) to :

$$\sqrt{\frac{1}{T}\int_{t-T}^{t} \left[\frac{1-\cos(4\pi Ft)}{2} + D\cos(4\pi Ft) - D\cos(8\pi Ft)\right] dt} \qquad (11)$$

Reducing to a form similar to equation 4, equation 11 becomes:

$$Err= D\sin(\omega T)/\omega T * \sin(2\omega t) - D\sin(2\omega T)/\omega T * \sin(4\omega t) \qquad (12)$$

A similar form of equation 8 can be derived for the 4*Freq ripple in equation 12. The ripple error is the smaller of:

Err= smaller of [2*D*50ns/Tsamp or D/Num] (13)

The purpose of equation 12 is to show that third harmonic distortion generates ripple components of 2*Freq and 4*Freq and that this ripple is much smaller than the main ripple. Equation 13 shows that with 1% distortion (D=.01), the magnitude of this ripple with a sample time of 1ms is only 1ppm. This is the maximum error that would exist if this distortion term was undersampled and aliased. To summarize then, under most circumstances, there isn't much need for the number of bursts to be any higher than 4 or 6.

INTEGRATING VOLTMETER LIMITATIONS and CORRECTIONS

The actual program includes various enhancements to the theory described above. Most are means to compensate for various deficiencies of the HP3458A.

Reference is made to the program listing contained in the appendix.

A/D aperture correction:

The DCV function of the HP3458A uses an integrating analog to digital converter (A/D) that integrates the input signal over a very specific time aperture. This aperture can be selected between 500ns and 1s with 100ns quantization and it's time accuracy is basically the accuracy of the crystal clock used to control the A/D (0.01%). In the time domain, a waveform is integrated over the aperture as defined by the following equation:

INTEGRATING A/D IN TIME DOMAIN:

$$\int_{t-Aper}^{t} V(t)/Aper \; dt \qquad (14)$$

The Fourier transform of equation 14 is sometimes a more convenient means for analyzing the A/D's behavior. This behavior is expressed in the frequency domain by a sinc function. The error relative to perfect sampling is shown below:

X= PI*Aper*Freq   Err= sin(X)/X -1   (15)

Notice that at DC (X=0), the error is zero and at X=n*PI the error is exactly -100%. This behavior is very desirable for a DC voltmeter since common interference due to power line and power line harmonic pickup is rejected if the aperture is selected to be an integer multiple of the power line period. Of greater concern to this article is the fact that this error is very repeatable and even large errors can be corrected with high precision. For example, an integrating A/D with a 1ms aperture sampling a 100Hz sinewave will introduce an error of -16368ppm in an RMS measurement. Since the A/D's aperture and the frequency of the measured waveform are known, equation 15 can be used as a correction factor to the computed RMS value of the sampled waveform. For the above example, the -16368ppm error can be corrected with an uncertainty of less than 3ppm. Referring to the appendix, line 830 to 1140 of the program show how this correction occurs.

For distorted sinewaves this correction is not perfect, however, since the distortion harmonics are attenuated more by the A/D's aperture than the fundamental frequency. The correction calculated for the fundamental frequency will then be insufficient for the harmonics. By limiting the distortion to some value (under 1% for example), the correction uncertainty becomes quantifiable.

Frequency Measurement:

The input signal's frequency is measured by the HP3458A and used as an input to an algorithm that computes sample time (Tsamp) and the number of samples in a burst (Num). Ideally, the samples are picked such that Num*Tsamp is an integral multiple of (1/Freq) with an uncertainty implied by equation 8. However, the voltmeter's time base uncertainty could lead to a larger error. The HP3458A's data sheet shows it's time base error as 0.01% which is a reflection of the accuracy of an internal crystal clock. For example, 10000 samples programed to be spaced 1ms apart may actually take 10.001s to complete instead of the ideal 10s. If the desire was to exactly sample 10 periods of a 1Hz sinewave, an unanticipated error of 1ms may occur.

Because the same clock used for sample timing is also used to set the gate time in the internal frequency measurement, in principle this 0.01% time base error is invisible. For the above example where the timebase is off by 0.01%, the 1Hz sinewave will be measured as 1.0001Hz. Then only 9999 samples will be picked for Num and the total sample time for the Num samples will be the ideal 10s instead of 10.001s. Exactly 10 periods of the 1Hz sinewave will be sampled. This won't happen automatically, however. When the HP3458A is calibrated, the FREQUENCY function of the HP3458A is compared to an external frequency standard. A correction constant is stored in permanent memory and used to scale raw frequency measurements (but not the sample timings). Therefore a frequency measurement won't show the same errors as the time base unless there is some way to "uncalibrate" the voltmeter. This is done by querying the FREQUENCY calibration constant and backing it out of the frequency measurement. The function FNFreq (line 1470) illustrates how this is done.

Bandwidth correction:

The input signal is effected by the HP3458A's bandwidth. To a large extent, this error is repeatable from one HP3458A to another and can therefore be backed out.

On the .1, 1, and 10V ranges, the input signal is effected by a 1 pole low pass filter with a nominal bandwidth of 120kHz. This error term is the dominant error for the 1V and 10V ranges:

Err= SQR(1/(1+(Freq/120kHz)^2)) - 1 (16)

On the 100V and 1kV ranges, the input signal is effected by the bandwidth of the 10M ohm high voltage input attenuator which is about 36kHz. This error term is the dominant error term for these ranges:

Err= SQR(1/(1+(Freq/36kHz)^2)) - 1 (17)

The 100mV range has the same error component as the 1V and 10V ranges plus an additional error term due to the input amplifier's bandwidth being substantially lower. At low frequencies the input amplifier is actually peaking with a 1 pole approximation frequency of 82000Hz. The 100mV range exhibits an error of:

$$Err= SQR((1+(Freq/82kHz)^2)/(1+(Freq/120kHz)^2)) - 1 \qquad (18)$$

The function FNVmeter_bw (line 1720) performs the bandwidth correction calculations in the program. The error estimation routines assume that the bandwidths of the HP3458A are only known to +-30% and calculates uncertainties accordingly.

It should be noted that for frequencies below 200Hz, the bandwidth uncertainties are insignificant. They become significant to the 40ppm level at 1kHz on the 10V and lower ranges and significant to the 150ppm level at 1kHz on the higher voltage ranges.

ERROR ESTIMATION

Referring to the appendix, the subroutine Err_est (line 1900) calculates an estimate for total measurement uncertainty. The various components of this calculation are discussed below.

Basic 1 year accuracy:

The DCV function's ppm of reading specification for 1 year after an ACAL DCV operation is close to 10ppm for all ranges. The ppm of range specifications can be ignored since this specification is intended to cover offset variations which add in an RSS fashion for ACV RMS calculations. If the ppm of range errors were large enough they would have to be considered, but they are of the order of 1uV which adds less than .005ppm error to a 10mV measurement!

It should be noted that if less than a 1 year calibration cycle is used for the HP3458A, this error can be substantially lower. Line 1970 is where this error is located. This error is of a random nature and is appropriately handled in a statistical fashion for error analysis purposes.

Voltmeter bandwidth:

Equation 16, 17, and 18 illustrate how corrections for errors induced by the limited bandwidth of the HP3458A are made. For error analysis purposes it is assumed that the various bandwidths are only known to +-30%. Line 2060 shows how this calculation is made.

This error is random and is handled statistically for error analysis purposes.

A/D gain uncertainty for short apertures:

The basic 1yr accuracy discussed above is based on an A/D aperture of 100 power line cycles or greater. For shorter apertures, the accuracy of the HP3458A is reduced. This effect is shown in the data sheet on page 11 in the form of a graph. Line 2120 of the program reduces this graph to equation form (it is valid only for short apertures).

This error is random and handled statistically for error analysis purposes.

A/D aperture uncertainties in the frequency domain:

Equation 15 and the related discussion concerns the nature of backing out gain errors that are a function of A/D aperture and input signal frequency. If the A/D is programed for a particular aperture, the actual aperture is only known to the tolerance of the crystal clock oscillator used to control the A/D (0.01%). Also, various A/D switching effects add another 50ns of uncertainty. Line 2290 shows how this uncertainty is quantified.

This error is random and handled statistically for error analysis purposes.

Errors due to 1% distortion of the input signal:

As mentioned in the discussion pertaining to equation 15, backing out sinc(X) errors due to A/D aperture can only perfectly correct the fundamental frequency of a distorted sinewave. Other frequencies due to 1% signal distortion are not corrected properly. For error analysis purposes it is assumed that a distortion component equal to 1% of the fundamental frequency amplitude is present at the third harmonic. The error due to incorrect A/D aperture correction is quantified on line 2420.

This error is minimized if the A/D aperture is as small as possible. This error is returned separately so that if the user of the program does not have a distorted signal the error can be ignored.

Individual sample noise:

The HP3458A exhibits reading to reading variation that is a function of A/D aperture and voltage range. This 1 standard deviation measurement noise is specified in a graph on page 11 of it's data sheet. Line 2740 translates this graph into an equation that is valid only for short apertures. The data sheet's noise multiplier of 20 for the 100mV range is overly pessimistic for short apertures and the more realistic value of 7 is used on line 2790.

This noise is multiplied by 10 to reflect the worst case of operation at 1/10 full scale (line 2760) and then further scaled by 2 to reflect variations at the 2 standard deviation level.

Most of the measurement noise determined above is uncorrelated from sample to sample. Therefore, the total noise of a measurement composed of a multitude of samples is then reduced by the the square root of the number of samples taken (line 2750).

This error term is handled absolutely to reflect the fact that it will eventually be seen if measurements are repeated enough.

Dissipation factor error:

The input signal of the HP3458A is routed to a 10Mohm input attenuator on the 100V and 1kV ranges. The output resistance of this attenuator is 100kohms and is routed to the input of the main DC voltage amplifier. On the way to the amplifier this signal sees about 30pF of good low dissipation factor (D.F.) capacitance (FET inputs, ceramic capacitances, etc.) and about 15pF of poor D.F. printed circuit (pc) board capacitance. The pc board capacitance has a dissipation factor value of about 0.6%. The effective D.F. of the combined capacitance of 45pF is about 0.2% (.6*15/45).

For the low voltage ranges, the input signal is routed to a 10kohm resistor whose output drives about 120pF of good D.F. capacitance and 15pF of bad D.F. pc board capacitance. The effective D.F. of the combination is about 0.07% (.6*15/135).

A capacitor that has a dissipation factor of Df acts like it has a parallel resistance across it equal to 1/Df times its capacitive reactance. Thus it's parallel resistance is 1/(Df*2*PI*C*Freq). This resistance creates a resistive divider with the input resistance described above.

Line 3050 quantifies this error. This error is only significant on the 100V and 1000V ranges and is always negative. It is treated in an absolute sense for error analysis purposes.

Total error calculation:

Random errors are handled in a statistical fashion. Other errors are added in an absolute fashion. Line 3100 shows how the program adds the various errors.

PERFORMANCE VERIFICATION

One aspect of verification is repeatability. That is, how stable are multiple measurements of the same source over some time interval? At 7V and 40Hz, informal comparisons with a Datron model 4200 AC calibrator over a week in an environment stable to +-2 deg.C varied less than 10ppm. The same measurement over 10 minutes exhibited a standard deviation of 1.5ppm. 10 minute standard deviations when measuring a 7V, 40Hz sinewave sourced from a thoroughly warmed up Hewlett Packard HP3245 universal source are 0.4ppm.

Another aspect of verification is accuracy. For audio band frequencies, thermal AC/DC converters can be traced to national standards with better than 10ppm uncertainty. This traditional procedure, while marginal for verifying a 10ppm measurement, can be used at these frequencies to verify the algorithm's performance. At lower frequencies where available thermal converters become less accurate, a different approach is required.

The United States' National Institute of Standards and Technology (NIST) has developed a digital synthesized calculable AC standard suitable for this verification. It uses an 8 bit digital to analog converter (DAC) in conjunction with sinewave look-up tables to generate stepped sinewave approximations. Varying the DAC's clock frequency allows the source's output frequency to vary from below 0.1Hz to above 20kHz (see Reference 1).

The accuracy of the AC standard is derived from DC measurements of the voltage steps composing the sinewave approximation. These steps are measured during a calibration procedure where the DAC's clock is paced off the "Measurement Complete" line of a precision DC voltmeter. Assuming that the voltages do not change at other clock frequencies or at a later time, the RMS voltage of the standard can be computed. The accuracy of this computation is relatively independent of the DAC's linearity.

Figure 3 is an illustration of the output of the AC standard (with the step size exaggerated for clarity).

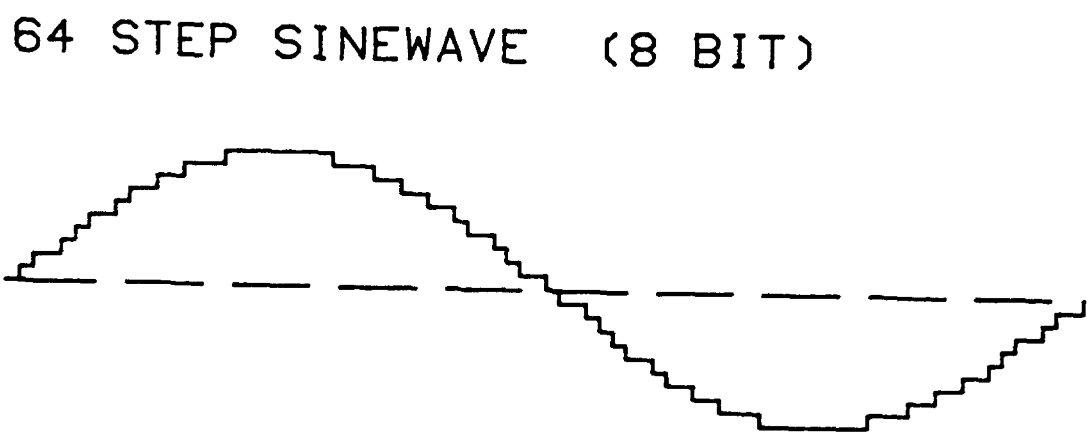

Figure 3 - NIST Calculable AC Standard Output (see reference 1)

The standard can be programed to output sinewaves approximated with 64, 128, 256, or 512 steps per period. All of these approximations are distortions of a pure sinewave and therefore contain energy at higher frequencies. Most of this energy is located near the DAC's clock frequency, but there also is a dispersed energy due to it's 8 bit quantization noise.

Digressing somewhat, it should be noted that when measuring non-sinewaves, the bandwidth of the measuring device will effect the measurement. Two "perfect" AC voltmeters with different bandwidths may measure the same signal differently if it contains energy outside the passband of one of the meters. Since the bandwidth of this algorithm is very low, the verification procedure using the NIST AC standard must consider this effect.

The calculated RMS output of the AC standard is the value that would be measured by a very high bandwidth AC voltmeter. Lower bandwidth meters will measure a somewhat lower value. If this bandwidth is known, the expected deviation is calculable given the number of steps per period being output by the standard. The RMS voltage in the fundamental period of the standard is described by the equation:

RMS_fundamental= RMS_highfreq* SIN(PI/Steps)/(PI/Steps) (19)

For verification purposes, the algorithm was modified so that it's measurement bandwidth would exclude the standard's clock frequencies. Referring to the appendix, on lines 360 and 370 the variables were changed to Aper_targ = 1 and Nharm = 10. These changes cause the algorithm to try and use the largest possible A/D aperture (1 second) conditional with being able to measure the 10th harmonic of the signal (by sampling at least 20 times the signal's frequency). For most frequencies this will force the A/D aperture to be about 1/20 the signal's period which leads to a measurement 3dB bandwidth of 10 harmonics. With the crudest sinewave approximation of 64 steps per period, the sampling harmonics are near the 64th harmonic which is well outside the algorithm's bandwidth. The algorithm's expected measurement is then described by Equation 19 which leads to a table of expected deviations (figure 4).

STEPS per PERIOD	EXPECTED DEVIATION
64	-401.5 ppm
128	-100.4 ppm
256	-25.1 ppm
512	-6.3 ppm

Figure 4 - Expected algorithm deviation when measuring NIST AC standard

In addition to figure 4, there is an additional expected -4ppm deviation due to the dispersed 8 bit quantization noise of the NIST standard. This noise relative to a sinewave is 0.32% and contributes 5.1ppm to a wide band RMS AC measurement. About 4ppm of this is outside the bandwidth of the algorithm.

Backing out the above expected deviations, 5 comparisons with the NIST AC standard were made over a period of 2 days. The results are reported in figure 5.

(Format is mean + 3 standard deviations in ppm)

Voltage	Steps	0.1Hz	1.2Hz	76Hz
7 V	512	6.0+2.0	.18+3.4	2.3+1.1
7 V	256	-2.7+1.4	-3.2+5.4	2.1+.8
7 V	128	-1.5+1.2	-1.2+1.5	2.1+2.6
7 V	64		-0.2+1.6	1.4+1.7
1 V	512			6.9+5.6
1 V	256			6.4+3.6
1 V	128			5.6+2.5
.1 V	512			7.2+0.1
.01 V	512			12 +6

Figure 5 - Agreement with NIST AC standard

CONCLUSION

The described algorithm, when used with commercially available equipment, advances the state of the art in low frequency AC measurement.

Feedback is desired from users of the algorithm. Interested parties are requested to contact the author for more information and program copies:

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phone (303) 679-2029
P.O. Box 301
Loveland, CO 80539

REFERENCES:

1 Oldham, Nile; Hetrick, Paul; Zeng, Xiangren, "A Calculable Transportable Audio Frequency AC Reference Standard", IEEE Transactions on Instrumentation and Measurement . Volume 38, Number 2, April 1989, pp. 368-371.

APPENDIX

Included are operating instructions and a listing of a program written in Hewlett Packard BASIC that incorporates the algorithm described previously.

Using the program:

The commonly modified variables are on LINE 200-280 and are the voltmeter address, the voltmeter DCV range, and the target measurement time. The voltmeter range should be picked so that a peak value of the input waveform will not overload the meter. The minimum voltage on a given range is what is necessary to operate the internal level trigger which has about 10% of range hysteresis. For example, the 10V range should be able to measure AC voltages from 1V to 7V. Measurement time is pretty self explanatory, longer times give higher accuracy. But experiment with measurement time since sometimes very short measurements are highly accurate.

When the program is run, the user is asked to apply the input signal and allow it to settle and then to press "CONT". If the input frequency is less than 0.5Hz, there will be a prompt for it's frequency. This value should be known to within .02% or so. Next the program prints out this frequency, a list of the sampling parameters, and an estimate of measurement uncertainty. Then the intermediate and final results are printed. Pressing "CONT" will generate another measurement, but the sampling parameters will still be the same. This is useful for observing measurement repeatability. If a signal with a different frequency is to be measured the program should be re-run.

The less commonly modified variables are on line 290-390. If Forcefreq is 1, the program prompts the user for the input signal frequency instead of automatically looking. This is convenient for frequencies below 0.5Hz where the HP3458A can't measure frequency. Otherwise 1.5 sec is wasted before the program realizes that it can't measure it and prompts the user. If Force=1, the sampling parameters on lines 330-350 are forced. In general, Tsampforce*Numforce are set to be an integral multiple of the period of the input signal. Keep in mind that it is possible to generate inaccurate measurements by forcing the wrong sampling parameters. This can also occur if a wrong or inaccurate input frequency is entered after the frequency prompt.

Nharm (line 370) is the minimum number of input signal harmonics that will be passed without aliasing before the program automatically speeds up its sampling. (At least 2*Nharm samples are forced to be present in each period of the input signal). If Nharm is too high, at higher input signal frequencies, the A/D aperture will be forced to such a low value that the basic gain accuracy of the program will be degraded (the HP3458A is less accurate with a short aperture than a long one). If Nharm is too low, small amounts of distortion may generate alias errors that can show up as measurement drift or error. A test for lack of alias error is to change Aper_target or Nharm or Nbursts slightly and verify that the measurement does not significantly change. In general, one shouldn't get too concerned about alias error with this program, it was designed to be highly resistant. The sample rate is picked so that 1/2/Tsamp is offset slightly from Nharm*Freq so as to resist aliasing up to 10*Nharm*Freq. Also, at these higher frequencies, the aperture of the A/D becomes an effective anti-alias filter. Nharm=6 is a good value.

Nbursts (line 380) selects the number of intermediate results that are used in computing the final result. Each intermediate result is computed from a burst of Num samples. Each burst of Num samples is delayed in time K/Freq/Nbursts from the input signal's zero crossing where K varies from 0 to Nbursts-1. Any value of Nbursts>=6 is good. Under some conditions, smaller Nbursts can be used. The purpose of using multiple bursts is to remove errors due to Num*Tsamp not being an exact integral number of periods in length and to further reduce sensitivity to aliasing.

Program listing:

```
10     !PROGRAM MEASURES LOW FREQ RMS VOLTAGES (<1KHz)     04/27/91
20     !RE-STORE "GODS_AC<RON>"
30     !
40     !CAN BE ACCURATE TO 0.001% IF Meas_time>30
50     !NOTES:
60     !1.  DISTORTED SINEWAVES HAVE HIGHER FREQ HARMONICS
70     !    THAT MAY NOT BE MEASURED IF MEASUREMENT BANDWIDTH IS TOO LOW.
80     !    COMPUTED ERROR IS INCLUDED FOR UP TO 1% HARMONIC DISTORTION.
90     !    THIS ERROR CAN BE REDUCED BY USING SMALLER Aper_targ(LINE 360)
100    !2.  ESPECIALLY AT LOW SIGNAL LEVELS, TWO AC VOLTMETERS WITH "PERFECT"
110    !    ACCURACY MAY READ DIFFERENTLY IF THEY HAVE DIFFERENT
120    !    NOISE BANDWIDTHS.  THIS IS TRUE ONLY IF THE SIGNAL BEING MEASURED
130    !    CONTAINS APPRECIABLE HIGH FREQUENCY NOISE OR SPURIOUS SIGNALS.
140    !    THIS PROGRAM DISPLAYS THE MEASUREMENT BANDWIDTH WHEN RUN.
150    !    THIS BANDWIDTH VARIES DEPENDING ON Freq.  IT IS APPROX= .5/Aper_targ.
160    !    ALSO, MAKING Nharm(LINE 370) HIGHER CAN INCREASE BANDWIDTH, BUT
170    !    CAN HURT BASIC ACCURACY BY FORCING SMALL A/D APERTURES.
180    !
190    !
200    !------------------------ MODIFIABLE VARIABLES
210    !
220    ASSIGN @Vmeter TO 722        !VOLTMETER ADDRESS
230    Range=10                     !VOLTMETER RANGE (.1,1,10,100,1000)
240    !                            !***RANGE MUST HANDLE > SIGNAL*CREST FACTOR
250    !                             i.e. Range=10 IS FOR 1V TO 7V RMS SINEWAVE
260    Meas_time=15                 !TARGET MEASUREMENT TIME (SEC)
270    !
280    !
290    !------------------------ LESS COMMONLY MODIFIED VARIABLES
300    !
310    Forcefreq=0                  !1=INPUT FREQ. OF SIGNAL, 0= AUTOMATIC IF>1Hz
320    Force=0                      !1=FORCE SAMP. PARAMETERS, 0= AUTOMATIC
330    Tsampforce=.001              !  FORCED PARAMETER
340    Aperforce=Tsampforce-3.E-5!  FORCED PARAMETER
350    Numforce=800                 !  FORCED PARAMETER
360    Aper_targ=.001               !A/D APERTURE TARGET (SEC)
370    Nharm=6                      !MINIMUM # HARMONICS SAMPLED BEFORE ALIAS
380    Nbursts=6                    !NUMBER OF BURSTS USED FOR EACH MEASUREMENT
390    !-----------------------------------------------------
400    !
410    OUTPUT 2 USING "#,B,B";255,75          !CLEAR DISPLAY
420    CLEAR @Vmeter
430    OUTPUT @Vmeter;"RESET;DCV 1000"
440    DISP "APPLY INPUT SIGNAL, LET SETTLE, PRESS CONT"
450    BEEP 2500,.05
460    PAUSE
470    DISP ""
480    OUTPUT @Vmeter;"DISP OFF,***GOD'S_AC***"
490    IF Forcefreq=1 THEN                    !IF MANUALLY ENTERING FREQUENCY
500      BEEP 2500,.1
510      INPUT "ENTER FREQ",Freq
520    ELSE
530      Freq=FNFreq(Range,@Vmeter)          !GET INPUT SIGNAL FREQUENCY
540    END IF
550    IF Force=1 THEN                        !IF NOT GETTING PARAMETERS AUTOMATICALLY
560      Tsamp=Tsampforce
570      Aper=Aperforce
580      Num=Numforce
590    ELSE                                   !AUTOMATICALLY GET SAMPLING PARAMETERS
600      Samp_parm(Tsamp,Aper,Num,Freq,Meas_time,Aper_targ,Nharm,Nbursts)
610    END IF
620    !
630    !------------------------------SETUP HP3458A
640    !
650    OUTPUT @Vmeter;"TARM HOLD;AZERO OFF;DCV ";Range
660    OUTPUT @Vmeter;"APER ";Aper;";NRDGS ";Num;",TIMER"
```

```
670   OUTPUT @Vmeter;"TIMER ";Tsamp
680   OUTPUT @Vmeter;"TRIG LEVEL;LEVEL 0,DC;DELAY 0;LFILTER ON"
690   OUTPUT @Vmeter;"MSIZE?"
700   ENTER @Vmeter;Storage
710   Storage=INT(Storage/4)      !STORAGE CAPACITY IN VOLTMETER (DINT DATA)
720   IF Num>Storage THEN
730     PRINT "******** NOT ENOUGH VOLTMETER MEMORY FOR NEEDED SAMPLES ***"
740     PRINT "          TRY A LARGER Aper_targ VALUE OR SMALLER Num"
750     BEEP 200,1
760     STOP
770   END IF
780   WAIT .1
790   !------------------------------------------
800   !
810   !------------------------------- PRELIMINARY COMPUTATIONS
820   !
830   X=PI*Aper*Freq
840   Sinc=SIN(X)/X                        !USED TO CORRECT FOR A/D APERTURE ERROR
850   Bw_corr=FNVmeter_bw(Freq,Range)      !USED TO CORRECT FOR Vmeter BANDWIDTH
860   Err_est(Err,Dist_er,Freq,Range,Num,Aper,Nbursts)!MEASUREMENT UNCERTAINTY
870   IF Force=1 THEN
880     PRINT "****** PARAMETERS ARE FORCED, ACCURACY MAY BE DEGRADED! ******"
890   END IF
900   PRINT "SIGNAL FREQUENCY(Hz)= ";Freq
910   PRINT "Number of samples in each of";Nbursts;"bursts= ";Num
920   PRINT "Sample spacing(sec)= ";Tsamp
930   PRINT "A/D Aperture(sec)= ";Aper
940   PRINT "Measurement bandwidth(Hz)= ";INT(5/Aper)/10
950   PRINT "ESTIMATED TOTAL SINEWAVE MEASUREMENT UNCERTAINTY(ppm)= ";Err
960   PRINT "ADDITIONAL ERROR FOR 1% DISTORTION(3rd HARMONIC)(ppm)= ";Dist_er
970   PRINT "NOTE: ERROR ESTIMATE ASSUMES (ACAL DCV) PERFORMED RECENTLY(24HRS)"
980   !-------------------------------------
990   !
1000  !
1010 Start:PRINT ""
1020  OUTPUT @Vmeter;"DISP OFF,***GOD'S_AC***"
1030  PRINT "The";Nbursts;"intermediate results:"
1040  Begin=TIMEDATE
1050  Sum=0
1060  Sumsq=0
1070  FOR I=0 TO Nbursts-1
1080    Delay=I/Nbursts/Freq+1.E-6
1090    OUTPUT @Vmeter;"DELAY ";Delay
1100    OUTPUT @Vmeter;"TIMER ";Tsamp
1110    CALL Stat(Mean,Sdev,Num,@Vmeter)          !MAKE MEASUREMENT
1120    Sumsq=Sumsq+Sdev*Sdev+Mean*Mean
1130    Sum=Sum+Mean
1140    Temp=Sdev*Bw_corr/Sinc                  !CORRECT A/D Aper AND Vmeter B.W.
1150    Temp=Range/1.E+7*INT(Temp*1.E+7/Range)!6 DIGIT TRUNCATION
1160    PRINT Temp
1170  NEXT I
1180  Dcrms=SQR(Sumsq/Nbursts)
1190  Dc=Sum/Nbursts
1200  Acrms=Dcrms*Dcrms-Dc*Dc
1210  IF Acrms<0 THEN Acrms=0                 !PROTECTION FOR SQR OF NEG NUMBER
1220  Acrms=SQR(Acrms)
1230  Acrms=Acrms*Bw_corr/Sinc                !CORRECT A/D Aper AND Vmeter B.W.
1240  Dcrms=SQR(Acrms*Acrms+Dc*Dc)
1250  End=TIMEDATE
1260  Acrms=Range/1.E+7*INT(Acrms*1.E+7/Range+.5)     !6 DIGIT TRUNCATION
1270  Dcrms=Range/1.E+7*INT(Dcrms*1.E+7/Range+.5)     !6 DIGIT TRUNCATION
1280  !
1290  !********************** PRINT RMS VALUES ***************
1300  PRINT "AC RMS VOLTAGE= ",Acrms
1310  PRINT "ACDC RMS VOLTAGE= ",Dcrms
1320  DISP USING "K,DDD.DDD";"PRESS CONT FOR NEW READING IF SAME FREQ, MEASUREMENT
```

```
1330  OUTPUT @Vmeter;"DISP OFF,";"'";Acrms;" VAC'"
1340  PAUSE
1350  DISP ""
1360  GOTO Start
1370  END
1380  SUB Stat(REAL Mean,Sdev,Num,@Vmeter)
1390    OUTPUT @Vmeter;"MEM FIFO;MFORMAT DINT;TARM SGL"
1400    OUTPUT @Vmeter;"MMATH STAT"
1410    OUTPUT @Vmeter;"RMATH SDEV"
1420    ENTER @Vmeter;Sdev
1430    OUTPUT @Vmeter;"RMATH MEAN"
1440    ENTER @Vmeter;Mean
1450    Sdev=SQR(Sdev*Sdev*(Num-1)/Num)      !CORRECT SDEV FORMULA
1460  SUBEND
1470  DEF FNFreq(Range,@Vmeter)
1480    OUTPUT @Vmeter;"TARM HOLD;LFILTER ON;LEVEL 0,DC;FSOURCE ACDCV"
1490    OUTPUT @Vmeter;"FREQ ";Range
1500    OUTPUT @Vmeter;"CAL? 245"
1510    ENTER @Vmeter;Cal                 !FREQUENCY CAL VALUE
1520    OUTPUT @Vmeter;"TARM SGL"
1530    ENTER @Vmeter;Freq
1540    Freq=Freq/Cal                     !UNCALIBRATED FREQUENCY IS USED
1550    !                                  FOR MORE ACCURATE SAMPLE DETERMINATION
1560    !                                  SINCE TIMER IS UNCALIBRATED
1570    IF Freq=0 THEN
1580      BEEP 2500,.1
1590      INPUT "FREQ MEASUREMENT WAS 0, PLEASE ENTER THE FREQ",Freq
1600      IF Freq>1 THEN
1610        BEEP 200,.1
1620        PRINT "******************** WARNING!! ******************"
1630        PRINT "WARNING!! AUTOMATIC FREQUENCY MEASUREMENT SHOULD HAVE WORKED"
1640        DISP "PRESS CONT BUT NOTE THAT LEVEL TRIGGERING MAY FAIL"
1650        PRINT "**************************************************"
1660        PRINT ""
1670        PAUSE
1680      END IF
1690    END IF
1700    RETURN Freq
1710  FNEND
1720  DEF FNVmeter_bw(Freq,Range)
1730    Lvfilter=120000                    !LOW VOLTAGE INPUT FILTER B.W.
1740    Hvattn=36000                       !HIGH VOLTAGE ATTENUATOR B.W.(NUMERATOR)
1750    Gain100bw=82000                    !AMP GAIN 100 B.W. PEAKING CORRECTION!
1760    IF Range<=.12 THEN
1770      Bw_corr=(1+(Freq/Lvfilter)^2)/(1+(Freq/Gain100bw)^2)
1780      Bw_corr=SQR(Bw_corr)
1790    END IF
1800    IF Range>.12 AND Range<=12 THEN
1810      Bw_corr=(1+(Freq/Lvfilter)^2)
1820      Bw_corr=SQR(Bw_corr)
1830    END IF
1840    IF Range>12 THEN
1850      Bw_corr=(1+(Freq/Hvattn)^2)
1860      Bw_corr=SQR(Bw_corr)
1870    END IF
1880    RETURN Bw_corr
1890  FNEND
1900  SUB Err_est(Err,Dist,Freq,Range,Num,Aper,Nbursts)
1910    !
1920    !Base IS THE BASIC NPLC 100 DCV 1YR ACCURACY, THIS NUMBER CAN BE
1930    !SUBSTANTIALLY LOWER FOR HIGH STABILITY OPTION AND 90DAY CAL CYCLES
1940    IF Range>120 THEN                         !SELF HEATING +BASE ERROR
1950      Base=15
1960    ELSE
1970      Base=10                                 !BASIC 1YR ERROR(ppm)
1980    END IF
```

```
1990    !
2000    !
2010    !Vmeter_bw IS ERROR DUE TO UNCERTAINTY IN KNOWING THE HIGH FREQUENCY
2020    !RESPONSE OF THE DCV FUNCTION FOR VARIOUS RANGES AND FREQUENCIES
2030    !UNCERTAINTY IS 30% AND THIS ERROR IS RANDOM
2040    X1=FNVmeter_bw(Freq,Range)
2050    X2=FNVmeter_bw(Freq*1.3,Range)
2060    Vmeter_bw=INT(1.E+6*ABS(X2-X1))  !ERROR DUE TO METER B.W.
2070    !
2080    !
2090    !Aper_er IS THE DCV GAIN ERROR FOR VARIOUS A/D APERTURES
2100    !THIS ERROR IS SPECIFIED IN A GRAPH ON PAGE 11 OF THE DATA SHEET
2110    !THIS ERROR IS RANDOM
2120    Aper_er=INT(1.0*.002/Aper)       !GAIN UNCERTAINTY - SMALL A/D APERTURE
2130    IF Aper_er>30 AND Aper>=1.E-5 THEN
2140      Aper_er=30
2150    END IF
2160    IF Aper<1.E-5 THEN
2170      Aper_er=10+INT(.0002/Aper)
2180    END IF
2190    !
2200    !
2210    !Sincerr IS THE ERROR DUE TO THE APERTURE TIME NOT BEING PERFECTLY KNOWN
2220    !THIS VARIATION MEANS THAT THE Sinc CORRECTION TO THE SIGNAL FREQUENCY
2230    !IS NOT PERFECT.  ERROR COMPONENTS ARE CLOCK FREQ UNCERTAINTY(0.01%)
2240    !AND SWITCHING TIMING (50ns).  THIS ERROR IS RANDOM.
2250    X=PI*Aper*Freq
2260    Sinc=SIN(X)/X
2270    Y=PI*Freq*(Aper*1.0001+5.0E-8)
2280    Sinc2=SIN(Y)/Y
2290    Sincerr=INT(1.E+6*ABS(Sinc2-Sinc))    !APERTURE UNCERTAINTY ERROR
2300    !
2310    !
2320    !Dist IS ERROR DUE TO UP TO 1% DISTORTION OF THE INPUT WAVEFORM
2330    !IF THE INPUT WAVEFORM HAS 1% DISTORTION, THE ASSUMPTION IS MADE
2340    !THAT THIS ENERGY IS IN THE THIRD HARMONIC.  THE APERTURE CORRECTION,
2350    !WHICH IS MADE ONLY FOR THE FUNDAMENTAL FREQUENCY WILL THEN BE
2360    !INCORRECT.  THIS ERROR IS RETURNED SEPERATELY.
2370    X=PI*Aper*Freq
2380    Sinc=SIN(X)/X
2390    Sinc2=SIN(3*X)/3/X      !SINC CORRECTION NEEDED FOR 3rd HARMONIC
2400    Harm_er=ABS(Sinc2-Sinc)
2410    Dist=SQR(1+(.01*(1+Harm_er))^2)-SQR(1+.01^2)
2420    Dist=INT(Dist*1.E+6)
2430    !
2440    !
2450    !Tim_er IS ERROR DUE TO MISTIMING.  IT CAN BE SHOWN THAT IF A
2460    !BURST OF Num SAMPLES ARE USED TO COMPUTE THE RMS VALUE OF A SINEWAVE
2470    !AND THE SIZE OF THIS BURST IS WITHIN 50ns*Num OF AN INTEGRAL NUMBER
2480    !OF PERIODS OF THE SIGNAL BEING MEASURED, AN ERROR IS CREATED
2490    !BOUNDED BY 100ns/4/Tsamp.  THIS ERROR IS DUE TO THE 100ns QUANTIZATION
2500    !LIMITATION OF THE HP3458A TIME BASE.  IF THIS ERROR WERE ZERO, THEN
2510    !Num*Tsamp= INTEGER/Freq, BUT WITH THIS ERROR UP TO 50ns OF TIMEBASE
2520    !ERROR IS PRESENT PER SAMPLE, THEREFORE TOTAL TIME ERROR=50ns*Num
2530    !THIS ERROR CAN ONLY ACCUMULATE UP TO 1/2 *Tsamp, AT WHICH POINT THE
2540    !ERROR IS BOUNDED BY 1/4/Num
2550    !THIS ERROR IS FURTHER REDUCED BY USING THE LEVEL TRIGGER
2560    !TO SPACE Nbursts AT TIME INCREMENTS OF 1/Nbursts/Freq.  THIS
2570    !REDUCTION IS SHOWN AS 20*Nbursts BUT IN FACT IS USUALLY MUCH BETTER
2580    !THIS ERROR IS ADDED ABSOLUTELY TO THE Err CALCULATION
2590    Tim_er=INT(1.E+6*1.E-7/4/(Aper+3.E-5)/20)!ERROR DUE TO HALF CYCLE ERROR
2600    Limit=INT(1.E+6/4/Num/20)
2610    IF Tim_er>Limit THEN Tim_er=Limit
2620    !
2630    !
2640    !Noise IS THE MEASUREMENT TO MEASUREMENT VARIATIONS DUE TO THE
```

```
2650    !INDIVIDUAL SAMPLES HAVING NOISE.  THIS NOISE IS UNCORRELATED AND
2660    !IS THEREFORE REDUCED BY THE SQUARE ROOT OF THE NUMBER OF SAMPLES
2670    !THERE ARE Nbursts*Num SAMPLES IN A MEASUREMENT.  THE SAMPLE NOISE IS
2680    !SPECIFIED IN THE GRAPH ON PAGE 11 OF THE DATA SHEET.  THIS GRAPH
2690    !SHOWS 1 SIGMA VALUES, 2 SIGMA VALUES ARE COMPUTED BELOW.
2700    !THE ERROR ON PAGE 11 IS EXPRESSED AS A % OF RANGE AND IS MULTIPLIED
2710    !BY 10 SO THAT IT CAN BE USED AS % RDG AT 1/10 SCALE.
2720    !ERROR IS ADDED IN AN ABSOLUTE FASHION TO THE Err CALCULATION SINCE
2730    !IT WILL APPEAR EVENTUALLY IF A MEASUREMENT IS REPEATED OVER AND OVER
2740    Noiseraw=.9*SQR(.001/Aper)          !1 SIGMA NOISE AS PPM OF RANGE
2750    Noise=Noiseraw/SQR(Nbursts*Num)     !REDUCTION DUE TO MANY SAMPLES
2760    Noise=10*Noise                      !NOISE AT 1/10 FULL SCALE
2770    Noise=2*Noise                       !2 SIGMA
2780    IF Range<=.12 THEN                  !NOISE IS GREATER ON 0.1 V RANGE
2790      Noise=7*Noise                     !DATA SHEET SAYS USE 20, BUT FOR SMALL
2800      Noiseraw=7*Noiseraw               !APERTURES, 7 IS A BETTER NUMBER
2810    END IF
2820    Noise=INT(Noise)+2                          !ERROR DUE TO SAMPLE NOISE
2830    !
2840    !
2850    !Df_err IS THE ERROR DUE TO THE DISSIPATION FACTOR OF THE P.C. BOARD
2860    !CAPACITANCE LOADING DOWN THE INPUT RESISTANCE.  THE INPUT RESISTANCE
2870    !IS 10K OHM FOR THE LOW VOLTAGE RANGES AND 100K OHM FOR THE HIGH VOLTAGE
2880    !RANGES (THE 10M OHM INPUT ATTENUATOR).  THIS CAPACITANCE HAS A VALUE
2890    !OF ABOUT 15pF AND A D.F. OF ABOUT 1.0%.  IT IS SWAMPED BY 120pF
2900    !OF LOW D.F. CAPACITANCE (POLYPROPALENE CAPACITORS) ON THE
2910    !LOW VOLTAGE RANGES WHICH MAKES FOR AN EFFECTIVE D.F. OF ABOUT .11%.
2920    !THIS CAPACITANCE IS SWAMPED BY 30pF LOW D.F. CAPACITANCE ON THE
2930    !HIGH VOLTAGE RANGES WHICH MAKES FOR AN EFFECTIVE D.F. OF .33%.
2940    !THIS ERROR IS ALWAYS IN THE NEGATIVE DIRECTION, SO IS ADDED ABSOLUTELY
2950    IF Range<=12 THEN
2960      Rsource=10000
2970      Cload=1.33E-10
2980      Df=1.1E-3            !0.11%
2990    ELSE
3000      Rsource=1.E+5
3010      Cload=5.0E-11
3020      Df=3.3E-3            !0.33%
3030    END IF
3040    Df_err=2*PI*Rsource*Cload*Df*Freq
3050    Df_err=INT(1.E+6*Df_err)!ERROR DUE TO TO PC BOARD DIELECTRIC ABSORBTION
3060    !
3070    !
3080    !Err IS TOTAL ERROR ESTIMATION.  RANDOM ERRORS ARE ADDED IN RSS FASHION
3090    Err=SQR(Base^2+Vmeter_bw^2+Aper_er^2+Sincerr^2)
3100    Err=INT(Err+Df_err+Tim_er+Noise)               !TOTAL ERROR (ppm)
3110    !
3120  SUBEND
3130  SUB Samp_parm(Tsamp,Aper,Num,Freq,Meas_time,Aper_targ,Nharm_min,Nbursts)
3140    Aper=Aper_targ
3150    Tsamp=1.E-7*INT((Aper+3.0E-5)/1.E-7+.5)        !ROUND TO 100ns
3160    Submeas_time=Meas_time/Nbursts                 !TARGET TIME PER BURST
3170    Burst_time=Submeas_time*Tsamp/(.0015+Tsamp)    !IT TAKES 1.5ms FOR EACH
3180    !                                               SAMPLE TO COMPUTE Sdev
3190    Approxnum=INT(Burst_time/Tsamp+.5)
3200    Ncycle=INT(Burst_time*Freq+.5)                 !# OF 1/Freq TO SAMPLE
3210    IF Ncycle=0 THEN
3220      Ncycle=1
3230      Tsamp=1.E-7*INT(1/Freq/Approxnum/1.E-7+.5)  !TIME BETWEEN SAMPLES
3240      Nharm=INT(1/Tsamp/2/Freq)       !# HARMONICS BEFORE ALIAS OCCURS
3250      IF Nharm<Nharm_min THEN         !NEED TO INCREASE SAMPLE FREQUENCY
3260        Nharm=Nharm_min
3270        Tsamp=1.E-7*INT(1/2/Nharm/Freq/1.E-7+.5)
3280      END IF
3290    ELSE
3300      Nharm=INT(1/Tsamp/2/Freq)       !# HARMONICS BEFORE ALIAS OCCURS
```

```
3310      IF Nharm<Nharm_min THEN        !NEED TO INCREASE SAMPLE FREQUENCY
3320        Nharm=Nharm_min
3330      END IF
3340      Tsamptemp=1.E-7*INT(1/2/Nharm/Freq/1.E-7+.5)  !FORCE ALIAS TO OCCUR
3350    !                                               EXACTLY AT Nharm*Freq !!
3360      Burst_time=Submeas_time*Tsamptemp/(.0015+Tsamptemp)
3370      Ncycle=INT(Burst_time*Freq+1)
3380      Num=INT(Ncycle/Freq/Tsamptemp+.5)
3390      IF Ncycle>1 THEN
3400        K=INT(Num/20/Nharm+1)
3410      ELSE
3420        K=0
3430      END IF
3440      Tsamp=1.E-7*INT(Ncycle/Freq/(Num-K)/1.E-7+.5)  !NOW ALIAS OCCURS
3450      !                                       MUCH HIGHER THAN Nharm*Freq
3460      !                                       K WAS PICKED TO TRY AND MAKE
3470      !                                       ALIAS ABOUT 10*Nharm*Freq
3480      IF Tsamp-Tsamptemp<1.E-7 THEN Tsamp=Tsamp+1.E-7
3490    END IF
3500    Aper=Tsamp-3.E-5
3510    Num=INT(Ncycle/Freq/Tsamp+.5)
3520    IF Aper>1 THEN Aper=1        !MAX APERTURE OF HP3458A
3530    IF Aper<1.E-6 THEN           !MIN APERTURE OF HP3458A
3540      BEEP 200,1
3550      PRINT "************** ERROR *****************"
3560      PRINT "A/D APERTURE IS TOO SMALL"
3570      PRINT "LOWER Aper_targ, Nharm, OR INPUT Freq"
3580      PRINT "***************************************"
3590      STOP
3600    END IF
3610  SUBEND
```

Overview of Radiometric Program of the NIST Thermal Imaging Laboratory

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Abstract

Radiometric Calibrations performed in the NIST Thermal Imaging Laboratory now support infrared detecting devices that operate in the temperature range of 0 to 100 °C, including devices that produce pictures of ambient temperature scenes. The laboratory provides characterization of the temperature and temperature-differences of infrared blackbody sources, and characterization of radiometers. Research into the quantitative performance of infrared cameras, and use of higher temperature calibrated heat pipe sources (to 1000 °C) is planned.

1. Overview

This paper summarizes the radiometric work of the Thermal Imaging Laboratory within the Radiometric Physics Division of the National Institute of Standards and Technology. The infrared radiometric work done in other laboratories within NIST will not be discussed.

The object of this lab is to support the operation of infrared detecting devices in commerce and the military, including those devices that produce visual pictures of scenes of ambient temperature, nominally 0 to 100 °C. This work is a continuation of that done by Charles R. Yokley and Henry Kostkowski. Although these people retired from NBS several years ago, we have not lost their expertise completely. Mr. Yokley visits frequently, and when the work load got heavy, we contracted with him to come back to NIST and work for several months.

2. Services Provided

a) Calibration of the effective radiant temperature of infrared sources,

b) Calibration of the temperature-difference of infrared sources:

1) at different operating settings of the same source,
2) at different locations within the area of a source, and

c) Radiometer characterization.

3. Calibration Facilities

The equipment used in providing the service includes an environmental chamber, a radiometer, well defined small-aperture blackbodies, and a large area blackbody. Mr. Oroshnik, a Navy employee who was a guest researcher at NIST for 3 years, designed the chamber and the physical layout of the experimental equipment. A diagram of the facility is shown in figure 1.

a) Environmental Chamber

The chamber provides an environment for our measurements where the infrared background is controlled, air currents are limited, and humidity can be controlled. Blackbody sources are mounted outside the chamber. The radiation from the sources enters through holes in the chamber wall to be measured by the radiometer inside the chamber.

b) Radiometer

The radiometer is usually filtered to detect radiation in the 8-14 μm range. The radiometer sits on a computer controlled two axis positioning table.

The radiometer is used to make comparisons of test and standard sources operating at the same radiance level, effectively a null comparison. This approach minimizes the sensitivity of the system to many errors. Though the radiometer is an old model, we could make comparisons with milli-kelvin resolution.

c) Standard Blackbody

The standard blackbody is a resistively heated copper-clad graphite cavity with a small aperture. The blackbody sits outside the chamber, in a position such as that labeled NIST BB in figure 1. It has been extensively analyzed by Mr. Yokley, by experiment, and by analog and theoretical analysis. Figure 2 shows a rejected graphite cavity cut in half. The internal temperature is measured near the end of the cavity using a standard platinum resistance thermometer (SPRT). The SPRT is inserted through a long hole drilled through the narrow portion of graphite. The uncertainty in calibration of a commercial blackbody is given in table 1.

Table 1.
Uncertainty in °C, at temperature

Source temperature:	10 °C	50 °C
Absolute:	± 0.11	± 0.25
Relative:	± 0.07	± 0.13

d) Large Aperture Blackbody

A waterbath blackbody developed at NBS provides a 4.25 inch diameter aperture, and is shown in figure 3. The results of our preliminary analysis indicate that the radiometric source properties might be as good as the properties of our small aperture characterized blackbody. The uniformity over the central 3 inches has been measured one time and found to be uniform to within ± 50 mK, impressive for such a large area source. Further analysis of the calibration data, and new measurements of replicate devices remains to be done to see if these results can be substantiated.

e) Large thermal mass dual-blackbody source

This blackbody source is an insulated 20 lb copper cylinder. We rely on this large mass to provide a radiant source that changes temperature slowly (a 19.2 hour time constant), allowing correction for radiometer drift. We do not have to know the absolute temperature of the source for this application. It is used at temperatures from ambient to 40 °C.

f) Miscellaneous

Additional equipment that supports the measurements includes temperature measuring apparatus, computers, and radiometer motion controller.

4. Present work

Using the equipment just described, we are able to calibrate commercial blackbodies between 0 °C and 85 °C.

We provide more general radiometric services also. We have just specified and ordered a commercial radiometer for the Navy MED. We will evaluate the instrument's performance before delivery to the Navy. During fiscal year 1991, we also will begin the evaluation of a thermal imaging test set for the Navy using this equipment.

We are also examining prototypes of a new type of thermal contrast target. With the assistance of Jouko Vahakangas, a guest researcher from Finland, we have evaluated low thermal-contrast targets developed by another group at NIST. The present form is four bars of silica cemented to a heat sink. The bars are coated with a resistive layer of inconel and then painted black. The uniformity of the infrared image is supposed to be much more uniform than is available from available commercial test devices at low thermal contrasts.

To examine the targets, we first evaluated the performance of a infrared camera for use as a quantitative radiometric device, as opposed to simply providing pictures. The Platinum Silicide camera is sensitive to the 3.4 - 6 μm radiation, and the camera head is shown in figure 4. Early measurements showed that both the camera and the test targets had problems that prevented the expected performance. Improved targets were made at NIST. The new targets could produce bar patterns with measurable contrast limited by the sensitivity of the camera and frame grabber (on the order of 0.1 °C). Since that time, the manufacturer has repaired the camera, and we have an improved frame grabber. Figure 5 shows data from a computer analysis of one of the early scans across the 4 warm bars. (The temperature difference of the peaks and valleys was not calibrated for this picture.) The general slope across the curves is assumed to be attributable to the error in the camera before repair.

5. Future work

We have recently received new improved equipment that will allow us to expand the range of our service. Work planned for the items discussed in this section will be delayed however due to lack of funds or manpower.

a) Standard sources at higher temperatures, 350 °C to 1000 °C: We have new pressure-controlled heatpipe blackbodies, shown in figure 6, that provide sources of infrared radiation over the range of 350 °C to 1000 °C. The manufacturer claims that the physical temperature will be uniform to ±0.01 °C over a 30 cm length of the cavity. If these sources provide anything near the claims, it should support a significant improvement in calibration and characterization services in this higher temperature region.

b) Quantitative measurements of image radiant temperature, using a PtSi Camera attached to a computerized frame grabber:

The repaired camera mentioned earlier should allow quantitative measurements of the difference in temperature within the field of view of the camera. We should sense differences on the order of 0.050 °C. Teamed with the power of fast computer acquisition, this could provide much faster measurements than can be done with a non-imaging radiometer that must be physically moved to scan an area.

6. Acknowledgements

Support for the laboratory comes predominately from the Department of the Navy through the Joint Services Calibration Coordination Group.

Other participants in the project:
Robert D. Saunders, NIST supervisor

Jesse Oroshnik, Navy Guest Researcher
(reassigned to the Navy Primary Standards
Department, East, April 1991)

July 17, 1991

'igure captions

'igure Caption

.. Schematic of the Thermal Imaging lab equipment. The environmental chamber is a box surrounding the radiometer. The standard and test sources, labeled NIST BB, DBA, AND WB-BB, sit outside the chamber.

!. A rejected standard blackbody cut in half. The blackbody cavity is the hollow cylinder of graphite at the left side of the picture. Copper surrounds the graphite.

3. A waterbath blackbody. A cone with a 4.25 inch aperture is surrounded by temperature-controlled water.

4. The head of a Platinum Silicide infrared Camera. The lens protrudes from the front, the blue dewar for the detector array protrudes from the top.

5. The curve is data from a computer analysis of one of the early scans across the 4 warm bars of the silica thermal contrast target.

6. Heat pipe blackbodies in furnaces. The central aperture is one inch. The tubes protruding from the rear connect to a pressure control system.

July 17, 1991

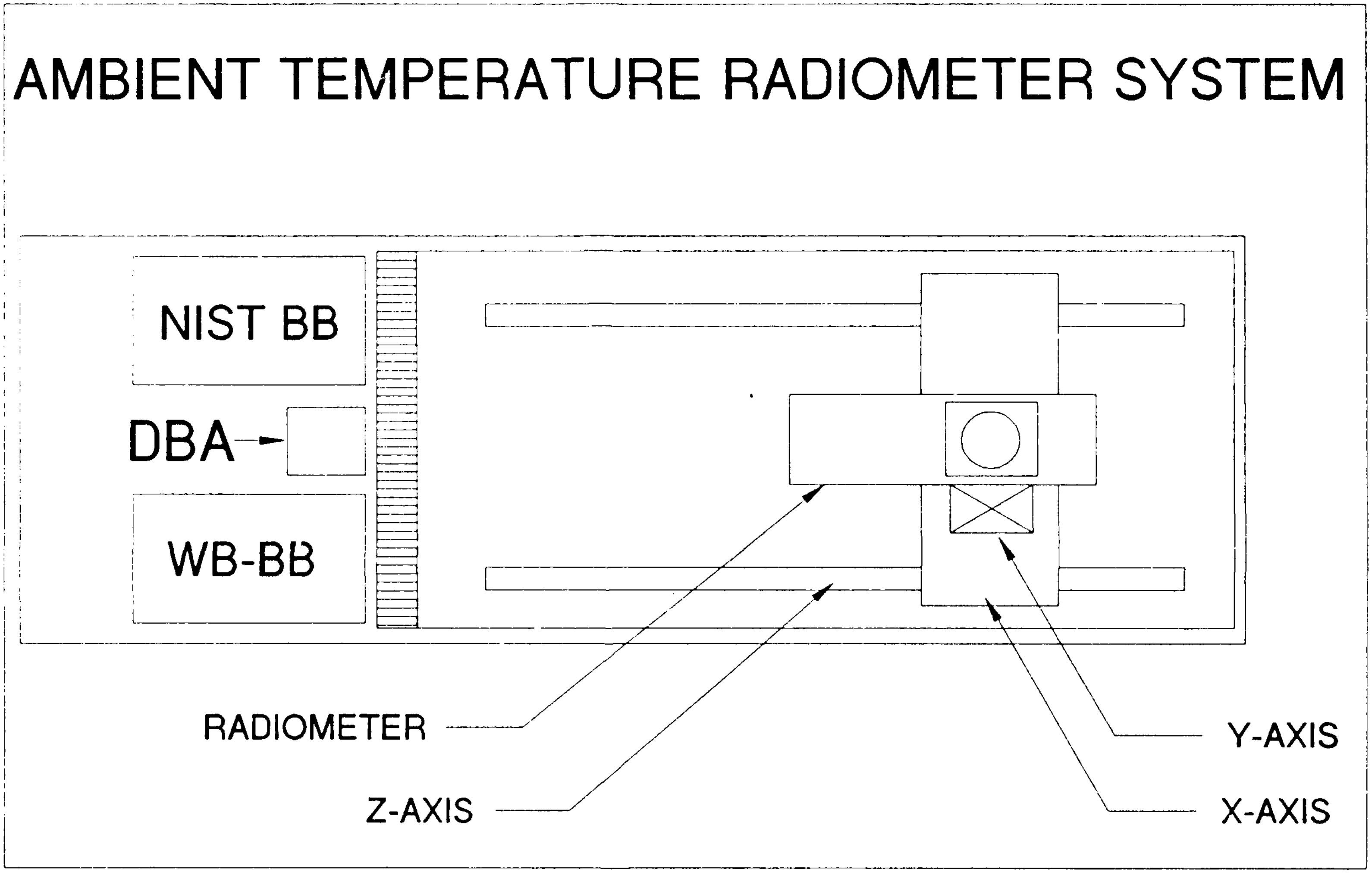

Figure 1. Schematic of the Thermal Imaging lab equipment. The environmental chamber is a box surrounding the radiometer. The standard and test sources, labeled NIST BB, DBA, AND WB-BB, sit outside the chamber.

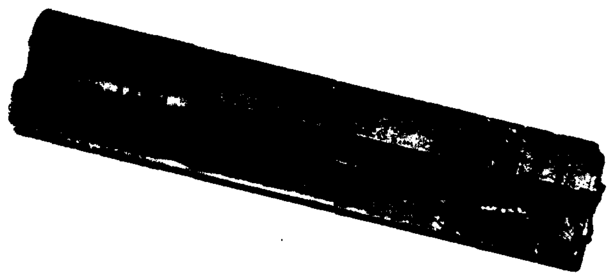

Figure 2. A rejected standard blackbody cut in half. The blackbody cavity is the hollow cylinder of graphite at the left side of the picture. Copper surrounds the graphite.

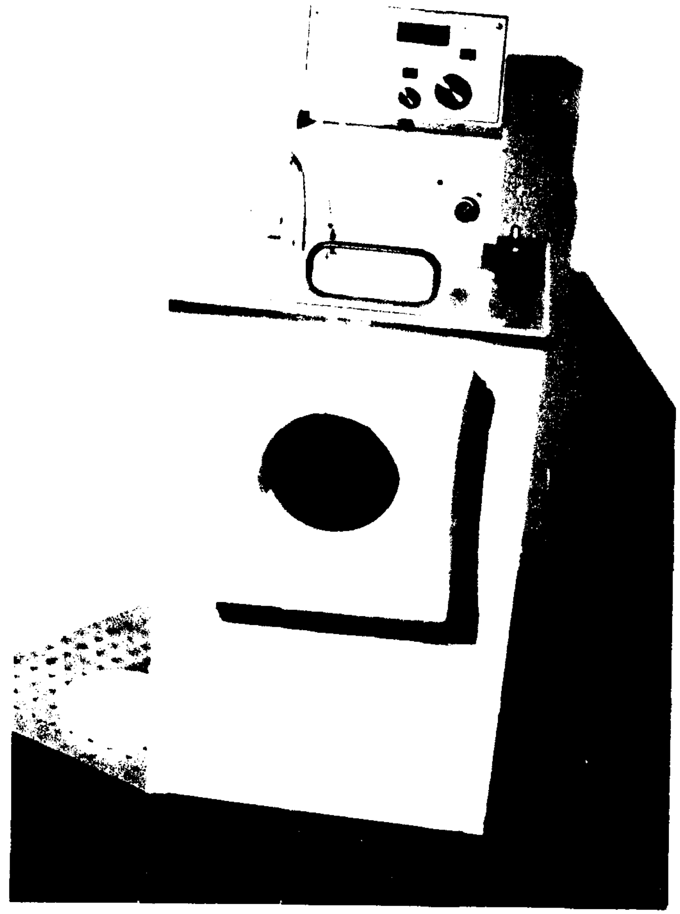

Figure 3. A waterbath blackbody. A cone with a 4.25 inch aperture is surrounded by temperature-controlled water.

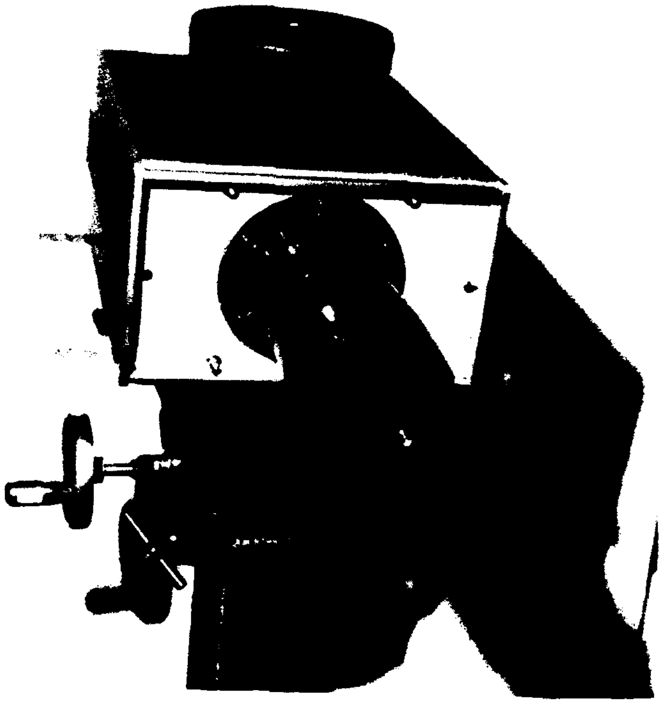

Figure 4. The head of a Platinum Silicide infrared Camera. The lens protrudes from the front, the blue dewar for the detector array protrudes from the top.

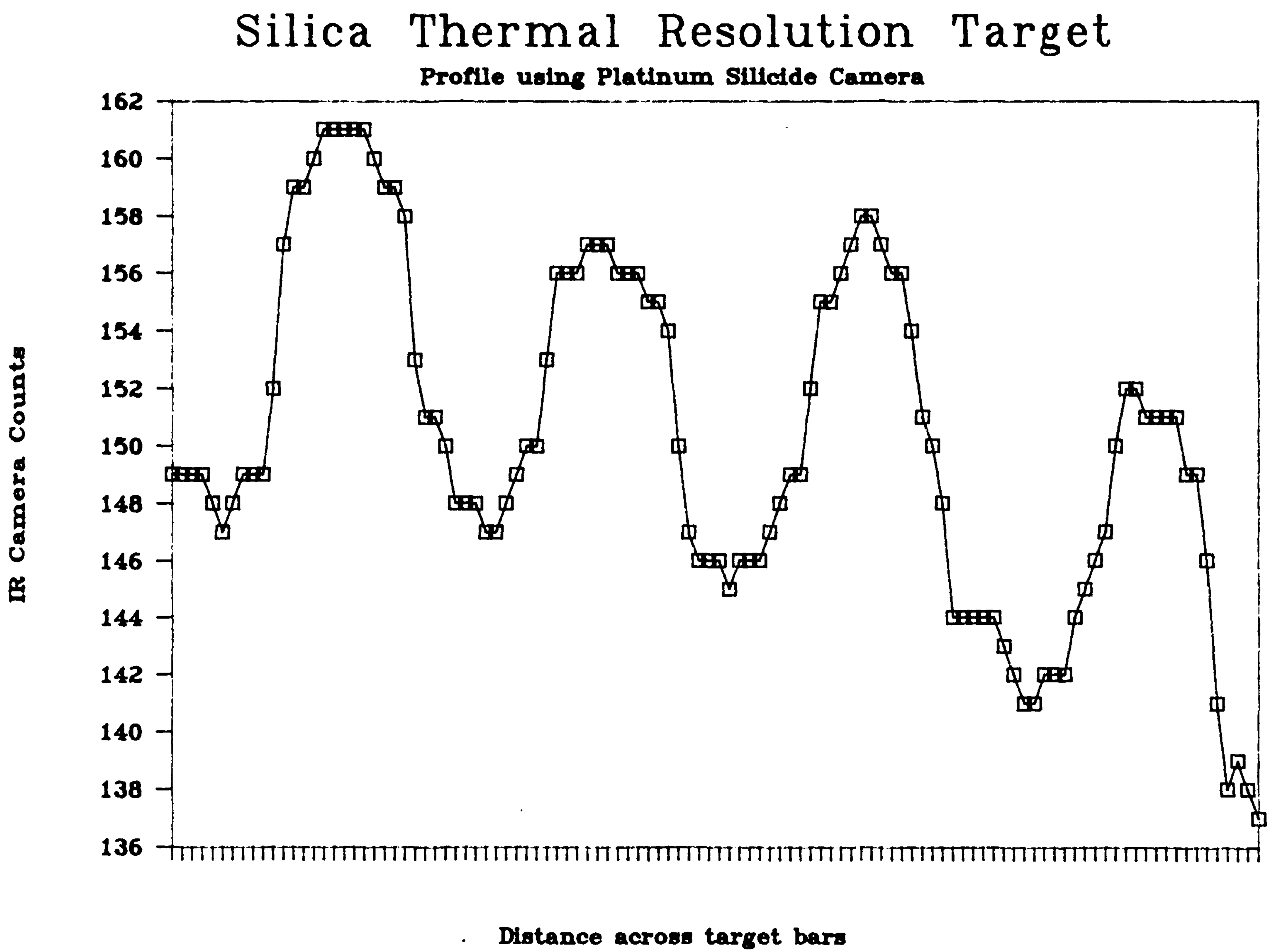

Figure 5. The curve is data from a computer analysis of one of the early scans across the 4 warm bars of the silica thermal contrast target.

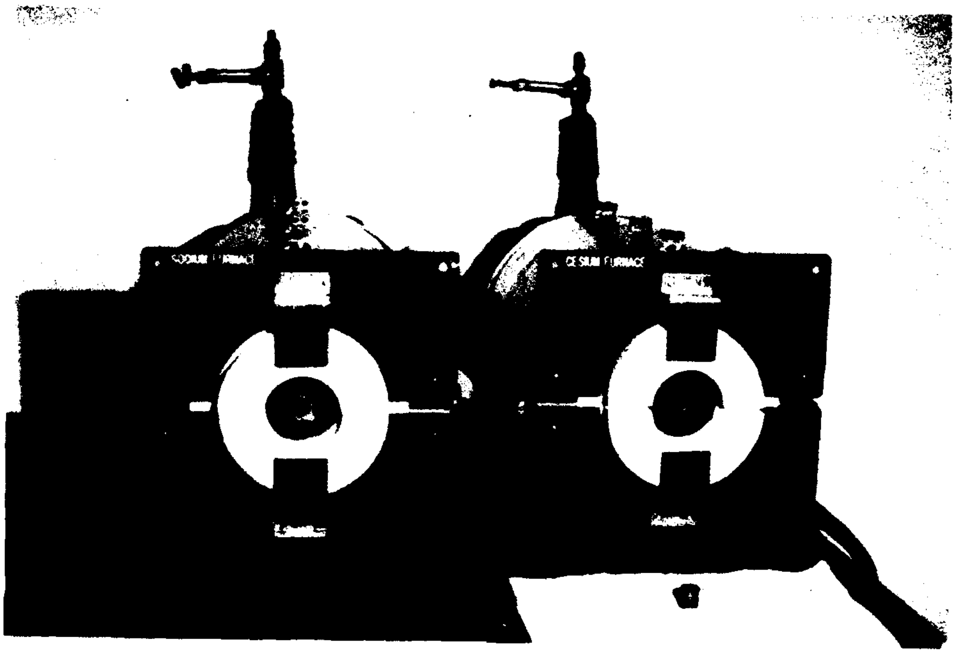

Figure 6. Heat pipe blackbodies in furnaces. The central aperture is one inch. The tubes protruding from the rear connect to a pressure control system.

Fractography of Tensile Fractured Optical Fibers Using Scanning Electron Microscopy

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A multitude of applications exist for fiber optic devices. Development of high strength, tough, and enduring fiber has proceeded through the years to a point where many uncabled applications are viable. This advance in strength has come from many processing improvements. Optical as well as mechanical properties have improved dramatically from such processing improvements.

Many advanced materials processing improvements are driven today by determination of the mechanisms of failure. For mechanical properties the inspection of mechanical fracture interfaces for failure origin and flaw type has become routine. Ideally the disclosure of flaw types and failure mechanisms can lead to design of both processing techniques which diminish the flaw sizes and frequency, and application modifications which reduce their affect on performance.

In the case of optical fibers exacting analysis of fracture modes has received little attention, and for good reason. The small size and dynamic nature of fiber fracture has inhibited such analysis. Typical optical fibers are 50 to 200 micron diameter glass rods with various metal, ceramic, and polymer coatings applied to enhance mechanical properties and handling characteristics. Strengths as high as 6GPa are attainable, and 5GPA is commonly reported. High strengths would indicate submicron origin of fracture flaws, inherently difficult to locate in any material. Fracture of these fibers is typically catastrophic, due to the storage of energy during elastic deformation approaching failure. For undamped fracture experiments the whipping action of newly generated fiber ends, and shock waves along the length of the fiber emanating from the fracture interface can result in multiple secondary fractures. Thus preservation of the initial fracture interface is difficult to achieve. The damping of tensile fracture in a water bath improves preservation of this primary fracture interface.

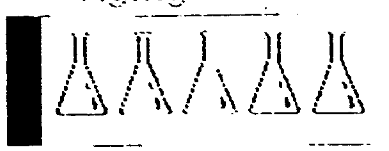
The small size of the interface, and the transparent nature of the glass make optical analysis of the interface virtually impossible. Scanning electron microscopy (SEM) has been used to evaluate these fracture interfaces to determine the origin, geometry, and size of flaws leading to failure. Theoretical work and studies of other fibers lead us to expect surface flaws of geometry best characterized by a semicircular or elliptical part-through crack, normal to the axis of a cylindrical fiber. This study attempts to establish the validity of these assumptions. It is proposed that the use of the techniques and information on critical flaws and projected fracture mechanisms discussed here will contribute to implementation of further design improvements in optical fiber processing.

FIBER STRENGTH ANALYSIS

Experimental

Receive Spools of Fiber
Cut fiber to sample length and randomize
Group fiber for aging and later tensile tests

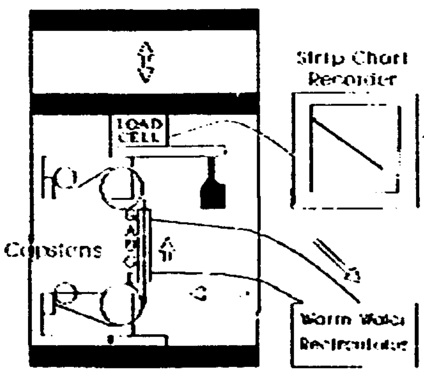
Aging Tank



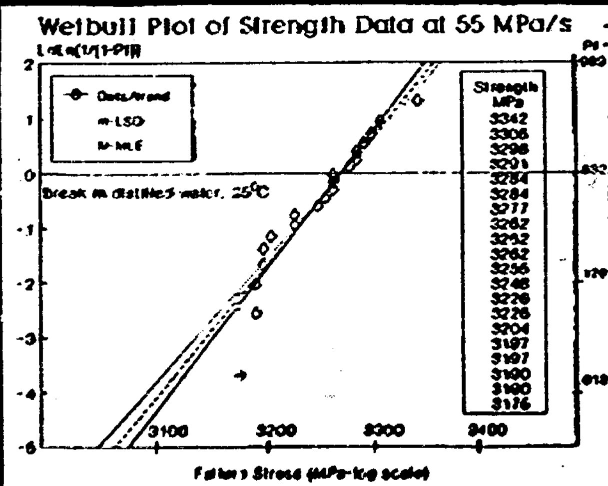
Unaged Fiber

Aged Fiber

Instron Tensile Tester



DRY, WET, WET & HOT broken fiber data



Predictive Analysis

Equations :

Weibull $\ln\ln(1/(1-P_f)) = m\ln(S_f/S_o)$, $P_f = (i-0.5)/n$

Static $t_f = BS_i^{(N-2)}/S_a^N$

Dynamic $S_f^{(N+1)} = B(N+1)\dot{S}S_i^{(N-2)}$

Aging $S_i = S_{io}(1+at)^b$

Parameters determined from data as follows :
So and m from Weibull Plot using Least Squares fit.
Sio from dry break data as an approximation.
B and N from stress rate and temperature data.
b and a from aged fiber strength behavior

Strength predicted with straight static or combined static-aging behavior

Equation 1, Static

$t_f = 2B(S_{io}(1/2))^{(N-2)}/S_a^N$

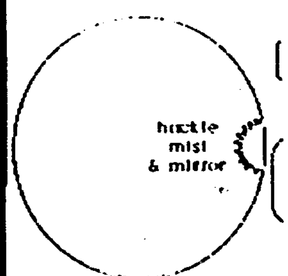
Equation 2 Combined Static Aging

$t_f = 2B[S_{io}(1+at/2)]^{b(N-2)}/S_a^N$

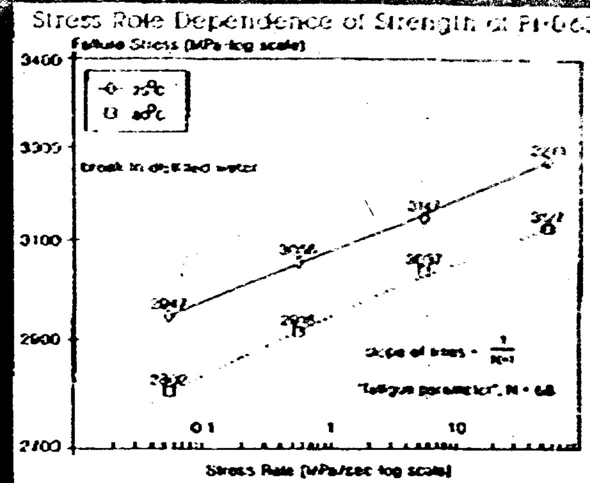
Fractography

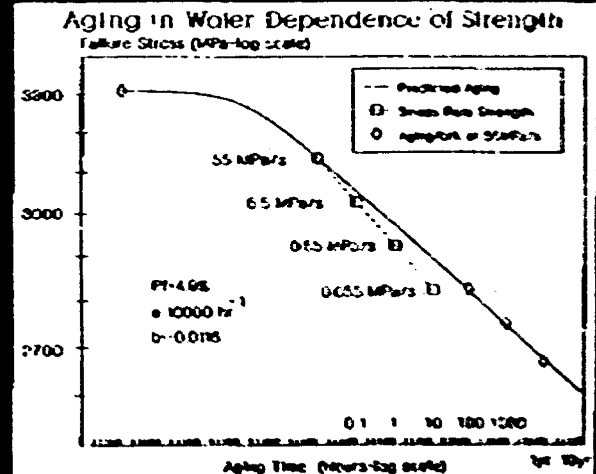
Scanning Electron Microscopy (SEM)
Magnification at 1000x to 20000x
Identification of:

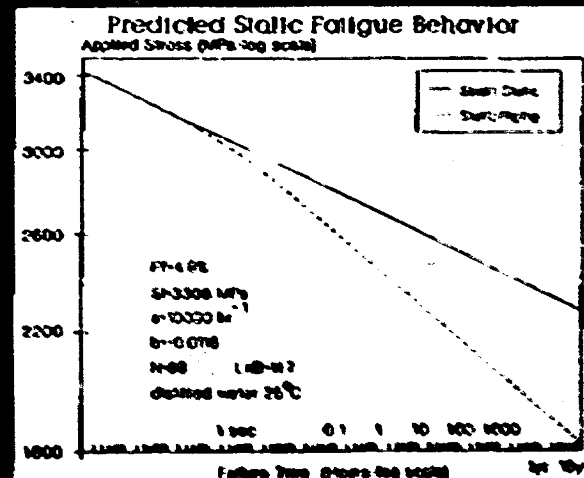
- surface fractures
  failure site shape appears as a semicircular crack
- flaw type
  pore
  scratch
  particulate
  pinhole in hermetic coating
- flaw size
  01 to 1.0 micron



Analysis of fracture origin leads to recommendations for processing improvement.







The viewgraph enclosed is a composite outlining the overall effort on fiber analysis at MTL. Fractographic analysis is but one element of this program. Much of this overall effort has been in concert with programs supporting materials requirements for fiber optic guided vehicles, FOG-M in particular. Certain elements of this analysis have been used to characterize structural fibers for ceramic composites at MTL.

A Front End Processor

By Curtis M. Low

Slide 1

This front end processor creates input for most standard logistics models using minimal information. During early system definition you usually have only minimal information. The process used allocated reliability, cost and maintainability using weighted distributions.

Slide 2

There are several advantages to using a standard model early in the system development process.

Slide 3

Most logistics models input component reliability, cost and maintainability as key inputs.

Slide 4

For the front end processor, only nine numbers are input: Four are system values; three weight distributions and two link the weighted distributions.

Slide 5

Three different distributions are weighted together to produce the component values.

Slide 6

For the expected distribution the exponential sequence is shown. Below that is the denominator values used to normalize. At the bottom of the chart is an expected distribution for four components.

Slide 7

The system value is raised to a power. The denominator of that power is the number of components. All minimum variance values are equal.

Slide 8

One component has all the failures and none of the other components fail.

Slide 9

The system values are raised to a power. The power is the normalized value from the exponential distribution.

Slide 10

On the weighting scale 0 links to the minimum distribution. The expected distribution links to .5 and the maximum distribution links to 1.0. The user input scaler is used with standard interpolation techniques to weight between which ever two distributions it falls between.

Slide 11

Cost is computed similar to reliability with small mathematical differences in computation.

Slide 12

The cost distributions are weighted in the same way that the reliability ones were.

Slide 13

The linking of cost and reliability is a weighted process also. Low cost to high reliability is associated with 0. Low cost to low reliability is associated with 1.0 and .5 is associated with random link between cost and reliability. The equations in the middle just produce random numbers between 1 and 4. Since a .4 was the scaler input by the user and .4 is close to the random .5 value, a flip flop occurs between the third and fourth components.

Slide 14

The actual link is as shown with the third and fourth components flip flopped on cost.

Slide 15

Maintainability values are done in the reverse order to cost. The link must be established first. Note that .6 is close to .5 (Random) and produced a flip flop between the second and third components.

Slide 16

The actual link is shown with the second and third components flip flopped. Note that order is shown because the maintainability values have not yet been calculated.

Slide 17

The maintainability is similar to cost and reliability. Note that reliability is used in the calculations which is why maintainability must be linked to reliability prior to computation.

Slide 18

The weighting is exactly the same as with cost and reliability.

Slide 19

The example for four components and the system and scaler values input produced these results.

MISSILE LOGISTICS CENTER

FRONT END PROCESSOR

CREATES

INPUT - STANDARD MODELS

FROM

MINIMAL INPUT (EARLY SYSTEM DEFINITION)

PROCESS

ALLOCATION - WEIGHTED DISTRIBUTIONS

MISSILE LOGISTICS CENTER

STANDARD MODEL ADVANTAGES

FAMILIAR TO ANALYST

UNDERSTOOD BY ANALYTIC COMMUNITY & CUSTOMERS

CONSISTENT FOR LATER RUNS

MISSILE LOGISTICS CENTER

PROCESSOR OUTPUT
(MODEL INPUT)

COMPONENT RELIABILITY

COMPONENT MAINTAINABILITY

COMPONENT COST

MISSILE LOGISTICS CENTER

PROCESSOR INPUT

1. NUMBER OF COMPONENTS
2. SYSTEM RELIABILITY (1 NUMBER)
3. SYSTEM MAINTAINABILITY (1 NUMBER)
4. SYSTEM COST (1 NUMBER)
5. RELIABILITY SCALER
6. MAINTAINABILITY SCALER
7. COST SCALER
8. RELIABILITY - MAINTAINABILITY SCALER
9. RELIABILITY - COST SCALER

MISSILE LOGISTICS CENTER

DISTRIBUTIONS

MINIMUM VARIANCE

- ALL COMPONENTS EQUAL

MAXIMUM VARIANCE

- ONE COMPONENT = ALL FAIL/ALL MAINT/ALL COST
- OTHER COMPONENTS = NO FAIL/NO MAINT/NO COST

EXPECTED VARIANCE

- COMPONENTS UNLIKE
- EXPONENTIAL SEQUENCE

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EXPECTED DISTRIBUTION

EXPONENTIAL SEQUENCE (NUMERATOR) N+1 = SUM(1 TO N) + N

1ST	2ND	3RD	4TH	5TH	6TH	7TH
1	2	5	13	34	89	233

NORMALIZE TO SUM TO ONE (DENOMINATOR)

ONE	TWO	THREE	FOUR	FIVE	SIX	SEVEN
1	3	8	21	55	144	377

FOR 4 COMPONENTS

1ST	2ND	3RD	4TH	SUM
1/21 +	2/21 +	5/21 +	13/21 =	1

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MINIMUM VARIANCE EXAMPLE

ALL COMPONENTS EQUAL

4 COMPONENTS

90% SYSTEM RELIABILITY

COMPUTATION

.90^(1/4) = .974

EACH COMPONENTS RELIABILITY = .974

CHECK

.974 X .974 X .974 X .974 = .90

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MAXIMUM VARIANCE EXAMPLE

ONE COMPONENT = SYSTEM VALUE

4 COMPONENTS

90% SYSTEM RELIABILITY

COMPUTATION

ONE COMPONENT = .90

OTHER COMPONENTS = 1.00

CHECK

.90 X 1.00 X 1.00 X 1.00 = .90

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EXPECTED VARIANCE EXAMPLE

MAXIMUM DIFFERENCES

4 COMPONENTS

90% SYSTEM RELIABILITY

COMPUTATION

$.90^{(1/21)} = .995$

$.90^{(2/21)} = .990$

$.90^{(5/21)} = .975$

$.90^{(13/21)} = .937$

CHECK

$.995 \times .990 \times .975 \times .937 = .90$

MISSILE LOGISTICS CENTER

RELIABILITY DISTRIBUTIONS WEIGHTED

MIN	EXP	MAX
.974	.995	1.00
.974	.990	1.00
.974	.975	1.00
.974	.937	.90

RELIABILITY WEIGHTING SCALE

0	.5	1.0

RELIABILITY WEIGHTING SCALER

FOR .9 SCALER .999 X .998 X .995 X .907 = .90

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COST

SYSTEM COST = $1000

4 COMPONENTS

MIN DIST COMP

$1000/4 = $250 FOR EACH COMPONENT

MAX DIST COMP

$1000 FOR ONE COMPONENT

$ 0 FOR THE OTHER COMPONENTS

EXP DIST COMP

$1000 X 1 / 21 = $ 48

$1000 X 2 / 21 = $ 95

$1000 X 5 / 21 = $238

$1000 X 13 / 21 = $619

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COST DISTRIBUTION WEIGHTED

MIN	EXP	MAX
250	48	0
250	95	0
250	238	0
250	619	1000

COST WEIGHTING SCALE

0	.5	1.0

COST WEIGHTING SCALER

FOR .3 SCALER $129 + $157 + $243 + $471 = $1000

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COST LINK RELIABILITY

LOW-HIGH	RANDOM	LOW-LOW
1	RN1 X 3 + 1	4
2	RN2 X 3 + 1	3
3	RN3 X 3 + 1	2
4	RN4 X 3 + 1	1

LINKING SCALE

0	.5	1.0

LINKING SCALER

FOR .4   1ST = 1.3   2ND = 2.8   3RD = 3.5   4TH = 3.4

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COST LINK

RELIABILITY	COST
.999	$129
.998	$157
.995	$471
.907	$243

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MAINTAINABILITY LINK RELIABILITY

LOW-HIGH	RANDOM	LOW-LOW
1	RN1 X 3 + 1	4
2	RN2 X 3 + 1	3
3	RN3 X 3 + 1	2
4	RN3 X 3 + 1	1

LINKING SCALE

0	.5	1.0

LINKING SCALER

FOR .6 1ST = 3.4 2ND = 2.5 3RD = 2.7 4TH = 1.5

MISSILE LOGISTICS CENTER

MAINTAINABILITY LINK

RELIABILITY	MAINTAINABILITY
.999	4TH
.998	2ND
.995	3RD
.907	1ST

MISSILE LOGISTICS CENTER

MAINTAINABILITY

SYSTEM MTTR = .5 HRS

4 COMPONENTS

MIN DIST COMP

.5 FOR EACH COMPONENT

MAX DIST COMP

ONE COMPONENT = (1-.90) / (1-.999) X .5 = 50 HRS

OTHER COMPONENTS = 0 HRS

EXP DIST COMP

(1-.907)X+(1-.998)(2)X+(1-.995)(5)X+(1-.999)(13)X = (1-.90)(.5)

X = .37

2X = .74

5X = 1.85

13X = 4.81

MISSILE LOGISTICS CENTER

MAINTAINABILITY DISTRIBUTION WEIGHTED

MIN	EXP	MAX
.5	.37	0
.5	.74	0
.5	1.85	0
.5	4.81	50

MAINTAINABILITY WEIGHTING SCALE

0	.5	1.0

MAINTAINABILITY WEIGHTING SCALER

FOR .1 1ST = .47 2ND = .54 3RD = .77 4TH = 1.36

MISSILE LOGISTICS CENTER

EXAMPLE RESULTS

RELIABILITY	COST	MAINTAINABILITY
.999	$ 129	1.36 HRS
.998	$ 157	.54 HRS
.995	$ 471	.77 HRS
.907	$ 243	.47 HRS

SHELF LIFE ISSUES WITH INFRARED DETECTOR/DEWAR ASSEMBLIES

28 AUGUST 1991

SECOND MICOM LOGISTICS
RESEARCH AND DEVELOPMENT WORKSHOP

NEIL SUPOLA
PROJECT LEADER, DETECTOR/DEWARS
CECOM CENTER FOR NIGHT VISION AND
ELECTRO-OPTICS

SHELF LIFE ISSUES WITH INFRARED DETECTOR/DEWAR ASSEMBLIES

OUTLINE

I. INTRODUCTION
- LOGISTICS PROCEDURES
- INFRARED SIGHTS/MISSILES
- DETECTOR/DEWAR FAMILY

II. SPECIFICATIONS
- REQUIREMENTS
- TEST METHODOLOGY

III. THEORETICAL DISCUSSION
- VACUUM LIFE PARAMETERS
- ACCELERATED TESTING

IV. CURRENT DEVELOPMENT ACTIVITIES

V. VACUUM LIFE DATA

VI. CONCLUSIONS

LOGISTICS PROCEDURES

- <u>MAINTENANCE</u>
  - MODULAR REPLACEMENT IN FIELD
  - REFIRE GETTERS AT DEPOT
  - GETTER FIRING SCHEDULE ON DEWAR
- <u>FIRST GENERATION</u>
  - <u>COMMON MODULES</u>
    - 1 YEAR SHELF LIFE - NO DEGRADATION
    - 2 REUSABLE, ELECTRICAL ACTIVATED GETTERS (7 ADDITIONAL FIRINGS)
  - <u>INTEGRATED DETECTOR/DEWAR ASSEMBLY (IDA)</u>
    - 5 YEAR SHELF LIFE - NO DEGRADATION
    - 10 YEAR SHELF LIFE -100% HEAT LOAD INCREASE
- <u>SECOND GENERATION</u>
  - <u>STANDARD ADVANCED DEWAR ASSEMBLY (SADA)</u>
    - 5 YEAR SHELF LIFE - NO DEGRADATION
    - 10 YEAR SHELF LIFE -17 % DEGRADATION

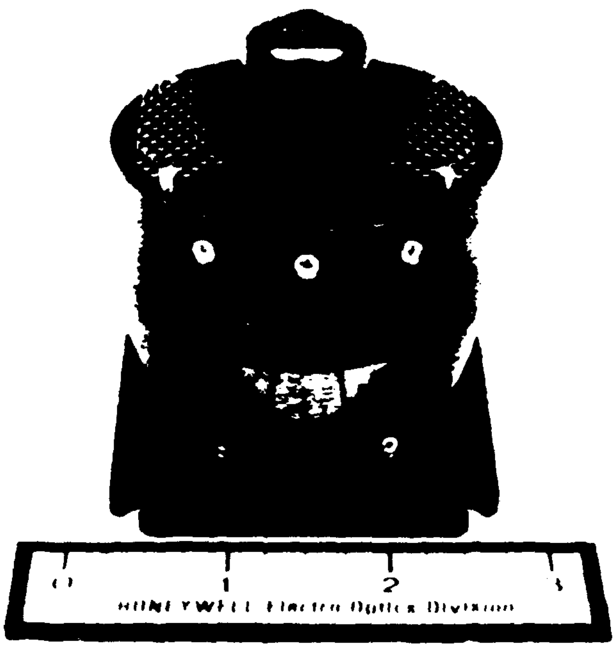
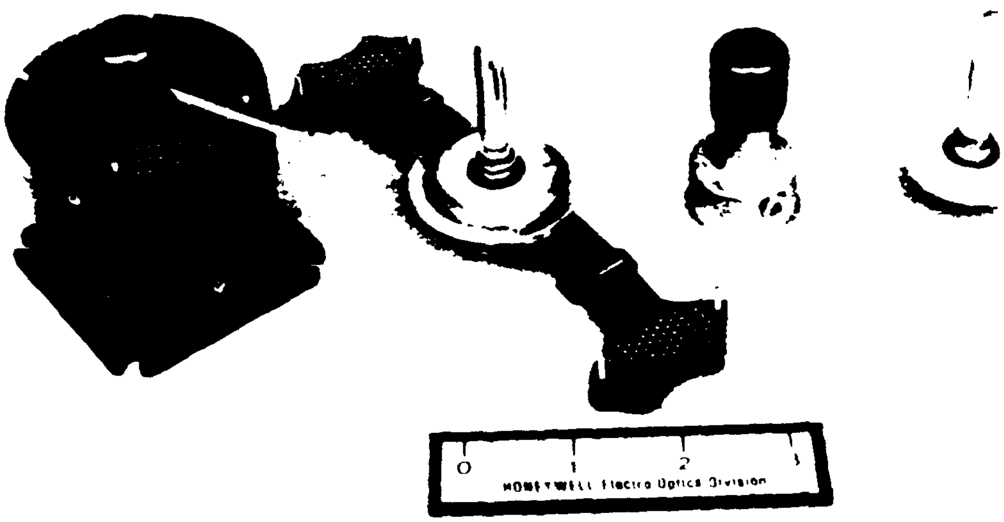


Figure 2-2. Assembled Dewar Vacuum Assembly



Disassembled TOW 591 Dewar Vacuum Assembly

VACUUM INTEGRITY SPECIFICATIONS REQUIREMENTS AND TEST METHODOLOGY

REQUIREMENT

THE DETECTOR/DEWAR SHALL MAINTAIN ITS SPECIFIED HEAT LOAD FOR A PERIOD OF AT LEAST ONE YEAR

TEST METHODOLOGY

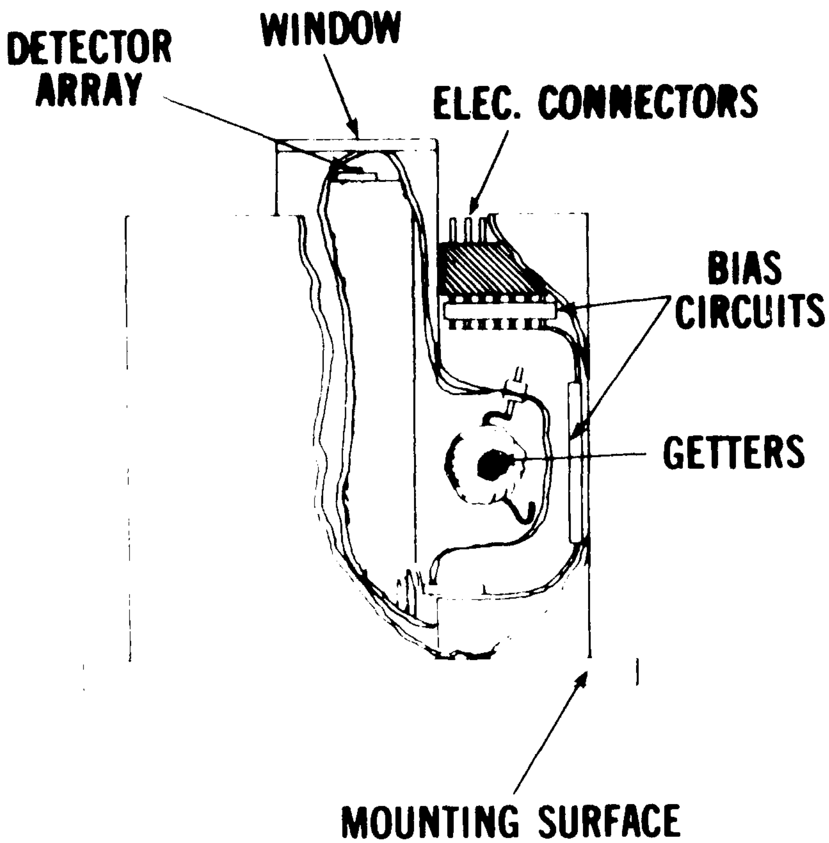
HEAT LOAD SHALL BE MEASURED ON THE UNBIASED DETECTOR/DEWAR. THE TEMPERATURE OF THE DETECTOR/ DEWAR SHALL THEN BE ELEVATED TO +71 C FOR A PERIOD OF 72 HOURS. AT THE COMPLETION OF THE TEMPERATURE EXPOSURE AND STABILIZATION AT AMBIENT TEMPERATURE, THE HEAT LOAD SHALL BE MEASURED AGAIN. GETTERS MAY NOT BE FIRED DURING THIS TEST. FAILURE OF THE DETECTOR/ DEWAR TO MAINTAIN ITS SPECIFIED HEAT LOAD OR 15% INCREASE IN HEAT LOAD BETWEEN THE MEASUREMENT BEFORE AND AFTER TEMPERATURE SHALL CONSTITUTE FAILURE OF THIS TEST

VACUUM LIFE ANALYSIS
VACUUM INTEGRITY VERIFICATION

- PARAGRAPH 4.5.23, 4.5.23.1, 4.5.23.2
  - HIGH TEMPERATURE STORAGE, TEMPERATURE SELECTED TO PRODUCE $\geq$ 20X ACCELERATION IN OUTGASSING AS COMPARED TO 27°C, DURATION OF STORAGE TO BE $\leq$ SIX (6) MONTHS.
  - HIGH PRESSURE AIR STORAGE, PRESSURE SELECTED TO PRODUCE 10X INCREASE IN LEAKAGE, SIX (6) MONTH STORAGE DURATION.
  - HEATLOAD TO BE THE METRIC AT TWO (2) WEEK INTERVAL TESTING FOR BOTH OF THE INTEGRITY DEMONSTRATION TESTS.

3/91
91-0190-166

DETECTOR-DEWAR DT-594/ʊA



SPECIFICATIONS

DETECTOR ARRAY

DETECTIVITY: 162 ELEMENTS $\geq 3.4 \times 10^{10}$ CM $Hz^{1/2}W^{-1}$
18 ELEMENTS $\geq 2.0 \times 10^{10}$ CM $Hz^{1/2}W^{-1}$

RESPONSIVITY: 171 ELEMENTS $\geq 1.6 \times 10^{4}$ VW^{-1}
ARRAY AVERAGE $\geq 2.0 \times 10^{4}$ VW^{-1}

TIME CONSTANT: $\leq 2.0\mu$ SEC

SPECTRAL RESPONSE: $7.5^{+0.25}_{-0.05}$ TO $11.75 \pm 0.25\mu$ M

BIAS CURRENT AVERAGE: $\leq$ 4.5 MA/ELEMENT

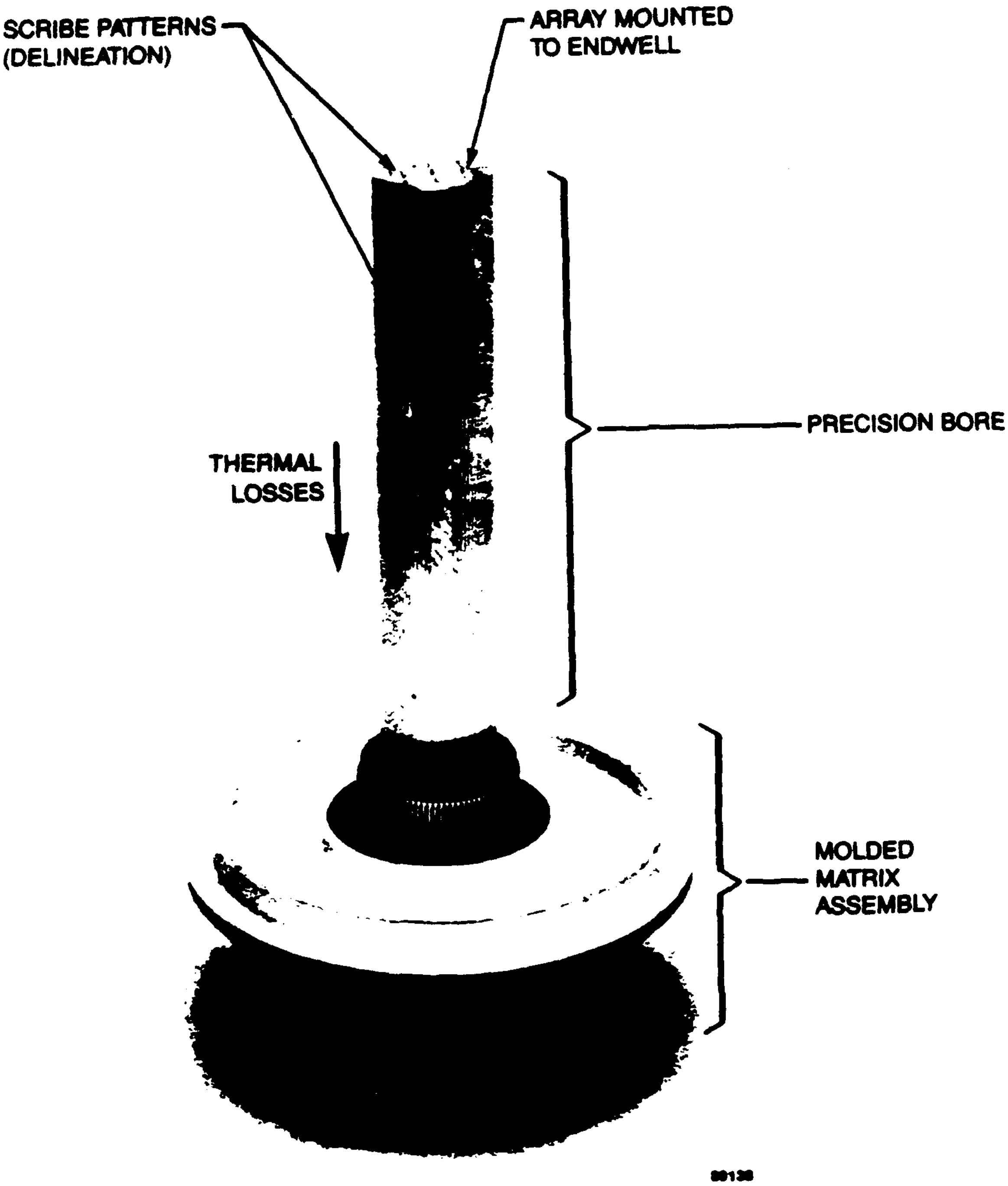
BIAS POWER (ARRAY): $\leq$ 100 MWATTS

DEWAR

HEAT LOAD (BIASED) $\leq$ 400 MWATTS

WEIGHT $\leq$ 0.715 LBS.

USES: 2 REUSABLE GETTERS
: INTEGRAL BIAS PACK (5 VOLTS)



TOW Delineated Coldwell Assembly

VACUUM LIFE PARAMETERS & FAILURE INDICATORS

VACUUM LIFE OF A DEWAR IS LIMITED BY FIVE PRINCIPAL MECHANISMS / DESIGN PARAMETERS:

- MATERIAL OUTGASSING
- AIR LEAK RATES
- GAS (HELIUM) PERMEATION
- GETTER CAPACITY
- VOLUME CAPACITY

RESULTS IN A GRADUAL INCREASE IN INTERNAL PRESSURE DEGRADES INSULATING PROPERTY OF DEWAR SPACE

FAILURES APPEAR AS:

- HEAT LOAD EXCEEDS SPECIFIED AMOUNT
- DETECTOR ARRAY WILL NOT COOLDOWN IN REQUIRED TIME
- WINDOW FROST ACCUMULATION FROM THE AIR OCCURS

VACUUM PARAMETERS
MATERIAL OUTGASSING/AIR LEAK RATES

OUTGASSING RATES FROM AMPOULE DATA

-MATERIAL SAMPLE CLEANED
-PIECE PART BAKED
-SEALED IN GLASS AMPOULE
-AGED AT ROOM TEMPERATURE
-OPENED IN EVACUATED CHAMBER
-EVOLUTION OF GAS MEASURED BY MASS SPECTROMETER

AIR LEAK RATES

LEAK DETECTORS OF SUBASSEMBLIES 6X10E-11 STD-CC/S
LEAK DETECTOR OF FINAL ASSEMBLIES 6X10E-14 STD-CC/S

- ACHIEVED THROUGH:

  -SOLDER AND VACUUM BRAZE JOINTS OF WINDOW & CERAMIC-TO-METAL SEALS

VACUUM PARAMETERS
GAS PERMEATION/GETTER/VOLUME CAPACITY

HELIUM PERMEATION

- HELIUM PERMEATION THROUGH GLASS
  - FUNCTION OF SURFACE AREA & THICKNESS , TIME PERMEATION CONSTANT
- HELIUM PERMEATION THROUGH THIN WALLED TUBE

GETTER CAPACITY

- ABSORBS H_2, CH_4, H_2O, N_2, CO, O_2, CO_2, C_3H_8
- ELECTRICALLY ACTIVATED
- INTERNAL TO VACUUM

VOLUME CAPACITY

- DEWAR VOLUME HAS ABILITY TO HOLD GASES UP TO ITS FAILURE PRESSURE

VACUUM LIFE EQUATION

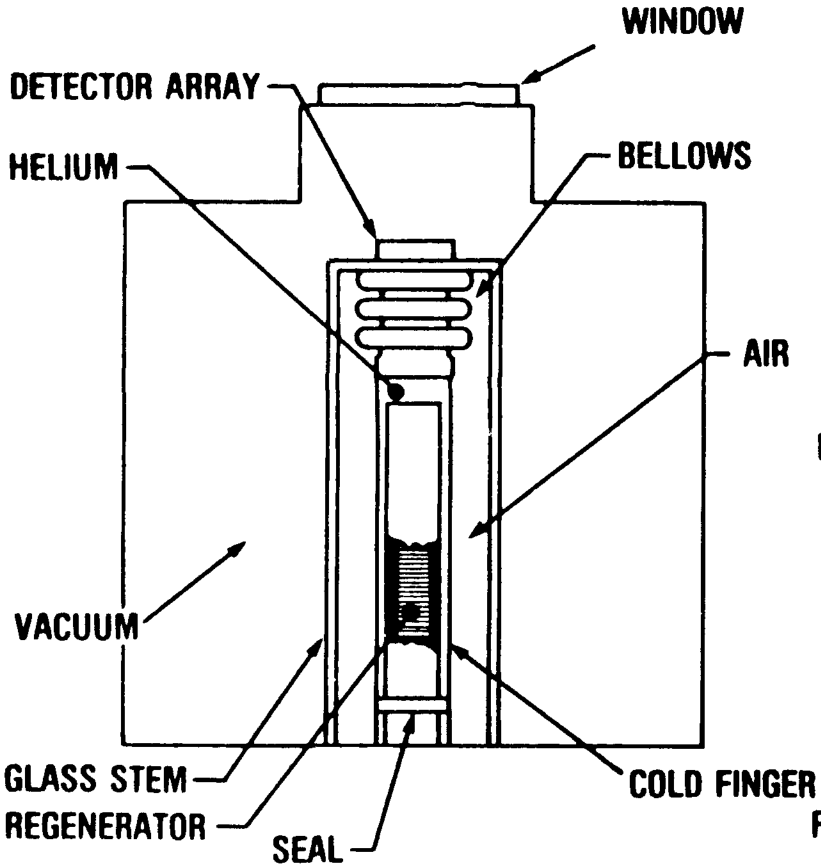
$$T_{LIFETIME} = \left\{ \sum_i Q_i / C_i \right\}^{-1}$$

WHERE:

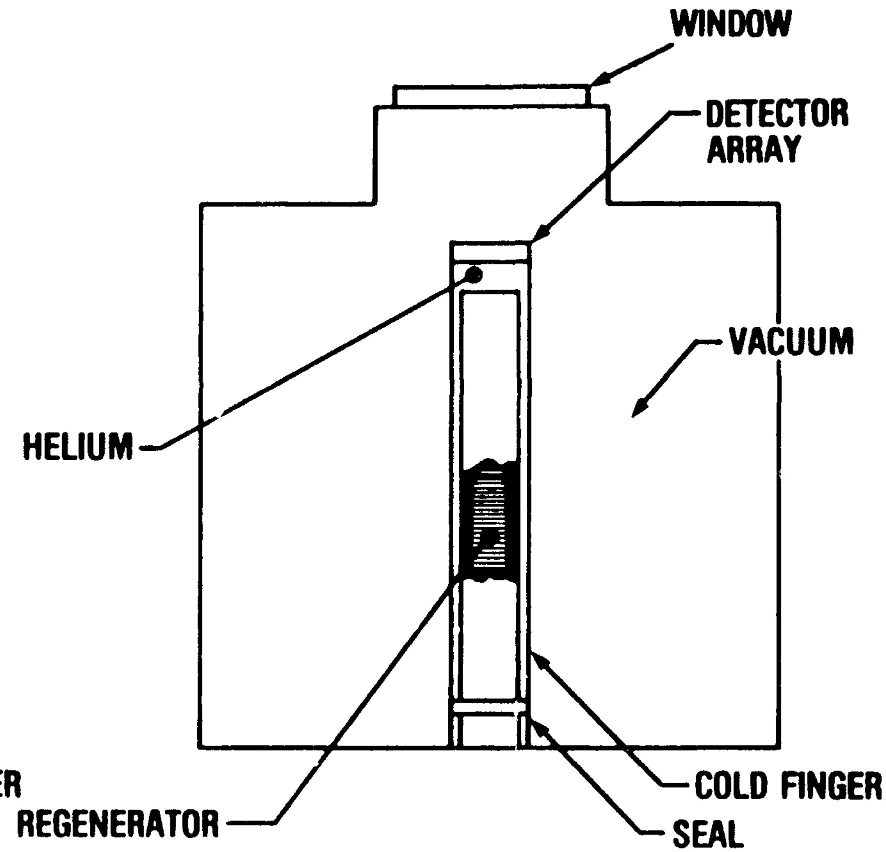
Q_i = TOTAL DEWAR OUTGASSING RATE, AIR LEAK RATE AND PERMEATION FOR EACH GAS SPECIES, i, TORR-L/SEC

C_i = VACUUM GETTER CAPACITY PLUS DEWAR VOLUME CAPACITY FOR EACH GAS SPECIES, i , TORR-L

COOLER/DEWAR INTERFACES

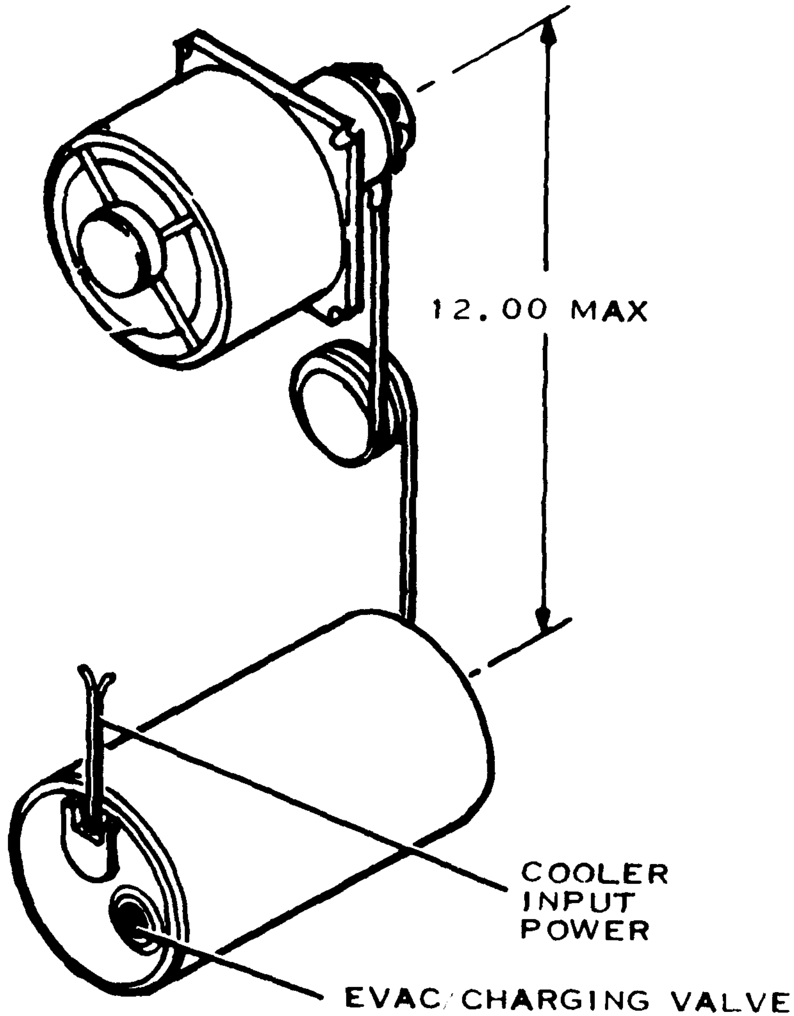


SEPARABLE DEWAR INTERFACE



INTEGRATED DEWAR INTERFACE

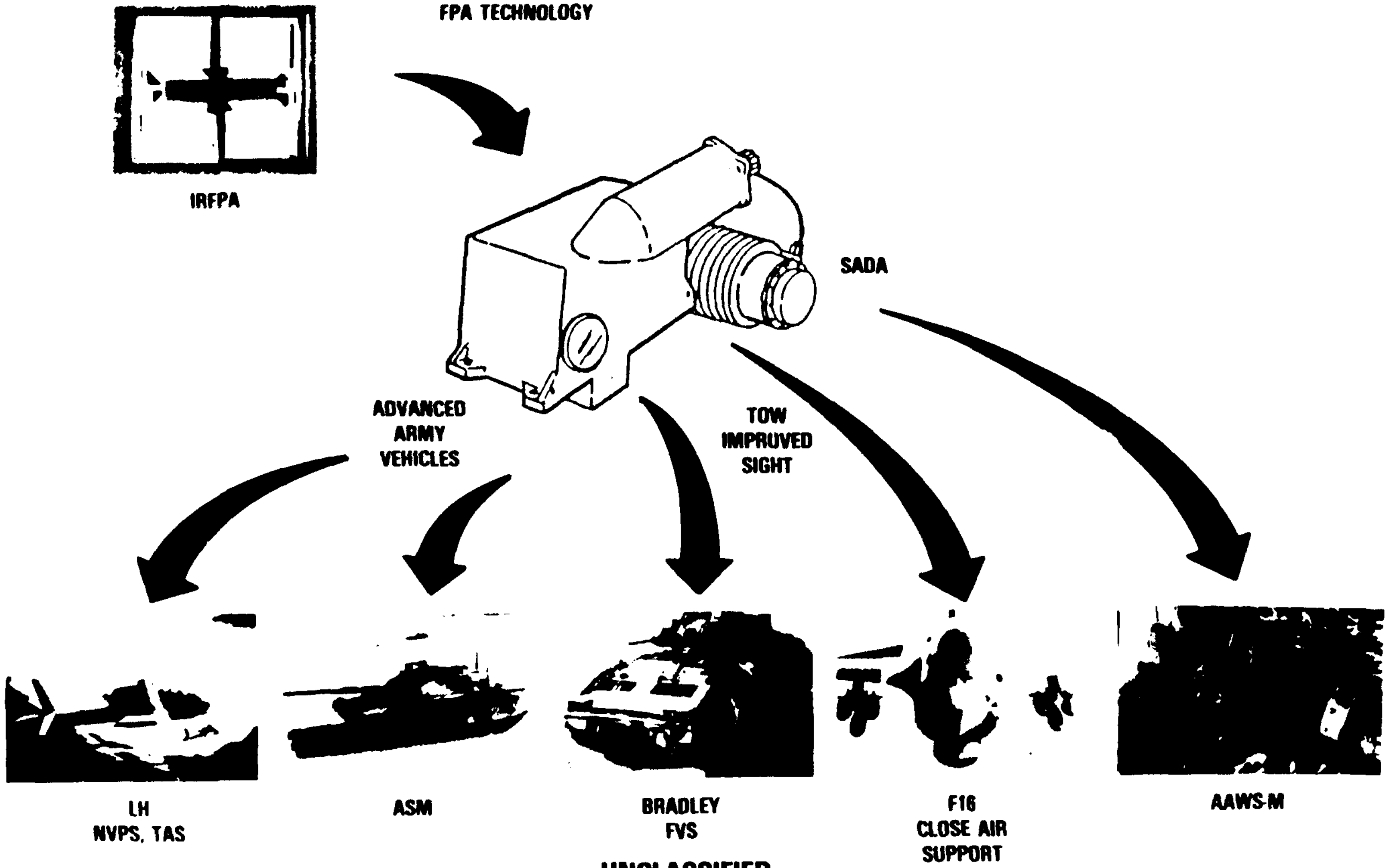
INTEGRATED COOLER/DETECTOR-DEWAR



VACUUM SEALING TECHNIQUES

Joint	Common Module	IDA
Window	Solder	Solder
Feedthrough	Fired dielectric	Fired dielectric
Bowl/cap	Laser-welded	Laser-welded
Stem/feedthrough	Glass fusion	Laser-welded
Getter pins	Braze	Braze
Bowl/feedthrough	Laser-welded	Laser-welded

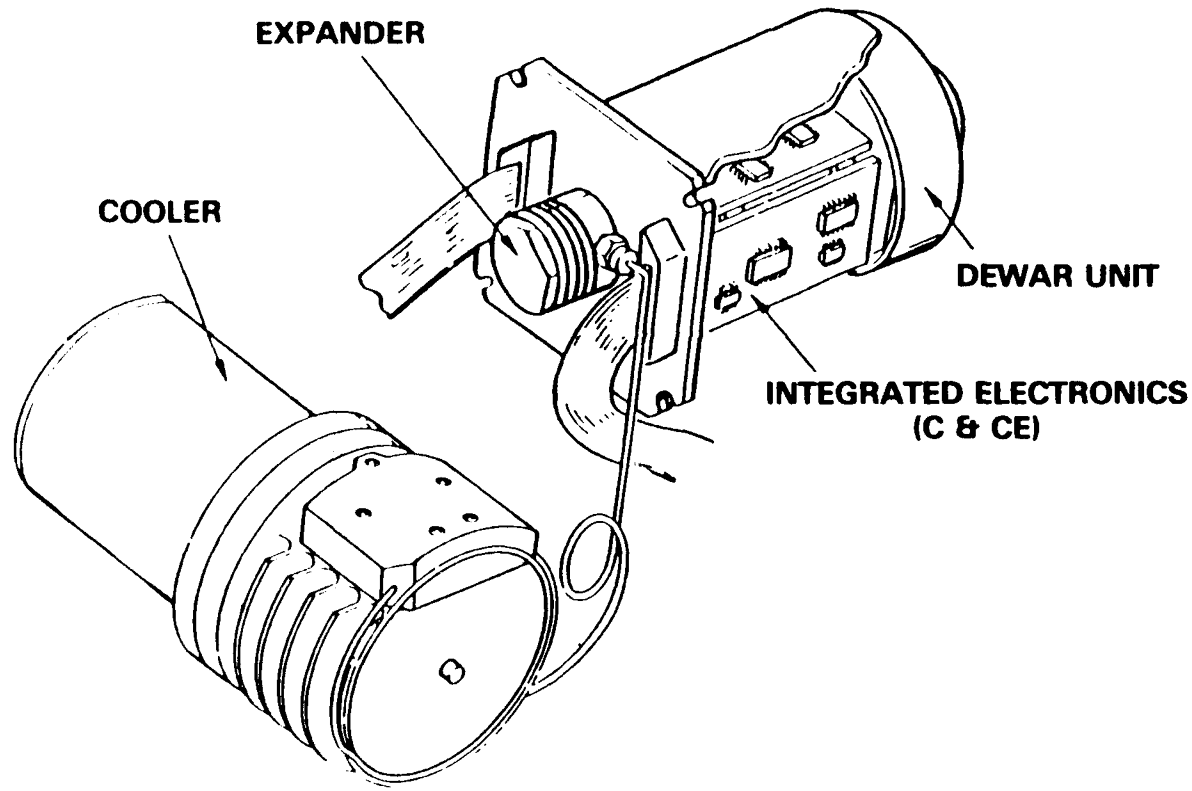
SADA MEETS TARGET ACQUISITION REQUIREMENTS OF ADVANCED WEAPON SYSTEMS



UNCLASSIFIED

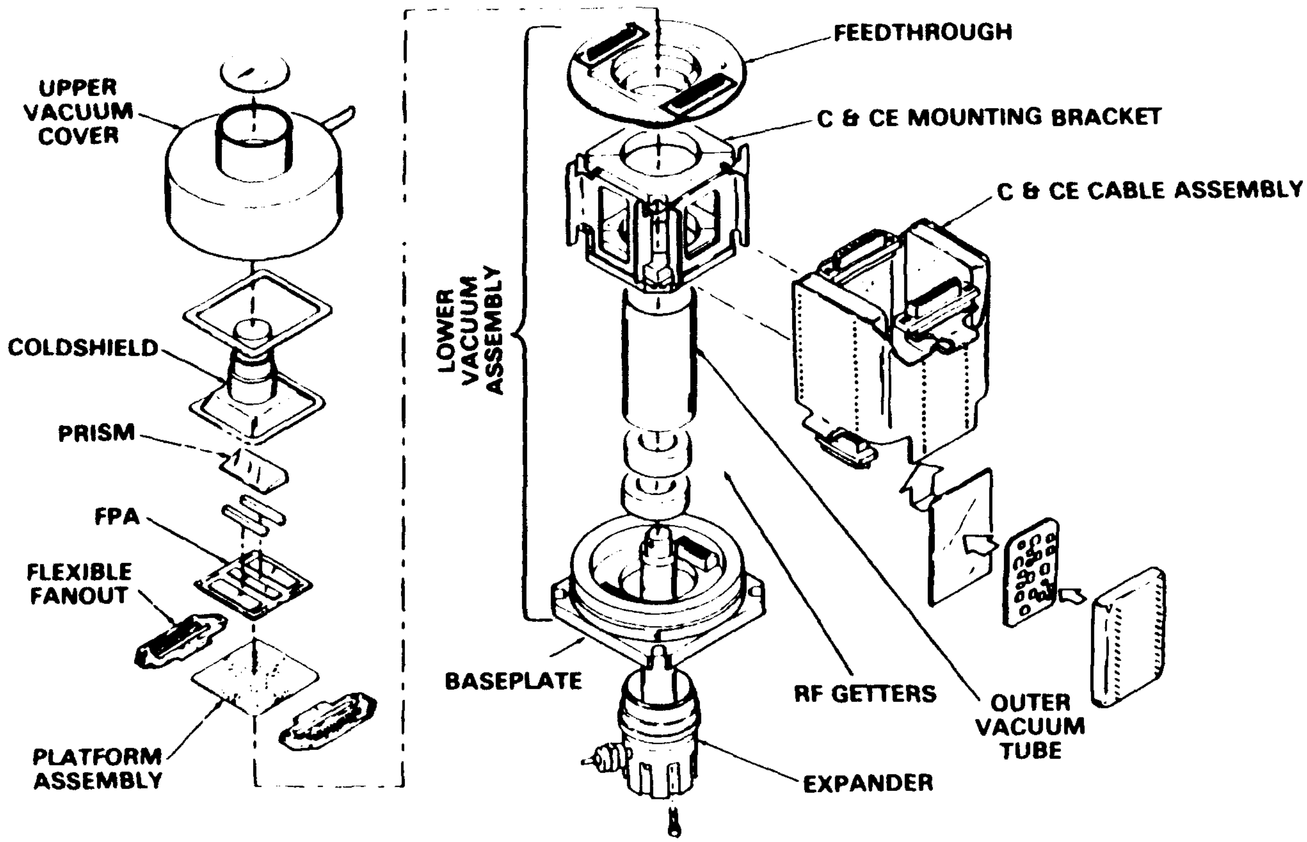
UNCLASSIFIED

SADA
DETECTOR/DEWAR AND COOLER SCHEMATIC

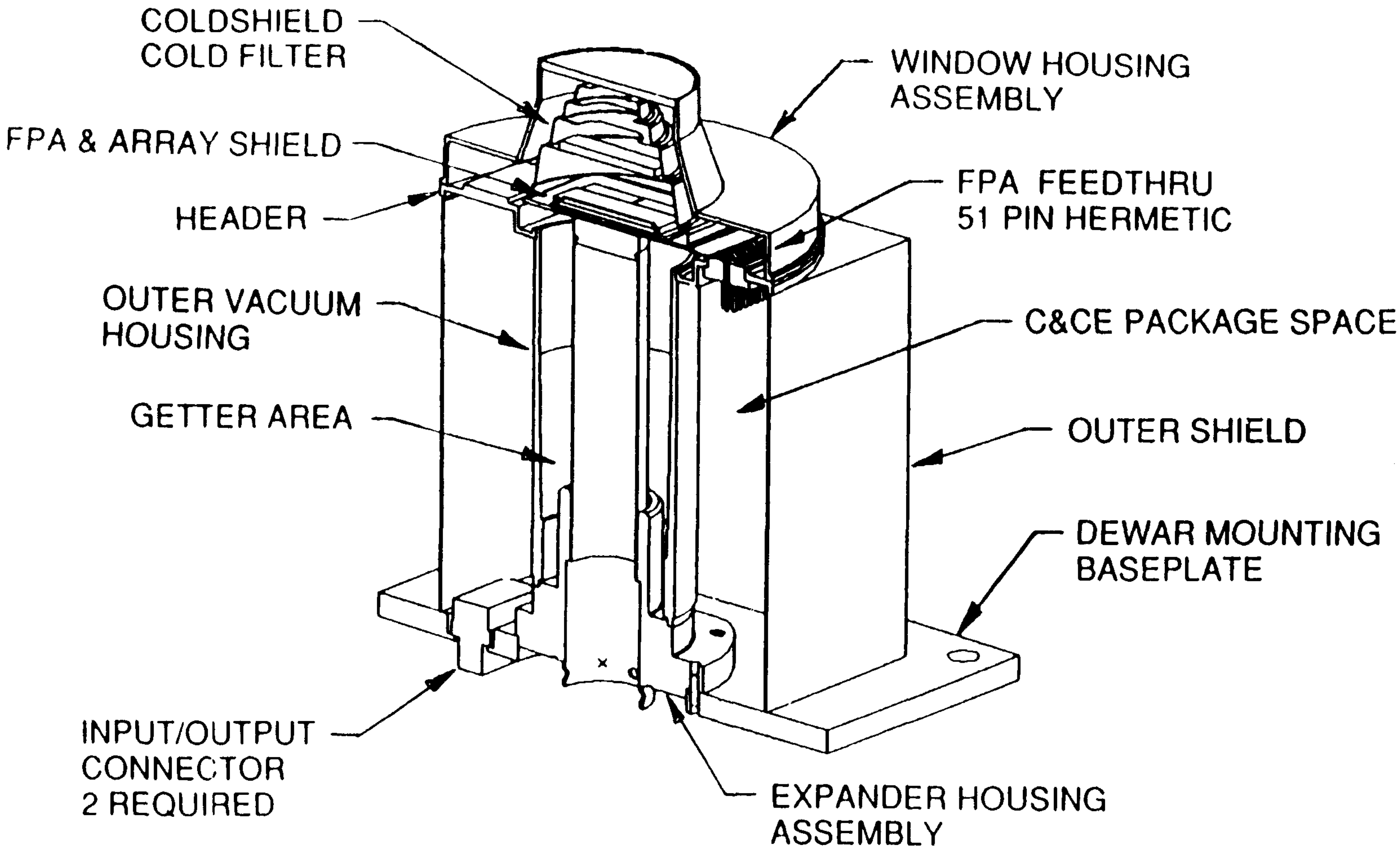


UNCLASSIFIED

SADA DEWAR
EXPLODED VIEW

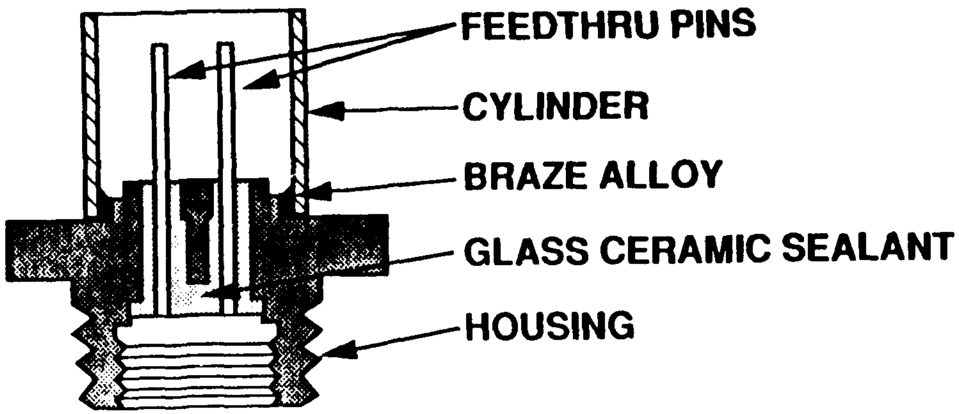


SADA TYPE I DEWAR DESIGN



GLASS CERAMIC SEALED FEEDTHRU

CROSS SECTION



CONCLUSIONS

- EVOLUTION OF REQUIREMENTS FROM COMMON MODULE TO SECOND GENERATION FROM 1 TO 10 YEARS SHELF LIFE

- FIRST GENERATION
  - TECHNOLOGY HAS CONSISTENLY SURPASSED REQUIREMENT

- SECOND GENERATION
  - TECHNOLOGY IS PREDICTED TO MEET FUTURE WEAPON SYSTEM REQUIREMENTS

ADDITIONAL TECHNICAL PAPERS NOT PRESENTED AT WORKSHOP

"VXI bus Calibration Techniques: What's Different, What's the Same?" by *Larry DesJardin* of Hewlett Packard, 303-679-5000.

"The Electronic Paperless Technical Data Manuel Comes of Age" by *Ira Gordon* of AIL Systems, Inc. 516-595-4648.

"The Miniature Automatic Network Analyzer, a New Approach for Reducing Cost and Increasing Capability" by *Alejandro Chu and Dr. H.M. Cronson*, 617-271-6917.

VXIbus Calibration Techniques: What's Different, What's the Same?

Larry DesJardin

Many users have pondered the impact that VXIbus instrumentation will have on their calibration techniques. These small, faceless instruments bear little physical resemblance to their larger GP-IB equivalents, suggesting that calibration and verification techniques may radically change as well. Upon detailed examination, however, there will be far more similarities than differences in calibration techniques.

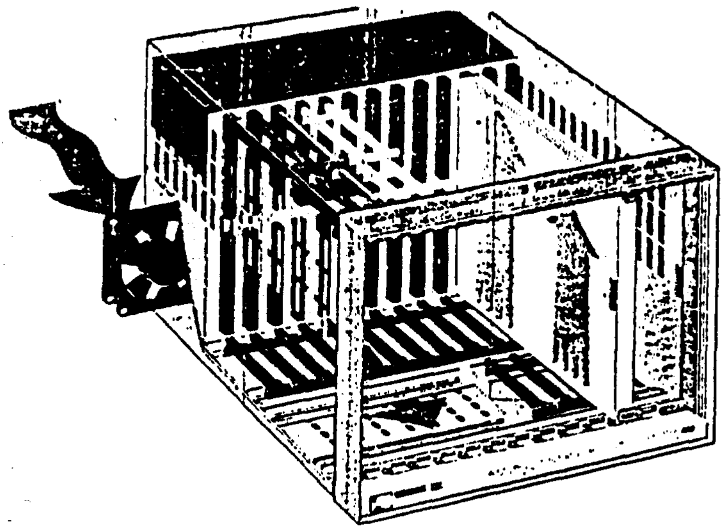
Any instrument requires a calibration process which consists of adjustments, and a verification process. VXIbus instruments are not different in this regard. However, the faceless front panels, reduced size, and system oriented applications of VXIbus products bring new challenges in calibration and the associated logistics. This paper examines each issue, and classifies it as a general ATE calibration issue, or one unique to VXIbus. Prevalent techniques for addressing general ATE issues are reviewed; while several additional solutions for VXIbus specific needs are suggested. The paper concludes with a summary of suggested logistical techniques that will allow a user to painlessly migrate to the use of VXIbus products.

CONTRASTING VXIbus WITH GP-IB

Any system instrument, GP-IB or VXIbus, requires power, cooling, a communication bus, and mechanical mounting. For GP-IB instrumentation, power is typically supplied from the AC power line. Cooling is supplied from the EIA 19 inch rack cabinet the instrument is mounted in, along with the instrument's fan that determines internal air flow path and direction. Communication is performed over the IEEE-488.1 bus that is routed over flexible cables between the instruments and controller.

For VXIbus, many of the resources supplied by the rack cabinet are now supplied by the VXIbus mainframe. Power is supplied to the VXIbus instrument by the seven DC power supplies on the backplane (eight, when +5 Volt Standby power is included).

Likewise, the mainframe delivers air to the modules and includes the mechanical mounting interfaces for the instruments. In the case of air flow, VXIbus actually delivers a more standardized environment since airflow direction is standardized for all modules, while GP-IB instrumentation typically supports a variety of intake and exhaust paths that are inconsistently used within a single rack, allowing one instrument's exhaust air to be another's intake air. Figure 1 shows the airflow for a typical VXIbus mainframe.



Of course, the VMEbus Data Transfer Bus embedded within the VXIbus backplane serves as the communication bus for VXIbus instrumentation.

CALIBRATION LOGISTICS

There are basically two choices facing the GP-IB or VXIbus system integrator regarding calibration logistics. The user may choose to send an instrument needing calibration to a calibration lab, or keep it in the system and bring a transportable transfer calibration source to the test system. Whether GP-IB or VXIbus, this choice is the same.

Bringing the instrument or module to a calibration lab maintains the highest accuracy of the calibration equipment and requires only each single instrument to be transferred between the test system and the calibration lab. However, the calibration lab environment may be significantly different from that at the test station, decreasing accuracy when the instrument or module is returned to the test station.

A "roll-up" transfer calibration standard may be used to calibrate the instruments in a test station, whether GP-IB or VXIbus based. Here, an instrument or module may be calibrated in its natural environment, so higher accuracy may be

Table 1 below summarizes the key differences between GP-IB and VXIbus instrument environments.

	GP-IB	VXIbus
Mechanical Mounting	19 inch EIA Rack 1.75 inch increments	Eurocard Mainframe 0.8 or 1.2 inch increments
Power	AC Line	DC Backplane Supplies
Cooling	Rack air routed through instruments	Mainframe air routed through instruments
Communication	IEEE-488.1	VMEbus
Triggering	Point-to-point	VXIbus Triggers
Signal Connections	Front and/or Rear Panel	Faceplate (typically "front")
Front Panels	Typically Keyboard and Displays	Typically no buttons or displays
EMC, Conducted	FCC, VDE	VXI Power Supply EMC
EMC, Near Field Radiation	None	VXI Near Field EMC

TABLE 1

maintained. Furthermore, an instrument may be calibrated at the test fixture point, compensating for many errors introduced by cabling or fixturing.

Since the calibration occurs at the test station location, the system instruments do not need to be mechanically removed or transported, so system down-time is minimized. However, a "roll-up" transfer standard may not be able to deliver the same accuracy as a calibration lab, and typically requires significant equipment to be transferred between the calibration lab and the test station.

Which strategy is best typically depends on the calibration philosophy of the particular user, and very little due to whether the test equipment is based on GP-IB or VXIbus. If a user chooses to calibrate VXIbus modules in the calibration lab, the calibration lab must make a modest investment into a VXIbus mainframe and controller (either embedded or GP-IB) to power and control the modules during the calibration process.

A third strategy has been emerging recently which is a variant on the "roll-up" transfer calibration scheme. Instead of bringing a transfer calibration system to the tester, a precision transfer standard such as a Digital Multimeter or calibrator is embedded within the test system to calibrate the other system instruments. It "bootstraps" the accuracy of the next most precise source and sensor. Similar techniques can be then used to calibrate the next most precise, but higher frequency instrument. This technique is used in some ATE applications, and can theoretically reduce the transfer standards needed to basic standards of voltage, resistance (or current), and time. Other electrical parameters are derivations or ratios of these fundamental electrical units.

This strategy can reduce the size of the calibration standards to be rolled up to the test system while calibrating the instruments in their final environment through their fixturing. However, the user must invest into this scheme by developing a comprehensive self calibration software program along with the needed switching and cabling paths to allow this "bootstrapping" algorithm to occur. Even this may not be enough, since many instruments still require mechanical tweaks for calibration to occur, prohibiting totally automatic calibration procedures. Additionally, this technique works well for the calibration adjustment process, but requires detailed review to determine the confidence level when used in the verification process, and typically requires additional instrumentation. Figure 2 shows a simple example of a system using an embedded transfer standard.

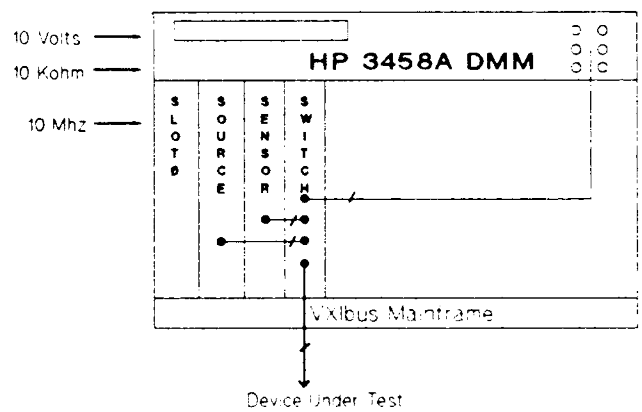


FIGURE 2

A precision DMM within the test station is used to calibrate other, less accurate instruments, whether VXIbus or GP-IB. In this example, it is essentially acting as a transfer calibration standard for the source and sensor instruments, which can be connected together by the switch as part of the bootstrapping algorithm during the calibration process. The HP 3458A DMM was chosen since it can be calibrated from only two standards, 10 Volts and 10 Kohms. The VXIbus Slot 0 device can be used to route the precision 10 Mhz to all modules within the VXIbus mainframe. This reduces many of the requirements of the "roll-up" standard to merely be 10 Volts, 10 Kohm, and 10 Mhz as the traceable paths to national standards.

THE VXIbus ENVIRONMENT AND EFFECT ON ACCURACY

Since accuracy can often be limited by environmental factors, it is necessary to understand the VXIbus environment, its potential differences from GP-IB, and the subsequent effect on calibration accuracy. In most cases, VXIbus delivers a similar environment to GP-IB. Table 1 shows the key architectural differences that will influence the respective environments.

In many respects, a VXIbus mainframe mimics the role of the rack cabinet in GP-IB systems. Temperature stability expectations remain about the same. In VXIbus systems, standardized air flow direction minimizes cross heating effects between instruments, one component of temperature instability. But since VXIbus mainframes are typically also mounted within an EIA 19 inch cabinet, care must be taken so that any remaining GP-IB instruments or other VXIbus mainframes do not cause cross heating effects by emptying exhaust air into another's air intake path. This is typically guaranteed by intaking air exclusively from the large space at the rear of the rack (or, conceivably, the front of the rack) and only exhausting air along the cabinet sides. This allows reverse mounted VXIbus mainframes to be integrated as well, without exhaust air flowing into intake air paths.

Electromagnetic Compatibility (EMC) is another interesting aspect. GP-IB should be able to deliver less Radio Frequency Interference due to the larger spacings available within the 1.75" rack height increments. On the other hand, VXIbus requires compliance to near field conducted and radiated EMC specifications, guaranteeing accuracy specifications in system environments, while there are no standard GP-IB near field EMC requirements. Practically speaking, users will see few EMC issues in either architecture.

In summary, VXIbus instruments and GP-IB instruments see very similar environments, and will deliver similar accuracies in most system environments.

CALIBRATING A VXIbus INSTRUMENT

The actual calibration of a VXIbus instrument may vary from that of many GP-IB instruments. For example, there cannot be a manual calibration mode for a module that has no buttons or displays, and can only be controlled via the data transfer bus on the backplane. On the other hand, if the calibration process at a site has already instituted automatic calibration procedures under computer control, there will be little, if any, difference between calibrating GP-IB instruments or VXIbus instruments.

For easiest calibration, the module's calibration adjustments should be performed by electronic calibration means under computer control, without manual adjustments or mechanical tweaks becoming necessary. Besides delivering better stability under shock and vibration, electronic calibration also eases the calibration procedure by not requiring a module's shield and the adjacent VXIbus modules to be removed to access a calibration point. This allows calibration of the VXIbus module in its final environment.

If mechanical adjustments are absolutely necessary, they should be available through front faceplate access to allow calibration of the module in its final environment. This is also the easiest location to calibrate an instrument, since no module shields need to be removed. Faceplate access to all mechanical adjustments also allows a visible location (the adjustment's access point) to place a calibration label that plays the equivalent role of a calibration label on a GP-IB instrument. There are similar calibration labeling techniques for instruments using electronic calibration that have already been utilized in GP-IB systems. Some VXIbus manufacturers, such as Hewlett Packard, have already made a corporate policy to supply all VXIbus modules with electronic calibration or faceplate access to maximize the ease of calibration.

MANUAL CALIBRATION

For the user that presently only performs manual calibration, VXIbus will force him to migrate to computer control during the actual calibration process. This migration is not as substantial a change as it might appear. Many vendors offer "soft front panel" programs that run on PCs and/or workstations that allow a user to set up an instrument "manually" using a mouse to simulate front panel key presses. A virtual display on the CRT, often imitating that of a GP-IB instrument, display's the current result much like the actual display of a GP-IB instrument would. If the "soft front panel" program supports all the functional access of a VXIbus module needed to perform calibration, a user can proceed with a "manual" calibration of the VXIbus instrument.

HP's ITG product (Interactive Test Generator) is an example of such a software package. It runs on PCs under DOS, and on HP 9000 Series 300 workstations with HP-UX or HP BASIC operating systems. It supports "soft front panel" operation of all HP VXIbus instruments, and allows enough access to perform calibration on these VXIbus modules. Since the soft front panels appear on a CRT, many instruments that usually have only simple single line displays can also take advantage of the friendlier window-like environment to help guide the user through the calibration process. Appendix A shows various panels that appear when adjusting and verifying the accuracy of the HP E1326A VXIbus DMM using HP ITG.

OTHER LOGISTICS

After adjustment and verification are complete, some combination of record keeping procedures are performed. This typically includes a calibration label that is attached to the instrument noting the most recent calibration date, or better yet, the due date for the next calibration. In GP-IB, this label is often placed across a cabinet seam on an instrument so that any access to the mechanical calibration adjustments will tear the label, delivering a good visible indication of tampering or repair occurring without recalibration. This is a form of calibration security.

With VXIbus, the procedure is made somewhat more difficult by the small faceplate area limiting valid label locations. One solution is to put the calibration label on the face of one of the two ejector handles typically located at the top and bottom of a module's faceplate. If an inventory tracking label is also desired, it can be placed on the face of the other handle. For this to work, the labels must be designed to fit within the space allowed on a handle face, which is not necessarily true of all labels being used today.

This solves the problem of calibration and inventory tracking, but not of detecting if the calibration integrity has been violated, such as during an unreported repair. Though no system can be devised to completely protect against a clever but malicious saboteur, some simple practices will detect most common calibration integrity violations. In addition to the calibration and inventory tracking labels, a label or colored tape may be placed across the seam between a module faceplate and the mainframe, tearing if the module is removed. This tape may also be placed over any faceplate calibration access holes, requiring the tape to be punctured to access the adjustments. This will solve the problem for mechanical adjustments.

For electronic calibration, two cases must be considered. First, if a repair or modification is performed on the module, the calibration is no longer valid. Since this requires removal of the module, tape across the faceplate to mainframe seam will detect this case as well. The second case is detecting whether the calibration constant was changed, typically by a subsequent calibration. Most instruments delivering electronic calibration today usually support security features to prevent this from happening. Common techniques include a combination access to the calibration mode, much like a combination lock, or a mechanical switch accessed by a screwdriver through an access hole on its front panel or faceplate where a security label may be placed. Accessing this switch would require puncturing the security label.

SUMMARY

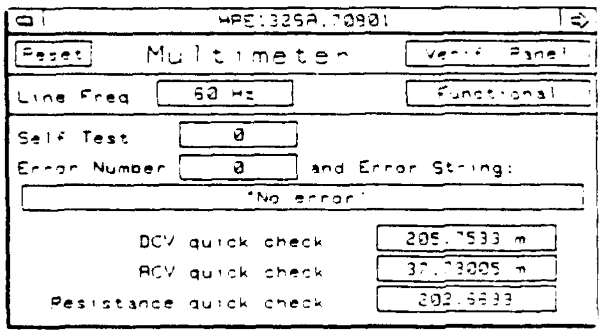
VXIbus instruments, though physically different than GP-IB, can be calibrated and verified using many of the same techniques used with GP-IB today. Features such as electronic calibration, faceplate mechanical access, soft front panel programs, and judicious design of calibration and inventory labels will further aid the logistics of calibrating VXIbus instruments.

APPENDIX A
MANUAL CALIBRATION OF A VXIBUS INSTRUMENT USING SOFT FRONT PANELS

This appendix gives an example of a calibration procedure using soft front panels to calibrate a VXIbus DMM. The soft front panel program is HP ITG (Interactive Test Generator), and can run on PC DOS platforms or HP 9000 Series 300 Workstations. The panels shown are the specific panels generated during the calibration or verification of the HP E1326A VXIbus DMM, and may coexist with other similar panels being displayed on the CRT simultaneously. This allows other VXIbus instruments to be used in the calibration process, but controlled in a manual manner.

This example will go through the typical calibration process. It will start with a simple self test and functional test as part of verifying that the DMM is operating. It will then go through some performance tests as part of the verification procedure. These tests check the accuracy with shorted inputs, various apertures, and with selected applied inputs. Finally, actual calibration adjustments will be shown using soft front panels.

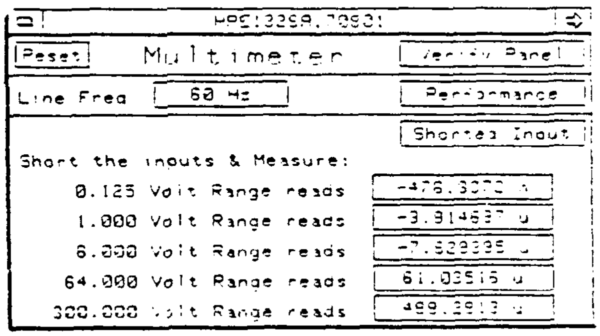
SELF TEST AND FUNCTIONAL TEST



The DMM is checked for functionality first, using the Functional check panel of the Verify panels shown above. Clicking the mouse on the Self Test box will initiate the DMM's internal self test, and it will return the number of self test failures, if any. This panel may also be used to read a description of any failures. Applying a DC, AC, or Resistance source and clicking the appropriate box will initiate a measurement to make a quick check of the DMM's functionality.

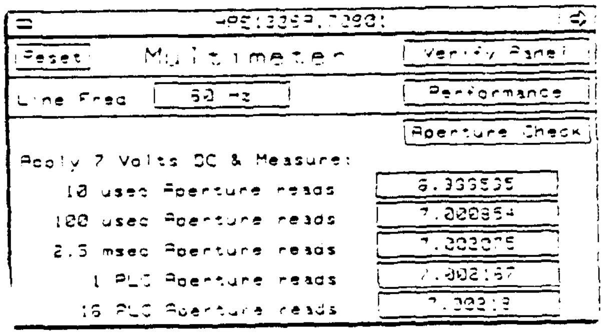
PERFORMANCE TESTS (VERIFICATION)

The first performance tests check the accuracy of the DMM with shorted inputs. This is managed through the "Shorted Input" panel shown below.

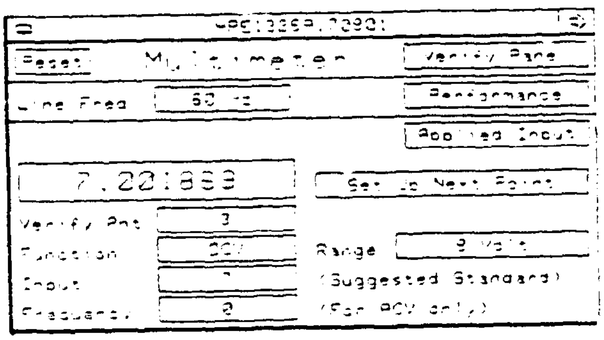


The user merely shorts the input terminals of the DMM module and clicks the mouse on any of the five lower windows. The panel will display the measured results on all five lower windows. The panel will display the measured results on all five ranges, which can then be compared to the device's specification. Since the DMM measures and displays all five results quickly, this is a much quicker procedure than the traditional manual operation that requires the user to set up the instrument for each range.

For the aperture check below, the user supplies a 7 Volt DC signal to the DMM (the accuracy of the signal is not critical for the test), and clicks any of the five bottom windows. The panel will display the results for all five apertures (speeds) of the DMM, which are then checked against each other for matching.



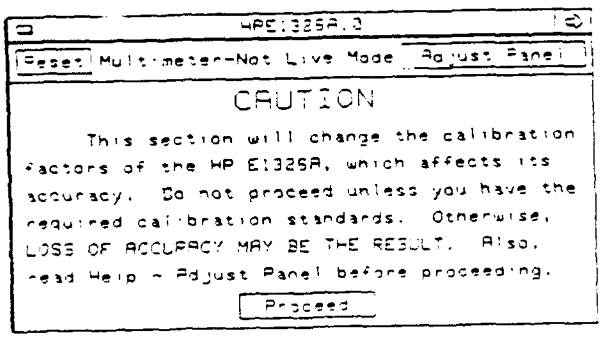
The Applied Input Panel below guides the user through 13 suggested performance points that require an applied input. The Verify Pnt window displays which of the 13 points is being checked, with the particular function and range displayed below that.



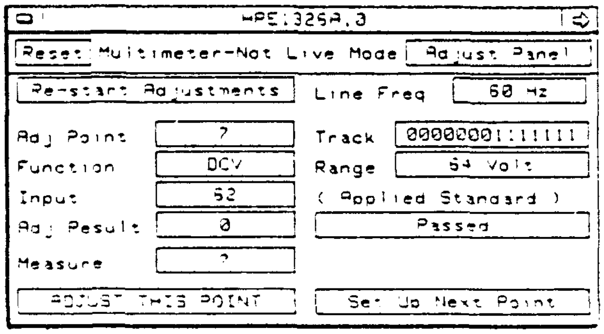
The Input window displays the suggested standard to be applied for each particular test point. If an AC signal is to be supplied, the suggested frequency of the source is displayed in the Frequency window. Clicking the large window in the upper left portion of the panel will initiate the measurement and display the results (shown here as 7.001869 Volts) to be compared to the specification. This display may be clicked before or after adjusting the DMM to determine whether or not the source is properly connected, or to determine whether the adjustment worked. Once verified, the user proceeds to the next point by clicking the "Set Up Next Point" window.

CALIBRATION ADJUSTMENTS

The preceding panels demonstrated those occurring during the functional test and verification process. To actually re-calibrate the module, not just check its performance, the user brings up the Adjust Panel. The first panel the user will see is the warning shown below to prevent accidental recalibration of the instrument.



The user hits the Proceed window if he still wishes to proceed with the calibration process. This will bring up the actual Adjust Panel shown below.



There are 14 adjustment points in the calibration sequence, and the Adj Point window displays which point is currently being adjusted. The Track display shows which points have been adjusted, up to nine times, since the calibration process began. Any "0"s left in the Track display indicate points that are still awaiting calibration. This prevents a user from accidentally skipping a calibration point.

The Function and Range displays indicate the calibration point being adjusted, while the Input display indicates the required calibration standard to be applied. If the actual calibration source doesn't have this exact value, the user clicks the Input display, and types in the actual value of the calibration signal.

Once the calibration standard is attached to the DMM, the user clicks the "ADJUST THIS POINT" display. The Adj Result window and the text window to its right will display the results of the calibration attempt. Normally, "0" is returned in the Adj Result display, while the text indicates "Passed". Otherwise an error number and a relevant error measure will be displayed in these two boxes. When calibrated, the track number will increment for this particular adjustment point. The user would then click "Set Up Next Point" to proceed to the next calibration point. Typically, once all points have been calibrated, the user clicks the Reset display to exit the Adjust Panel, and then brings up the Verify Panels to verify all accuracies before returning the module to the system.

The above examples show how soft front panels can actually enhance the ease of calibration over that of typical GP-IB front panel calibration, while remaining a primarily manual operation. Of course, the above verification and calibration procedures can be performed by a software program, automating the calibration procedure even more.

THE ELECTRONIC PAPERLESS TECHNICAL DATA MANUAL COMES OF AGE

by

Ira Gordon

ABSTRACT

An overwhelming supply of technical data has been thrust upon our industry. Since 1980, the amount of technical data has at least doubled in size and is increasing in almost geometric proportions. This technical data, commonly referred to as technical orders (T.O.'s), has, up to the present, been provided in the form of paper-based drawings, manuals, and other document formats.

This paper describes an on-going development program at AIL Systems Inc. specifically involved in the design and development of electronic paperless T.O.'s. The AIL Systems Inc. HyperManual initiative addresses the use of high-performance desktop personal computer (PC) systems using Hypertext software-based designs. These designs employ the use of high-resolution digitized image data bases and icon-based man/machine interface tools to facilitate ease of access and rapid location of pieces of information pertinent to the user's application.

AUTOMATED TECHNICAL MANUAL BACKGROUND AND HISTORY

In the mid-1980's, the Department of Defense (DoD) recognized the growing problem of T.O. management. With the acquisition of new weapon systems such as the B-2 Bomber and the C-17 Transport Programs, several million new pages of technical data would be added to the current T.O. inventory. To cope with this situation, the US Air Force pursued the development of the Air Force Technical Order Management System (AFTOMS). AFTOMS promised a potential solution for replacement of the services antiquated T.O. system which could be characterized as follows:

- Manually oriented with operating procedures defined in the 1940's
- Over 150,000 active T.O.'s (managed by 6 AFLC's)
- Average T.O. contains 100 – 150 pages (60 percent text, 40 percent graphics)
- Estimated T.O. data base approximately 20 x 10^6 pages
- Each year 10 percent of T.O. data base must be revised
- Growing backlog of unfulfilled requirements estimated to be as much as 2 x 10^6 page changes

The AFTOMS undertaking advocated a strategy which would:

- Use new technology to capture the existing T.O. data using optical scanning methods
- Capture numeric, textual, photographic images, and computer art
- Distribute T.O. data using optical storage technology
- Support real-time, on-line data retrieval
- Establish organizational and operational procedures
- Permit concurrent T.O. preparation with development of weapon systems

The AFTOMS approach represented first-generation thinking regarding the management and control of technical data. Due to funding problems, the AFTOMS project was terminated in 1989. A second-generation approach, sponsored again by the AF, originated in the late 1980's and was named the Improved Technical Data System (ITDS). Unlike AFTOMS, this system was primarily conceived to support the B-2 Program. ITDS was developed, under an AF contract, by Northrop's B-2 division as a means to generate (author) all operational, maintenance, and training documents. Authoring of original technical data would be created electronically right from its inception. All textual data, graphics, and other forms would be captured in a central information data base from authoring workstations and CAD/CAM systems.

The ITDS concept would support receipt, maintenance, and control of technical data for prime and associated requirements. ITDS would manage updates to all AFLC's and commands. All technical data would be maintained in a central library to be electronically distributed to authorized Technical Order Distribution Offices (TODO). Data would be transmitted by means of data links or by bulk 9-track magnetic tape.

The users of the ITDS system would include weapons system planners, depot repair agencies, and weapon system specialty agencies.

CALS REQUIREMENTS FOR ITDS

The ITDS Program was mandated to be capable of operating within and interface to the DoD's Computer-Aided Acquisition and Logistics Support (CALS) Program. CALS requires the integration of information, both text and graphics, into electronic data bases so that it can be archived and accessed for multiple purposes. The multiple purposes include plans for concurrent engineering and information sharing by multiple disciplines.

CALS is intended to coordinate the information generated by various phases of development of a weapon system including acquisition, design, manufacturing, support, and maintenance. CALS is expected to provide long-term productivity and quality gains. Although initial overhead costs for implementing the program will be high, the DoD expects to save billions of dollars in the long run. The following benefits are expected to materialize:

1. Elimination of error due to outdated or redundant information. Electronically stored information stemming from one source can be updated more quickly and easily. Electronic access and on-demand printing guarantees acquiring the most up-to-date information.
2. Quicker access to information via electronic data bases and computer-aided searching.
3. Reduced lead times for data delivery and spare parts procurement.
4. Savings in costs for paper and the manual processes involving paper handling.

The US Navy has an identical situation to the AF: it too is awash in a "sea" of paper. Unlike land-based T.O. repositories, real-estate aboard an aircraft carrier or submarine is very expensive. Aboard a nuclear class carrier there are approximately 23.5 tons of avionics maintenance T.O. manuals. Converting this paper-based data to Hypertext driven, optically stored media would enhance the ship's military mission. One estimate is that using a paperless technical data system will eliminate several thousand pages of technical manuals used for equipment maintenance, weapons, and targeting system operations aboard a single ship.

THE HYPERMANUAL PROJECT

Recognizing the importance that the DoD was placing on the elimination of paper-based T.O.'s, an IRAD project was launched at AIL Systems Inc. to acquire tools and techniques to create electronic T.O. packages. The objective of this project was to select an existing paper-based document of key importance and convert it into an intelligent electronic paperless format. The selection of a candidate document included such criteria as:

1. Frequency of use
2. Value of document in field use
3. Text/graphics content
4. Reading level of personnel who use document
5. Overall size of document

6. Number of topics contained within document
7. Potential productivity improvements and gains

Using the above seven criteria, a candidate document was selected: a Fault Isolation Procedure (FIP) for the ECM system.

The development of a paperless technical data manual at AIL Systems Inc. was designated as the HyperManual Project.

The FIP contains approximately 500 paper pages. The text-to-illustration mix is 60/40. The structure is centered around multiple sections, each dealing with individual electronic subsystem checkout and functional checkout procedures.

Currently, the paper-based FIP is used daily by both AIL Systems Inc. and USAF maintenance personnel. The detailed functional checkout procedures guide technicians to isolate faulty line replaceable units (LRU's) contained within the aircraft.

The graphics material contained within the FIP provides the test technician with data flow diagrams, switch panel settings, external special test instrumentation usage, application and parametric data tables.

HyperManual's Primary Objectives

The key to creating the electronic FIP is to first determine the requirements that will embody the final deliverable product. The requirements that HyperManual must have are listed below:

1. Quickly access and query documents from a single workstation (desktop or portable laptop CPU configuration)
2. Menu controlled via keyboard and/or mouse device
3. Allow user to easily navigate through electronic document
4. Display both text and graphics simultaneously
5. Provide real time in context topic searches
6. Provide audit trail and history of topic searches
7. Be capable of linking to external application programs (expert systems – automated trouble shooting aids)
8. Provide technical data information quickly and repeatably

To accomplish the above eight requirements, a basic understanding of the past and present state of electronic technical data documentation is necessary. Our analysis concluded that both paper and electronic technical data documents contained three types of information: content, format, and organization. Content refers to the words, pictures, and tables that are the subject of the technical manual. Format controls how the content is displayed. Format includes typography, layout, and color. Organization specifies the order in which topics are presented and the relationships among them.

Electronic technical data documents differ from paper documents in that on the printed page, content, format, and organization are indelibly bound together. You cannot alter one without affecting the others or without destroying the work. Electronic technical data documents totally separate content, format, and organization, and the document author must manage each element separately and in overall combination.

The electronic technical data document was not to be created from a page-scanned clone of its paper-base counterpart! It was a document that would be written specifically for access only by means of a computer terminal. The electronic technical data document (AIL Systems Inc.'s HyperManual), when completed, would provide real-time query and access to multiple topics and illustrations in a method which benefits people who are pressed for time.

Benefits of the HyperManual Approach. Obviously, before people read, they must find what they want to read (reference 1). Both novices and experts in a specific domain can read equally well, but experts excel at finding information. Electronic technical data documents would enable inexperienced users to find information as quickly as experts do with paper documents (reference 2).

The electronic technical data document will use the power of the computer to locate and display high-resolution images. It will relieve the user of the chore of physically locating and finding the correct document. In addition, the task of opening, scanning the table of contents for the topic sought, and turning to the appropriate page would be done by the computer. By reducing the number of physical and cognitive actions required to get to the information, the electronic technical data document would remove the hurdles between the user and needed information. A good electronic technical data document implementation will overcome one of the most common objections to paper-based technical data documents, namely, that it takes too long to find information (reference 3).

The HyperManual Development Tool Set. To develop the FIP electronic technical data document, a computer platform and operating system environment would have to be selected. Based upon the current installed base of PC's in the government inventory, and available development tools, an IBM PC compatible computer system, operating under the MS-DS environment, was targeted for the development platform.

In supporting the requirement for an electronic technical data document that would allow users to get data on demand, a decision had been made to use Hypertext data access techniques. The Hypertext software would allow users to jump from one topic of information to a myriad of other related topics, choosing their own branching paths at their own pace, thus gathering individually relevant information with the ultimate efficiency.

It was decided to acquire the Hypertext application design tools rather than create them for technical reasons. Several commercial PC-based tools were evaluated and tested. Based upon these tests, the Ntergaid Inc. tool (Hyperwriter) was selected. This tool provided all required authoring and browsing features along with the ability to utilize touch screen displays, CD-ROM, and laser-video storage devices.

Once the main tool was selected and acquired, the next step was to design the electronic format of the FIP...in other words, how were we to redesign a paper document and add intelligence to it?

General Hypertext Design Considerations. Both paper-based and electronic technical data documents are comprised of pieces of information and relationships among these pieces. The pieces of information can be called "topic" and the relationships called "links." The topic and links are the fundamental building blocks in a Hypertext-based electronic document. Figure 1 illustrates the topic/link concept graphically.

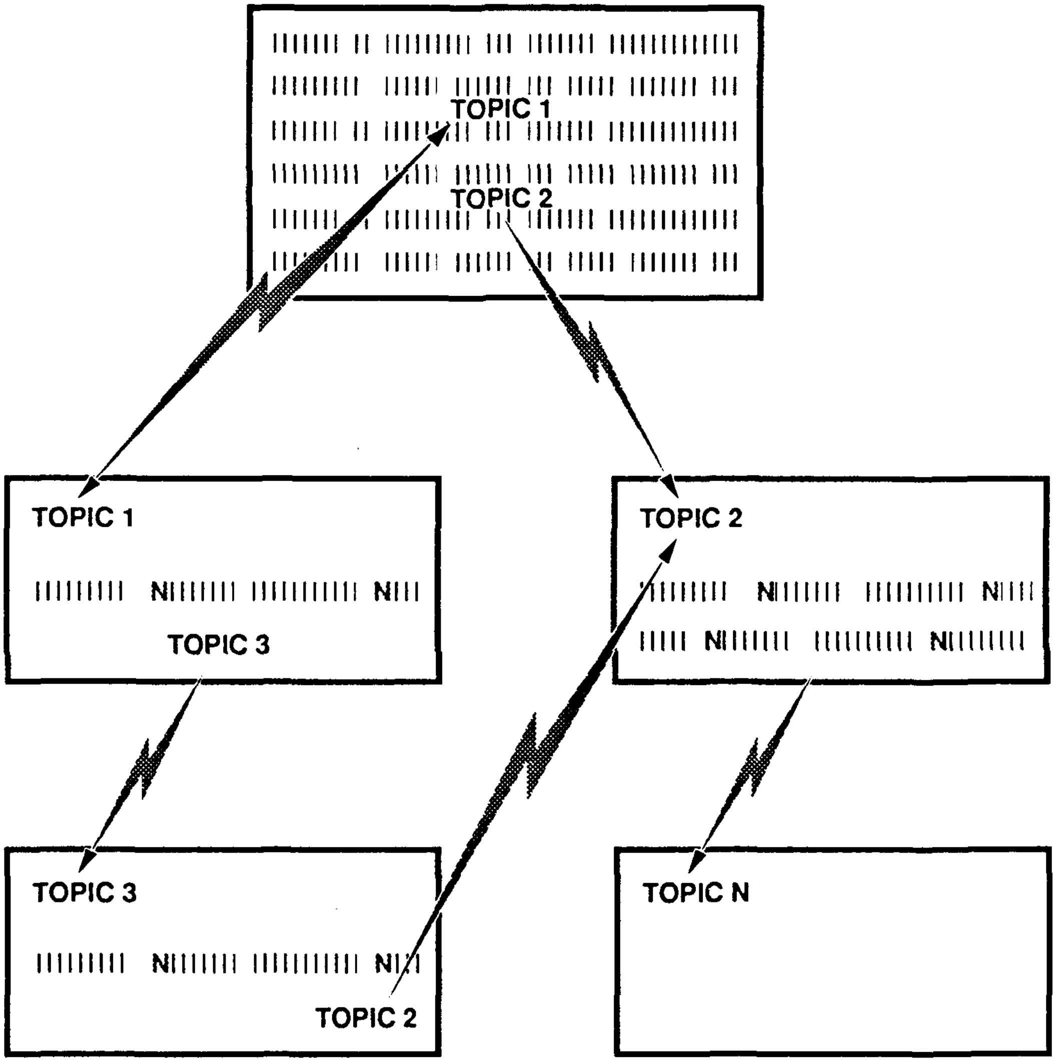
Topics represent a unique "chunk" of information about a specific view of a piece of technical data. A topic can deal with subjects in great detail or concentrate on a singular piece of minuscule data.

One of the most difficult tasks in designing electronic technical data documents is dividing the content into topics. How large should you make topics? Our design approach considered the grouping of topics in a way the user may query data or the way a user might want to access information.

The approach that we followed used large topic sizing to represent chunks of information. Large topics simplified the design and made navigating the document faster and easier. Dividing a technical subject into discrete topics is as much art as science and requires compromise. The rules of thumb that we followed to create each topic were to:

1. Answer one specific question (topic query)
2. Display one topic on to one window or screen
3. Make topics from one to seven paragraphs long (reference 4)

Links Defined. Links are the structural and navigational pathways connecting topics. In general, a link defines a specific relationship between the two topics it connects. For example, topic B is a subtopic of topic A and that topic C is cross-referenced from topic A. Links also provide access to all linked topics. Selecting a link causes the system to display the destination of the link.



HYPERTEXT IS USUALLY DEFINED AS THE NONLINEAR VIEWING OF INFORMATION. "*NONLINEAR*" MEANS THAT YOU CAN EXAMINE INFORMATION IN ANY ORDER YOU WISH BY SELECTING THE TOPIC YOU WANT TO SEE NEXT. IT PROVIDES A NEW WAY OF ACCESSING AND ORGANIZING ANY TYPE OF INFORMATION. HYPERTEXT CAN MAKE IT EASIER AND FASTER TO FIND THINGS AND ABSORB IDEAS. INSTEAD OF HAVING TO SPECIFY SPECIFIC KEYWORDS OR SEARCH STRINGS, YOU SIMPLY BROWSE THROUGH A DATA BASE BY "*JUMPING*" FROM LINK TO LINK.

1391-126

Figure 1. Document Navigation

The source or anchor point of a link may be the entire current topic, a block or text passage within that topic, or a specific point within that topic. Links are usually shown by a menu of choices, an icon symbol embedded in the text (see Figure 2) or a button on the CRT display. The link's destination may be a whole topic, a block or passage, or a specific point.

In developing the FIP application, using Ntergaid's Hyperwriter tool, three link types were at our disposal. The three link types used were:

1. Link to text
2. Link to graphics
3. Link to actions (animation, sound, video disc player, multimedia applications)

The link to text has a destination of paragraphs of textual information. The link to graphics has a destination of a graphic image (digitized photograph, computer line art, etc.). The link to action has a destination of an action command or a script to execute. Table 1 summarizes the various classes and subclasses of links available.

Table 1. Summary of Various Classes and Subclasses of Links Available

Link Type	Description
Link to Text	This creates a link to text material.
Jump Link	This creates a link for cross-referencing.
New Window	This creates a cross-referencing link for you to enter new information into.
Existing Window	This creates a cross-referencing link to an already existing window. When creating this link, no editing is possible.
Another Document	This creates a cross-referencing link to another document. When creating this link, no editing is possible.
Comment Link	This creates a link that displays a pop-up window overlapping the current window.
Swap Link	This creates a link that replaces text on-screen with alternative text.
ASCII File Link	This creates a cross-referencing link to an ASCII file on disk. The ASCII file cannot be edited although it can be browsed.
Link to Graphic	This creates a link to bitmapped graphics.
Full Screen	This displays full-screen .PCX graphics.
Pop-Up	This displays .MGR graphics files in a window on-screen.
Link to Action	This creates a link to an action.
DOS Link	This creates a link that activates external DOS programs.
Menu-Action Link	This creates a link that activates one of Hyperwriter's internal menu functions.
Script Link	This creates a link that activates a scripts.

Multimedia Considerations. Using the Hypertext link to action, script scenarios can be created leading to multimedia applications. The marriage of text, graphics, moving images (animation), and sound create a new medium for technical data access and display. Multimedia will change the way people will work

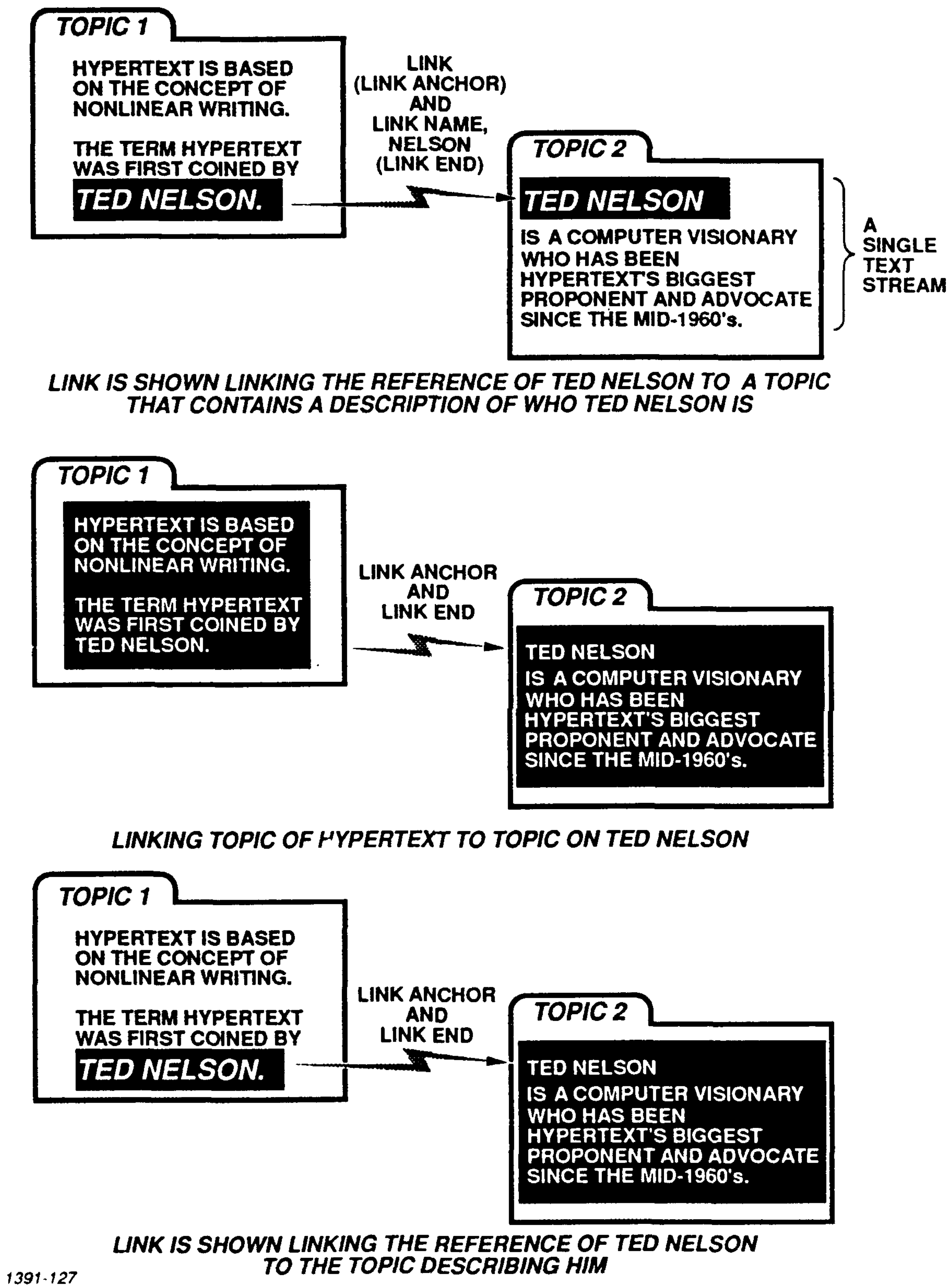


Figure 2. Sample of Icon Symbols Embedded in Text

and learn. The role that multimedia will play is to transform the paper-based PC information tool to a powerful information communication system.

The link to action will permit control of randomly accessible laser video storage systems, digital sound devices, musical devices, projection systems, and optical read/write devices. Figure 3 illustrates the multimedia environment.

Information Structuring in an Electronic Document. Throughout all disciplines, certain ways of organizing and presenting information have been popular. These patterns include sequences, hierarchies, grids, and webs, as well as simple variants and combinations of these structures. They are popular because they are conceptually simple and hence are easily learned and remembered (reference 5).

The web structure, common in Hypertext systems, offers the ultimate in expressive power (Figure 4). The FIP document was designed using this structure as a guideline. The web structure allows any topic to refer to any other topic, and webs can join topics together in vast networks of related information. In a pure web structure every topic is directly linked to every other topic. In a large Hypertext system, the overhead of storing and maintaining the large number of links can result in sluggish performance and a enormous appetite for disk storage space. The number of links increases dramatically with the number of topics (Table 2).

Table 2. Number of Links Increases with the Number of Topics

Topics	Links
1	0
2	1
3	3
4	6
5	10
10	45
100	4,950
1,000	499,500
10,000	49,995,000

To reduce the storage space and improve performance, the FIP implementation used a modified partial web, which linked each major topic to no more than a few other topics (Figure 5).

FIP Topics and Link Structuring. The HyperManual FIP is comprised of fundamental topics which include purpose, scope, applicable documents, overview, and use of the manual. Each topic is menu selectable from the top-level menu. The main body of the FIP is a collection of functional checkout procedures for each LRU comprising the ECM system. The design uses a specific LRU checkout procedure as a large Hypertext topic. Anchor links are embedded within each of the LRU's functional checkout topics which point to secondary and tertiary topics. Typical secondary topics include subjects such as use and application external special test equipment and component descriptions. Tertiary topics consist of data items dealing with electrical and signal wiring and physical placement of LRU aboard the aircraft.

The use of graphic links embedded within various LRU topics provided a means to display images of LRU assemblies, control panels, switch positioning,and cabling data. A typical graphic is depicted in Figure 6.

FIP Author and Browser Programming. The creation of the FIP was performed using the Ntergaid's Hyperwriter author programming software. This programming provided for the organization of the FIP textual and graphic data. The embedding of links and the structuring of topic pathways is also performed by this software.

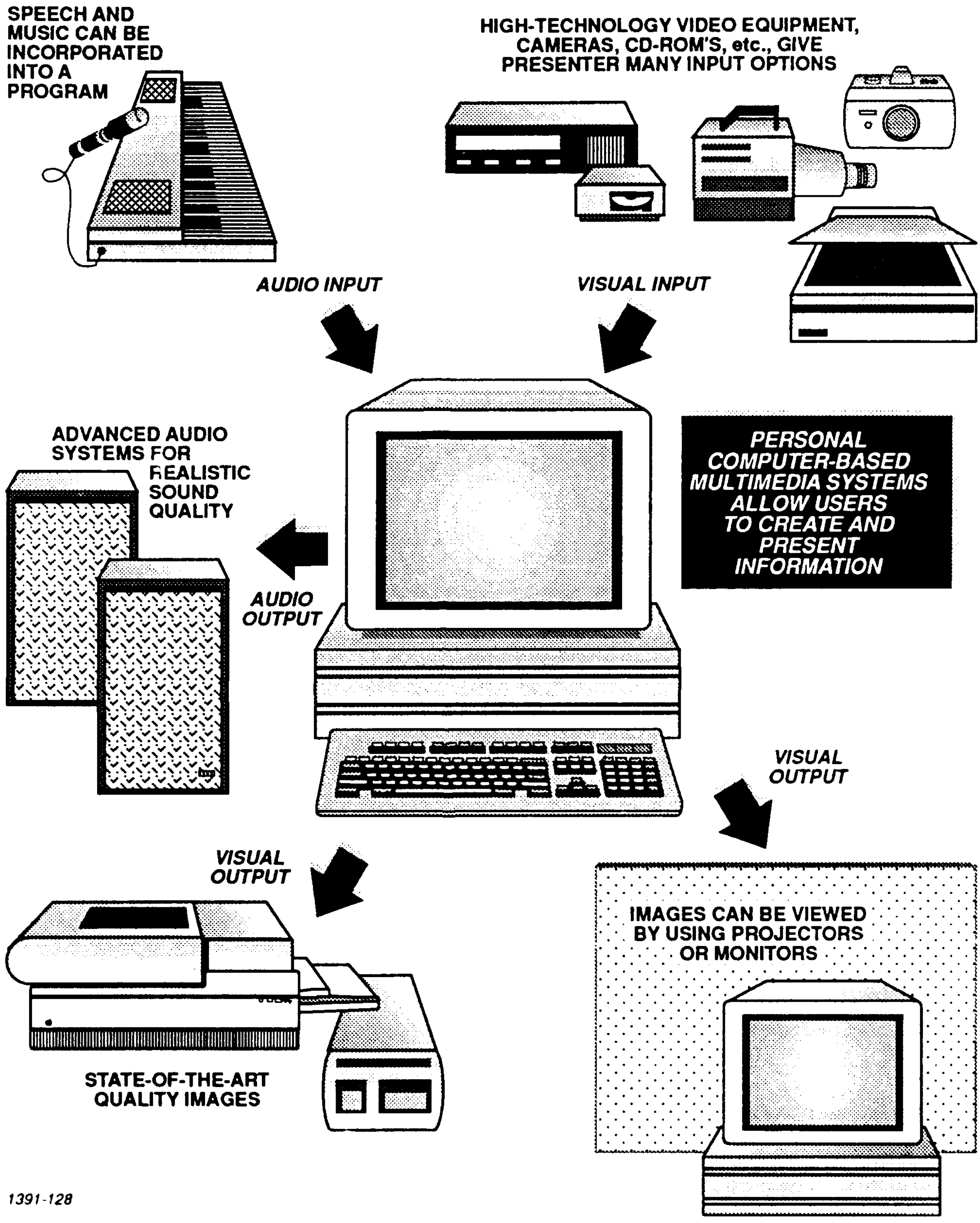


Figure 3. Latest Equipment Using Advanced Technologies Present Designer with Many Output Options

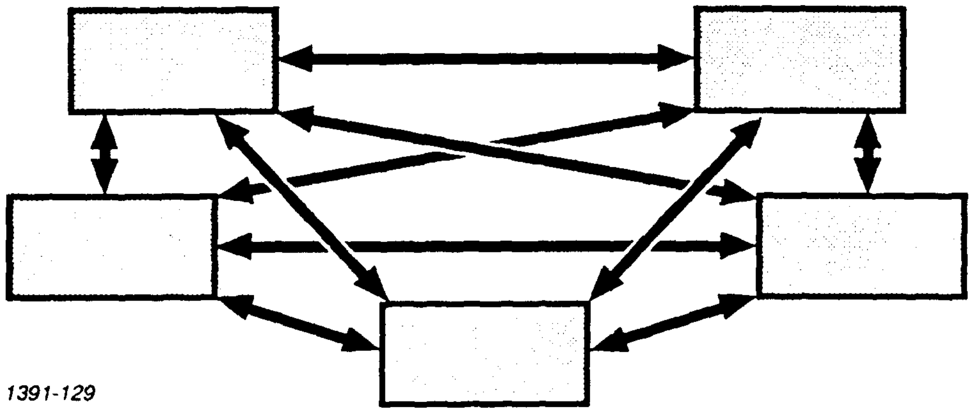


Figure 4. Web Structure

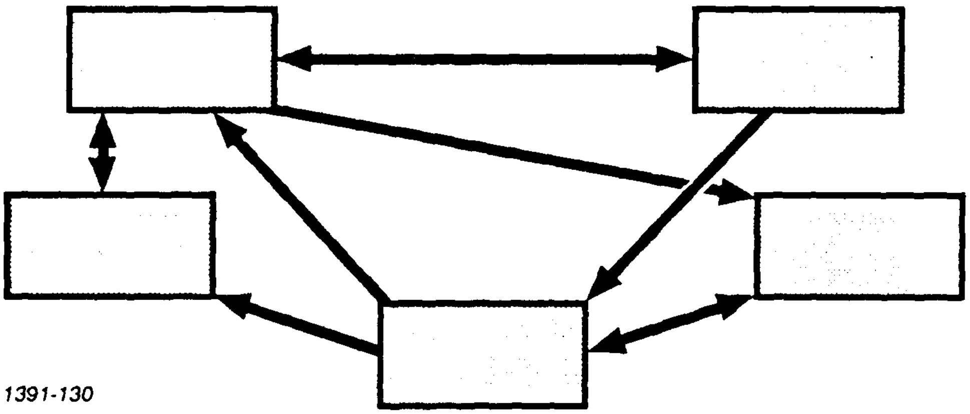


Figure 5. Partial Web Structure

When the authoring activities are completed, the Hypermanual FIP can be viewed and read by the end user. This is accomplished by using a reader or browser program. The browser displays some or all of the FIP HyperManual document as a graph, providing an important measure of contextual and spatial cues to supplement the reader's model of which topics he or she is viewing and how they are related to each other and their neighbors in the graph.

Using the browser can be likened to using visual and tactile cues when looking for a certain page in a book. Figure 7 illustrates a typical CRT screen image of the browser environment.

Photographic Image Requirements. AIL Systems Inc.'s HyperManual requires the use of high-resolution photographic quality images to convey information to the user. This gives even more credence to the old adage that says, "a picture is worth a thousand words." An update to this adage may be that a digitized computer image is worth 10,000 words when it provides details on complex technical data entities. HyperManual's purpose in using high-resolution images is to communicate and clarify, not to decorate and beautify.

HyperManual expresses visual and spatial concepts in pictures, especially those that involve physical actions. Pictures increase the speed at which users carry out actions (reference 6) and help them visualize complex processes.

The use of near photographic quality, digitized images in the HyperManual FIP catch and focus the users attention. They are designed to draw attention to essential information, especially if it is unfamiliar to the user or differs from what the user expects (reference 7).

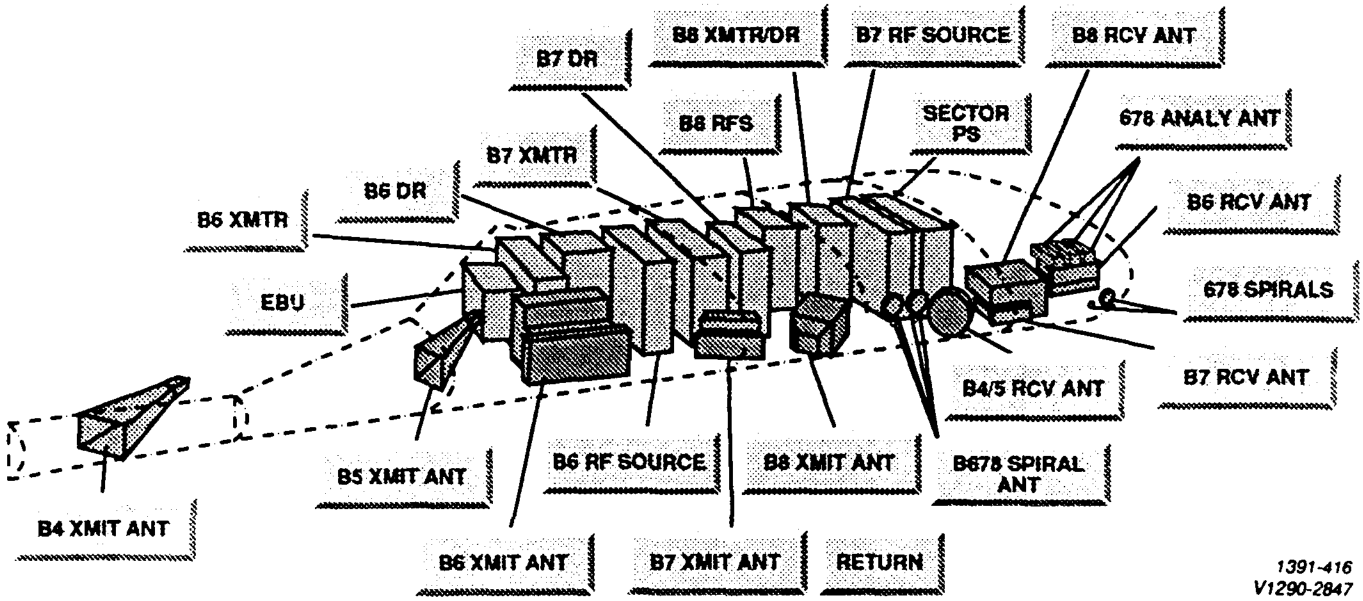


Figure 6. Typical Graphic Used Linking Topics

The power of images is used to highlight:

- Key facts
- Changed information
- Dangerous conditions

Most users would rather look at pictures than read text, especially if the pictures (images) look interesting and are clearly displayed.

Figure 8 illustrates a digitized printed-circuit board assembly which is typical of the quality and information content used in the HyperManual FIP T.O. During the HyperManual design activities, an analysis was performed to determine the required CRT display resolution, color or gray scale shading, and on-line magnetic storage requirements. Our tests were conducted using the IBM Video Graphics Array (VGA) standard display electronics contained within a Compaq 386, 33 MHz desktop PC system.

Tests were performed at the 320 x 200 pixel, 64 color-display resolutions and 640 x 480 pixel, 16 color-display resolutions. The CRT monitor utilized had an effective display area of 8-in. height and 10.5-in. width, yielding and effective 60 pixel/in. density at the 640 x 480 mode and 30 pixel/in. at the 320 x 200 mode. The quality of the images that were captured by either the video frame grabber or desk-top scanner were of equal or greater densities of that of the VGA video display hardware.

The 640 x 480 capture and display resolution proved to offer photographic print quality when used in conjunction with the 64 gray-scale coloring. This resolution was ideal for the close-up electrical panel, PC board-component layouts, and any application requiring up close detailing. The 640 x 480 16 gray-scale images were not as high a quality due to a smaller number of gray scale shades, however, they still provided a reasonable level of quality for on screen viewing.

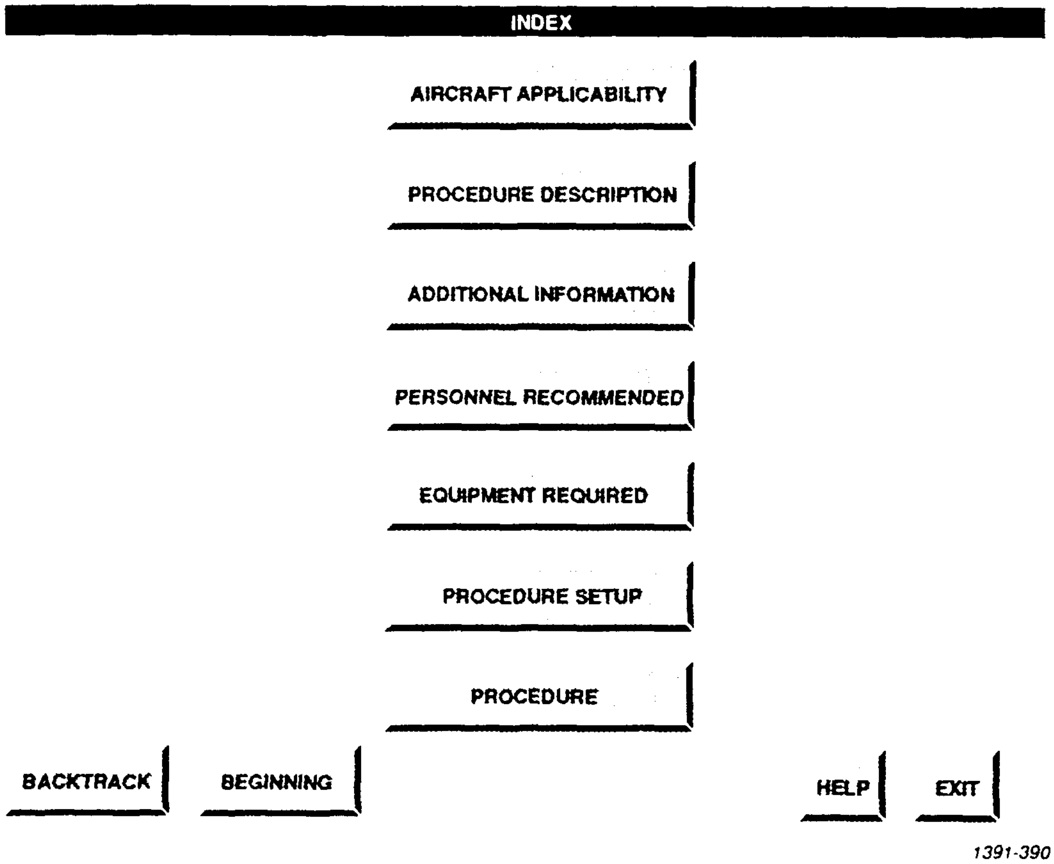


Figure 7. Typical CRT Screen Image of the Browser Environment

Image Storage Requirements. The captured digitized photographic quality images required a hard disk storage medium with fast access (28 msec or faster). The storage requirement was directly based upon the size of the image, the capture resolution, and the number of shades of gray or colors. Table 3 depicts the raw storage of images based upon the variations in the above parameters.

Image Capture Techniques. Graphic images were captured using equipment illustrated in Figure 9. The video frame grabber hardware and desktop scanning equipment facilitate all image capture. The video frame grabber provided a maximum of 640 x 400 in 64 shades of gray, while the HP ScanJet Plus desktop scanner provided images at 300 dots/in. at a maximum of 256 shades of gray scaling.

Image data files were stored in Zsoft's .PCX file format. Additional image processing was later performed using Zsoft's PC Paint Brush IV Plus paint program. The addition of captions and titles, labeling of parts of illustrations, and textual comments were performed by the PC Paint Brush program.

CONCLUSIONS

Information is one of the most important resources required by organizations to solve problems and achieve objectives. The value of information varies according to its quality and completeness, its accessibility, the frequency of the need to use it, and the gravity of the need for it at specific, sometimes critical, moments.

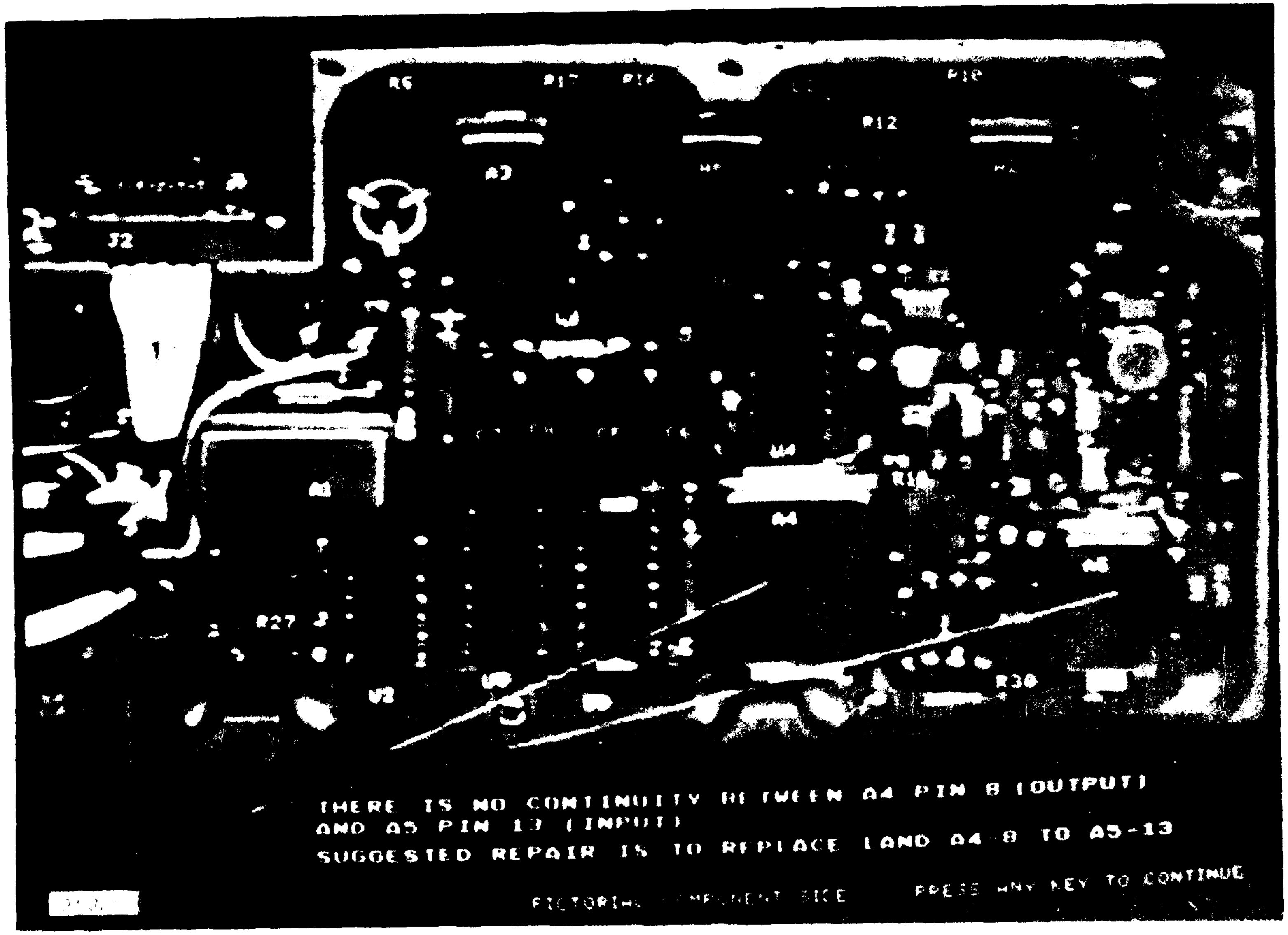


Figure 8. Digitized Photograph of a Typical SRA Module

Table 3. Disk Storage Required for Various Image Sizes*

1-Bit					6-Bit				
in.^{2}	75 (dots/in.)	150 (dots/in.)	200 (dots/in.)	300 (dots/in.)	in.^{2}	75 (dots/in.)	150 (dots/in.)	200 (dots/in.)	300 (dots/in.)
6	4	16	29	66	6	25	99	176	396
9	6	25	44	99	9	37	148	264	593
12	8	33	59	132	12	49	198	352	791
15	10	41	73	165	15	62	247	439	989
20	14	55	98	220	20	82	330	586	1318
24	16	66	117	264	24	99	396	703	1582
30	21	82	146	330	30	124	494	879	1978
36	25	99	176	396	36	148	593	1055	2373
40	27	110	195	439	40	165	659	1172	2637
48	33	132	234	527	48	198	791	1406	3164
56	38	154	273	615	56	231	923	1641	3691
64	44	176	313	703	64	264	1055	1875	4219
72	49	198	352	791	72	297	1187	2109	4746
80	55	220	391	879	80	330	1318	2344	5273
4-Bit					**8-Bit**				
6	16	66	117	264	6	33	132	234	527
9	25	99	176	396	9	49	198	352	791
12	33	132	234	527	12	66	264	469	1055
15	41	165	293	659	15	82	330	586	1318
20	55	220	391	879	20	110	439	781	1758
24	66	264	469	1055	24	132	527	938	2109
30	82	330	586	1318	30	165	659	1172	2637
36	99	396	703	1582	36	198	791	1406	3164
40	110	439	781	1758	40	220	879	1563	3516
48	132	527	938	2109	48	264	1055	1875	4219
56	154	615	1094	2461	56	308	1230	2188	4922
64	176	703	1250	2813	64	352	1406	2500	5624
72	198	791	1406	3164	72	396	1582	2813	6328
80	220	879	1563	3516	80	439	1758	3125	7031

*Values are in thousands of bytes.

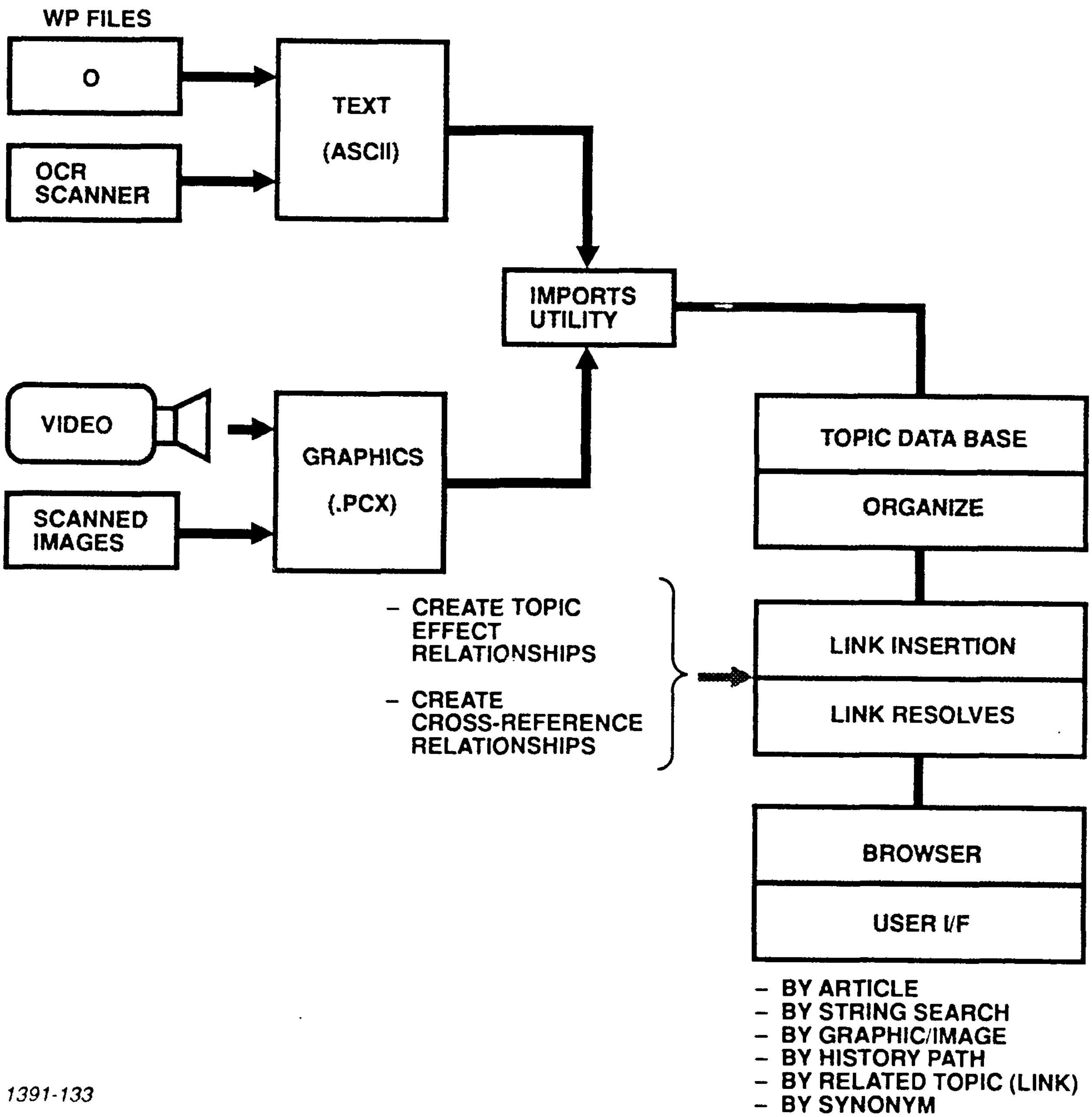


Figure 9. HyperManual Information Capture Process

In short, having the right information at the right time has a positive impact on worker productivity and on an organization's ability to achieve its mission.

AIL Systems Inc.'s HyperManual is expected, when its starts actual field tests early in 1991, to see a potential productivity gain ranging from 30 to 50 percent over its paper-based counterpart. This gain will be directly attributable to the user's ability to navigate through and locate specific pieces of technical information (topics) within seconds, rather several minutes. (See Table 4 for typical productivity enhancements.)

Table 4. Productivity Analysis: Paper-Based vs. HyperManual

Activity	Paper-Based	Hyper Manual
Document Retrieval	3 - 30 min	10 - 30 sec
Topic Search and Locate	2 - 5 min	3 - 20 sec
Topic Navigation to Related Subtopics	2 - 15 min	5 - 10 sec
Access Data From External Reference Documents	5 - 60 min	10 - 30 sec
Space and Weight Requirements	5500 pages/55# 6-1/2 ft Bookshelf Space	5500 pages/15 16[1] 1/2-ft Bookshelf Space
Information Sharing	Standalone	Digital Transmittable

(1) Includes the weight of a laptop computer.

The use of the power of the computer for information searching and the ability to instantly display high-resolution images (static or animated) will eliminate the time-consuming retrieval and location problem inherent in today's voluminous paper-based T.O. manuals.

Additional enhancements to the HyperManual FIP are planned in early 1991. These include the integration of the touch screen CRT system, the interface of a data base of images and text stored on a laser video disc storage device, and the use of digitized sound narrations.

The HyperManual project demonstrates the feasiblilty of implementing a detailed, frequently used paperless T.O. document. Hypertext techniques coupled with the use of multimedia programming will lead to powerful applications in the following areas:

- Training (operational and maintenance)
- Troubleshooting expert system scenarios
- Massive reference libraries

ACKNOWLEDGMENTS

The work described in this paper is currently being developed at AIL Systems Inc. under an IRAD program. The creative efforts of Mr. B. Ford and Mr. D. Franklin have greatly contributed to HyperManual's current state of development.

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2. Carlston, P. A., "Hypertext: A Way of Incorporating User Feedback into OnLine Documentation," Text, ConText,and Hypertext: Writing with and for the Computer. Cambridge, MA: The MIT Press, 1988, pp. 93 - 106.
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18 June 1991

ABSTRACT

The Miniature Automatic Network Analyzer A New Approach for Reducing Cost and Increasing Capability for Logistic Support of RF Systems*

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This paper describes the development of miniature automatic network analyzers (MANAs) using novel, extremely simple[1] microwave sources and miniature six-port subsystems.[2] These MANAs could drastically reduce cost and increase capability for RF built-in-test (BIT) and portable automated test equipment (ATE). Benefits of extensive BIT at lower frequencies have already been demonstrated in hardware and software applications; however, at RF, BIT is often limited to simple tests (such as using diodes to detect power levels). One of the limitations has been that the measurement of complex quantities (such as scattering parameters) requires the use of ANAs, which, up until now, have been large and expensive.

Here, we report on our work that demonstrates critical technologies for MANAs. These include a family of simple fixed- and swept-frequency microwave sources, and microwave integrated circuit (MIC) and monolithic MIC (MMIC) six-port subsystems that include six-port junctions with matched diode detectors and low frequency amplifiers. The signal sources are voltage-controlled oscillators exhibiting swept frequencies from 6.5 to 13 GHz. They employ novel, focused ion-beam-implanted Gunn-effect devices that have linearly graded doping concentrations. We also have been developing miniature six-port-based ANAs for several years in coaxial and MIC configurations, and have achieved good reflection measurement agreement with a conventional ANA. Recently, we designed an 8-GHz MMIC six-port subsystem having 0.12" x 0.12" dimensions with on-chip junction, detectors, and amplifiers. We plan to integrate these two critical components in a multichip package to realize a MANA.

---

*This work was sponsored be Electronic Systems Division [AFSC], Hanscom AFB, MA.

[1] A. Chu, et. al., "Performance and Applications of Novel Oscillators utilizing Focused Ion Beam Implanted Gunn-Effect Devices," *1991 IEEE MTT-S International Microwave Symposium Digest*, pp. 1179-1182, Boston, MA, 11-13 June 1991.

[2] C. A. Hoer, "A Network Analyzer Incorporating Two Six-Port Reflectometers," IEEE Trans. Microwave Theory Tech., Vol. MTT-25, pp. 1070-1074, December 1977.

VG-2

Problem/Solution

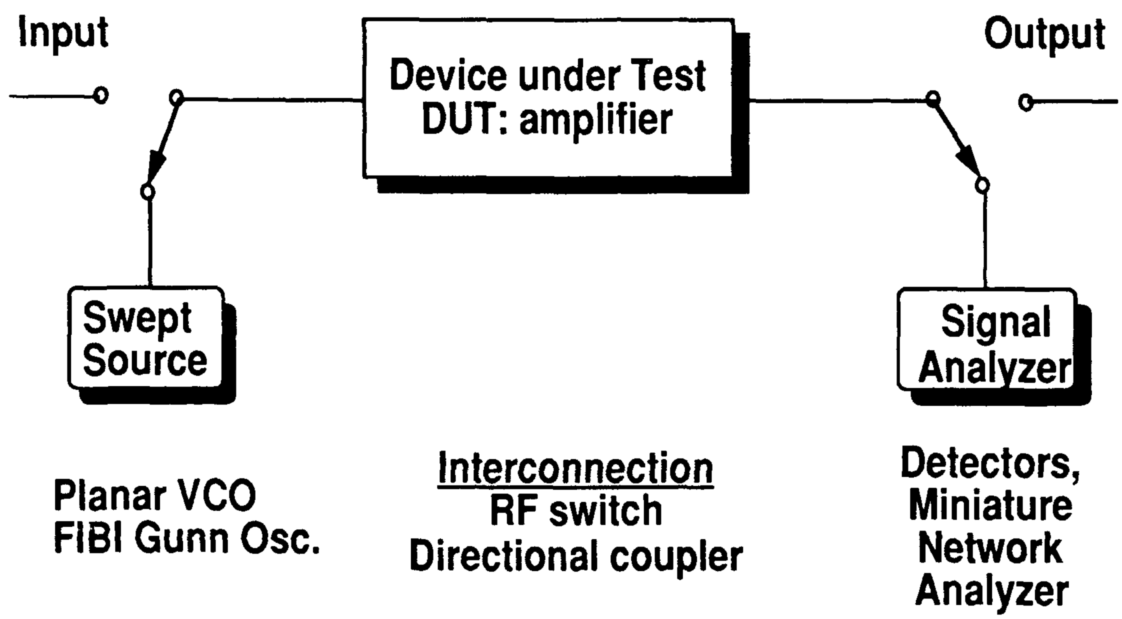
- Problem
  - High cost and large size of conventional microwave/millimeterwave ATE
  - Primitive capability of microwave/millimeterwave BIT/BITE
- Solution
  - Low cost miniature automatic network analyzers (MANAs)
    - *Based on microwave integrated circuits (MICs) and monolithic MICs (MMICs)*

MITRE

Now microwave/milllimeterwave ATE consists of large racks of expensive general-purpose equipment dedicated to special purpose tests. In addition, any RF BIT is usually limited to a simple coupled diode detector to sample the RF power level. However, as the RF part of systems becomes more complex, more sophisticated BIT and ATE is necessary to ensure system availability. However, RF test equipment has remained large and expensive making more sophisticated BIT, such as measuring amplitude and phase, impossible because of either size and/or cost constraints. With continuing advances in MIC and MMIC technology it is becoming possible to build very small and potentially inexpensive microwave and millimeterwave network analyzers for BIT and ATE applications.

VG-3

Built-In-Test Concept at Microwave Frequencies



MITRE

For example, to test the phase and amplitude response of an amplifier within an RF subsystem would require the BIT configuration shown above. The major MANA components are a swept source to cover the operational frequency range, an interconnect device to switch or couple in the DUT, and a signal analyzer to measure the amplitude and phase. Not shown are a direct path to serve as an amplitude and phase reference, and low frequency analog and digital input/output lines. Now the implementation of BIT is impractical because of the large size and cost of a swept source and signal analyzer. The technologies described in this paper would greatly reduce the size and cost of critical MANA components.

VG-4

Approach

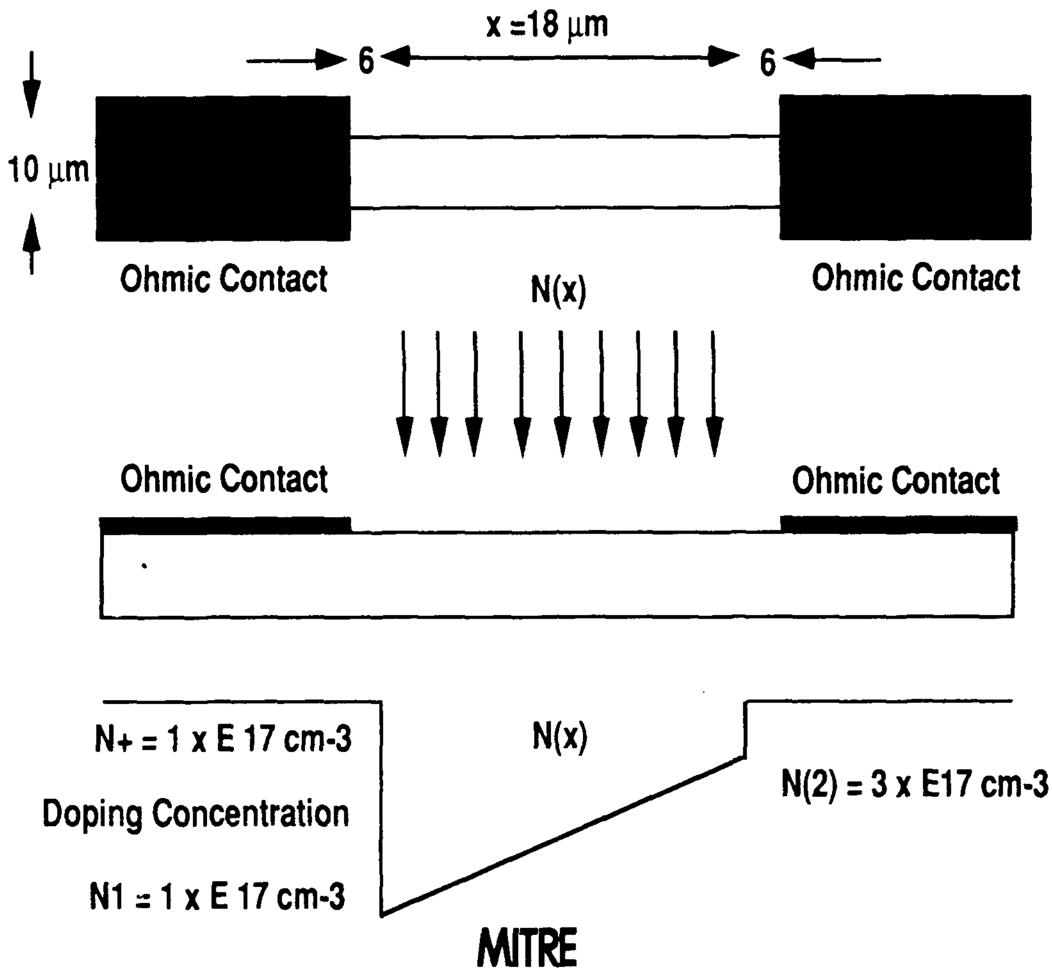
- Continue development of critical technologies for MANAs
  - Gunn-effect devices
  - Six-port subsystems
- Focus on high priority logistic 'fixing' needs

MITRE

The most critical technologies for developing practical MANAs are the swept source and the signal analyzer. In collaboration with MIT and Lincoln Lab, MITRE has been developing very small (~25 x 25 μm) MMIC Gunn-effect devices with microwave bandwidths of several GHz controlled by a DC voltage. The signal analyzer is a passive six-port junction with matched diode detectors and amplifiers. MITRE has been developing MIC six-port subsystems for several years and will soon test a MMIC integrating a six-port junction, 5 detector diodes, and 4 amplifiers. We anticipate that through interactions at this workshop, we will direct our research to address significant issues in logistic support.

VG-5

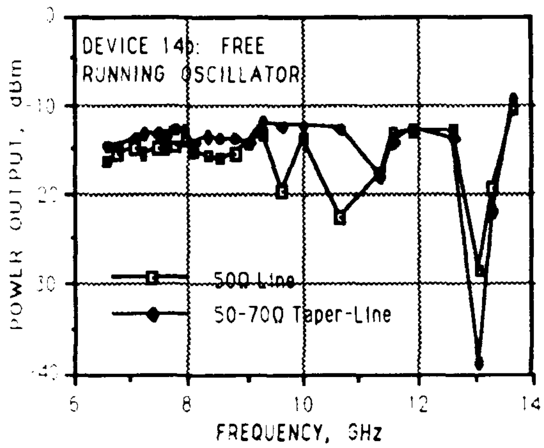
Gunn-Effect Devices: MITRE/LL/ MIT Work

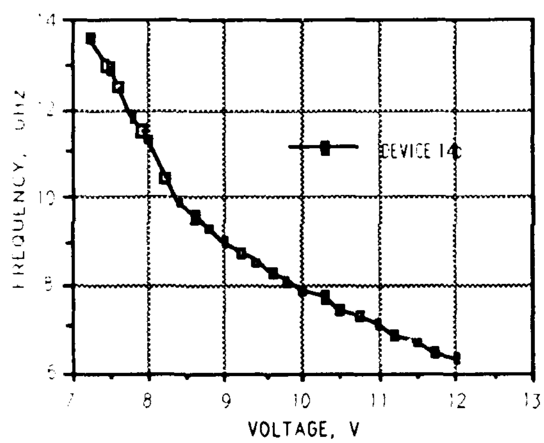


The planar tunable Gunn diode is a novel device, fabricated by focussed ion beam implantion. The ion beam is rastered to produce graded doping concentration gradients in the active area. Placement of ohmic contacts enables biasing of the device to induce the propagation of Gunn domain in the active layer. Control of the formation and decay of Gunn domains by the bias voltage provides frequency tuning to this device of extreme simplicity. The RF impedance of the device can be designed to be close to 50 Ω eliminating the need for complex matching circuits.

VG-6

Gunn-Effect Devices: Experimental Results





- **Low Cost Sources**
  - Simplicity
  - Re (Z) ~ 70 Ω
  - Small Area: 10 μ by 18 μ
- **Voltage Controlled Oscillators**
  - Tuning range: 6.5 to 13.5 GHz
  - single linearly graded doping concentration

MITRE

The RF performance of a FIBI Gunn device connected to a 70 to 50 Ω tapered microstrip line are shown in this figure. The upper curves display the output power of the FIBI Gunn oscillators as a function of frequency. With the 70 to 50 Ω tapered-microstripline, the output power varies from -13+/-3 dBm from 6.5 to 12.5 GHz. The tuning range is from 6.5 to 13.5 GHz, when the bias voltage is varied from -12.0 to -7.25 V, respectively. The significant of these results is tunability over wide frequency range and low power variation for an extremely simple device. Hence, enabling their use as a low-cost signal sources in BIT.

VG-7

Six-Port Analyzer Characteristics

- What is a six-port junction?
  - A junction with six-ports
    - 1 input port, 1 output port, 4 power detection ports
  - Power at 4 detection ports must be linearly independent
- Advantages over conventional heterodyned analyzers
  - Very small junctions with diodes
    - Built from components (couplers, diodes, etc.) easily fabricated on ICs
  - Simpler analog hardware
    - Amplitude and phase information deduced from power measurements
      - No frequency translation means no LOs, mixers, and RF filters

MITRE

Six-port based ANAs were developed at the National Institute of Standards and Technology (NIST) around 1972 and are now used for very accurate measurements of amplitude and phase at microwave and millimeter wave frequencies. There has been considerable work in six-ports during the last 20 years, mostly in the design of coaxial and waveguide systems, and in developing various calibration techniques. The NIST measurement systems, like conventional ANAs such as the HP8510B, cost about $200K and now occupy an entire equipment rack. However, they could be inexpensive and very small because of their simple analog hardware and potential for MMIC integration.

VG-8

MITRE Six-Port ANA Highlights

- MITRE is a leader in miniature ANA (MANA) technology
- Completed and calibrated baseline coaxial system
  - Commercial components and instrumentation
- Fabricated and calibrating MANA
  - MITRE-built MIC six-ports junctions and hardware
- Designing MMIC six-port junctions
  - For general use and for MMIC BIT internal program

MITRE

We have designed, built, and tested a 2- to 12-GHz baseline coaxial six-port reflectometer system and obtained excellent agreement with measurements on our Wiltron 360 ANA. We have also been building the next generation system including the breadboard analog and digital circuits needed in the MANA. The analog portion has a microwave integrated circuit (MIC) six-port junction with diodes, and a printed circuit board with low noise DC amplifiers and filters. A Macintosh NuBus board with integral 16-bit analog-to-digital converter has been built to serve as the digital portion of the test bed. We also designed a GaAs MMIC six-port subsystem on a 0.12" x 0.12" chip with a lumped element six-port junction, matched diode detectors, and amplifiers that is being processed at Triquint.

VG-9

Plans

- Continue development of next generation critical components
  - Gunn-effect devices
    - Improve devices in next fab
  - Six-port MMIC subsystem
    - Complete processing
    - Test
- Integrate Gunn device and six-port junction in multichip module
- Identify next generation systems applications
- Seek additional support to accelerate development

MITRE

After we receive the Gunn-devices and six-port subsystem from the Triquint foundry, we plan to test them individually and then integrate them in a multi-chip package for further testing. The pay-off of these technologies is to drastically reduce cost, size, and weight for RF ATE and BIT. We plan further discussions with the logistics community to focus on applications significant to their work.

VG-8

MITRE Six-Port ANA Highlights

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VG-9

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Toney, Ollie B.	205-842-8266

Tranquill, August A. 205-955-6206
Trent, Michael G. (Asst. Administrator) 205-876-3739

Vance, JoAnn 205-876-9861
Vaughn, Julia H. 205-876-4470
Von Mayerhoten, Peter P. 205-955-3053

Wachs, Kathleen J. 205-876-1075
Walczyk, Mark S. 205-955-3617
Wallick, Donald J. (Log. Mgt. Inst.-MD) 301-320-7225
Weissman, Vanessa M. 205-876-1697
Wetheral, Thomas G. 205-876-0470
Wharton, Kesty J. 205-842-9415
Whisenant, David J. 205-534-8013
White, Marshal F. 205-876-2228
Wiggins, John .... –
Wigginton, Rachel S. 205-842-9987
Williams, J. Delbert (Moderator) 205-876-4727
Williams, Lee I. 205-876-8162
Williamson, Roy J. 205-876-8168
Wilson, Sheila A. 205-876-3693
Wingfield, Charles .... AV 289-8994
Wolfson, Mark M. 205-722-1967
Wood, Nancy L. Dr. 205-842-2935

REGISTERED ATTENDEES
NON-GOVERNMENT

ACE Cryogenic Engr, Inc.	- Dr. Myron E. Calkins Jr.	205-536-8629
	- Dr. Michael Nilles	205-536-8629
AEPCO, Inc.	- Ronald H. LaFond	301-670-6770
AEROMET, Inc.	- Carlton L. Sweetland	205-830-0900
AGFA, Corp.	- Charolotte P. Sloan	404-587-1357
Allied Signal Aerospace	- Larry Sheaks	205-837-2227
Allied Signal, Inc.	- Martin P. Chobrda	201-455-6541
Alternate Approach	- Lonnie P. Hearne	904-651-8882
American Global Svs, Inc.	- Larry N. McNay	817-441-7835
ANADAC, Inc.	- Brian C. Reed	703-271-6830
ANADAC, Inc. (Speaker)	- Hubert C. Upton	703-692-1504
ANT Telecommunication, Inc.	- Thomas W. Gilmore	301-670-9777
ARC Professional Svs.	- Buck Ozment	205-830-9523
	- Oliver J. Ozment	
ARC Professional Svs.	- Cheryl L. Eldridge	205-837-7252
	- Edward D. Powell	205-837-7252
ARETEX US	- Richard W. Radler	313-668-8828
Arlyn Associates	- Robert L. Nathan	205-883-0660
ATT-Bell Laboratory	- Dennis J. Lynes	908-582-4832
Auburn University	- Paul Bemaine	205-844-6306
Awtry & Hunter (Speaker)	- Mark H. Awtry	617-942-2000
B-K Mfg Co., Inc.	- Bob Kelley	205-753-2252
	- Brett Kelley	205-753-2252
Battelle Huntsville Institute	- Lawrence E. Sisterman	205-881-0262
Boeing Co.	- Mark J. Steinbuchel	205-461-3333
	- Larry J. Harrell	205-461-2063
	- John E. Butler	205-461-2758
	- Lewis W. Jarman	205-461-2758
	- Marc K. Hughes	205-461-2758

Boeing Co.	- Paul Nelson	205-461-2758
	- John E. Butler	205-461-2758
	- Bob O'Donnell	205-461-2758
	- David E. Hembree	205-461-2758
	- Bruno C. Wargo	205-461-2758
	- William T. Clark	205-461-2758
	- Phillip S. Hillman	205-461-2758
	- David W. Muecke	205-461-2758
	- Leroy Thompson	205-461-2758
	- Vinson Moore	205-461-2758
	- Robert A. Baumann	205-461-2063
	- Virgil D. Cooper	205-461-2063
	- Kevin N. Wolf	205-461-2063
	- Rodney Crawford	205-461-2063
	- Kenneth Neuschaefar	205-461-2063
	- Thomas Hardy	205-461-2063
	- Robert W. Elliott	205-461-2063
	- Jan McDonald	205-461-2063
	- Siegfried H. Krahner	206-657-8240
Booz, Allen & Hamilton, Inc.	- James E. Henderson	205-895-8260
Boston Digital Corp.	- Juan M. Wells	704-567-1016
CAS, Inc.	- Scott C. Brand	205-722-5463
	- John L. Nicely	205-895-8600, 8801
	- John C. Christopher	205-895-8600, 8801
	- Alan L. Compton	205-895-8600, 8801
Camber Corp.	- Charles D. Cox	205-881-2672
Canadair Challenger, Inc.	- Ronald E. Rezek	703-486-5842
Chamberlain Waterloo	- Robert Rathe	319-291-1706
Coleman Research Corp.	- Kenneth F. Wohlfort	205-830-4484

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Colsa, Inc.	- Dr. Thomas L. Cromer	205-922-1512
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Computer Resource Mgt., Inc.	- Peter Johnson	703-435-7613
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CST	- Brian D. Godsy	205-837-7613
Cubic Corp.	- Dr. Gerald Ravenis	619-277-6780
Cuputervision	- Robert C. Badgett	617-275-1800
Datatronics	- John R. Harris	601-348-2531
David Sarnoff Research Ctr.	- James S. Crabbe	609-734-3299
Digital Engineering	- James K. McFetridge	205-922-0700
Dynamics Research Corp.	- Daniel T. Risser	603-437-7824
Eagle-Picher Ind., Inc.	- Jim R. Harvel	417-623-8000
EER Systems	- Virgie F. Towry	205-837-4400
	- Carmen D. Williamson	205-837-4400
	- Earl L. McLain	205-837-4400
	- Woomi Chase	205-837-4400
	- Marvin E. Bridges	205-837-4400
	- Beverly J. Fuller	205-837-4400
	- Albert G. Torres	205-837-4400
	- Jay M. Hightower	205-837-4400
	- Thomas A. Gilbert	205-837-4400
	- Willie D. Brunetti	205-837-4400
	- George E. Vinson, Jr.	205-837-4400

Electro-Tech, Int'l	- Edward G. Newman	703-354-5714
Ferrett Enterprises	- Virginia N. Blount	205-881-6102
Fluke, John Mfg Co.	- Larry Kimmons	205-887-0584
	- Calvin R. Menchey	301-770-1570
	- Tom Withrow (Speaker)	205-356-5950
G/E Aerospace	- William B. Greer	205-883-1170
GEC Aerospace	- James D. Smith	316-522-5030
GEC Marconi Electronic Sys Corp.	- Joseph A. Sturno	201-633-3430
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General Dynamics	- Mark E. Davis	714-945-8644
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Hilton Systems, Inc.	- Harold R. Bright	205-883-2260
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	- Curtis L. Ferrell	205-880-0884
Integrated Support Sys, Inc.	- Everett L. Thomas	803-654-1284
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Knowledge Base Int'l	- William G. Beasley	713-690-7644
Lockheed Corp.	- Ivan R. Prince	205-722-4020
	- Marshall L. Ogne	415-424-3470
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NAS, Inc.	- Gerald Chaikin	205-539-7928
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Nat'l Inst of Stds & Tech	- Robert J. Bruening (Speaker)	301-975-2318
	- Dr. Michael Gaitan (Speaker)	301-975-2070
Neotek Corp.	- W. R. Adkins	205-883-0796
Neuteric Technologies, Inc.	- James W. Neiers	-
	- William R. Adkins	205-881-8295
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	- James S. Reeves	205-883-8590
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Northrup Corp.	- Richard D. Graham	213-600-1010
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	- Harold A. Caudle	308-595-4000
Optodyne, Inc.	- Dr. Charles P. Wang (Speaker)	213-635-7481
Oracle Corp.	- Craig Baum	314-537-0057

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Pentastar Electronics	- Robert G. Sickler	205-895-2262
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S-Cubed	- William B. Johnson	205-837-7757

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SRS Technologies	- Mike David	205-971-7823
	- Ken Noland	205-895-7000
	- Jimmie Upshaw	205-895-7000
	- Steve Lee	205-895-7000
	- Brenda Young	205-895-7000
	- Bill Sharp	205-895-7000
	- Vern Gehm	205-895-7000
	- D. Hamesley	205-971-7041
	- Chuck Nicky	205-971-7041
	- Michael Stewart	205-971-7041
	- Brad Atkins	205-971-7041
	- Jonathan Phillips	205-971-7041
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Stone Engr. Co.	- Herbert L. Reichert	205-539-7812
Summa Technology, Inc.	- Thomas L. Hollingshead	205-922-4000
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Sverdrup Tech/TSG	- John D. Fuqua	904-833-7600
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	- Carl R. Steimke	205-726-1187
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	- William A. Moore	205-726-1187
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	- J. Scott Shurtleff (Speaker)	203-385-3813
	- Marcos V. Simon	203-385-1322
Titan Systems	- Fortunato F. Cataldo	205-895-9113
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	- Paul E. Williams	205-882-8108
	- Ronald S. Wells	205-882-8326
	- James H. Ashcraft	205-882-8241
TRW	- Jerry Dombrowski	-
	- Rhonda Barnes	-
	- Rich Rinkel	-

U of A	- Dr. Larry T. Wurtz	-
	- William Wheless Jr.	205-348-1757
UAH	- William D. Engelke	205-895-6496
	- Dr. Jeffrey L. Riggs (Speaker)	205-895-6817
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United Technologies	- Larry A. Weinert	205-721-2296
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	- Dane Kenney	205-721-2236
	- Fred Laracuente	205-721-5702
	- Tom Miller	205-721-2213
	- Rena Patel	205-721-5620
	- Dennis Thatcher	205-721-2701
	- Marsha Wade	205-721-2212
	- Larry Weinert	205-721-2296
United Technologies Chem. Sys	- Patrick M. Loftus	513-256-5411
Univ of Louisville	- Kenneth E. Stoll	502-588-0478
USBI ATE Dev. Ctr.	- Lawrence G. Crochet	–
USBI Bus Dev	- William R. Dunkelberger	205-721-2605
	- Robert L. Griffith	205-721-2605
Uwohali, Inc.	- Jeffry P. Brody	205-539-0954
Uwohali, Inc.	- James A. Dailey	205-837-3066
	- Charles D. Stroud	205-539-0959
Varian Associates	- James B. McDonough	508-922-6000
Vigyan, Inc.	- Dr. Sudhir C. Mehrotra	804-865-1400

Vitro Corp	- Bill Coe	205-461-8895
	- Scott Gray	205-461-8895
Wego Precision Mach, Inc.	- Kenneth W. Carlton	800-752-6789
Westinghouse Corp.	- James T. Boyd	205-722-4741
	- William R. Middleton	205-584-5382
Westinghuse Elec. Corp	- Paul S. Rodriguez	205-722-4710
	- Naomi J. McAfee	301-765-3400
Westinghouse Science&Tech Ctr.	- Arthur H. Long	412-256-2163
West Virginia Univ.	- Suren N. Dwivedi	304-293-6689
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