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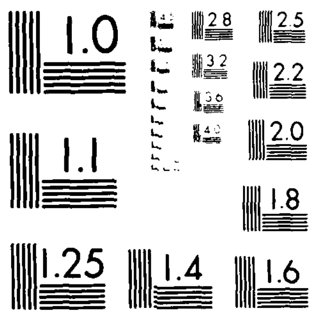

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IDA REPORT R-272

IDA/OSD RELIABILITY AND MAINTAINABILITY STUDY

Volume IV: Technology Steering Group Report

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November 1983

Prepared for
Office of the Under Secretary of Defense for Research and Engineering
and
Office of the Assistant Secretary of Defense
(Manpower, Reserve Affairs and Logistics)

IDA

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This report is in four volumes: Vol. I, Executive Summary; Vol. II, Core Group Report; Vol. III, Case Studies Analysis, and Vol. IV, Technology Steering Group Report. Study results were derived from case studies performed on eight existing weapon systems and from working groups that examined sixteen individual technology areas. Specific R&M recommendations are made in the following eight areas: Technology Base R&M Programs; R&M Demonstration Programs; FSED Planning and Analysis; R&M Standards; FSED Management Awareness of R&M; (contd)

20. (contd) New System Maturation; Collection and Use of R&M Data; and R&M Training.

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And finally, thanks to our editor, Richard Cheney, and his staff for their publication assistance and Bob German and his staff for their tireless efforts in supporting the many expedited reproduction requests required for meetings and associated study activities.

John R. Rivoire
Director

CONTENTS

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ABBREVIATIONS

AI	Artificial Intelligence
ALCON	Advanced Logistics Control Network
ATE	Automatic Test Equipment
ATF	Advanced Tactical Fighter
BIT	Built-in-Test
C&C	Cabling and Connectors
C^3L	Command, Control, Communications and Logistics
C^3I	Command, Control, Communications and Intelligence
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CND	Cannot Duplicate
DARPA	Defense Advanced Research Projects Agency
DE	Directed Energy
DSARC	Defense System Acquisition Review Council
DSP	Digital Signal Processor
ECS	Environmental Control System
EMI	Electromagnetic Interference
EMS	Engine Monitoring System
EPIC	Electronic Packaging and Interconnection
EW	Electronic Warfare
FDIC	Fault Detection and Isolation
FEG	Functional Element Group
FOM	Facilitate Other Maintenance
FT	Functional Test
HW	Hardware
IC	Integrated Circuit
IDA	Institute for Defense Analyses
IOC	Initial Operational Capability
ISOM	Integrated Systems of Manufacture
LPRF	Low Power Radio Frequency
LRU	Line Replaceable Unit
MDCS	Maintenance Data Collection System
MED	Microelectronic Device
MPT	Manpower, Personnel and Training
MRA&L	Manpower, Reserve Affairs and Logistics
MSCM	Mechanical Systems Condition Monitoring
MTBF	Mean-Time-Between-Failures
MTBM	Mean-Time-Between-Maintenance
MTTR	Mean-Time-to-Repair

119/12-1

NASC	Naval Air Systems Command
NDE	Nondestructive Evaluation
NOSC	Naval Ocean Systems Center
OSD	Office of the Secretary of Defense
P^3I	Pre-Planned Product Improvement
RDT&E	Research, Development Test and Evaluation
R&M	Reliability and Maintainability
RF	Radio Frequency
RIW	Reliability Improvement Warranty
ROI	Return on Investment
RTOK	Re-Test OK
SBA	Sea-Based Air
SDC	Sample Data Collection
SOW	Statement of Work
SSARC	Service System Acquisition Review Council
STARS	Software Technology for Adaptable and Reliable Systems
STOL	Short Takeoff and Landing
SW	Software
UHF	Ultra-High Frequency
UMA	Unscheduled Maintenance Action
USDR&E	Under Secretary of Defense for Research and Engineering
VHSIC	Very High Speed Integrated Circuit
VLSI	Very Large Scale Integration
WUC	Work Unit Code

119/12-2

I. INTRODUCTION

This report is a synthesis of 15 individual technology working group reports and an analysis of future technology impacts and requirements. It represents a portion of a large study effort focused on improved readiness through improved R&M. It was made possible only by the extraordinary support of the leadership and personnel of the Office of the Secretary of Defense, the military services, government, industry and academia.

The overall IDA study is divided into two major segments--one to undertake case studies of existing systems, contained in Volume III, and this volume, to examine existing opportunities to use new technology. This report, Volume IV, summarizes the findings and conclusions of the fifteen individual technology reports and provides an insight into their interrelationships. The relationship of this report to the other study reports is indicated in Fig. 1.

The study was done for OSD (MRA&L) and (USDR&E). Russell R. Shorey (MRA&L) has been the Department of Defense point of contact throughout.

The initial attempts to synthesize the findings and recommendations for this technology report met with remarkably consistent support at the numerous meetings and briefings. The following ideas and general findings emerged:

- The necessity of maturing "off-line" the high risk technologies represents a common theme. The problems that arise from attempting to mature tecchnologies "on-line" are well documented.

- The need to gain a deeper understanding into the causes of failure is widely supported. It appears that there is agreement on the symptoms of failure. One issue

200/2-1

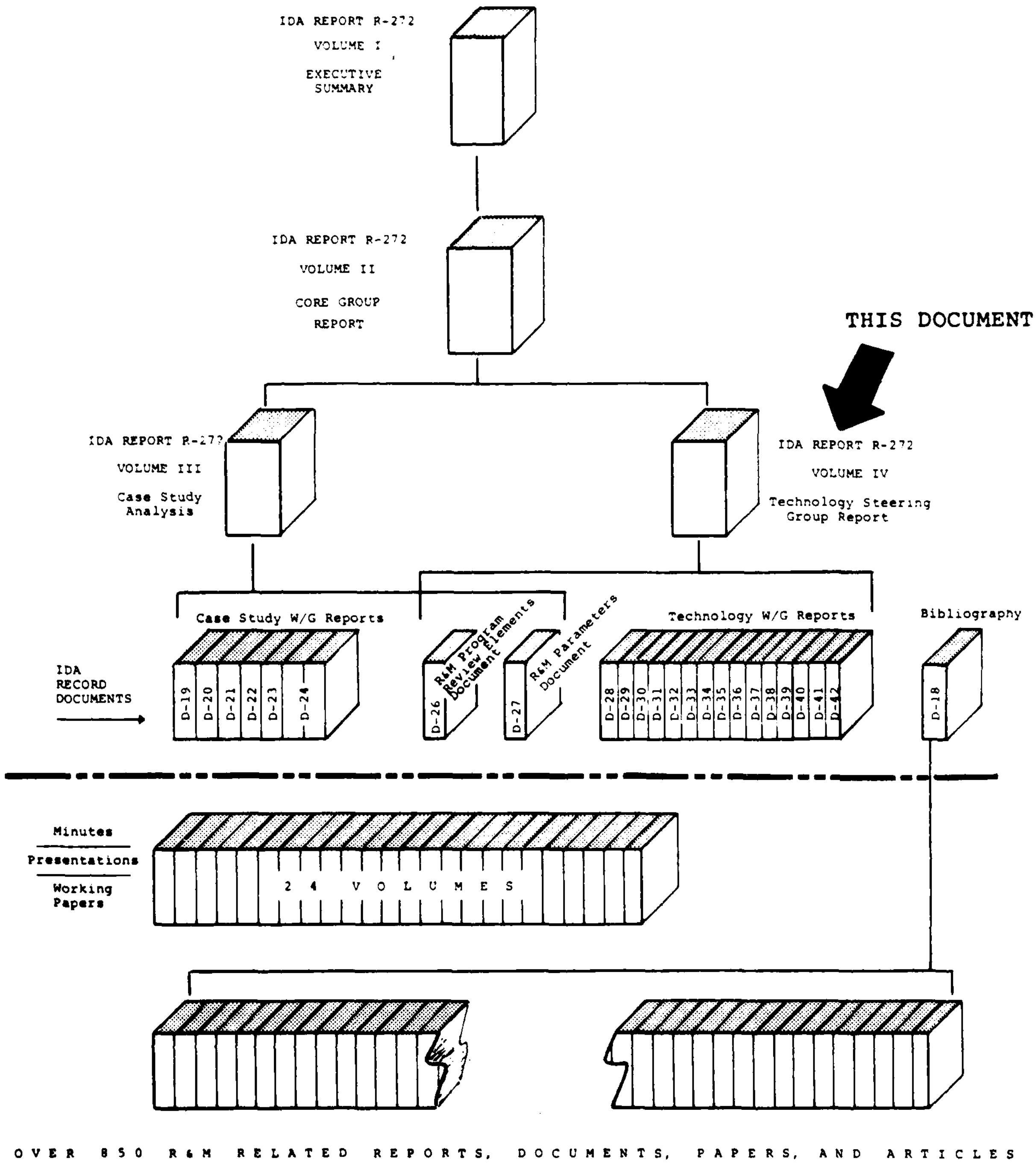


FIGURE 1. R&M Study Report Structure

is that there are common precursors to failures and mechanisms for failure itself which we have not captured. Another issue is a lack of basic knowledge of the cause of failure.

- The need to address the dependencies between technologies early in their development became apparent. There appears to be an overconfidence that spontaneous processes in our system will correct for the deficiencies created by these interdependency effects. It appears that a reasonable level of effort spread out over a number of presently underfunded component programs is necessary.

- Investigation of the concept of "innovative use of technology for R&M" has demonstrated that a wide array of techniques must be involved, many of which previously were considered as performance technologies.

- The statement that "performance and reliability objectives can be compatible" appears to be widely accepted, provided both of these attributes are given early consideration in R&D programs. VHSIC, Software and Fiber Optics technologies are obvious examples.

II. BACKGROUND

In recent years there has been a rising concern about DoD's ability to keep weapon systems both modern and combat-ready. At any given time the availability of many of these systems has been below that needed to maintain the required force posture. The seriousness of this problem was highlighted in the report of the 1981 Defense Science Board (DSB) study of the Operational Readiness of High Performance Systems. One of the major recommendations of that study was to design reliability into the systems from the start and mature that capability prior to full-rate production. The 1981 DSB study also highlighted problems with diagnostics and recognized that increasing system complexity, while not incompatible with readiness, made it imperative that the Department of Defense (DoD) demand and manage acquisition to achieve readiness requirements.

Because of the well-publicized problems in reliability, readiness and support, DoD put improvements in this area high on its priority list. The Carlucci initiatives directed at reforming the acquisition process gave reliability and support considerations a very high priority. As a result there has been a major increase in DSARC and top management attention. On each major program there is visibility at the top on progress in meeting R&M objectives through development, production and in early field experience.

The track record from these efforts is uneven. Many of the more mature technologies have done relatively well in meeting reliability objectives. Newer, fast-developing technologies often have serious problems, however, as do any programs with accelerated or compressed schedules. The latter are becoming more frequent due to the Administration objectives of fielding new hardware faster. Thus, there is a major challenge in learning to manage acquisitions on accelerated programs so as to attain desirable R&M objectives. Technology advances are potentially helpful in such areas (e.g., in electronics) by providing opportunities to improve both performance and R&M, provided the problem is attacked in both the technology base and the acquisition process.

In the future, increasing weapon system complexity and rising maintenance costs will lead to demands for higher levels of R&M. A review of the Services' Year 2000 studies identified a common theme calling for more flexibility, more autonomy, more dispersal, and reduced support tail dependency in combat forces. While the validity of the presumptions on which these requirements are based may be challenged, their general thrust is unmistakable.

All of these demands, i.e., fast-developing technologies, short development cycles, increased complexity and new operational concepts, point toward reexamination of the balance between technology base efforts and the needs for new systems. This technology portion of the study focused on this issue.

A number of examples exist which highlight the problems discussed above. One such example is from a major system which recently ran into reliability problems at production start-up. The predicted reliability values and the number of estimated failures were, in general, achieved during the R&M demonstrations. Yet, at production start-up, interconnect problems were five times more prevalent than anticipated. Faulty workmanship in the cables of the system were a major problem, causing the total system reliability to fall to unacceptable levels. The solution was made difficult by the nearly one-million connectors involved. Similar stories are fresh in the memory of most participants in this study. Even though each participant recognized there will always be unexpected problems as systems move to production and operational use, a general feeling was that the development community must do better than in the past. This report prescribes action to begin that process and includes a recommendation to change the process by which technology is matured for military use.

200/2-5

III. OBJECTIVE & SCOPE

The broad objective of this segment of the study was to look at specific new technologies for their potential contribution to R&M improvements and for the problems that might be anticipated in their application, with particular attention to any that might lead to a "quantum jump" in R&M. Sixteen working groups were formed and asked to address these two distinct tasks:

(1) Assess the impact of advancing technology on future DoD requirements for improved R&M readiness; and

(2) Evaluate the potential and recommend strategies that might result in quantum jumps in R&M readiness through innovative use of advancing technology.

In addressing these tasks the groups were asked to determine how new technologies should be developed and employed to meet R&M improvement goals and to identify any changes needed in reliability procedures because of new technologies.

The technology areas selected for study were as follows:

Technology	IDA Document No.*
• Artificial Intelligence	D-28
• Cabling and Connectors	D-29
• CAD/CAM	D-30
• Structural Composites	D-31
• Directed Energy	D-32
• Fiber Optics	D-33
• Integrated Systems of Manufacture	D-34

*See Section VI Reference List.

200/2-6

- Manpower, Personnel and Training D-35
- Mechanical Systems Condition Monitoring D-36
- Nondestructive Evaluation D-37
- Operational Software D-38
- Electronic Packaging and Interconnection D-39
- Power Supplies D-40
- Testing Technology D-41
- VHSIC D-42
- Diagnostics --

A synthesis of the findings and observations of the working group reports is contained in Section VI of this report.

The methodology used for technology selection and a detailed description of the study organization, working group members, and the statement of work (SOW) for each group is contained in Appendix A. The goals of the working group and the issues to be addressed are also identified. A problem that surfaced early for the technology groups as they attempted to write their statements of work was "what is needed from technology." Failures associated with equipment already in the field are not often identified in a manner that can lead to system improvement. In addition, the R&M requirements for future systems are not always understood. Appendix B examines the R&M requirements identified by the Services for future systems and, from a technology perspective, analyzes the likelihood of achieving those objectives based on historical trends. The requirement is analyzed from the system level to the component level and assessments of the technology impacts on readiness are made.

As the study progressed, the importance of the interrelationships among the individual technologies was highlighted time and time again. These interrelationships are sometimes subtle and often complex but understanding their importance is central to

200/2-7

achieving the quantum improvements in R&M through technology. These "circle of dependencies," as they came to be known in the study, are described in more detail in Appendix C.

An important aspect of the technology efforts conducted under the aegis of the overall study was the independence of the individual working groups. Their reports are their own and they should be examined separately. A summary of the fifteen reports and an analysis of issues associated with technology insertion, maturation and creation are covered in Section VI.

200/2-8

IV. FINDINGS

A consensus from the many experts that participated in this study was that if we are to achieve our readiness and maintainability objectives, then additional technology base emphasis on these needs is required. Specific technology areas that should be emphasized were identified. In addition, a recurrent theme was the need for "off-line" maturation programs (also referred to as demonstration programs) to address the system level problems of technology interdependencies.

A. TECHNOLOGICAL CONTRIBUTIONS TO READINESS

One of the underlying issues in this study was to determine the extent to which the improvements that have been made in the past, or are working their way through the system today, will be sufficient to meet the perceived needs of the future. A number of attempts to find data and establish trends were undertaken to get some visibility into this issue. One effort to analyze future requirements (Ref. Appendix B) clustered around three major subsystems: electronics, structures and propulsion. Trend data for these three subsystems indicate that the propulsion sector may be well on its way to achieving the required R&M performance levels that Service studies indicate are needed, presuming, of course, there is still growth potential remaining. Continuation and expansion of present efforts in propulsion technology are still required but with continued support it does appear that they will be successful over the next two decades.

The message for structures and electronics appears to be different. The twenty-year history for these systems shows some progress, but the rate of advance is not comforting. Future trends indicate a significant shortfall is likely in electronics even with the advances that are now working within the system.

Emphasis is necessary for both the electronics and structures areas if the qualitative and quantitative R&M requirements, identified by the Services for the Year 2000, are to be achieved.

An analysis of the sixteen topic studies (Section VI) led to the awareness of the interrelationships between technologies (Ref. Appendix C). This awareness, in turn, led to the conclusion that these interdependencies must be addressed in the technology base, if the goal is improved system level readiness. Improvement of component reliability is a necessary, but not sufficient, determinant of achieving the system level goals. There is a need for a concerted effort by the Services and DoD management to review the current technology efforts in this light starting with the areas identified in this study.

B. "QUANTUM" IMPROVEMENTS

Quantum improvements in R&M and Readiness through innovative uses of advancing technology are not only possible, but essential to meeting projected R&M requirements for the future (Ref. Appendix B). The meaning of the word "quantum" has been defined in the study to include three measures:

(1) The ability to conduct dispersed operations for long periods of time with reduced dependency on traditional maintenance concepts.

(2) The increase in data intensity for both operations and logistics.

(3) The improvement in failure rates necessary to obtain fielded capability significantly above today's performance.

200/2-10

These future postures indicate a requirement for, and at the same time a bigger payoff from, improved R&M. The perceived new threats to centralized logistics operations coupled with new operational concepts create requirements for much smaller support tails and for decentralized logistics support. At the same time weapon systems are rapidly increasing in complexity. This combination of factors puts a great premium on improved, fail-safe designs and on improved diagnostics systems. Initial attempts at quantification indicate goals of 3 to 10 in reliability improvement at the weapon system level, and factors of 10 in reduction of false alarms are not unrealistic. To achieve such goals will require substantial augmentation of technology maturation programs.

C. FUTURE STRATEGY

Many meetings and interchanges with military and industry were crucial to finding the elements of the strategy. The sixteen technology groups (Ref. Appendix A) also provided guidance directly through the steering group, but more importantly, through the consistency in the themes of their reports.

The necessity to achieve a structure for system development which minimizes failures through adequate and proper early design is a widely-perceived need which is addressed directly in the case studies segment of this study. There are numerous assertions in the various reports on the importance of this early discipline. Key to this discipline is an adequate design data base. The analysis of the fifteen technology reports and the case studies analyses support the finding that many design decisions are made without data available to indicate the consequences. One of the major responsibilities of the technology base is to provide an adequate data base for engineering design. The central issue here is how this function can be strengthened and prioritized. Specific recommendations are presented in Section V.

D. THE TECHNOLOGY ISSUES

A summary of the results of the individual working groups is contained in Section VI. In these summaries, each of the study technologies is analyzed relative to three groups of issues--insertion issues, maturation issues and creation issues.

The group of "insertion" issues as addressed by the working groups includes actions required to initiate widespread use of an already developed technology. If additional work is still required to fine-tune a fairly well-developed technology, these issues are grouped in a category referred to as "maturation". Finally, when major improvements are identified as still required, but no clear path to a technological solution is perceived, the "creation" label is assigned. A preview of how each working group viewed their technology relative to these three groups of issues is shown in Fig. 2.

Technology Areas	INSERTION	MATURATION	CREATION
• Artificial Intelligence	X	X	X
• Cabling and Connectors	X	X	
• CAD/CAM	X	X	X
• Structural Composites	X	X	X
• Directed Energy		X	X
• Fiber Optics	X	X	
• Integrated Systems of Manufacture	X	X	
• Manpower, Personnel and Training	X	X	X
• Mechanical Systems Condition Monitoring	X	X	X
• Nondestructive Evaluation	X	X	X
• Operational Software	X	X	
• Electronic Packaging & Interconnection	X	X	
• Power Supplies	X	X	X
• Testing Technology	X	X	
• VHSIC	X	X	
• Diagnostics		X	X

FIGURE 2. Technology Issues

200/2-12

V. RECOMMENDATIONS AND OBSERVATIONS

A. RECOMMENDATIONS

The following recommendations were reached as a consensus of the conclusions of the sixteen technology working groups.

1. Technology Base R&M Programs

There was general agreement that there is a need to selectively expand technology base programs specifically directed at improved reliability and maintainability of components subsystems and systems for current and future military systems. Specific areas were targeted in the individual reports.

Recommendation:

The Logistics R&D Working Group under the direction of the Policy Council is assembling individual Service plans and an integrated DoD plan for "Log R&D." It is recommended that the fifteen Technology Working Group Reports be reviewed by appropriate Service agencies and laboratories as an input to the formulation of Service plans.

2. R&M Demonstration Programs

There was also general agreement on the need for "off-line" maturation, i.e., applied technology demonstration programs, as an integral part of achieving advanced performance objectives. Such demonstration program plans should include "road maps" which relate the timing of technology developments to their use in the demonstration program.

200/2-13

Recommendation:

The Services should establish, with concurrence of the Logistics R&D Policy Council, a set of quantitative, user-approved R&M Objectives, which in turn can be used to structure quantitative design objectives for advanced technology subsystems and components. The Services should then prepare, and include in their plans given to the Logistics R&D Working Group, a coordinated program of demonstrations, based on technology availability, to reach these objectives. A set of time-based "road maps" to connect technology availability to end-use demonstrations should be constructed.

3. R&M Standards

It was concluded that advancing technology and the need to emphasize R&M point to the need for improvement in specific R&M standards.

Recommendation:

It is recommended that a Tri-Service Board be convened to develop a specific implementation plan to review and update within the next 24 months standards and specifications for electronic or electromechanical systems, specifically related to:

- Testing procedures
- Packaging standards
- Power supply design
- Software design
- Connector standards (including fiber optics)

and, more generally, human factors standards and composite materials design specifications as they relate to R&M requirements.

200/2-14

4. Use of Field R&M Data

There appears to be insufficient technology base efforts directed at identifying the underlying causes of equipment failures.

Recommendation:

Lead laboratories should be designated in major technology areas for analysis of field data on failures. These laboratories should be supported to initiate research studies of generic problems in order to expand the technology base information available to designers.

5. Diagnostics

As was discussed above the increasing complexity of weapon systems together with the operational need for reduced support tails makes improved diagnostics a high payoff area.

Recommendation:

It is recommended that in preparing the DoD Logistics R&D plan special emphasis be given to technology base programs for the development and demonstration of improved diagnostic systems.

B. OBSERVATIONS

1. Technology Base R&M and Demonstration Programs

For several reasons discussed in Section IV of this report, there are known deficiencies in the maturity of the technology base. These deficiencies restrict our ability to improve system failure rates and our ability to maintain system performance now and in the future.

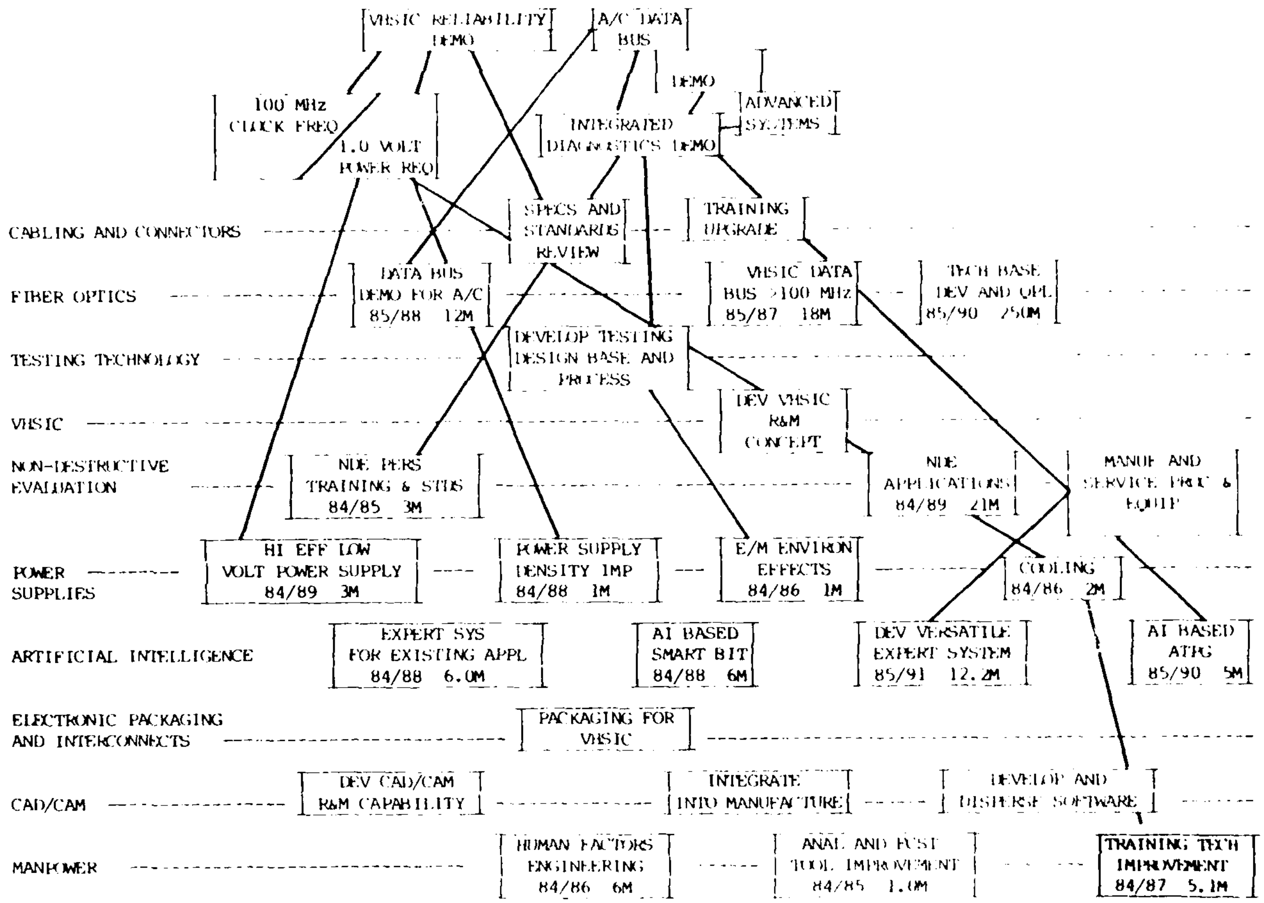
200/2-15

An inordinate amount of confidence is placed in the self-correcting nature of our system operating within the hectic pressures of the system development process. The elements that follow focus on other aspects of the solution. This element focuses on the need to mature a whole class of new technologies for the purpose of reducing failures, minimizing their impact on operations and reducing the effort necessary to conduct maintenance.

There are three essential features of the "off-line" maturing element as it is proposed. The first is that a set of technologies should be matured in a manner which reflects their interdependencies (Ref. Appendix C). Second, the target chosen to provide the measure of success should be as realistic as possible, if not an existing system. Third, the results achieved should be generalized so that it may become the new level of acceptable performance.

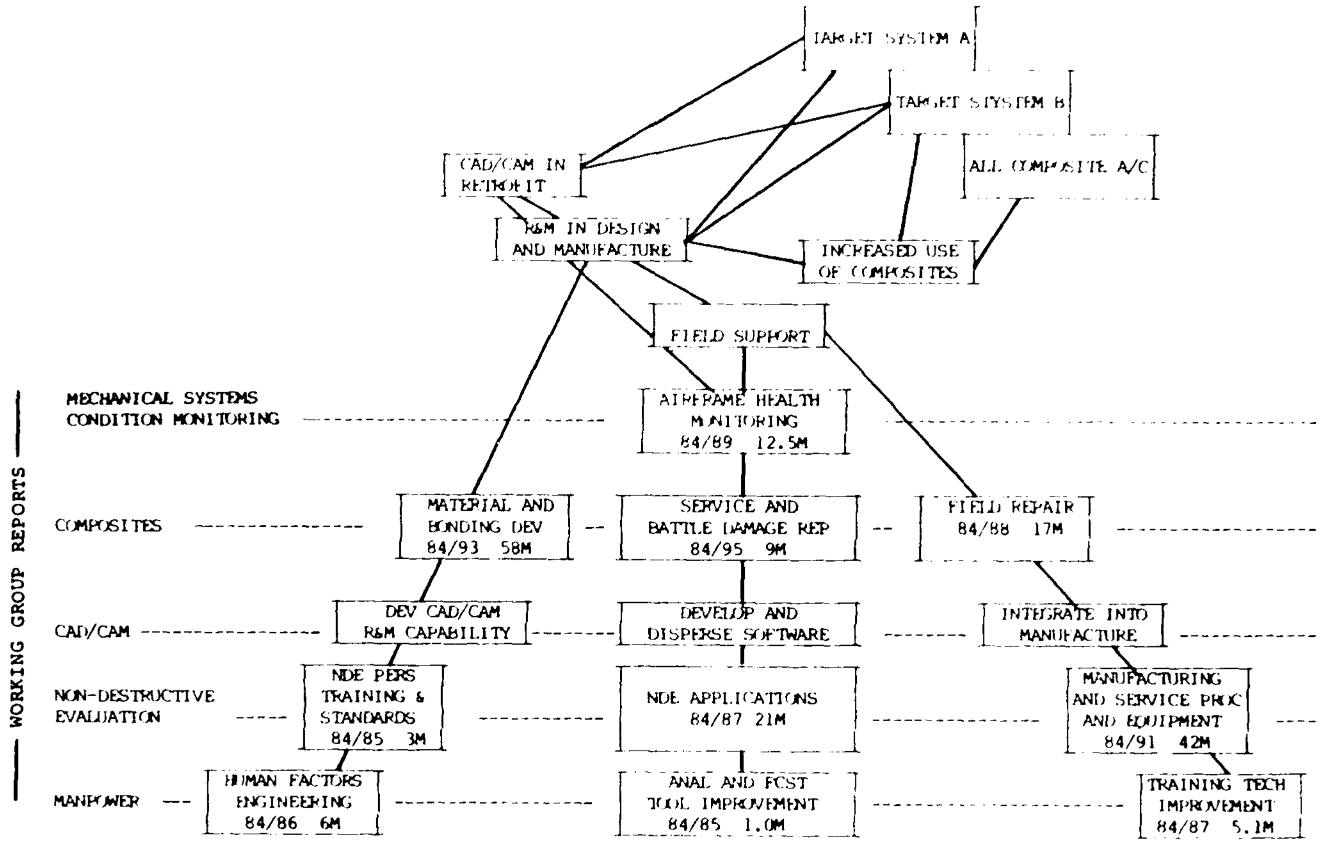
There are a number of approaches to this "off-line" maturing concept. One approach is presented in the form of technology road maps which follow: one each for electronics, propulsion and structures. These road maps integrate the Year 2000 goals, the interdependency requirements, and technology needs identified in the technology working group reports. Indicative outlines of these road maps are in Figures 3-5. The road maps are organized to reflect the expert opinions from the individual working groups as they pertain to what needs to be done, when it should be done and in some cases how much it can be expected to cost.

These road maps are not presented as the prescription for success but instead represent a point of departure for each Service to use in structuring their own activity. Some of the activity presented on the road map has already begun.



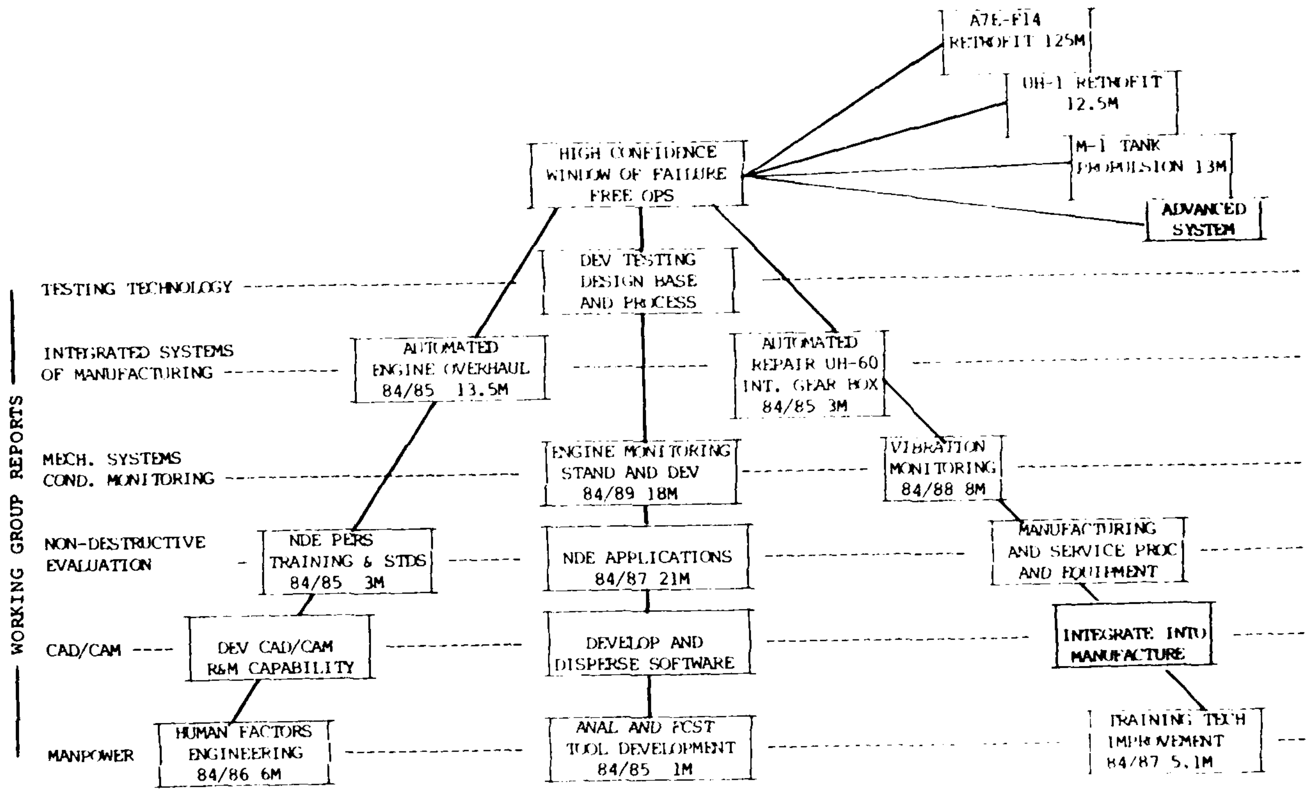
126/8-3

FIGURE 3. Electronics Road Map



126/8-2

FIGURE 4. Structures Road Map



126/8-1

FIGURE 5. Propulsion Road Map

2. Specific Interdependencies

The study explored many topics which too often fall into the category of the "overlooked or unexamined assumptions" in decision-making (Ref. Appendix C). The results of these oversights are presented here under the title "Specific Interdependencies." We may have been overly confident about the ability of our system of research and development to capture and respond to the ripple effects of technological change. Consequently, a number of important issues, despite their importance, have been de-emphasized. As a result, in several places these issues identify technology areas in which the rate of growth of the technology base was judged to be inadequate, especially in view of unquestionable demands of the future.

The management challenge posed by the interdependency issue is to change the priorities accorded to these topics. The approach proposed is to establish technological performance targets that unequivocally draw the attention of the system to their importance and if pursued will draw a number of other factors into the right perspective. Four such targets are presented:

(1) The need to establish an alternative to the existing interconnect technology to cope with the 100 MHz clock frequencies of the I/C's of the 1990's and the need for system level structures to enhance control of equipment status and reconfigurations.

(2) The need to provide reliable, efficient power supplies for electronics capable of delivering the 1-volt high-amperage DC power required by VLSI/VHSIC with power densities in the 10 w/in^3 range.

(3) The need to establish high confidence estimates of "failure-free" windows of performance for critical military subsystems. This requirement is an extension of the ability of health monitoring systems to capture incipient failures and extends the concept to allow weapons systems to continue battle action prior to cycling the unit back to a repair facility. (This capability is presently more mature for mechanical systems than for electronic systems).

(4) The need to grasp all the implications of the increased use of composite materials in the structure of military platforms. The need is brought about by the constantly increasing content of composite materials in military systems. The side effects of this evolution create challenges for platform design engineers as well as new requirements for consideration by electronics design engineers.

The approach of using technological targets which are virtually inevitable was chosen in order to call attention to a few items. In this way a larger set of priorities may be realigned with enough clout to survive. This approach was chosen since the other alternatives lead to the statement of technological goals in terms that have been overused to such an extent that legitimate claims are discredited because of the aura of special pleading that surrounds them.

The concept of technology performance targets is mixed with the strategic goal of "off-line" maturing, resulting in road maps for the conduct of research and development (Ref. Figs. 3-5).

3. The Discipline and Structure of R&M Management

The past techniques of establishing requirements and structuring them to achieve the desired fielded capability have proven

200/2-18

to be flawed. Initial efforts often resulted in requirements for unrealistic performance levels or were so obviously biased that they faced significant political challenges such as those raised by the Commission of Federal Procurement and Directive A-109.

The net results have been requirements written with all good intentions but flawed in their ability to provide a realistic framework. Therefore, priorities were not stabilized within the large efforts necessary to produce systems with fielded performance that met the original expectations. The number of success stories are far too few.

The need to change this situation is highlighted by the arrival of a "system on a chip." The complexity of modern systems such as Directed Energy or Super Computers holds forth the possibility that feasibility may be driven by reliability concerns. The complexity may be so great that the very process of prototyping may hinge completely on getting them to work just once. Their structure, as a result, appears as a collection of imbedded, highly-complex systems. There will have to be early considerations during the requirements process as to how these imbedded systems relate one to the other. The Directed Energy study (Ref. IDA Record Document D-32) is a good case study of this type of problem.

One further claim can be made for the early consideration of reliability and maintainability. A common theme was that the same kinds of considerations that can lead to successful proof of concept often are the same as the considerations that would lead to savings in downstream costs (i.e., life-cycle costs). In several instances such awareness has existed. However, due to the way in which priorities have been set in the evolution of these systems, key elements were often given superficial treatment. One of the reasons for this oversight is that the consequences of a design decision are presently not known until much later in the life of a system. Thus, the fault, when it does occur, is buried deep within the design and seldom corrected; a band-aid or patch is introduced as the only realistic option available at the time the fault is detected.

The study found that there were widely differing skill levels in dealing with these problems. As a result, there are a number of straightforward criteria which could be used by OSD to define whether the broad interests of the DoD are being met. Figure 6 highlights those areas where deficiencies were noted in each report.

4. Research Thrusts

The fifteen working group reports indicated a number of research topics which in the aggregate point to six lines of scientific inquiry. In each of these cases, a significant amount of detailed research effort should be actively pursued. The areas are: composites, manpower, corrosion, predictive techniques, diagnostics, and architecture for reliability.

1. Composites

The increased use of composites will highlight additional deficiencies in our scientific understanding of these materials. Research into bonding of different materials and adhesives underlies many of the potential issues. This is another area where attention should be sustained to ensure adequate resources are applied for a significant period of time.

2. Manpower

The research base underlying the design trade-off process, especially for human factors, has been and continues to be deficient. The importance of continuing and expanding this base of knowledge is increased with the advent of more imbedded complexity and the forecast patterns of demographic change.

	Artificial Intelligence	Cabling & Connectors	CAD/CAM	Composites	Diagnostics	Directed Energy	Electronic Packaging	Fiber Optics	Integrated Systems of Manufacturing	Manpower & Training	Mechanical Systems Condition Monitoring	Non-Destructive Evaluation	Operational Software	Power Supplies	Testing Technology	VHSIC
Are the full set of R&D efforts identified?				■		■				■	■	■		■		
Are DOD & commercial efforts coordinated?	■						■							■		
Are manpower requirements established?	■			■		■					■					
Are demonstration projects established & properly guided?			■		■			■			■					
Is management experienced? Are services coordinated?	■	■	■						■	■	■	■	■			
Are adequate advisory mechanisms established for SPO/PMA?							■					■		■	■	
Are specs, stds & guidelines adequate?	■	■		■	■		■	■				■		■	■	
Are incentives adequate?			■	■				■	■			■	■	■		
Are DSARC/SSARC criteria adequate?																■

FIGURE 6. Deficiencies Identified by Working Group Reports

120/16-36

3. Corrosion

The historic claims of the impact of corrosion should not obscure the importance of corrosion as a failure mechanism in the advanced technology systems of the next two decades. A new focus to this age-old issue is necessary to support the corrective actions for the anticipated problems that appear on the horizon.

4. Predictive Techniques

A number of scientific phenomena explain the chain of events that precede a failure. The material science discipline is leading the way to making this understanding applicable to the management of failure in mechanical systems, potentially achieving a sufficient alert to allow for repairs to be scheduled. There is an analog in electronic systems that is not being adequately addressed. The precursors to electronic failure and schemes to detect them could lead to enhanced diagnostics and an improved ability to estimate the time to failure of a component or system.

5. Diagnostics

During the era when discrete components were used in quantity, it was possible to probe electronic assemblies to isolate failures. Now there are layers of hermetic seals and programs stored in memory that obscure the technician's visibility into the physical processes of system operation. The whole discipline of diagnostics is in a state of flux caused by the rapid advance of hardware complexity going on behind the interface. The research base should be reassessed to ensure the various disciplines that could contribute to the solution of the diagnostics problem are properly funded (also see Case Study Analysis, Volume III).

6. Architecture for Reliability

The need to understand new concepts for fault tolerance and automatic reconfiguration is latent throughout this study. Now that systems on a chip are feasible, it is possible to reconsider redundancy and other schemes of isolating component failures from system failures. The theoretical basis for various schemes needs to be strengthened. The array of ongoing research tasks should be addressed to determine what in addition could be undertaken. As an example, non-Von Neumann architectures or multiprocessor data flow machines for computers may have uniquely different failure schemes from the present-day systems.

VI. SUMMARY OF TECHNOLOGY WORKING GROUP REPORTS

In the appendixes of this volume, the overall technology study structure is described (App. A) followed by an analysis of requirements and projections of how well those requirements could be met by both existing and emerging technologies (App. B). It is made clear that the proper use of the emerging technologies is the key to meeting the future mission requirements. However, it is explained that one could not simply intensify development of one technology by itself. The complex interaction of technologies is displayed to show that adjustments must be made to several interdependent technologies in any effort to obtain significant improvements in equipment performance and readiness, i.e., off-line demonstration programs are needed.

Here, a brief summary of the results of the specific technology studies is provided. This is followed by an analysis of the technology group recommendations. These are independent conclusions of each group; hence their recommendations may not appear explicitly as recommendations of the overall study (see Section V of this volume and Vol. II for the study recommendations). A reference list at the end of this section identifies each of the fifteen working group reports.

A. TECHNOLOGY SUMMARIES

1. Artificial Intelligence (Ref. 1)

The maintenance of military systems employs a variety of automation such as built-in-test, which provides on-line fault detection and isolation, and automatic test equipment for intermediate and depot repair stations. Automated maintenance aids and trainers abound.

The increasing complexity in military systems and the decline in personnel skill levels will burden the maintenance process. Testing technology evolution will be able to compensate for some of this eventually; however, the need for significant improvements in maintenance will require radical changes in approaches, e.g., the use of "artificial intelligence."

A technology working group was established to study the employment of artificial intelligence technology to maintenance, to assess the costs, risks and development times and to provide recommendations. The group examined the use of artificial intelligence in the DoD and the present state-of-the-art. The conclusion was that DoD efforts are small and exploratory. Based on the data it gathered, the committee developed a series of recommendations for expanding the use of artificial intelligence and facilitating its use and the development of artificial intelligence systems.

2. Cabling and Connectors (Ref. 2)

It is almost impossible to find electrical or electronic equipment anywhere that does not use one or more types of connectors. These connectors not only influence system design but also frequently determine whether a system is functionally and economically viable. In current electronic packaging concepts, connectors have become very vital links in electronic systems. Therefore, connector and cable technology is a significant subject for study in any attempt to improve weapon system performance and readiness.

The working group that was created to study this technology set the objectives of determining the major causes of malfunctions and failures in cabling and connectors and identifying the constraints created by the incorporation of new technology into military systems. The group determined that cable and connector failures are due to the following factors, which are provided in descending order of contribution: attachment, application, abuse, corrosion/oxidation, design deficiency. As a result of the analysis of the data, the group recommended that additional data be collected on connector failures and that research and development be conducted to evaluate the means of cable termination in a manner consistent with VHSIC and fiber optics requirements.

3. CAD/CAM (Ref. 3)

Computer-aided Design and Manufacturing (CAD/CAM) provides a means of automating the design and manufacturing process and, consequently, improving the efficiency and comprehensiveness of the design process and improving the manufacturing process through increased production rates and higher defect-free yields. It is a technology that is receiving increasing use in U.S. commercial industry.

This technology working group was set up to study CAD/CAM applications for defense material. The objectives of the group were to define a model of the process for taking a weapon system from concept to product by means of computer-aided technologies, to identify critical information flows and to define the engineering process that takes advantage of these technologies. As a result of the study effort, the group identified two major issues: effective application of existing computer-aided technologies and communications among subsets of computer-aided technologies. In the case of existing technologies, the group found that excellent capabilities exist but frequently are improperly applied, are applied too late, or simply are not used enough. Several specific examples were studied and recommendations were developed. In the case of subset communication, the group found that subsets do not communicate effectively with each other or, in most cases, do not communicate at all. The result was found to be the added expense and delay of data reentry. The group examined a number of promising CAD/CAM projects but concluded that, as beneficial as these were, their effectiveness would be reduced unless suitable interfaces were developed. The group developed several recommendations for specific CAD/CAM capabilities and compatibility among CAD/CAM subsets. These recommendations are discussed in Section B following.

4. Structural Composites (Ref. 4)

Structural composites are another technology which is being used more frequently in modern DoD systems. Most of the new fighter aircraft have significant amounts of composites in their structures.

A working group was set up to study the structural advantages of composites, the non-structural advantages and the barriers to the application of composites. This group decided to focus its attention on long-term durability, repairability in the field or depot, maturity of design and manufacturing methods, prediction of life-cycle costs and the impact of other technology areas such as NDE, CAD/CAM, robotics, testing, and fiber optics. The study included examination of Air Force and Navy studies of composites and manufacturer data. The group developed recommendations that were associated primarily with composite damage and repair and with establishing proper requirements and verification techniques.

5. Directed Energy (Ref. 5)

Although actually a mix of unique and conventional technologies, directed energy technology was included in this study because of the current consideration of directed energy for weapons purposes. The focus of the effort was to establish reliability and maintainability guidelines for the acquisition of directed energy weapons systems and to determine what cost-effective design approaches should be considered.

The working group for directed energy selected weapons systems scenarios and defined both missions and readiness conditions. Models were used to establish reliability and maintainability goals based on the nature of the equipment and its environment. Allocations to subsystems were also performed. The allocations were evaluated against the current state-of-the-art and trends in technology. Functional areas for improvement were identified. As a result of the analyses, those specific support technologies which have the potential for significant readiness improvement were identified. An overall engineering approach was defined.

The study identified a number of significant issues that pertain to the use of directed energy technology in weapon systems. Technical challenges were defined and potential trade-offs were identified. The specific recommendations of the working group are presented in Section B following.

6. Fiber Optics (Ref. 6)

Requirements for data transmission have increased dramatically in complexity with the rapid infusion of digital integrated circuits and the need to transfer data in real time. With this increase in complexity, the reliability and maintenance problems associated with electronic cables have increased significantly. For example, estimates state that aircraft wiring failures constitute approximately one-third of the total failures in military aircraft. The use of fiber optic technology to eliminate these problems would have a significant effect of the operational availability of all military systems and could result in savings of billions of dollars over the service life of these systems.

Fiber optics technology currently is receiving much attention as a new "high-tech" industry. The transmission of data via optical fibers rapidly is becoming a commercial reality as an option to the transmission media of copper and radio waves. In addition, the use of fiber optics for sensing also provides a breakthrough in the sensitive measurement of physical phenomena. The use of this technology for both data transmission and sensing has not received widespread use in military systems.

Since fiber optics offer a variety of advantages to military equipment, a technology working group was established to study the benefits to be obtained from fiber optic technology. This group concentrated on two issues:

1. What is the potential contribution of fiber optics to operational readiness?

2. Where do fiber optics contributions fit into the overall integration of the new technologies?

It identified the improvements in operational readiness possible in the utilization of fiber optics in military systems. The methodology included case studies on the application of fiber optics in the military and commercial sectors to date, the detailed assessment of fiber optics components and systems, and an analysis of the technical management needs, financial implications, and political impediments to the use of this technology. The key applications that were examined were:

1. Fiber Optics for high speed logic circuits.
2. Fiber Optics in security applications.
3. Fiber Optics for improved reliability, survivability, shielding effectiveness and safety.
4. Fiber Optics in combination with optical sensor technology for advanced sensor systems.
5. Fiber Optics as a tool for weapon system integration.
6. Fiber Optics as an architectural tool.

As a result of the study the group concluded that the use of fiber optics can improve the operational readiness of military systems based on the results of military and commercial applications. It also concluded that R&M improvements and life-cycle cost reductions have been demonstrated in fiber optic telecommunication systems. It was found that the military sector neither used fiber optic technology widely nor made a commitment to develop and use the technology. The working group provided recommendations oriented toward the creation of a DoD-wide program to ensure that fiber optics becomes the standard data communications medium in military systems. This program would encompass developmental efforts, standardization of fiber optic components, and logistics support efforts. Specific recommendations are described in Section B following.

7. Integrated Systems of Manufacture (Ref. 7)

One of the principle means of implementing the computer-aided manufacturing is through the use of robots. It is the most commonly understood use of robots. However, robots also may be used to assist in maintenance.

A technology working group was established to focus on existing applications of robotics in industry as well as emerging applications which may have immediate and important implications for DoD performance and readiness. Primary emphasis was given to the following aspects of robotics:

- Sensor Technology
- Computer
- Electronics
- Mechanical Engineering
- Other physical sciences
- Energy
- Communications.

The group was able to define the following issues in the application of robots:

Robots in service and maintenance
Robots in small lot production
Universal robotics language (software)
Robotics diagnostic systems.

As a result of its study of the use of robots, the group developed several recommendations oriented toward the improved design, procurement, maintenance and application of robots.

8. Manpower, Personnel and Training (Ref. 8)

Early in the study, it was recognized that manpower, personnel and training are important considerations in the readiness equation. Human error not only affects overall system performance but also affects system maintainability. The subject has its own technologies for testing, job design and training. It uses a variety of other technologies related to the computer and electronic graphics fields and is in a constant state of change to remain relevant to the changes in other technologies.

To address this technology, a working group composed of government and industry representatives was established. It was subdivided into three subsets: human engineering, manpower, and personnel, training and training technology. Other topics such as biomedical support and test and evaluation were not overlooked but rather received a much lower degree of emphasis. For each of the three major areas, the group studied the existing practices and drew upon recent studies to assist their efforts.

The findings of the group showed a definite need for the DoD and industry to improve the employment of manpower, personnel and training technology. These resulted in recommendations by the group for improving design specifications, design methods and analysis techniques for human engineering. For manpower and personnel, the recommendations concentrated on improving analysis and management tools. In the training and training technology area, the recommendations encouraged preparation to use the results of the 1982 Defense Science Board Summer Study on Training and Training Technology. The findings are discussed in more detail in Section B following.

9. Mechanical Systems Condition Monitoring (Ref. 9)

The Mechanical Systems Condition Monitoring working group concentrated on the key technology area of condition monitoring of the major mechanical portions of weapon systems, turbine engine and power transmissions, and formulated specific reliability and maintainability improvement proposals. Because of the potential for high returns on investment, turbine engine condition monitoring and engine transmission failure detection and prognosis technology were the major areas of interest. This group addressed three facets of the subject:

1. Determination of current technology to current program marriages where near-term high return improvement could be made with modest investment.

2. Determination of developmental or emerging technologies that, if expeditiously developed and applied, could provide significant improvements in readiness.

3. Use of case studies to determine programmatic changes that could result in significant readiness improvements.

The group found that the application of filtration and diagnostic techniques could improve helicopter fleet readiness significantly. It also found that application of the trial A-7E monitoring system to all A-7Es and F-14s could improve aircraft readiness significantly. The group also recommended exploration of new technology and programmatic changes, which are discussed in more detail in the next section.

10. Nondestructive Evaluation (Ref. 10)

Nondestructive evaluation (NDE) methods have been valuable tools for quality control and maintenance for decades. During the past several years, they have provided an opportunity to improve readiness. New concepts, however, are required to properly evaluate the increasingly complex DoD systems with their requirements for high reliability under adverse conditions and after long periods of storage.

The working group for NDE first examined a number of related studies that included work by the AIA, the Q-Tech Committee, the Technical Cooperation Program and the JTCG. The group then examined the role of NDE and particular NDE techniques for the following platforms: tanks, fixed-wing aircraft, rotary-wing aircraft, submarines, armaments. A survey of new and emerging NDE was conducted and generic problem areas and opportunities were identified in the following areas: data bases, reference documentation, manpower and personnel, management. For each of these areas, a set of specific recommendations was developed. These recommendations are discussed in more detail in Section B following.

11. Operational Software (Ref. 11)

Operational software was examined from several aspects. It was examined as an operational component of the system, as a means for compensating for failures, as a tool for developing reliable components and as a means of supporting on-line or field diagnostics and test. To accomplish this, the working group built on the STARS material. To amplify this, extensive literature searches on fault tolerance were conducted. The group was supported by Service, industry and academic experts.

The evolution of software importance and how pervasively computers have penetrated modern land, sea and air systems was examined. Software adaptability was described and contrast between hardware and software reliability and maintainability was drawn. The actions required to define the software development process, including both techniques and standard components, were defined. Fault-tolerant and software intensive systems were analyzed. Finally, acquisition considerations were described with emphasis on the full-scale development phase.

The Operational Software working group developed short-term recommendations that addressed acquisition practices, professional training and technology infusion. The group also provided long-term recommendations that addressed adjustments to the STARS program.

12. Electronic Packaging and Interconnection (Ref. 12)

Electronic packaging in this study was defined as the essential mechanical product design functions required to convert the proposed design into the final hardware configuration. Included were the following levels of packaging: chip, package, hybrids, printed wiring board, backplane, system interconnections and environmental control systems.

The first step taken was the examination of the present state-of-the-art in electronic packaging and the identification of the various critical packaging technologies. Also examined were the interfaces with the other functional areas that would require careful integration for optimized results. It was concluded that much could be done to improve the existing packaging state-of-the-art with regard to the reliability and maintainability of military electronic systems. The current generation of integrated circuits was found to be much more reliable than the electronic packaging that surrounds them. It was noted that some positive steps, e.g. VHSIC, were being taken.

The second step was the definition of technology and management issues. The focus of the technical aspect of this step was on the quantity and type of interconnection. Trends in the quantity of interconnection and failure rates were examined. The synergism of government and industry technology programs also was examined and major contributions were identified. The roles of standardization and testing methods also were identified.

As a result of the study, a variety of recommendations was put forth. These covered design automation, data collection, improved government coordination and improved military test documentation. They are examined in more detail in Section B following.

13. Power Supplies (Ref. 13)

Power supplies have been a reliability problem in the past and much work is being done to improve their reliability. As electronic systems become more complex, the burden on power supplies will also increase.

A power supply technology working group was established to identify the necessary areas of investment to ensure the availability of reliable and maintainable power supplies over the next decade. This group studied the management and technical issues associated with present power supply design and application. As a result of the study, the group found that the use of warranties, standardization and enforced power system engineering was required in the management area. The group also defined power/current density, component, cooling, and environmental tolerance actions that would enhance power supply performance and ensure compatibility with forthcoming electronic technologies such as VHSIC.

14. Testing Technology (Ref. 14)

Testing technology embraces all weapon system testing related to the maintenance of those systems. It includes test equipment and logistic support of the equipment, including test program sets and calibration of the test equipment itself. Embedded test support includes built-in-test, readiness monitoring and system self-alignment. Two closely related technologies are fault-tolerant design techniques and testability design techniques. Both diagnostic and prognostic techniques are integral parts of both test equipment and embedded test support.

The working group established to study testing technology limited the scope of study to testing technology required to maintain all types of weapon systems. No attempt was made to address development and operation testing or assurance testing such as that done for reliability and maintainability. In performing the study, the working group set the following objectives:

1. Identification of the required technology developments.

2. Estimates of the impact of these developments.

3. Identification of key management actions required to support the development and application of this technology.

4. Preparing a detailed analysis to justify the priorities for this technology.

In conducting the study, the work done by the Joint Logistics Commanders' Panel on Automatic Testing and Joint industry/government panels was examined.

As the result of the study, the Testing Technology working group identified an approach to testing technology that included: (1) development of the technology itself; (2) the tools used to apply this technology in the weapon system acquisition process; (3) appropriate management attention to ensure proper use. An analysis of the benefits and technology payoffs was conducted and several key parameters were evaluated. The conclusions of the group can be summarized as follows:

1. Traditional weapon system reliability and maintainability techniques are no longer satisfactory.

2. Improvements in the technology base are required.

3. Injecting testing technology into weapon systems design must be institutionalized.

4. The management of testing technology requires improvement.

The group provided recommendations based on these conclusions. The recommendations are described more specifically in Section III.

15. VHSIC (Ref. 15)

The VHSIC program is an ongoing technology development program that emphasizes the coupling of integrated circuit technology to complex system development and implementation. One of its foremost objectives is to raise system reliability significantly beyond what more conventional circuitry would allow.

Since VHSIC offered the potential for significant reliability and performance improvement, a technology working group was formed to study the VHSIC technology and development program. This group examined the VHSIC technology, the DoD VHSIC development program and the candidate applications proposed by the armed services. Although is many cases firm data were lacking, the group assembled an analysis of VHSIC reliability. This was based in part on information obtained from the six VHSIC Phase I contractors. The analysis showed that use of VHSIC could improve reliability significantly. It also showed that use of a diagnostics processor could reduce repair time and, therefore, increase system availability. The group also assessed the status of the VHSIC development program and found that it was proceeding satisfactorily. As a result of the study the working group put forth several recommendations oriented primarily to facilitating the use of VHSIC in system development programs.

B. ANALYSIS OF TECHNOLOGY ISSUES

In the preceding section, a digest of the objectives, approaches, findings and recommendations of the technology working groups has been presented. While each of the technology reports has considerable merit on its own, a better understanding of the overall state of technology can be obtained by examining the aggregate of the issues and recommendations raised by the reports.

The issues that face technology can be divided into three parts: technology insertion issues, technology maturation issues, and technology creation issues. "Insertion" issues address what is required to initiate widespread use of an already developed technology. These are primarily management issues in nature, although there are a few technical issues also. "Maturation" issues address the identification of actions required to bring a technology to the point where it can be used widely. These are predominantly technical matters that focus on extending present work in specific technology development projects. Finally, "creation" issues are those that address the initiation of technology development projects that are required to enable future systems to achieve projected performance requirements.

1. Technology Insertion Issues

As stated above, technology insertion issues are those addressing what is required to bring a developed technology into wide use. An "eyeball integration" approach was used to discern that most of the technology insertion issues could be categorized as awareness issues or management issues. Awareness issues derive from well-established technologies that do not have their full capabilities recognized. The Nondestructive Evaluation and Mechanical Systems Condition Monitoring technologies are excellent examples of this. For these and other technologies in similar circumstances, the issues focus on the conduct of demonstration projects to show the full capability of the existing technology. Management issues differ in that the acquisition community generally recognizes the benefits derivable from the existing technology but lacks the motivation to use technology. Therefore, the management issues center about the creation of technology sponsors, organizations, directives, standards and incentives as means for motivating the acquisition community to use the existing technology to the fullest advantage. In the following paragraphs, the technology insertion issues raised by the study working groups are discussed.

2. Technology Maturation Issues

Unlike the technology insertion issues, technology maturation issues raised during our study consisted primarily of the conduct of projects that would "fine-tune" fairly well-developed technology concepts. If any more detailed groupings could be discerned, they were development or demonstration of the technology itself and development of analytical techniques to support development or application of a given technology.

3. Technology Creation Issues

In the past two sections, we have examined the issues that surround the use of existing technology and the issues that face the development of technology to the point of being ready for use. The remaining area of technology that needs discussion is that which pertains to initiating major technological improvements--"technology creation."

Not all of the technologies covered in our study identified creation issues. Indeed, only about one-half of the working groups were able to identify such issues. The issues that were identified consisted primarily of specific projects with few identifiable major research themes. These creation issues are described below.

In the forthcoming paragraphs, each technology area studied is examined relative to the three issues within each technology area, a relative importance is identified as either "primary" or "secondary," as appropriate.

a. Artificial Intelligence

(1) Insertion: The maintenance of modern military systems employs a variety of automation. Built-In-Test (BIT) provides on-line fault detection and some isolation, Automatic Test Equipment (ATE) is indispensable at the intermediate and depot repair stations, and automated maintenance aids and maintenance trainers abound. However, to make significant improvements in maintenance, there must be radical changes in maintenance technology. One of the most promising sources of these changes is the application of Artificial Intelligence techniques.

At the present time, DoD applications of artificial intelligence techniques to maintenance are small, exploratory and uncoordinated. Coordination could be effected by the establishment of a tri-service group under the JLC Automatic Testing Panel or possibly under the JDL Working Group for Artificial Intelligence. This would also serve as an interface to industry. One useful function that this group could perform could be the prohibiting of inflexible sequential test programs.

(2) Maturation: Artificial Intelligence is a newly emerging technology that offers great promise in easing the operation and maintenance burden placed on military personnel by the increasingly complex modern weapon systems. Since it is so new, the primary issue it faces is one of establishing its value in the modern technological environment. To do this, two forms of capability demonstration are required. The first type of

demonstration is one that shows how the application of artificial intelligence can ease the maintenance burden. This can be accomplished by developing maintenance-expert subsystems for current systems in cases where existing automatic test equipment has been inadequate. The second form of capability demonstration is one in which artificial intelligence is applied to the design of new technologies. For example, artificial intelligence technology could be applied to the design of VLSI and VHSIC to design in testability and fault tolerance.

A lesser issue confronting artificial intelligence technology is the need to establish guidelines for computer languages associated with artificial intelligence. At first, artificial intelligence efforts should be allowed to use any convenient language with the constraint that any test programs for external use would be written in Atlas. This policy, in lieu of specifying any particular language, will accelerate the maturity of artificial intelligence by at least two years.

(3) Creation: Technological developments in this area center around the contribution of artificial intelligence to maintenance. The projects that are required are: versatile maintenance expert systems (an expansion of a maturity item); development of a technique that automatically creates system specific data for use in maintenance expert systems; "smart" BIT to lessen the likelihood of false alarms; the development of artificial intelligence systems for automatic generation of test programs.

b. Cabling and Connectors

(1) Insertion: Connectors and Cabling are the elements that integrate electronic and electrical systems. They perform this integration at all levels of systems and exist in a great variety of types, sizes and functions. Their role on system

performance becomes more critical as systems become more complex because the increased complexity generally requires more parts and, therefore, more connections.

The principal problem facing connector and cabling technology today is a lack of specific connector failure data from users. These data are needed to differentiate between inherent design defects or improper applications. Management feedback of these data to system and connector designers would enhance the ability of the connector industry to produce a better product and provide better design guidelines for proper connector application.

(2) Maturation: The maturity of issues for connector and cabling technology is limited to the establishment of a tri-Service program that would examine causes of connector and cabling failure in the field and develop either specific corrective actions or major technological improvements.

c. Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM)

(1) Insertion: In this study, Computer-Aided Design and Manufacturing (CAD/CAM) is considered in its very broadest definition from establishment of an early design concept, through detailed design development and production, to a final product. It covers the broad spectrum of computer-aided technologies such as computer-aided engineering, computer-aided design or drafting, computer-aided manufacturing, numerical control and computer integrated manufacturing.

(2) Maturation: There are now several programs under way for the maturation of computer-aided design and manufacturing (CAD/CAM) technology. Consequently, the primary issue for rapid CAD/CAM maturity is one of accelerating these programs in order to conduct critical capability demonstrations. Programs that should be accelerated and/or expanded are: the NSAA IPAD project; the NBS IGES working groups; the Air Force I-CAM project; development of generic geometry manipulation modules starting with CAM-I

interface specifications and geometry specifications. Projects that develop compatibility among the several communication protocols and the development of contractor data base systems should be strongly encouraged to control the data flow between different distributed data bases. These efforts should be accompanied by the establishment of an integrated CAD/CAM system at major defense contractors to serve as a demonstration of CAD/CAM capability.

(3) Creation: The primary technology creation issues for CAD/CAM techhology are the development of:

- A generic three-dimensional geometry model or "engine".
- A generic interface module.
- Systems to control the flow of data between distributed data bases of various CAD/CAM subsets.
- Modules to provide manufacturing constraints and related data in real-time during the engineering design process which would provide a feedback loop to design from manufacturing.

d. Structural Composites

(1) Insertion: Structural composites offer many readiness-related benefits to present and future military systems. They allow performance improvements by reducing the fraction of the system weight required for the structure. Organic matrix composites eliminate many of the corrosion problems that have been a major maintenance expense in previous systems. Furthermore, composite laminates have excellent durability (fatigue life) and extend allowable system life beyond that allowed by comparable metal structures.

Significant advances have been made in composite technology in recent years. In the aerospace industry, composites are being used increasingly for major aircraft, spacecraft, and missile structural components (Ref. Fig. 7). Composite use in aircraft is approaching the point where it could make up 50-70 percent of the structure of modern tactical aircraft.

Composite manufacture has progressed significantly. There is an increasing use of automatic composite lay-up methods as opposed to the earlier manual lay-up techniques. The number of successful demonstrations, the improved manufacturing techniques, and the increasing understanding of the physical properties of composite materials create an available technology base with a significant potential for improving system performance at lower acquisition cost.

The primary remaining issue confronting the use of composite technology in current military systems is achievement of a practical balance between vehicle performance and R&M requirements. Previous applications have been motivated primarily by the desire for minimum-weight structures with little emphasis on reliability and maintainability. Explicit, quantified R&M requirements should be included in proper balance with vehicle performance during the preparations of vehicle specifications.

Two needs must be addressed as composites are applied to a greater degree. There is a lack of contract incentives that encourages the use of composites when advantageous in terms of cost, performance, and maintenance. More importantly, there is a need to enhance the technical data base for composites by the collection of data on maintenance actions involving composites and comparable metal structural components. These data would be useful for developing application and maintenance guidelines and for differentiating the benefits of composites from those of metal in comparable structural applications.

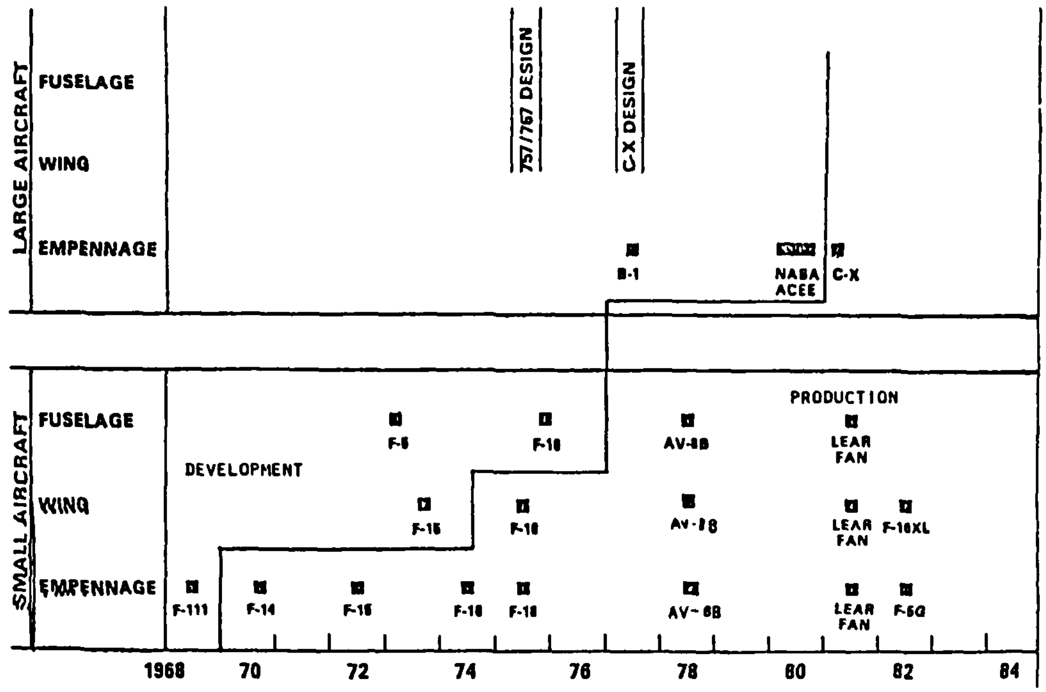


FIGURE 7. *Composites Usage in Aircraft*

(2) Maturation: Major R&M issues associated with bringing structural composite technology to full maturity are associated with damage tolerance and maintenance; e.g., inspection and repair.

There is a need to establish design procedures which apply the developing understanding of damage tolerance in these laminated structures. Composites exhibit damage characteristics very different from those of metal structures. The damage mechanisms and techniques to enhance damage tolerance are not completely understood.

As composites see broader usage in large transport aircraft, ship hulls and superstructure and armored ground vehicles, the specific R&M requirements and damage tolerance design concepts will not necessarily be identical to those applied to previous designs of tactical aircraft and missiles. There is a need to establish programs with these applications in mind to address the specific R&M issues in these applications.

The issue of improved maintenance for composites is composed of several interrelated needs. There is the need to design for ease of visual inspection and to upgrade depot level NDE equipment for large area, automated inspection. There is a need to develop training in the handling and repair of composites. Improved in-process control and inspection during the manufacture of composites is also important.

A secondary issue associated with the maturity of composites is the inclusion of R&M requirements in the system performance specifications in a sufficiently quantitative manner so that trade-offs can be made in the initial design phase.

(3) Creation: For composites, the focus of development for R&M should be on the damage and maintenance aspects. Attention to battle damage should be given high priority in the form of projects that develop battle damage tolerant design concepts and battle damage repair technology. Material improvements such as tougher matrices, concepts for the through-thickness reinforcement of laminates, and repair adhesives which can be stored at room temperature are needed. Related projects of importance to R&M include NDE evaluation of bonded and bolted joints, automated large area inspection technology, moisture content measurement during depot repair, and the development of repair procedures for emerging organic-, metal-, and ceramic-composite materials. A prioritized list of these technology programs is presented in the Working Group Report.

e. Directed Energy

(1) Maturation: Directed energy technology is in its infancy. Although addressed through a variety of DARPA and Armed Service programs for several years, it has only recently become a highly visible subject both in terms of work done by the USSR and by the U.S.

Several important and directly related issues exist with respect to sustained performance and reasonable maintenance of a directed energy system. The scaling and packaging of weapon system designs for specific application, the impact of prevailing atmospheric, meteorological and platform environmental conditions on system performance, and the potential neutralizing effects of countermeasures all represent technical challenges that must be addressed adequately in order to obtain satisfactory directed energy weapon systems.

The technology that is envisioned for directed energy weapon systems is a mixture of conventional (mature) technologies and a new state-of-the-art (see Fig. 8). Given the present state of high energy technology, however, considerable risk would be encountered in the development of a weapon system at this time. It is for this reason that new and emerging support technologies should be exploited for applications that may offer potential risk reductions that would permit an earlier deployment.

Although most of the issues surrounding directed energy technology are "creation" issues, several maturity issues can be identified. These are associated closely with existing weapon system technology and the maturation of the electronics and materials technologies. For directed energy weapon control, the impacts of computer-aided design, VLSI/VHSIC and fiber optic technologies need analysis. Improvements and demonstrations of the sensitivity and reliability of detector arrays need to be made for target acquisition, weapon pointing and tracking. The laser technology itself requires additional laboratory assessments of device operation in order to bring it from a laboratory environment. Existing computer-aided design and manufacturing technology needs to be applied to explore and develop subsystem designs. Also, the employment of composites should be studied as a means of reducing the weight and volume of directed energy devices. There are two maturity issues associated with the optics required for directed energy systems: the need to develop techniques for performing maintenance and improving the quality of mirror reflective coatings.

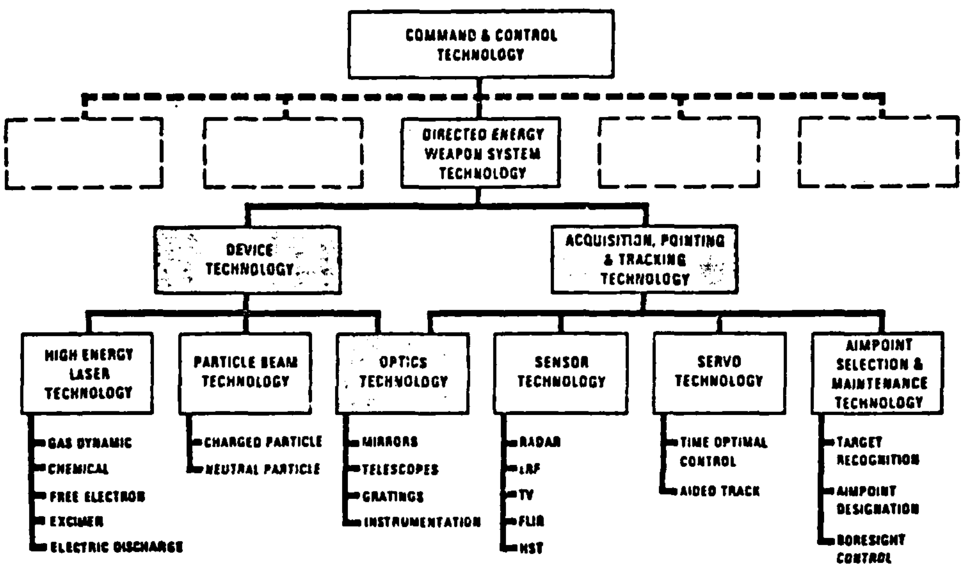


FIGURE 8. Directed Energy Weapon Systems Technology

(2) Creation: As stated earlier, directed energy technology requires a great deal of research to evolve a weapon system suitable for field use. Projects that are required are: development of fault-tolerant or self-healing designs, especially for space-based applications; improvements in pulsed-power supply technology to support application in weight- and volume-critical situations; development of technologies that provide common beam paths for the laser beam, the target return beam, and the system alignment beam; development of improved mirror heat exchangers; development and demonstration of high-speed active tilt mirrors; development of diagnostic and prognostic techniques, especially phase meters, for the unique directed energy components; development of very lightweight, high-strength materials with which to fabricate larger optical apertures and very-high-speed active optics; development of high-resolution deformable mirrors for short wavelength systems; development of polishing techniques for short-wavelength mirror surfaces.

f. Fiber Optics

(1) Insertion: Fiber Optics technology is currently receiving much attention as a new "high-tech" industry. The transmission of data via optical fibers represents a technological leap forward, a breakthrough, in data transmission. Fiber optics are rapidly becoming a commercial reality as an alternative to the transmission media of copper and radio waves. The use of fiber optics for sensing also provides a breakthrough in the making of highly sensitive measurements of physical phenomena. This technology, however, has not received widespread use in military systems.

There are several primary issues that affect the use of currently available fiber optic technology in military systems. The first is one of awareness. Although many in the DoD development and acquisition communities are aware that this technology is evolving, they lack an adequate base of demonstration projects to serve as a foundation for application in existing systems or those presently under development. These demonstrations are needed to pinpoint deficiencies or confirm the adequacy of the existing technology. Significant areas in which demonstrations should be continued are: high speed data bus, wavelength division multiplex, fiber optics sensor systems, and optically-guided weapons. The second primary issue is one of establishing a framework for the use of fiber optic components. If fiber optic technology is to be used widely, a "Qualified Parts List" should be established. The absence of tested and qualified components has become a severe stumbling block since component manufacturers do not consider the DoD as a significant market. A variety of actions are associated with addressing this problem. They include part testing, development of specifications and standards, and establishment and maintenance of the Qualified Parts List. Some part testing is done now, but this is not well-coordinated from a DoD point of view. Finally, the issue of logistics support of applied fiber optics technology must be addressed. Appropriate built-in-test requirements, test and repair equipment and maintenance training and procedures must be developed. Demonstration projects provide excellent opportunities for developing the necessary logistics support for fiber optic technology.

The secondary issue that applies to the use of current fiber optic technology is the establishment of procedures that report wire and cable maintenance. These actions are generally not reported. Proper reporting would provide the basis for assessment of the problems related to wire and cable maintenance and the contribution that fiber optics can make to reduce these failures.

(2) Maturation: A sustained level of technology base funding is the principal issue affecting the maturation of fiber optic technology and its widespread utilization in military systems. The DoD investment to date has helped spawn the fiber optic component industry but has produced only a limited selection of components capable of meeting the needs of the full military environment. Sustained funding is required at the technology base to assure multiple sources for militarized fiber optic components.

g. Integrated Systems of Manufacture

(1) Insertion: In this study, the treatment of Integrated Systems of Manufacture focused on Robotics. At the present time, industrial robots do not have the full capability to replace their human counterparts. They are applied most effectively in the performance of relatively simple, highly structured tasks. One should not be misled, however, by the limitations of current industrial robots. There is a great deal of research and development being conducted to expand the capability and intelligence of robots. Improved optical, tactical and acoustic sensors are being developed; more powerful and more effective grippers are being created; significant improvements are being made in robot control software. All of these offer the promise of an effective robotic technology to support the manufacture of military systems in the near future.

The principal issue facing robotic technology is one of awareness. There is a general lack of understanding of how beneficial use of robotic technology can be in selected applications. There needs to be a focus on the establishment of procurement policies that encourage consideration of robotics for manufacturing.

(2) Maturation: The central maturity issue for this technology is the evaluation of the design, support, and manufacture of robotic equipment. One specific area that should be studied is robot downtime. This information is extremely important to the maturation of robotic technology because insertion of robotics frequently excludes fully effective backup capabilities in the event of robot failure.

h. Manpower, Personnel and Training

(1) Insertion: Manpower, Personnel and Training play an important role in system performance and readiness, not only from the maintenance and maintainability standpoint, but also as a human error input into system operation. Human error impacts both operator tasks and maintenance tasks and, therefore, needs to be considered in system specification and design.

In this study, the topic of Manpower, Personnel and Training is subdivided into three distinct areas: human engineering; manpower and personnel; training and training technology. There are other aspects of manpower, personnel and training that could be considered, but the above three offer the greatest potential return on investment. "Human engineering" is defined as the integration of job function design with hardware and software engineering at the system level. "Manpower and personnel" addresses the manpower and personnel data bases in analytical and projection terms. It provides inputs to training and imposes constraints on job design. "Training and training technology" takes what is known about available personnel and designs a learning system to accomplish required performance capabilities.

There is an ample quantity of manpower, personnel and training technology available at the present time. The results of this study indicate that the technology is not currently used to the fullest. The primary issue surrounding this lack of use is that there are inadequate management motivations for the consideration of manpower, personnel and training in system development and design. The key to correcting this situation is to establish the proper management motivation to include human engineering, manpower, personnel and training requirements into procurement documents such as RFPs, source selection criteria and contracts.

A second major issue in the use of available technology is the implementation of the recommendations of the 1982 Defense Science Board Summer Study on Training and Training Technology. These

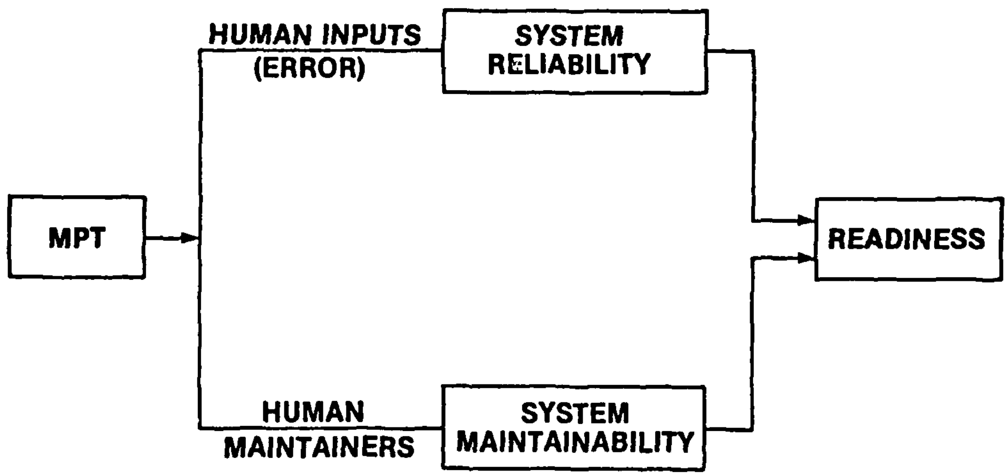


FIGURE 9. Impact on Readiness

recommendations are oriented toward the development and application of new technologies for effective training. The emphasis in these recommendations is on the use of advanced electronics to provide highly realistic, easy-to-use training devices.

A lesser issue that is closely related to the first is the inadequate use of existing analysis methods, mock-ups and manpower forecasting methods. The increased use of analytical tools can provide earlier, more accurate data to material developers at a time when the system design has sufficient flexibility to accommodate it. There is strong evidence that current practices provide information that is either too amorphous for engineering consideration or too late for inclusion in the design without extensive increases in cost or delays in schedule.

(2) Maturation: The current scope of manpower and training technology includes several analytical techniques that require additional development in order to fulfill their potential. In particular, there is a need to complete the development of mission analysis techniques so that they have the ability to address operational requirements pertaining to system maintenance, to determine the sensitivity of man-machine system performance to variations in mission, to construct logical and realistic scenarios and to provide other engineering disciplines with useful engineering data. There is also a need to refine existing maintenance technician performance prediction techniques so that system maintenance concepts, maintenance procedures, and physical configuration can be evaluated. Finally, in order to prevent the projected manpower shortages from having an adverse impact on the readiness of military systems, manpower forecasting techniques need to be refined. Once the existing techniques are refined, they will be able to identify high-payoff embedded operation and maintenance requirements for new systems.

A secondary issue that applies to manpower and training is a need to increase the number of demonstrations that illustrate the benefits that can be provided by applying current or emerging training technology, such as voice recognition and synthesis and interactive displays. To conduct these demonstrations, program managers and laboratories need to work together more closely to select, plan and conduct such demonstrations.

(3) Creation: For this area, the need exists for the development or extension of several significant areas of analysis. Techniques need to be developed for conducting human factors engineering design trade-offs and obtaining human factors engineering data. There is also a need to develop models that predict the impact of system design on manpower and training. Finally, there is a need to develop technologies that apply to readiness critical training.

i. Mechanical Systems Condition Monitoring

(1) Insertion: "Mechanical Systems Condition Monitoring" in this study combines measurement of performance and the detection of damage with the possibilities of prognostics to eliminate unnecessary and premature removals. There is a proven technology base and a variety of successful demonstrations that indicate that significant reliability and readiness improvements can be obtained by application of the technology to current or future systems.

Propulsion, transmission and structural components are significant contributors to performance and readiness of weapon systems and platforms. As a consequence, these provide the focal points for the study of Mechanical Systems Condition Monitoring. The focus on propulsion and transmission allows the examination of technologies with the potential for a wide range of applications on Army, Navy and Air Force systems and greatly increases the utility of the resultant recommendations.

Hardware Approach

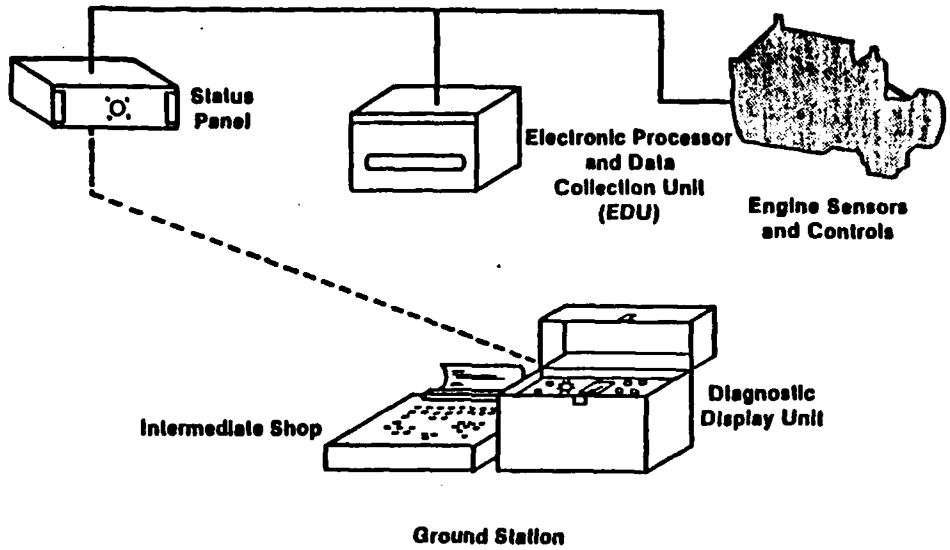


FIGURE 10. Engine Monitoring System (EMS)

The primary issue in this area is one of awareness of the capabilities that the current technology can provide. This lack of awareness can be alleviated by conducting jet engine monitoring demonstrations on several major combat aircraft such as the F-16 and the F-14. Another constructive demonstration could be conducted on the M-1 tank. Engine diagnostic technology capabilities could be illustrated with a demonstration on the F-15 and F-16 engines. Finally, structural condition monitoring could be demonstrated on the T-38 aircraft. This series of demonstrations would provide high visibility examples of the capabilities of the current condition monitoring technology.

A secondary issue associated with condition monitoring is the cross-fertilization of ideas among the Services. For example, an acoustic leak valve detector developed by the Navy could be used by the other Services as well.

(2) Maturation: Unlike some of the other technologies, the issues in mechanical systems condition monitoring center around the development of the following specific condition monitoring technologies: techniques for the electrostatic monitoring of engines, ultrasonic wear particle sensors, advanced engine diagnostic technology, integrated shipboard machinery monitoring, integrated transmission monitoring and structural monitor. These technologies need refinement, demonstration and integration with automatic data processing equipment. Preliminary demonstrations have shown that each of these technologies has the potential to correct some of the defects in the existing condition monitoring technology. For example, the late consideration of health monitoring in mechanical systems results in additional costs, weight penalties and some unnecessary false alarms. If properly incorporated in the initial design, these devices can mature with the system design, will minimize the weight penalty and can reduce costs of the initial subsystem testing and manufacturing validation phase as well as the operational support phase.

Additionally, technology developed and proven on one program has often been "re-invented" on the next, rather than translated. Low risk and cost avoidance benefits are therefore missed. Two such high-payoff technology areas ready for translation are engine condition monitoring with airframe structural fatigue tracking capability added and advanced engine and transmission lube oil diagnostics and fine filtration. The former has been demonstrated on the F-7, F-18 and A-10 aircraft and can be beneficially translated to the F-14. The latter has been demonstrated on the UH-1 and can be beneficially translated to the UH-60, CH-47, and AH-64.

(3) Creation: For this technology, there are several specific developments that are required: a fiber optic bearing monitor, a high temperature probe for rotating shaft diagnostics, and engine-mounted vibration analyzer, and vibration analysis techniques for gearboxes.

j. Nondestructive Evaluation

(1) Insertion: Nondestructive Evaluation (NDE) methods have been valuable tools for quality control and maintenance for some decades. During the past several years, work with these methods has shown outstanding promise for reducing maintenance costs, maintenance time, manpower requirements, and the elimination of operational hazards.

In this study, the potential benefits from these methods are evaluated for several major classes of platforms: tanks, fixed-wing aircraft, rotary-wing aircraft, submarines, armaments. Each of these platforms has a body of maintenance data that serves as the basis for evaluating specific benefits obtained from various NDE technologies as they might be applied to systems now in development or approaching deployment.

There are several major issues that affect the insertion of existing or near-term NDE technology. The first of these is the inadequacy of present methods of selecting and training NDE personnel. Qualifications for NDE trainees need to be established and need to reflect the expansion toward automated or computerized NDE. Trainees need to be given "hands-on" experience with the latest state-of-the-art inspection equipment, complete with advanced signal processing and data reduction equipment. This updated training needs to be accompanied by periodic recertification of NDE personnel. The second major issue is that of management and coordination of NDE technology applications within the DoD. There is a need to establish a central OSD authority for NDE and other performance monitoring activities. This authority should be able to address RDT&E, manpower, logistics and other elements that pertain to NDE. The present application of NDE within the DoD could be coordinated through the development and enforcement of a DoD-wide inspection manual and through the establishment of standards for generic areas of NDE. Wider use of NDE needs to be motivated through the use of contract incentives that address NDE and reliability-centered maintenance. The third major issue associated with the insertion of NDE technology is the creation of NDE advisory boards. With OSD support, one of these boards should be created for each major weapon system. An NDE advisory board would be in a position to advise designers, production engineers and maintenance planners and to evaluate system performance with the intent of determining the need for corrective action.

The secondary issue pertaining to the application of existing NDE technology is the lack of NDE-related data from deployed systems. Present field service data systems do not provide such data; hence, there is a limited data base upon from which to determine the effectiveness of specific NDE applications. It would be useful to have data reported from field service organizations to both the government and the contractors. The latter are hampered in developing effective corrective actions by this lack of data. It is anticipated that the introduction of computerized data collection and reduction technology will reduce or eliminate many of the obstacles to developing this field service data.

(2) Maturation: The primary thrusts recommended for nondestructive evaluation technology consist of improving existing equipment and continuing the development of several specific technologies. The improvement of existing nondestructive evaluation and nondestructive inspection equipment would consist of introducing currently available advanced technologies such as computerized ultrasonic systems and ruggedized X-ray systems

into the field for demonstration of effectiveness and ease of use. There could be several applications to aircraft inspections and the introduction of embedded nondestructive evaluation equipment into inaccessible parts of submarines. The second significant thrust is the continued development of advanced evaluation technologies such as automated ultrasonic inspection techniques for composites, automated nondestructive testing software, X-ray diffraction techniques for measuring residual stresses in torsion bars and track pins, and advanced weld monitoring techniques.

A matter of secondary importance is the development of a computerized data analysis technique for determining trends in the application of nondestructive evaluation technology in maintenance. This trend data would be useful in determining potential problem areas in the use of nondestructive evaluation techniques.

(3) Creation: The required developments for non-destructive evaluation technology consist of major initiatives as well as specific technical projects. Major initiatives are needed for nondestructive evaluation of corrosion, electronics and composites. Specific projects that are required include: filmless radiography, automated inspection systems, an N-ray tube for composite inspection, embedded acoustic sensors, automated X-ray inspection, automatic Compton scattering inspection, photothermal imaging for coating inspection, NMR imaging, ultrasound acoustic imaging techniques, Mossbauer residual stress measurement techniques and real-time radiography.

k. Operational Software

(1) Insertion: Little needs to be said to emphasize the rapid rate of growth of software in modern military systems. Computers and their software are being used increasingly in military systems to meet increasingly sophisticated and varied threats. The complexity of the software associated with military

200/3-39

systems frequently is so extreme that the cost of software development often approaches or exceeds the cost of hardware development. In recognition of the technical and fiscal importance of software, the DoD has initiated a major initiative entitled "Software Technology for Adaptable and Reliable Systems (STARS)." This effort is aimed at producing integrated and automated software design tools for realtime computers.

There are two major issues that are associated with the use of software in current or near-future military systems: the need for acquisition guidelines and software engineering training. The guidelines are partially existent in the form of a military standard and a military specification on software development and software quality assurance, respectively. However, there is a consensus that they are being rendered obsolescent by the rapid advance of software technology. Training is required because program managers and, often, systems engineers underestimate the difficulty associated with developing and maintaining adequate system software.

The requirements for built-in software for on-condition weapon system health monitoring (performance capability) and diagnostics have not been well specified and coordinated in conjunction with the prime operational software. This leads to lower overall weapon system readiness rates and sometimes compatibility problems between operational software and test software.

(2) Maturation: The present mechanism for software maturation within the DoD is the previously described STARS program. Within that program, three technical issues need to be addressed: error classification, suitable reliability models for software intensive systems and the software itself and studies of fault tolerant system and software architectures. Error classification is significant because the introduction of software creates the possibility of many degrees of impact on system performance. As a consequence, one hears the terms "error," "fault," and "failure" associated with improper system operation due to software. Studies

are required to identify the characteristics of each type of event and to establish frequency distributions and causes. Software reliability models have been a subject of debate because the concept of software reliability has not been defined adequately, if accepted at all. Refinements in software reliability concepts and models should be conducted in close association with the above described software event studies.

RELIABILITY:

	ENVIRONMENT MALFUNCTION	WEAR & TEAR	DESIGN/PRODUCTION FAULT
H/W	X	(X)	X
S/W	X		(X)

MTBF: RESULTS OF PHYSICS FAILURE VS. FAULTS & USE PATTERNS

MAINTAINABILITY:

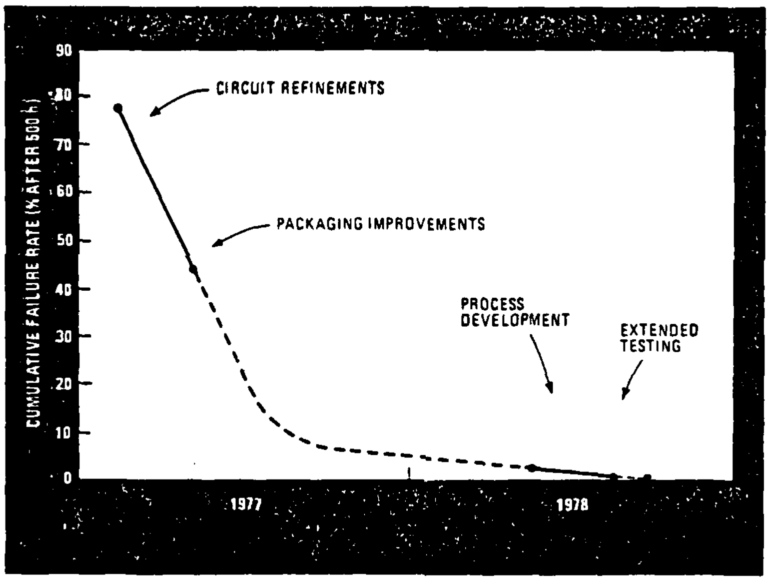
	REPAIR	RECURRENCE
H/W	REPLACE/REPAIR COMPONENT	WILL FAIL AGAIN IN TIME
S/W	REDESIGN & RECODE COMPONENT	PROBABLY WILL NOT FAIL THE SAME WAY AGAIN

MTTR: WELL-DEFINED PER COMPONENT VS. RANGE OF POSSIBILITES

FIGURE 11. Hardware Versus Software

1. Electronic Packaging and Interconnection

(1) Insertion: Electronic Packaging and Interconnection is the "glue" that holds a system together and allows it to function properly. Although packaging has made great advances in the recent past and promises to make similar advances in the near future (see Fig. 12), it is not as reliable as the integrated circuits it frequently surrounds. The most significant problem that packaging must address is the dissipation of heat from microcircuits. This particular problem will become more severe as microcircuit density increases.



Learning curve. Over the two-year development period from 1977 through 1978, 40-pin plastic-packaged Bidfet ICs showed a tenfold decrease in failure rate. The primary improvements responsible were in packaging and circuit refinements.

FIGURE 12. Packaging Improvements

As in the case of testing technology, the employment of standardized packaging techniques lacks a substantive management framework. Two steps that will correct this are: the establishment of a DoD focal point to coordinate the government packaging and interconnection programs with commercial technology research; the establishment of a joint DoD-commercial task force to provide guidance on the application of various packaging technologies and to develop or upgrade military packaging standards to either correct known deficiencies or prepare for the types of packaging that will be accompanying new microcircuit technologies.

(2) Maturation: The maturation issue identified for electronic packaging and interconnection technology is associated closely with the development of VHSIC. That issue is one of expanding the capability of the VHSIC Integrated Design Automation Program to analyze and optimize VHSIC chip packaging for a given system application. At the present time, there is no task associated with the VHSIC program. Therefore, a new task would require initiation to establish this capability. Associated with the VHSIC packaging design capability is the need to revise DoD electronics test documents, such as MIL-STD-883, to accommodate the new VLSI and VHSIC technologies.

The need for improved data on electronics failures related to packaging and interconnection is a secondary issue. These data are needed to determine the distribution of failure modes, identify the causative factors, and provide a basis for the consideration of new technologies such as VHSIC and Fiber Optics.

m. Power Supplies

(1) Insertion: Power Supplies have been a readiness problem both past and present. Part of the problem has been the relegation of power supply design to the later stages of system development. Power supply designers frequently complain that their specifications resemble the "odds and ends" of thermal and spatial budgets and some very uncoordinated electrical requirements. A few demonstration projects and design guidance documents have shown that power supply design can be improved with the technology available today. As electronic systems become more complex, the burden on the power supplies will also increase. It is imperative that power supply design be advanced to allow it to keep pace with other advances in electronics such as VHSIC.

The primary technology insertion issue facing current power supply technology is the lack of management attention to power supplies and power subsystems in general. Three areas require special attention: use of warranties; power supply standardization; power system engineering. The intent of warranties, which could be based on maintenance services, is to secure continued levels of power supply reliability through rewards and penalties based on performance (i.e., incentives). At the present time, warranties are not widely used and management guidance of their use is lacking. Guidance and training will be required for program managers to be able to use power supply warranties effectively. The second area, standardization, provides a good vehicle for amortizing the time, effort and expense of high quality power supply design over a larger market. Standardization also eases many system design requirements. The power system engineering area requires management functions as well as technical disciplines. It involves government/industry coordination of power supply information, including anticipated needs and developments. It also involves establishing a point of knowledgeable authority and responsibility for power system integration in each new system development.

(2) Maturation: There are two major thrusts in development that are required to prepare power supply technology for the demands of forthcoming electronic technologies such as VHSIC: improvement in heat dissipation and improvement in resistance to hostile environmental factors such as electromagnetic pulse and radiation.

At the present time, inadequate management of heat dissipation is a major cause of power supply failures. The increasing density of electronic functional elements creates an increase in required power supply thermal density which aggravates the heat dissipation problem. There is a need to develop isolated semiconductor junctions to alleviate EMI problems while maintaining or improving thermal resistance. As a consequence of this trend, there is a need to improve the heat dissipation capabilities of power supplies. Advanced cooling technologies (phase-change) should be developed.

The second major developmental thrust for power supplies is the development of power supply designs that will accommodate mission requirements such as built-in-test, radiation hardening, and electromagnetic pulse. These requirements are forcing increases in electronic function density accompanied by requirements to increase power supply density. There are several specific technological developments that are required to respond to this situation. The effects of changing threats and system requirements need to be evaluated by a joint DoD-industry group for their impact on power supply design. For example, the effect of composites on electromagnetic interference requires study and eventual translation into power supply design requirements. A similar requirement exists for the effects of electromagnetic pulse, radiation hardening and directed energy requirements.

(3) Creation: There is also a need to develop power supply designs that meet the anticipated need for increased power at high current densities. There is also a need to develop high-efficiency, low-voltage components for use with VHSIC. This can be seen clearly in Fig. 13.

Present \ Future	Ship	Air	Ground	Missile
Air Cooled	1.5-6 / .5-2	3-15 / 1-5	1.5-6 / .5-2	N.A. / N.A.
Conduction Cooled	3-15 / 1-5	6-13 / 1-6	3-15 / 1-5	6-24 / 2-8

FIGURE 13. Estimated Power Supply Density (Low Voltage) Output Watts/Cubic Inch

n. <u>Testing Technology</u>

(1) <u>Insertion:</u> "Testing Technology", as we have defined it in this study, applies to all weapon system testing needs (e.g., electronics, avionics, propulsion, machinery) that relate to the maintenance of those systems. It includes test equipment, test programs for that equipment, and calibration of the equipment. It also includes embedded test support such as built-in-test, readiness monitoring and system self-alignment. There are also two systems design considerations that relate to testing technology: fault-tolerant design techniques and testability design

techniques. The sole testing technology insertion issue is one of establishing a framework for the incorporation of testing technology into near-term system development programs. Rapid advances in system complexity and testing technology have reduced the effectiveness of conventional reliability and maintainability design techniques. System testability as a discipline needs to be incorporated into the system design process. The design discipline needs to be supported by a much more effective management system. At the present time, responsibility for testing technology is fractionated within the OSD and within the Services. The Services each have designated focal points but often lack funding control and, hence, their effectiveness is diluted. Industry exhibits a similar lack of attention to testing technology in IR&D, where like DoD RDT&E, funding is significantly lower than the level required to develop testing technology and use it to the fullest advantage. In addition to the lack of funds, there is a need to update guidance documents, directives, specifications, standards, data bases and training courses that pertain to the use of testing technology; hence, there are deficiencies in the management framework (Ref. Fig. 14).

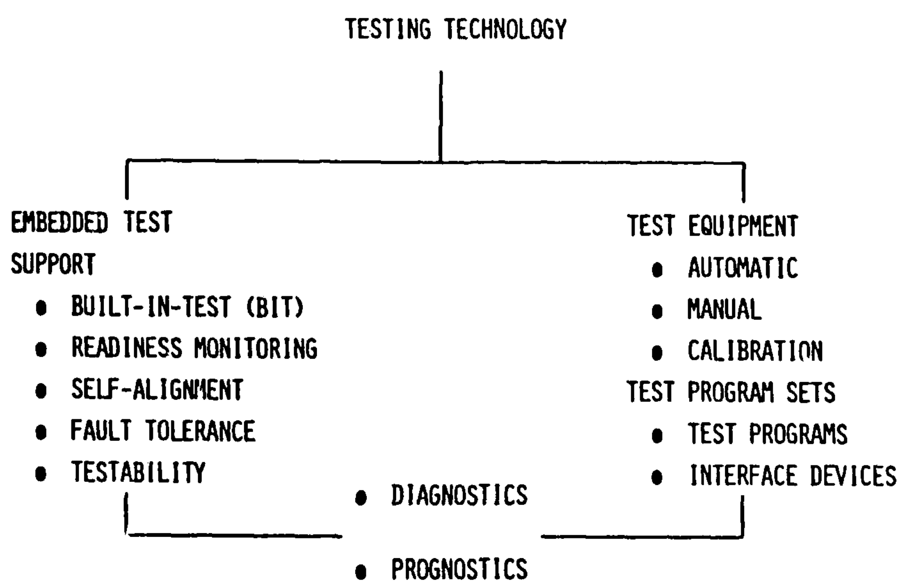


FIGURE 14. Testing Technology Framework

(2) Maturation: The sole maturation issue facing testing technology is the expansion of the technology base to provide "off-the-shelf" proven alternatives for use in weapon system design. These alternatives should apply to non-electronic monitoring systems and diagnostic/prognostic techniques; system level testing techniques; performance monitoring hardware and software; training methods.

o. VHSIC

(1) Insertion: The present VHSIC program (Ref. Fig. 15) consists of a two-phase approach that initially develops 1.25 micron integrated circuit technology and then develops submicron circuit technology. There is a consensus in the technical community that VHSIC offers the possibility of significant improvements in both performance and reliability.

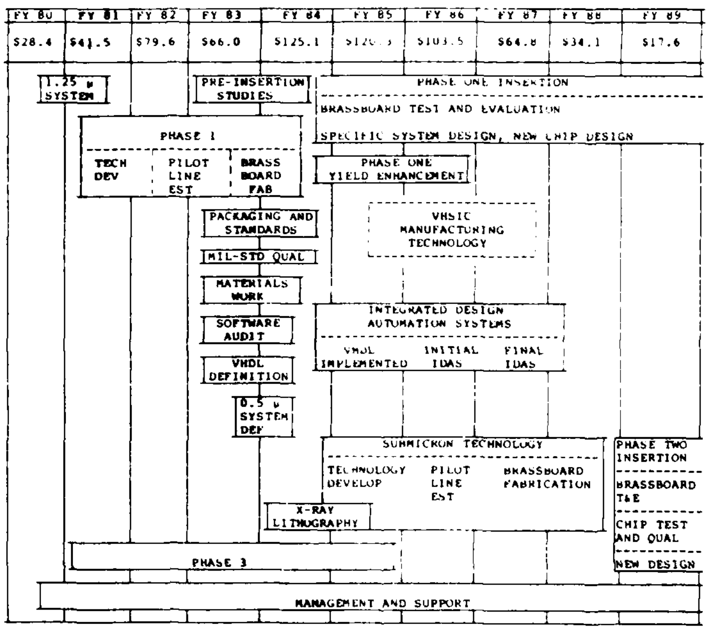


FIGURE 15. VHSIC Road Map

200/3-48

The VHSIC insertion issues are management issues. Primarily, the problem is in lowering the acquisition program review thresholds to $10M and $100M for RDT&E and Production, respectively. The present levels do not permit review of many of the programs that could be using VHSIC. Lowering the thresholds would allow more programs to be reviewed for VHSIC applicability. Attendant with the need for making it easier to use VHSIC is the need to assess formally its use in any given acquisition program. The most direct way to accomplish this is through the inclusion of VHSIC as a specific topic in major program reviews, such as DSARCs and SSARCs.

(2) Maturation: The primary maturation issues that apply to VHSIC address the demonstration of device performance and quality, demonstration of how application of VHSIC enhances system performance and readiness and demonstration of the producibility of VHSIC devices in both quantity and quality and at a sufficiently low cost to support wide applications within DoD. VHSIC Phase I technology is approaching the point where such demonstrations can be conducted within the next two or three years. VHSIC Phase 2 technology development will be required before Phase 1 technology is ready for such demonstrations.

As a secondary issue, studies need to be conducted to assess the impact of VHSIC use on operational availability and intrinsic availability. VHSIC capabilities offer significant improvements to sustained system performance and ease of maintenance but little has been done to quantify the magnitude of the improvements. Also, VHSIC cost and maintenance requirements introduce unknowns into logistic support considerations and, therefore, require further analysis.

As can be seen in Fig. 16, each of the six contractors has a different design approach in the Phase I VHSIC program. In addition, the devices are being structured differently with various interconnecting and packaging techniques with peculiar built-in-test (BIT) and functional test (FT) approaches. While allowing conceptual design freedom, some BIT/FT partitioning and

Contractor	Technology	Design Approach	Design Tools	Inter-Connection Scheme	Packaging Technique	BIT/FT Approach
Honeywell (Air Force)	Bipolar ISL, CML	Custom-chip Based macrocell library	DAS (Unified Data Base) AIDA (Advanced integrated design automation	Multiplier high speed lead bus & medium speed global bus	Multilayer ceramic carrier with beantape inter-connections	LSSD signature analysis
Hughes (Army)	CMOS on SOS	Standard and custom recon-figurable chips	Hercules CAD data base	pipeline interconnects	leaded ceramic flatpack leads on 25 mil pitch	set/scan, signature analysis redundancy
IBM (Navy)	NMOS	Master image with microcell library	VHD^{2}L (VHSIC Hard-ware design and description language) EDS engineering design system	pipeline on chip	single chip flexible film module package	LSSD, signature analysis, redundnacy parity
Texas Instruments (Army)	Bipolar STL, NMOS	Programmable chip set	HDL, INTSIM (integrated simulator)	Multi-master synchronous paralles bus (S-bus)	JEDEC Type C leadless chip carrier	error correcting code, TMR
TRW/ Motorola (Navy)	Bipolar 3d TTL CMOS	Standard chip set	ADLIB/SABLE HSL-Hierarchical Systems Language multilevel data base	V-bus inter-connect (multiloop)	Ceramic Hermetic chip carrier, 132 edge chip attach	Set/Scan
Westinghouse	Bluk CMOS	Standard chip set	ISPS, LOGIC V, ASSIST, CABBAGE CALMA	Dual phase open drain bus and high speed ring network	leaded chip carrier with 25 mil pitch	RADSS (Scan/ set)

FIGURE 16. VHSIC Contractors

2003-50

standardization will be necessary at the chip set levels to allow for weapon system optimization and incorporation by yield and optimum overall weapon system performance that has been tempered by R&M considerations for testability and overall condition monitoring/diagnostics rationale.

p. Diagnostics

(1) Maturation: Like the other electronic technologies such as VHSIC and Fiber Optics, the primary issue confronting the maturation of diagnostics technology is one of demonstrating the obtainable capabilities. The best way to address this issue is for each Armed Service to select an existing equipment and demonstrate the diagnostic improvements that are possible using new semiconductor technology, such as non-volatile memories, microprocessors, and buffer registers (where there is a multiplex bus).

A second issue that complements the demonstration of diagnostic capabilities is the development of design rules that relate to diagnostics. These rules should address functional partitioning and tolerance derating. They should be developed in a form that facilitates their incorporation into computer-aided design techniques.

(2) Creation: A mix of projects is required to enhance diagnostic technology. These are: determination of the relationship between system complexity, diagnostics and humans, the development of testing vector generators to reduce memory requirements and the development of techniques for testing and fault isolation in connectors, cables and antennas.

C. TECHNOLOGY TRENDS

In the preceding sections we presented a catalog of the technology issues raised by our technology working groups. We sorted these issues into three large groups: insertion, maturation and creation. This sorting was useful for determining the state-of-the-art for each technology area.

If one examines the issues again from a different point of view, one discerns that the technology issues represent thrusts in three basic areas: propulsion, electronics and structures. The Manpower, Personnel and Training and the Directed Energy technologies, however, cannot be put into any one or two of these areas. Manpower, Personnel and Training technology extends into all three of the basic areas as a contributor. Directed Energy technology on the other hand is a user of technologies from the three areas as well as from Manpower, Personnel and Training technology.

The need to achieve high reliability estimates of remaining operating life through technology for propulsion systems is being driven by the scenarios identified in Section VI-A. Factors such as thrust, fuel efficiency, wear, problem diagnosis, and parts replacement make increasingly severe demands on designers to meet the requirements for dispersed autonomous operation. Three of the technology groups directly impact technology evolution to meet this more demanding situation: Mechanical Systems Condition Monitoring (MSCM), Nondestructive Evaluation (NDE), and Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM). The direction they establish is one that emphasizes the simplification of maintenance, the reduction of design development costs and improvements in the materials used to construct propulsion units. The focus on propulsion units is provided primarily by the MSCM and NDE groups, which set forth a proposed evolution of diagnostic and condition monitoring technology to enhance present capabilities.

The CAD/CAM working group identifies a capability for reducing initial design and development costs through the use of automated design techniques that reflect known performance enhancing design guidelines and through the use of performance simulation and diagnosis techniques that obviate the need for costly developmental testing. Less direct, but equally important, are the issues raised in the Composites, Integrated Systems of Manufacture, and Testing Technology reports.

The trend in electronics is well-known--"do more in less volume." Many of the technology groups addressed the problems that accompany this trend. The "do more" part of the trend is addressed in a functional sense by the Artificial Intelligence, Operational Software and Diagnostics groups, which address the configuration and programming of increasingly sophisticated machine tasks to expand system capabilities, the extension of system life through self-comprehensive diagnostics and automation reconfiguration. The "less volume" part of the trend is addressed by several of the technology groups: VHSIC, Cables and Connectors, Fiber Optics, Power Supplies, and Electronic Packaging and Interconnection. They address the need to increase functions per component in a manner that meets performance and environmental needs without reducing operating life. There are two significant challenges that are discontinuities in the evolution of electronics: The advent of 100 MHz clock rates and the need for 1-volt DC power supplies for VHSIC/VLSI chips. If these goals are met with reliable technology, a large step toward the Year 2000 goals will have been taken. In a manner similar to the increased demands it makes on system design, the trend is equally demanding on design and manufacturing methodologies. These aspects are addressed by the CAD/CAM and Integrated Systems of Manufacture (ISOM) groups. They describe the processes for the design and manufacture of systems in situations that tax the capabilities of design and assembly personnel.

Increased performance requirements for future systems require less weight, more strength, more resistance to environmental effects and hostile action and easier maintenance. In many cases, these can be met only by new materials such as composites. Four of the groups address meeting the future requirements for structures: Composites, NDE, CAD/CAM and ISOM. Although the Composites group considered the intrinsic characteristics of composites, it concentrated on the need for assessing the quality of repairs to composite structures and evaluating the sensitivity of composites to battle damage. Some of the technology required to support these assessments was identified by the NDE group. The CAD/CAM and ISOM groups addressed the automation of the design and fabrication process for structures. However, the increased use of composites creates a number of new considerations that require early design decisions.

As we stated earlier, Manpower, Personnel and Training technology is considered a contributor to the propulsion, electronic and structures technologies. Its challenge in relation to the other technologies is one of simplifying the performance of complicated or unfamiliar operator tasks and easing the maintenance to compensate for the limited number of projected skill levels of personnel. The functions of Manpower, Personnel and Training technology in the near future will be to establish system architectures that have a high degree of operator and maintainer "friendliness" and to provide training strategies for which suitable system architectures cannot be devised (Ref. 8).

Directed Energy technology is in something of an opposite position. While the Manpower, Personnel and Training technology contributes to most other technologies, Directed Energy blends the others into a unique, system-oriented technology (Ref. 5). Currently envisioned directed energy system configurations are a combination of propulsion, materials and electronics technologies that have been structured to meet requirements for higher-power, fast-reaction and very high accuracy. There are a number of new systems in the electrooptic world, phased array radar, etc., that could have been studied. Due to constraints on energy and time, only one was taken as a case study. The general conclusion is that all these systems are reliability dependent with ever-increasing challenges in the early design considerations. The self-evident conclusion is that we must improve our ability to deal with R&M issues early on. The less evident conclusion is that the feasibility and proof of concept for some of these new systems may be field reliability driven at the first instance, even for lab demonstrations. Yet, our greatest weakness is how to link the field to the laboratory and design process when it comes to reliability and maintainability.

REFERENCES

SECTION VI

1. Institute for Defense Analyses, "Artificial Intelligence Applications to Maintenance Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-28, Anthony Coppola, Working Group Chairman, August 1983.

2. Institute for Defense Analyses, "Cabling and Connectors Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-29, J.W. Bird, Working Group Chairman, August 1983.

3. Institute for Defense Analyses, "CAD/CAM Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-30, Jack D. Osborn, Working Group Chairman, August 1983.

4. Institute for Defense Analyses, "Structural Composites Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-31, Frank Crossman, Working Group Chairman, August 1983.

5. Institute for Defense Analyses, "Directed Energy Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-32, Bruce R. Mayo, Working Group Chairman, August 1983.

6. Institute for Defense Analyses, "Fiber Optics Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-33, Andrew S. Glista and Rodney S. Katz, Working Group Charimen, August 1983.

7. Institute for Defense Analyses, "Integrated Systems of Manufacture Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-34, Joseph Bosworth, Working Group Chairman, August 1983.

8. Institute for Defense Analyses, "Manpower, Personnel and Training Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-35, Paul A. Watson and Wolf Hebenstreit, Working Group Chairmen, August 1983.

9. Institute for Defense Analyses, "Mechanical Systems Conditioning Monitoring Technology Working Group, (IDA/OSD R&M Study)", IDA Record Document D-36, Paul Howard, Working Group Chairman, August 1983.

10. Institute for Defense Analyses, "Nondestructive Evaluation Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-37, George Mayer, Working Group Chairman, August 1983.

11. Institute for Defense Analyses, "Operational Software Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-38, LTC Lawrence E. Druffel, USAF, Working Group Chairman, August 1983.

12. Institute for Defense Analyses, "Electronic Packaging and Interconnection Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-39, Richard J. Clark, Working Group Chairman, August 1983.

13. Institute for Defense Analyses, "Power Supply Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-40, Donald Hornbeck, Working Group Chairman, August 1983.

14. Institute for Defense Analyses, "Testing Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-41, George W. Neumann, Working Group Chairman, August 1983.

15. Institute for Defense Analyses, "VHSIC Technology Working Group Report (IDA/OSD R&M Study)", IDA Record Document D-42, Egbert Maynard, August 1983.

APPENDIX A

TECHNOLOGY ORGANIZATION AND PARTICIPANTS

120/16-18

APPENDIX A

TECHNOLOGY ORGANIZATION AND PARTICIPANTS

This appendix describes the organization established to treat the technology aspects of the study objective. In addition, the methodology for selecting technologies for study, the goals of the working groups and the issues to be addressed are identified, along with the major participants.

A. OBJECTIVE

The overall study objective stated in the Task Order is:

> "To identify and provide support for high-payoff actions which the DoD can take to improve the military system design, development and support process so as to provide quantum improvements in R&M and readiness through innovatives uses of advancing technology and program structure."

From this objective, two distinct technology related tasks were derived:

(1) To assess the impact of advancing technology on future DoD requirements for improved R&M and readiness; and

(2) To evaluate the potential and recommend strategies that might result in quantum increases in R&M or readiness through innovative use of advancing technology.

121/3-1

B. APPROACH

A Core Group member of the IDA study, Dr. Hylan B. Lyon, Jr., was appointed Chairman of the Technology Study Group. He in turn selected the chairmen for the individual working groups that would examine technology areas selected by the core group for study. The process for the selection of the technologies to be studied and for their participants is illustrated in Fig. A-1. Each group was instructed to examine the impact of technological advances in its area on Service R&M goals with parcicular attention to technology applications which had the potential for making a major impact. The Study Groups met on an average of four times each over a six-month period and each produced a report giving their conclusions and recommendations. There were 142 persons participating, 52 from the Department of Defense and 90 from industry and other government agencies. The chairmen of the individual working groups made up the Technology Steering Group and coordinated the efforts of the individual technology area study groups.

C. TECHNOLOGIES SELECTED FOR STUDY

After consultation with the Services and industry groups, and examination of pertinent reference documentation such as the Militarily Critical Technologies List, sixteen technology areas were selected for study as follows:

Technology	IDA Document No.
• Artificial Intelligence (AI)	D-28
• Cabling and Connectors	D-29
• Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM)	D-30
• Structural Composites	D-31
• Directed Energy	D-32

121/3-2

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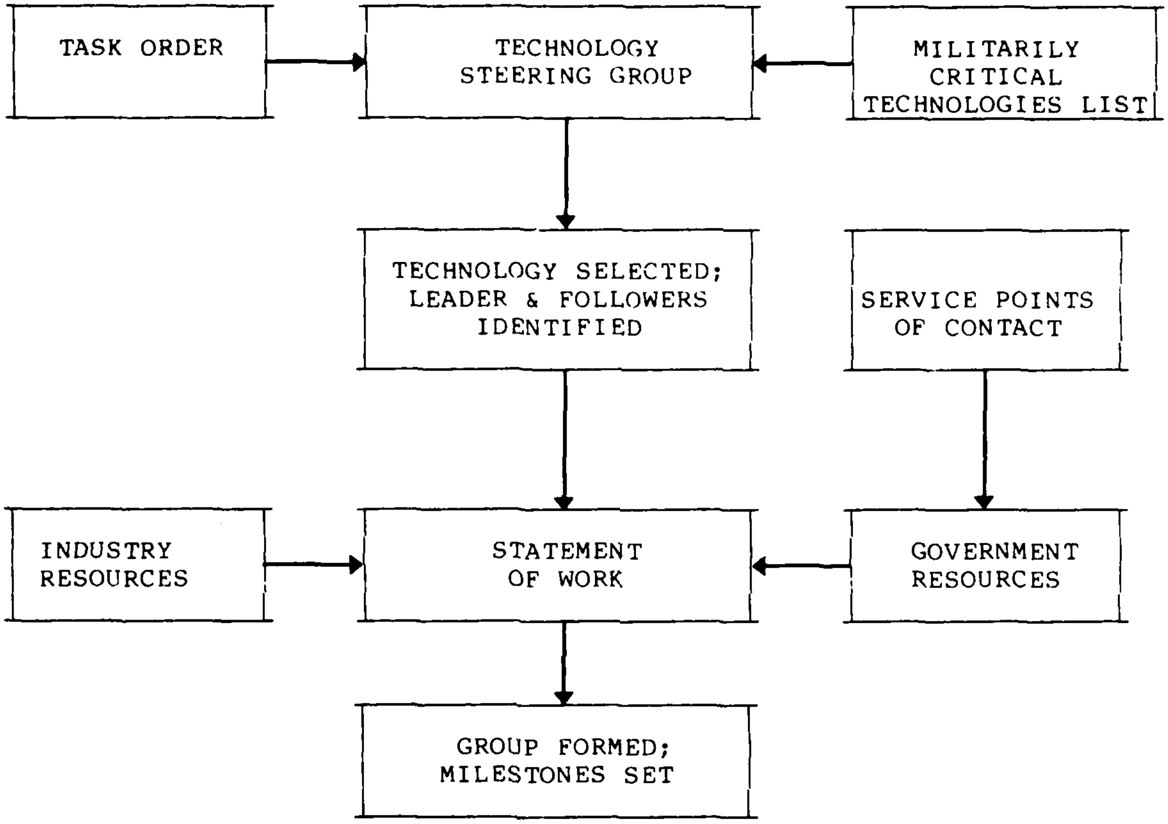

Figure A-1. Technology Selection Process

121/3-22

The selection of these technologies was intended to cover some of the major areas perceived to have potential impact on the R&M characteristics of readiness at the weapons system level.

In each technology area, a statement of work (SOW) was prepared and reviewed with the study director and subsequently approved by the Core Group. The statements were focused on the elements of the technology that affect readiness. This was important because many of these technology areas also are contributors to the performance of systems as well. Each group was encouraged to recommend actions to be taken. The following three levels of technology were considered:

(1) Technology ready for program application; i.e., technology ready now for "utilization."

(2) Technology ready for incorporation in demonstration programs--technology in need of maturation.

(3) Technology in need of proof of feasibility; i.e., still in the "creation" state and R&D discipline oriented.

A summary of each group's findings is presented in Appendix D.

121/3-3

D. TECHNOLOGY STEERING COMMITTEE

The Technology Steering Committee members are shown in Fig. A-2.

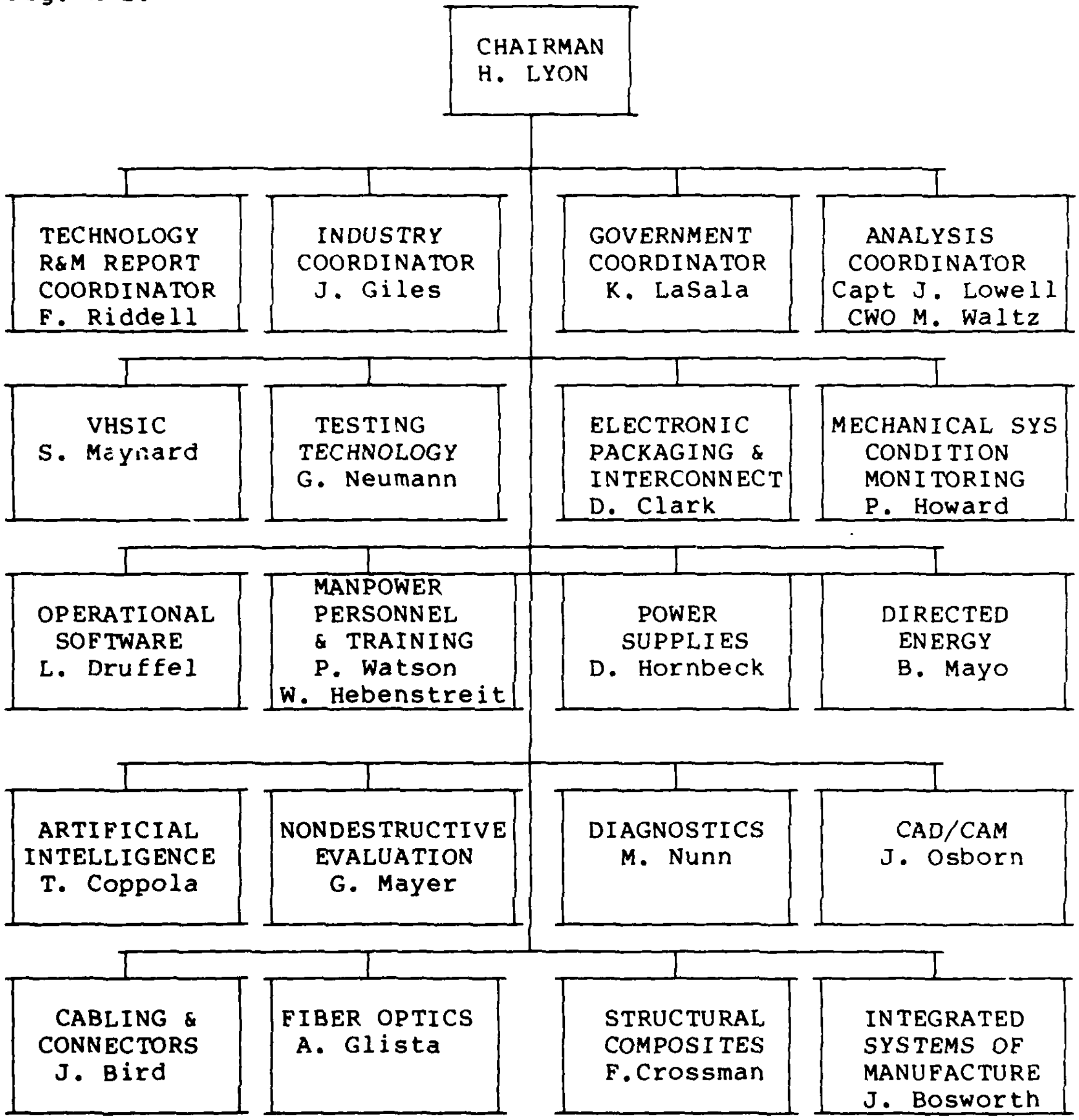

FIGURE A-2. Technology Steering Committee

121/3-4

The chairman of each working group was ultimately responsible for the preparation of the working group reports identified in paragraph C.

E. WORKING GROUP SOW's

The SOW for each Working Group was reviewed by the Core Group of advisors for the overall study. The resulting SOW and the working group members are shown in Figs. A-3 through A-18.

TECHNOLOGY AREA: Artificial Intelligence (AI) Application to Maintenance
CHAIRMAN: Mr. Tony Coppola RADC (315)330-4726
GOAL: To develop a plan for the cost-effective implementation of artificial intelligence techniques for the detection and isolation of failures in military systems.
SCOPE: 1. Determine what AI techniques can be implemented immediately and evaluate their cost effectiveness. Recommend applications. 2. Determine applications possible in the near future (i.e., 1-3 years), assess cost effectiveness and recommend developments. 3. Determine potential applications in the long term, cost effectiveness and technological risk, and recommend developments. WORKING GROUP MEMBERS: Mr. Eric J. Braude — RCA Mr. R. P. Caren — Lockheed Mr. Leonard Friedman — JPL Mr. Russell M. Genet — USAF/HRL Ms. Lorraine M. Gozzo — RADC Mr. John H. Hinchman — GD Mr. Robert Hong — Grumman Mr. Robert Schrag — RADC

FIGURE A-3. Artificial Intelligence Application to Maintenance--Statement of Work and Working Group Members

121/3-6

TECHNOLOGY AREA: Cabling and Connectors
CHAIRMAN: Mr. Joe Bird Martin Marietta (301)338-5724
GOAL: To identify the characteristics and/or the technologies that will lead to quantum improvements in readiness
SCOPE: Examine, define and quantify the major contributory causes of malfunctions, i.e., design, application or usage/handling. 1. Define the constraints created by new technology, i.e., VHSIC, Packaging, Operational Protocol, Fiber Optics, etc. 2. Define and quantify the physical and electrical performance requirements for: A. Internal wiring, i.e., Wiring harness B. External wiring, i.e., Cabling ISSUES: What if any factor(s) can be identified as the primary driver(s) of malfunctions. 1. What new technological constraints are driving the reconfiguration of connectors and what are the common factors to be addressed by change. 2. What are the present and identifiable manfacturing/producibility problems that contribute to the reduction of reliability and maintainability of weapon systems. 3. How can the Department of Defense better manage the control of design and usage/application of the connectors and cable assemblies. WORKING GROUP MEMBERS: Mr. L. Mahoney Raytheon Mr. R. Pietroski G.E. Space

FIGURE A-4. Cabling and Connectors--Statement of Work and Working Group Members

121/3-7

TECHNOLOGY AREA: CAD/CAM
CHAIRMAN: Mr. Jack Osborn Structural Dynamics (513)576-2400
GOAL: To identify the means by which computer-aided technologies can lead to quantum improvements in R&M
SCOPE: 1. Articulate a model of the process of taking a weapons system from concept to product using computer-aided technologies. 2. Identify critical information flows. 3. Define the engineering process that takes advantage of these technologies. ISSUES: 1. Using CAD/CAM to "wire in" the implementation of R&M 2. Identifying the unnecessary loops in the process 3. Establishing the concept of significant reduction in manufacturing time 4. Information flows WORKING GROUP MEMBERS: Dr. Albert A. Klosterman Structural Dynamics Research Corp.

FIGURE A-5. CAD/CAM--Statement of Work and Working Group Members

121/3-8

TECHNOLOGY AREA: Structural Composites
CHAIRMAN: Dr. Frank Crossman Lockheed (415)858-4034
GOAL: To identify the characteristics of composite materials which can lead to quantum improvements in system readiness, reliability, and maintainability.
SCOPE: 1. Structural Advantages: Thermal-Mechanical 2. Non-Structural Advantages - Armor, Electro-Magnetic 3. Identify barriers to application of composite materials to structures where their use provides an R&M system payoff ISSUES: 1. Long-term durability: fatigue, aging, environmental degradation 2. Repairability in field and at depot 3. Maturity of design/manufacturing methods (including testing and quality control) 4. Prediction of life-cycle costs 5. Impact of technology advances in NDE, CAD/CAM, Robotics, Testing, Fiber Optics, Artificial Intelligence, and Diagnostics on Application of Structural Composites

WORKING GROUP MEMBERS:

Mr. Joseph Augl	Naval Surface Weapons Center
Mr. John Foltz	Naval Surface Weapons Center
Mr. Ray Garrett	McDonnell Aircraft Co.
Mr. Bernard Halpin	Army Mechanics/Materials Research Center
Mr. Larry Kelly	AFWAL/FIBCB Wright-Pat AFB
Mr. James Labor	Northrop Corporation
Mr. L.E. Meade	Lockheed-Georgia Co.
Mr. Daniel R. Mulville	Naval Air Systems Command
Mr. Bryan R. Noton	Battelle Columbus Labs.
Mr. Kenneth Reifsnider	Virginia Polytechnic Inst.
Mr. Roy W. Rice	Naval Research Lab.
Mr. G. L. Roderick	U.S.Army R/T Labs (AVRADCOM)
Mr. Richard A. Schapery	Texas A&M University
Mr. William Schweinberg	WR-ALC/MMTRC Warner-Robins AFB
Mr. Joseph Sonderquist	Federal Aviation Admin.AWS-103
Mr. Robert Stone	Lockheed-California Co.
Mr. John Fant	General Dynamics/Fort Worth
Mr. Jerry Yanker	AFALD/PTE Wright-Pat AFB

FIGURE A-6. Structural Composites--Statement of Work and Working Group Members

121/3-9

TECHNOLOGY AREA: Directed Energy
CHAIRMAN: Mr. Bruce Mayo Sperry Systems (516)574-2955
GOAL: Establish reliability and maintainability (R&M) guidelines for the acquisition of directed weapon systems.
SCOPE: Investigate directed energy weapon systems technology, and define specific high payoff actions that can contribute significantly to increased weapon system readiness and availability ISSUES: 1. How to ensure a high R&M payoff in the development of directed energy weapon system technology 2. What new and emerging support technology can be used to enhance the probability of success WORKING GROUP MEMBERS: Lt Col D. Boesen — AFWL Kirtland AFB Mr. M. Cole — MICOM Redstone Arsenal Dr. D. Ahouse — AVCO Research Center Dr. G. G. Pippert — MIT/Lincoln Labs Mr. F. Staudt — UTRC/OATL Mr. J. Bracken — Sperry Corporation

FIGURE A-7. Directed Energy--Statement of Work and Working Group Members

121/3-10

TECHNOLOGY AREA: Fiber Optics
CHAIRMAN: Mr. Andy Glista Naval Air Systems Cmd (202)692-2510
GOAL: To identify the R&M (as well as operational improvements) possible through the utilization of fiber optics on military platforms.

SCOPE: Determine the past impediments to utilization of this technology and recommend means of overcoming these barriers - methodology will include:

- Case Studies
- Technology Assessment

ISSUES:
1. Will the basic fiber optics components have reliability equal to or better than existing components (cables, connectors, etc.)?
2. Is this technology capable of being maintained by service personnel?
3. What are the technical/managerial/political issues which need to be overcome?

WORKING GROUP MEMBERS:

Mr. Rodney S. Katz	Naval Avionics Center
Mr. Larry Abernathy	ITT Electro-Optics Div.
Mr. Claud Bain	Consultant
Mr. Robert Baumbick	NASA Lewis Research Ctr.
Mr. Albert Bender	Fibercom, Inc.
Mr. Robert Betts	IBM Federal Systems Div.
Mr. J. Robert Baird	Honeywell Optoelectronics
Dr. Joseph Bucaro	Naval Research Lab
Mr. Robert Gallawa	Nat'l Bureau of Standards
Mr. Roger Greenwell	Naval Ocean Systems Ctr.
Mr. Charles Hurwitz	Lasertron
Mr. George Kaposhilian	Hewlett Packard Co.
Mr. Charles Kleekamp	MITRE Corp.
Mr. John Kolling	Sperry Univac
Mr. Robert Kochanski	Naval Ocean Systems Ctr.
Dr. Henry Kressel	RCA
Mr. Owen Mulkey	Boeing Aerospace Co.
Mr. John R. Peronnet	Grumman
Mr. Richard Plunkett	Western Electric
Dr. Howard Rast	Naval Ocean Systems Ctr.
Mr. Donald Reis	Grumman
Mr. Paul Sierak	RADC
Dr. George Sigel	Naval Research Lab
Mr. Ronald Solomon	McDonnell-Douglas
Mr. Larry Spencer	NASA HQ.
Mr. Russell Stanten	Army Applied Tech. Lab
Dr. Howard Wichansky	U.S. Army CECOM

FIGURE A-8. Fiber Optics--Statement of Work and Working Group Members

121/3-11

TECHNOLOGY AREA: Integrated Systems of Manufacture (ISOM)
CHAIRMAN: Mr. Joe Bosworth RB Robot (303)279-5525
GOAL: To identify ways in which ISOM can be applied to bring major improvements to R&M readiness.
SCOPE: Dealing with the multidisciplinary nature of ISOM technology, this effort will focus on existing applications of robotics in industry as well as emerging applications which have immediate and important implications for DoD, R&M and readiness. Primary emphasis will be given to robotics implementations involving: • Sensor Technology • Electronics • Other Physical Science • Mechanical Engineering • Computers • Communications • Energy   ISSUES: 1. Robotics in service and maintenance 2. Robotics in small lot production 3. Universal robotics language (software) 4. Robotics diagnostic systems   WORKING GROUP MEMBERS: Professor Robert Emerson — University of Arkansas Mr. Daniel S. Appleton — D. Appleton Co., Inc. Mr. Roger Schappell — Martin Marietta Aerospace Mr. John Meyer — Tech Tran Mr. Bruce W. Christ — Nat'l Bureau of Standards Mr. James C. McGuire, PhD. — Douglas Aircraft Co.

FIGURE A-9. Integrated Systems of Manufacture--Statement of Work and Working Group Members

121/3-12

TECHNOLOGY AREA: Manpower, Personnel and Training
CHAIRMAN: Mr. Paul Watson, Hughes, (213)513-4389 Mr. Wolf Hebenstreit, Boeing, (206)251-4579
GOAL: Improve readiness through identified areas of potential high payoff due to manpower, personnel, and training.
SCOPE: Investigate advanced technology contributing to improved readiness in the following areas: 1. Manpower/Personnel 2. Human Engineering 3. Training & Training Technology ISSUES: 1. Hardware/Software people cost & readiness trade-offs 2. Numbers of people entering work force declining 3. High cost of training WORKING GROUP MEMBERS: Dr. Jesse Orlansky — IDA Dr. Fred Muckler — Canyon Research Mr. Doug Metcalf — Essex Corp. Mr. Steve Merriman — NADC Mr. Peter Weddle — Dynamics Research Corp. Dr. Thomas Sicilia — OASD MRA&L DASD Dr. James Gardner — Honeywell, Inc. Dr. Richard Vestewig — Honeywell, Inc. Dr. Harry O'Neill — Army Research Institute Dr. Leon Nawrocki — Army Research Institute

FIGURE A-10. Manpower, Personnel & Training--Statement of Work and Working Group Members

121/3-13

TECHNOLOGY AREA: Mechanical Systems Condition Monitoring
CHAIRMAN: Mr. Paul Howard TEDECO (215)583-9400 x259
GOAL: To identify the techniques of mechanical systems condition monitoring and determine how they can be more effectively utilized.

SCOPE: Determine how diagnostics techniques and requirements for mechanical systems are introduced into new programs through:

1. Program Case Studies -- M-1, Blackhawk Propulsion System, F-18, (Westland)
2. Technology Assessments -- (Payoff analysis used as measurement criteria)

ISSUES:

1. Can mechanical systems condition monitoring increase operational readiness through preventive maintenance actions at reasonable costs?
2. Any mechanical systems monitoring techniques being properly utilized in present systems acquisitions to the proper extent through R&M logistics analysis?

WORKING GROUP MEMBERS:

Mr. Andy Hess	Naval Air Systems Cmd.
Mr. Wayne Hudgins	Army Research & Tech. Labs (AVRADCOM)
Mr. Dick Lee	Army JOAP
Mr. Al Lemanski	Sikorsky Aircraft
Mr. Mike Green	ASD Wright-Pat AFB
Mr. Robert Stenberg	Army Aviation Res. & Development Command

FIGURE A-11. Mechanical Systems Condition Monitoring--Statement of Work and Working Group Members

121/3-14

TECHNOLOGY AREA: Nondestructive Evaluation (NDE)
CHAIRMAN: Dr. George Mayer Army Research Office (919)549-0641
GOAL: To identify where NDE and associated inspection technologies contribute (+) to reliability and maintainability of weapon systems. Identify where NDE and associated inspection technologies, methodologies and management need improvement. To define where and how, in the acquisition cycle, NDE and associated inspection technologies can be injected into programs.
SCOPE: Examine impact of nondestructive, chemical, mechanical and electronic inspection technologies on R/M, the application and development of these technologies during acquisition of weapon systems, and the development of new NDE and associated inspection technologies. ISSUES: 1. How can NDE and associated technologies be better applied to improve R/M of weapon systems? 2. What improvements in these technologies would result in significant improvements in R/M of weapon systems? 3. How can these technologies be better managed by Department of Defense WORKING GROUP MEMBERS: Mr. Francis E. Alloway — General Dynamics Dr. Joseph Argento — Army (ARRADCOM) Mr. George M. Behen — Army (AVRADCOM) Major John Breland — Air Force (HQ AFSC/DLF) Mr. John T. Conroy — Army (AVRADCOM) Dr. Thomas Cooper — Air Force (AFMLK) CMS John F. Dorgan — Air Force Kelly AFB Mr. Paul Finn — Sikorsky A/C Mr. Robert Green, Jr. — JHU Mr. Harold Hatch — Army (AMMRC) Mr. J. C. Herr — General Dynamics Mr. Chester T. Kedzior — Army (TACOM) Mr. Daniel Lacedonia — Hamilton Standard Mr. W. H. Lewis — Lockheed-Georgia Mr. Harry L. Light — Army (HO DARCOM) Mr. J. Nicholas — Navy (NAVSEA) Major L. D. Phifer, III — Air Force (SA/ALC/MMEI) Mr. Michael Stellabotte — Navy (NADC)

FIGURE A-12. Nondestructive Evaluation--Statement of Work and Working Group Members

121/3-15

TECHNOLOGY AREA: Operational Software
CHAIRMAN: Lt Col Larry Druffel OUSDR&E (202)694-0208
GOAL: To identify where software technology and methodology contributes (+) to R/M of weapons systems. To identify areas where software technology and methodology needs improvement
SCOPE: Examine software delivered to the operational site (both operational & maintenance software) to identify contributions to system R/M and to software R/M. This examination will cover systems requirements, software requirements & design including fab., test, and documentation. Software not included in this study: ATE Software; Development Test Software; CAD/CAM Software; Compliers. ISSUES: 1. Define software: software failures, develop vocabulary for this area. 2. Identify frequent W/S SWR failures 3. Identify DoD initiatives, directives in the software area 4. Assess state of implementation of #3 5. Identify high payoff areas 6. Recommend Action: (A) R&D - $ from software initiatives (B) Policy Action WORKING GROUP MEMBERS: Mr. Andy Farrantino Software A&E

FIGURE A-13. Operational Software--Statement of Work and Working Group Members

121/3-16

TECHNOLOGY AREA: Electronic Packaging & Interconnection
CHAIRMAN: Mr. Richard J. Clark General Electric (315)456-2876
GOAL: To identify the potential improvements possible through the use of improved packaging and interconnection of electronic parts technology.

SCOPE:

1. Package device to Printing Wiring Board PWB (SEM) and backplates
2. ICs and other discrete components
3. On-module connectors

ISSUES:

1. High density interconnections (chip carriers, levels of interconnect)
2. Fine line printed wiring boards
3. Impact of packaging on electrical parameters
4. New material development (substrates, solders, encapsulants)
5. Interrelationships between system packaging and device design CAD systems
6. New thermal management techniques

WORKING GROUP MEMBERS:

Mr. Eugene Blackburn	RADC
Mr. Joseph Ciccio	Raytheon
Mr. S. G. Konsowski	Westinghouse
Mr. Steve Linder	Naval Air Systems Cmd
Mr. Dean McKee	Naval Ocean Systems Ctr
Mr. Isaac Pratt	ERADCOM
Mr. Jon Prokop	Texas Instruments
Mr. Maurice Robbins	IBM
Mr. Robert Unger	Applied Electronics Tech.
Mr. Dan Zimmerman	ISHM

FIGURE A-14. Electronic Packaging & Interconnection--Statement of Work and Working Group Members

121/3-17

TECHNOLOGY AREA: Power Supplies

CHAIRMAN: Mr. Don Hornbeck EG&G (603)635-3292

GOAL: Project near/far term power processing technology required to meet energy, reliability & maintainability objectives.

SCOPE:

1. To tailor power supply topology to the unique needs of medium scale integration/large scale integration
2. To emphasize/minimize life cycle cost (LCC)
3. To enforce a high degree of reliability with minimal maintenance and ease of maintenance via component selection, development and application

ISSUES:

1. Power supply volume, efficiency and cost versus the utilizing system, system volume, dissipation and cost
2. Emphasis by management as the system architecture evolves
3. Power supply standardization at the platform level
4. Manufacturing techniques as related to labor content and producibility

WORKING GROUP MEMBERS:

Mr. William Singleton	IBM
Mr. Peter Asman	Naval Sea Systems Cmd
Mr. Mike Williams	Consultant
Mr. Jerrold Foutz	Rockwell
Mr. Homer Shapiro	Hughes Aircraft Co
Mr. John C. Wright	General Electric
Mr. William Shaw	Modular Power System
Mr. Lawrence S. Colwell	Simonds Precision
Mr. Joseph D. Segrest	NADC

FIGURE A-15. Power Supplies--Statement of Work and Working Group Members

121/3-18

TECHNOLOGY AREA: Testing Technology
CHAIRMAN: Mr. George Neumann, Giordano Assoc. (703)521-1358
GOAL: To identify the impact and process of introducing testing technology.
SCOPE: 1. Define where and how, in the acquisition cycle, testing technology can be injected into programs 2. Define how to develop testing technology options ISSUES: 1. How to manage the transition from ATE to BIT/BITE 2. How CAD/CAM leads to a new capability for testability tradeoffs 3. Testing Technology = (Test, Efficiency, Effectiveness, Burdens, Equipment, ATE, BIT, Diagnostics) WORKING GROUP MEMBERS: Mr. Mel Nunn — Naval Ocean Systems Ctr Mr. Robert Bareford — Northrop Mr. Paul Giordano — Giordano Associates RADM Duncan McGillivary, USN — Defense Logistics Agency

FIGURE A-16. Testing Technology--Statement of Work and Working Group Members

121/3-19

TECHNOLOGY AREA:	VHSIC
CHAIRMAN:	Mr. Sonny Maynard OSDR&E (202)697-4198 Mr. Richard Urban NASC (202)692-7640
GOAL:	To identify the impact of VHSIC on systems R&M
SCOPE:	1. Define requirements for field failure analysis and quality assurance of VHSIC chips 2. Prescribe specific R&M policy changes necessitated by the advent of VHSIC 3. Develop specific plans for a VHSIC R&M demonstrator
ISSUES:	1. Intrinsic Reliability 2. Susceptibility 3. Longevity/Life Characteristics 4. Manufacturing/Special Processes
WORKING GROUP MEMBERS:	Mr. Tom Mitchell Digital Systems Research

FIGURE A-17. VHSIC--Statement of Work and Working Group Members

121/3-20

TECHNOLOGY AREA: Diagnostics

CHAIRMAN: Mr. Mel Nunn NOSC (619)225-6173

GOAL: To define the ground rules for design of equipment which will yield the maximum potential for diagnostics capability.

SCOPE: The "design rule" approach to diagnostics will be dealt with, at least initially, by a different approach than other R&M technology topics. Aspects of diagnostics cut across all of the topics presently under study or envisioned for study. The proposed effort will cut across the entire field of system design and should reflect, as well, the needs of the user. Technology topic study group chairmen will be apprised of the development of this initiative, can be involved and will have full access to how the results of this effort are incorporated into the technology study report by virtue of their participation in the technology steering group.

ISSUES: In preparing these ground rules, the following issues will be addressed:

- At what level (or levels) should functions be partitioned?
- What should the strategy be to interrelate functions, interconnects and modes as a means of defining test points?
- How can the use of design rules be reviewed and verified?
- What are the feasible CAD options to enhance ease of application and verification of design rules?
- Is there a reasonable tradeoff between automated and manual diagnostics?
- How does it relate to the test point selection criteria?
- How can credibility of this approach be demonstrated to create a predisposition by analysts, engineers, managers, users and decisionmakers to accept the approach?

WORKING GROUP MEMBERS:

Mr. Martin Meth OASD

FIGURE A-18. Diagnostics--Statement of Work and Working Group Members

121/3-21

APPENDIX B

TECHNOLOGY ASSESSMENT AND ANALYSIS OF REQUIREMENTS
(SYSTEM TO COMPONENT)

123/1-51

APPENDIX B

TECHNOLOGY ASSESSMENT AND ANALYSIS OF REQUIREMENTS (SYSTEM TO COMPONENT)

A. OVERVIEW

This appendix describes the review of documents to establish future weapon system reliability and maintainability (R&M) needs and the techniques used to assess the potential impact of technology on those R&M needs. A discussion of the Service's perceived needs is followed by an explanation of the methods used to quantify and evaluate present and future weapon system performance. Primarily, two such methods were used. The first was that of functional element groups (FEG), which relate technology impacts by functional groups such as electronics, propulsion and structures. Second was the idea of subsystem hierarchy, where a model is developed from a top-down approach to determine the overall impact of each component level technology enhancement.

1. Future Force Requirements

A number of studies and point papers, broadly classed as "Year 2000 Studies," were reviewed in order to examine the proposed range of operational requirements which may be imposed on weapon systems in the future. This review examined how future needs drive improved R&M capabilities of systems, equipment, components and people. The source documents (see Appendix B reference list) used in review include a cross-section of DoD and industry studies, and show a broad consensus across the spectra of services and missions concerning the requirements imposed on people and equipment by the battle scenarios of the not-distant future.

123/1-1

2. Year 2000 Requirements and Implications

With the "Year 2000" studies taken as a consensus of current thinking on future requirements, it is clear that significant improvement in weapon system reliability and maintainability characteristics is needed. Even though the debate continues on the effect of complexity on readiness and cost of operation, there is agreement that the increasing capability and diversity of the threats faced by U.S. forces drive weapon systems to higher levels of effectiveness and consequent complexity. Well-known demographic projections will constrain the quality and quantity of the "people pool" available to operate and maintain equipment. The implications of the cumulative effect of the acquisition and fielding of ever-more-complex hardware, software, and attendant support systems run counter to the need for weapon systems which are capable of extended, dispersed operations while less closely tied to the "support tail." Though much has not yet been quantified, it seems clear that meeting operational objectives in an affordable manner requires quantum increases in weapon system reliability and maintainability.

3. Mission Scenarios

The combat scenarios have a number of common themes which directly impact the readiness and sustainability needs of future forces. Despite the fact that there is wide recognition of the need for intense rates of operation of combat systems in at least the initial phases of a war, there is not a great deal of attention paid to the necessary span of time in which surge conditions must be met and sustained by our fighting units in order to survive and win. Key questions, then, are how long must combat operations be sustained, at what rates, and how long can they be currently sustained. There is general agreement that weapon systems must

123/1-2

become more reliable, more maintainable, more supportable, etc., but there is not much quantitative data, data analyses and extrapolations that provide meaningful goals or objectives in quantified terms.

4. Environment and Capability

The missions, battle areas and conditions which seem likely to be encountered impose the necessity for endurance of intense, extremely mobile and violent operations with rapid expenditure of high-value munitions and resources and probable high rates of attrition. Compared to the present, future battles will require forces to be capable of operations with units more widely dispersed over distance and time. Units will have to mass to concentrate firepower and disperse quickly to survive. The battle environment has the potential to be extremely dirty with units undertaking combat in heavy nuclear, biological and chemical conditions.

It is also necessary to consider the effects of low-intensity, high-threat warfare made more likely by the acquisition of modern weapons throughout the world. The defensive systems of a naval vessel or battle group must be capable of dealing with isolated actions by unfriendly governments or terrorist organizations on a sustained basis.

5. Mission Equipment

As the threat increases both quantitatively and qualitatively in the coming years, weapon systems must become ever more capable. Each new or enhanced dimension of the threat requires some added capability in a system. The net effect over time is an ever-increasing range and diversity of different types of mission equipment and functional subsystems which must be maintained. The increase in capability invariably means an increase in weapon system complexity with the concomitant ripple effect through the support system. As weapon systems have grown in complexity and capability, they have, in some instances, also tended to become more reliable and maintainable than predecessor systems (Ref. B-1). The proper concern is with the cumulative effect of the projected complexity of systems and equipments proposed for acquisition over the coming decade; that is, that the R&M characteristics of developing systems and modified existing weapons must be managed carefully and comprehensively to avoid an overwhelming net effect. While readiness is only one factor in combat capability, it is a central one. The R&M parameters of weapon systems and their attendant maintenance and support equipment and personnel are directly influenced by equipment complexity and increased functional capability. These factors must be analyzed in order to identify barriers to sustained performance, assess limits of endurance, and derive indicators of where to apply technological improvements to the greatest advantage.

6. Mission Needs

A pertinent study (Ref. B-2) foresees ground and air forces engaged in combat over a very wide front and perhaps to a depth of several hundred kilometers. Units would require capability to operate and engage the enemy in a continuous, all-weather, round-the-clock, dirty battlefield scenario with surges in excess of 72 hours. Equipment will require longer endurance, lighter weight, and be maintenance-free over extended combat periods of one to four weeks. The units must operate on a dispersed tactical front with a greater proportion of smart weapons capable of multi-target engagement in fire-and-forget modes in an independent, sustained battle. The requirements for maintenance of equipment, battle damage repair, resupply, retrograde of repairables, surveillance, target acquisition, damage assessment, and battle management are virtually overwhelming in such a scenario. Even so, all forecasts of future demands contain these common elements and features. In such a scenario as this, it is easy to determine that substantial improvements in logistics (spares and repair capability) would not be as beneficial as improvements in reliability and the sustainability of weapon systems to operate for extended periods of time.

Scenarios such as these highlight the need for greatly increased weapon system reliability and maintainability. Battle management will require more sensors of all kinds and greatly increased capability in real-time capture, processing, and distribution of data at all echelons of command. The quantity and capability of data processors and displays will proliferate with attendant demands for trained operators and maintenance personnel for the equipment. The necessity for integration of air defense and air space management compounds the difficulty faced by military planners, commanders, and soldiers. Applications of artificial intelligence and robotics are seen as key technologies in such scenarios. Modularity and commonality across families of vehicles and other systems are seen as avenues to increased maintainability. It may be that a form of automated equipment status and diagnosis capability is possible. Such a system has the potential to enable maintenance of systems by the operators.

A need is foreseen for a C^3L system capable of communicating system configuration and status conditions, such as the Navy's Advanced Logistics Control Network (ALCON) system, which has undergone sporadic, low-level development for the past several years. The C^3L system would, in some scenarios, automatically monitor and communicate inventory levels, resupply needs, and maintenance requirements. Such a C^3L system could be coupled with applications of robotics for some equipment handling and resupply functions in efforts to improve efficiency and responsiveness of the support system.

123/1-5

Navy studies (Refs. B-3 and B-4) have explored the implications of the multi-dimensional sea battle problem posed for fleet defense. Battle groups centered on aircraft carriers or battleships face perplexing problems in opposing attacks by long-range cruise missile equipped air, surface, and sub-surface weapon systems. Sensor and C^3I system requirements border on the astonishing and successful repulsion of massed, multi-directional attacks on fleet units requiring quick and accurate reaction times of weapon systems with heavy expenditures of high-value weapons. Studies call for the fleet units to be capable of highly-integrated operations while dispersed to the maximum extent possible. The trends evident today will only intensify, and as the threat of extended-range cruise missiles capable of being launched from a variety of platforms becomes a reality, the layers and permeability of fleet defense will become ever more dependent upon reliable, redundant, overlapping defensive and offensive weaponry, C^3I systems and sensors. The continuous operational availability of defensive weapon systems will be imperative.

Air Force scenarios (Ref. 5) projecting mission utilization for tactical aircraft tend to key on the 4S concept of Speed, Stealth, STOL (Short Take-Off and Landing) and Support and explore the projected need for very high sustained sortie generation rates. The mix of forces and missions is not seen to change significantly from those tasked presently but increased sortie rates and weapon capability are seen to be necessary. It is quite possible that aircraft will need to be capable of extended periods of operation, free from maintenance other than servicing and re-arming and to be able to do so from bare bases chosen from necessity or opportunity. Various explorations of the need for increased capability per weapon platform and increased sortie capability in ever more stressful environments tend to generate system reliability requirements of three to five mean flight hours between failures and eight to eleven maintenance manhours per flight hour with overall 80% to 90% readiness rates. Surge requirements are four to five sorties per aircraft per day for three to seven days with requirements then tapering but still very intensive, depending on assumptions on success rates and attrition of opposing forces. Again, the need to operate in dispersed modes independent of the logistics system for long periods places a premium on reliability, redundancy and real-time reconfiguration.

7. Projections and Limiters

The consensus across a wide range of independent evaluations of future requirements in land, sea and air battle scenarios is that capability and performance of weapons must continue to expand and that weapon and support systems must become more reliable, more maintainable, and less demanding of support resources. Recent DoD and industry initiatives have provided a growing recognition of the need for management attention and application of resources to the resolution of the cross-currents of the conflicting demands of the scenarios. A common feature of many studies is the recognition of the need for increased capability and distribution of C^3I assets and the creation of C^3I systems in the intensive electronic warfare (EW) environment of a battle. The capability of operators and equipment to cope with incredibly heavy streams of data under battle-stressed conditions is simply unclear at this point even though many scenarios are almost totally dependent upon this capability.

A salient feature of the sustained performance equation is the necessity to couple high mission rates with operations from dispersed sites. The technology advances necessary to provide the increased capability for more exotic performance of systems drives the related support equipment and skill-level capability and complexity. Economies of scale in maintenance systems tend to be diluted when the queuing of systems is dispersed. Such scenarios drive toward the necessity of mobile maintenance teams with dedicated communications, transportation, and some measure of self-defense as the retrograde problem becomes ever more difficult with greater degrees of dispersal. The economics of support of dispersed weapon systems can become burdensome and even prohibitive beyond certain points as demonstrated in the Sea-Based Air Logistics Study (Ref. B-6). Rigorous analytic investigation of points of diminishing or vanishing return is necessary for force planners tempted to advocate dispersal tactics for the complex systems of the future.

8. Readiness Rates

Required operational availability rates for weapon systems have been confined to tactical systems in the "Year 2000" studies reviewed for this report. Fielded equipment readiness rates are seen to be an increasingly important force multiplier in the years ahead, since virtually all studies contain requirements for improved readiness figures ranging from 80-95% for mobile ground systems, fire control systems, missile systems and C^3I equipment. Tactical aircraft availability requirements range from 80-90%, as compared to a current weighted average of 54-57%. All of the weapon systems and attendant support systems, whether ground, air or sea-based will require system populations able to attain and sustain virtually a 100% availability rate for significant periods of time.

9. Sortie Rates

The increased availability is contingent upon the perceived need for high sustained sortie generation rates for weapon systems.

For instance, one tactical aircraft scenario (Ref. B-5) foresees the need for the capability figures shown in of Table B-1. These compare to current requirements of .5 sorties/day to as many as 3 sorties/day for some aircraft in mobilization/surge exercises. Such a scenario requirement is the rule, not the exception, in the studies and is common across literally all families of equipment. Such sortie rates can only be met by greatly improved system reliability and by maintainability levels which enable rapid and efficient maintenance. When the sortie rates are combined with the requirement for dispersal of combat units and the commonly accepted demographic projection, the equation becomes formidable.

TABLE B-1. SORTIE GENERATION RATE

D-Day to D+6	5.0 sorties/acft/day
D+7 to D+29	4.5 sorties/acft/day
D+30 to D+59	4.0 sorties/acft/day
D+60 on	3.5 sorties/acft/day

123/1-9

B. ANALYSIS AND ASSESSMENT OF REQUIREMENT

Some investigations have been done on tactical aircraft reliability levels which have attempted to evaluate both what is necessary and what is technically feasible. These coupled with maintenance data of current inventory aircraft were used in analysis to project R&M needs and the ability of technology to fill those needs.

1. Functional Element Groups

The first method of evaluation used was that of functional element groups (FEG). The contention was that both technology and aircraft subsystems may be grouped by function, such as electronics, propulsion, and structures. There is a direct interface of the like functions between subsystems and technologies in addition to indirect interactions. Through a system of unlayering tasks we were able to identify a means by which the impact of technology on each subsystem could be assessed. Table B-2 provides a listing of the FEG breakout and indicates the percent of maintenance workload presently attributed to each functional area.

As can be seen, 82 percent of the maintenance currently performed on aircraft is due to the three FEGs of structures, electronics and propulsion. Because of this, we focused our investigation in these three areas.

An initial assessment using the FEG methodology was accomplished to baseline R&M needs for future aircraft. This baseline was developed using current inventory fighter aircraft and both Navy (Sea-Based Air study) and Air Force (Advanced Tactical Fighter) projections. Data for the inventory aircraft was extracted from the

TABLE B-2. FIGHTER AIRCRAFT FUNCTIONAL ELEMENT GROUPS

WUC	Nomenclature	FEG	PERCENT WORKLOAD
11	Airframe		
12	Crew Station	Structures	30
13	Landing Gear		
14	Flight Controls		
23	Engine		
24	Auxiliary Power	Propulsion	22
29	Propulsion Installation		
51	Instruments		
55/58	Malfunction Analysis		
62	VHF		
63	UHF		
64	Interphone		
65	IFF	Electronics	30
71	Radio Nav		
72	Radar Nav		
73	Bomb Nav		
74	Fire Control		
75	Weapons Delivery		
76	Penetration Aids/ECM		
41	ECS		
42	Electrical Power		
44	Lighting		
45	Hydraulic/Pneumatic		
46	Fuels		
47	Liquid Oxygen	Miscellaneous	18
49	Misc. Utilities		
91	Emergency Equipment		
93	Drag Chute		
96	Personnel Equipment		
97	Explosive Devices		

123/1-11

Service's maintenance data collection system (MDCS), while the data used for the ATF and the SBA are speculation. For comparative purposes, the data collection and reduction techniques used by the Air Force to define mean flight hours between inherent maintenance and the Navy's mean flight hours between verified failures are considered equivalent.

An initial assessment to approximate current reliability growth trends was completed using the data of Table B-3. These data are a reflection of the current MTBF experience for inventory fighter aircraft which have been developed over the past several years. Also included in Table B-3 are the potential requirements of future fighters for both the Air Force and Navy. The data are presented in ascending order by date of initial operational capability for each aircraft. In each functional element group (FEG) there is an obvious growth trend which is somewhat promising. The question, however, is whether the growth rate is rapid enough to make the transition from the latest technology weapon (F-16, F/A-18 vintage) to the potential requirements. To quantify this growth trend, growth factors between individual weapon systems and the average growth for each FEG have been calculated with results as displayed in Table B-4.

Using the average growth factors for each functional group, it is reasonable to expect that evolutionary development efforts will likely produce engines to meet the next generation requirements as depicted by the ATF, while structures and electronics will likely experience a shortfall in achieving the stated need with electronics being seriously deficient.

For example, when the current best propulsion MTBF is compared to the next generation requirement (17.24 to 19.71) as shown in Table B-3, and the average growth factor of 1.34 from Table B-4 is applied, propulsion systems can be expected to exceed requirements by a safe margin if propulsion trends continue to improve as expected. Using the same methodology to compare structures

TABLE B-3. Fighter Aircraft MTBF By Year of Introduction

AIRCRAFT	YEAR	PROPULSION	STRUCTURE	ELECTRONIC	TOTAL
F-111	1965	5.50	1.43	1.54	0.65
F-14	1972	7.07	1.59	1.68	0.73
F-15	1973	10.17	3.69	3.76	1.56
F-16	1975	12.00	5.81	6.76	2.48
F/A-18*	1979	17.24	3.05	3.84	1.54
ATF	1995	19.71	9.00	24.90	4.95
SBA	2000	30.13	8.90	17.20	4.91

*Not a mature system

TABLE B-4. Fighter Aircraft Growth Factors

AIRCRAFT	PROPULSION	STRUCTURES	ELECTRONICS	TOTAL
F-111-->F-14	1.28	1.11	1.09	1.12
F-14--->F-15	1.44	2.32	2.24	2.14
F-15--->F-16	1.18	1.57	1.80	1.59
F-16--->F/A-18	1.44	.52	.57	.62
AVERAGE GROWTH	1.34	1.38	1.43	1.37

130/9-1

and electronics, a shortfall of approximately 1 hour, or 30 percent of the growth needed to achieve the 9 hour requirement, is apparent for the structures FEG. For electronics, the shortfall is more dramatic. From the current best system MTBF of 6.76 hours (see F-16, Table B-3) to the required 24.9, a higher order of growth than the 1.43 shown for electronics in Table B-4 is required. Using the average growth experienced for electronics as shown in Table B-4, a shortfall of approximately 15 hours can be expected.

As a result, if one must rely on historical growth patterns that are evident from the evolutionary trends seen in Table B-4, deficiencies in satisfying the next generation requirements for both structures and electronics systems should be anticipated.

2. Technology Assessment

The gap between future weapon system requirements and status quo growth potential indicated by the initial FEG analyses became the object of further investigation. Our goal was to determine what technological advancements could have the greatest impact on subsystem and system R&M requirements.

To make a determination of technological impact, it was first necessary to define the relationship of technology to each FEG. This was accomplished by what was called the unlayering task. In a manner similar to the development of subsystem FEGs, Technology Functional Groups were formed as shown in Figure B-2.

TECHNOLOGY	FUNCTION
VHSIC, EPIC, PWR SPLY, Fiber Optics, C&C	Electronics
AI, Diagnostics, MSCM, Testing Tech	Testing
Composites, NDE	Structures
MPT, Software, DE, CAD/CAM, ISOM	Systemic

FIGURE B-2. Technology Functional Groups

As has been illustrated by earlier sections, an overall operational readiness improvement is not only vitally needed, but also must be sustained for long periods of use with very little access for maintenance purposes. To be able to realize these needed improvements, a translation must be performed between individual weapon system requirements as categorized and expressed by the individual work unit codes (WUC) into the specific technologies that comprise that particular WUC. That is, the WUC's requirements must be broken down into the technologies that can be applied effectively to increase the weapon system performance to the required levels. This task is illustrated by Figure B-3. Once performed, a realistic assessment can be performed and return on investment (ROI) can be properly analyzed. Synergism can be expected with technology improvements and with the application of technological improvements for the enhancement of R&M. Individually applied, many technologies can make incremental improvements, but properly coupled and inserted under management planning and direction, they can make quantum increases in overall force effectiveness.

123/1-16

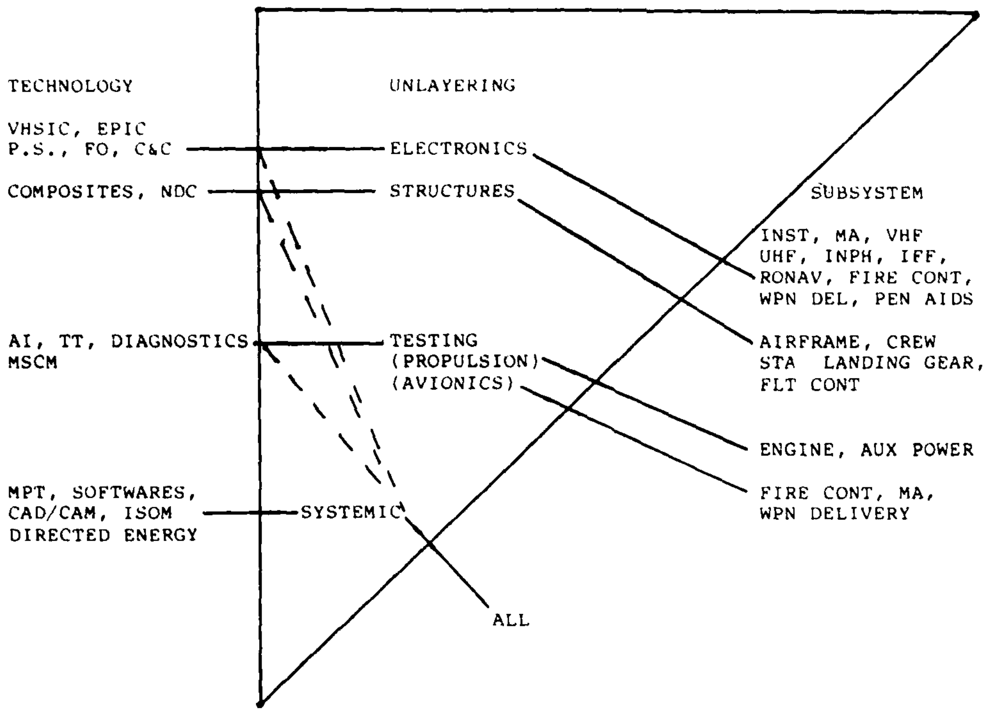

FIGURE B-3. Unlayering Task

New technologies and significant enhancements to existing technology have been developed and applied to products with little thought given to R&M considerations. Rather, primary emphasis has been given to performance enhancements. In fact, DoD weapon systems are rapidly becoming increasingly sophisticated and complex due to weapon system performance demands. There is always a corresponding requirement to sustain and maintain performance levels at acceptable readiness rates with affordable costs. Technology advances have primarily been evolutionary and incremental in nature with an occasional revolutionary development such as the integrated circuit. During the last two decades, however, application of new

123/1-17

weapon system technology has been advancing at such an explosive rate that the present "in-place" maintenance activities will be hard-pressed to keep pace with modern weapon systems. A concerted effort must be organized and planned such that proper R&M applications and forethought can be applied at the proper time, both in technology development and in application of that development. With the increase in weapon system complexity, proper partitioning of hardware and software to enhance "transparency" and overall simplicity of operations and maintenance must be emphasized in the early design phases of future weapon systems.

As a step in the direction of intelligent application of technology we assessed current maintenance drivers to get a feel for the target of technological impact. Table B-5 lists the top 10 maintenance drivers for the F-16, F-18 and E-3A aircraft. A cursory overview of the data is all that is needed to recognize that high payoff potential exists in the areas of electronics, structures and propulsion.

3. System Hierarchy View (Aircraft)

Functional element groups and unlayering provide an insight to where and how technology should be applied but are not adequate measures of the impact technology has on either R&M or readiness. In an effort to evaluate technological impact from a bottoms-up approach, a WUC hierarchical structured model was constructed. This WUC structure was used to assess data at the level which would be most directly affected by technology. For each technological area under investigation, a baseline was determined from existing data and compared to the future requirements to establish the potential improvement needed within the technology. An assessment of the potential of each technology to fulfill the required need could then be performed.

Table B-5. TOP 10 MAINTENANCE DRIVERS

F-16 Sub-system	Percent Total Main-tenance	F-18 Sub-system	Percent Total Main-tenance	E-3A Sub-system	Percent Total Main-tenance
Engine	15	Weapon cont	17	Radar	10.6
Fire Control Systems	12	Airframe	16	Computers	10.2
Airframe	12	Landing Gear	11	ECS	6.5
Landing Gear	7	Flt Cont	7	Airframe	6.3
Flt Cont	7	Electrical	7	Flt Cont	5.7
Weap Del	7	Fuel	6	Landing Gear	5.2
Aux Pwr	7	Weapon Del	5	Propulsion	5.2
Fuel Sys	6	ECS	5	UHF	4.3
Crew Sta	4	Lighting	3	Intercom	4.2
Pen Aids	4.0	Propulsion Inst	3	Electrical	3.7
	81		80		61.9

The bottoms-up assessment of technological impact on readiness was deemed necessary to determine the impact of technology at the component level, and to express that impact in terms of the "black box" subsystem and finally the entire weapon system. In addition to the quantitative assessments of how technology can affect readiness, graphic expressions of the data are presented as Figures B-4 through B-8. Figure B-4 represents the entire weapon system. In this case, the F-16 fighter aircraft current reliability is displayed. Mean-time-between-maintenance (MTBM) is the parameter used to express subsystem level reliability in this example. Each block within the large frame represents a homogeneous group of subsystems. Block A, for example, includes the airframe and associated subsystems; Block B is the power plant; Block C is the avionics, etc. The numbers within each block indicate the MTBM for each group of subsystems and the percentage of these subsystem's contribution to weapon system maintenance requirements. As can be seen, a technology directed toward improving reliability in Groups A, B and C has potential for a substantial impact while improving D, E and F will provide lesser gains in overall weapon system reliability.

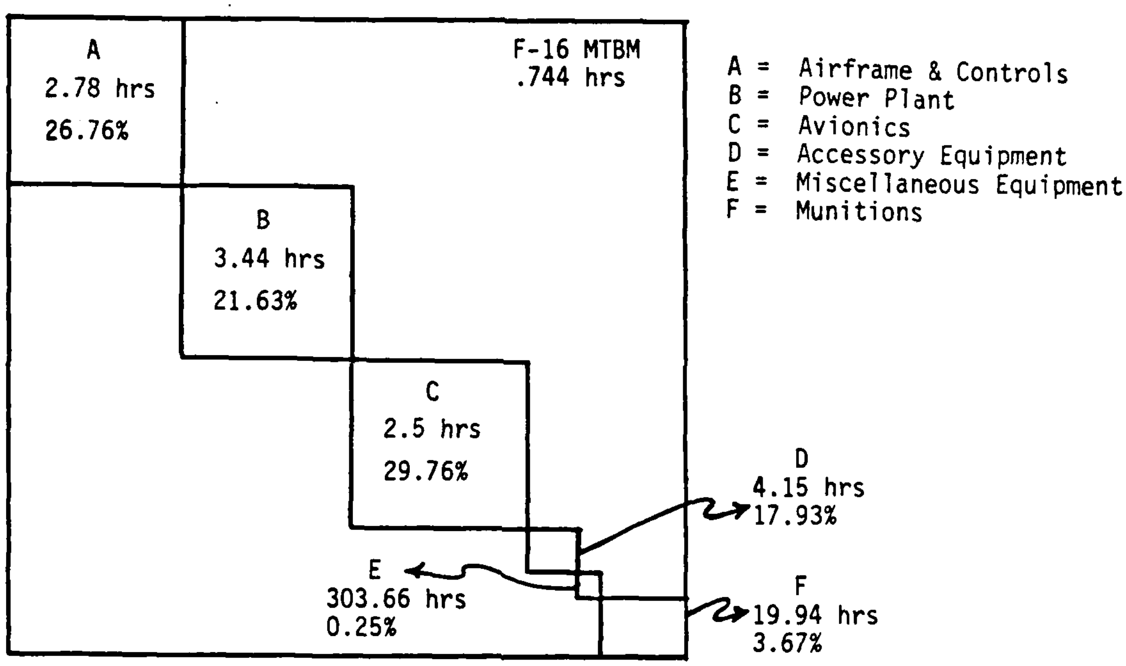

FIGURE B-4. Weapon System Reliability

123/1-20

Figure B-5 is the detail of Block C from Figure B-4. This block represents avionics, which is a major contributor to weapon system maintenance requirements and is used here to show how investigation into the cause of maintenance can be conducted. In Figure B-5, each avionics subsystem is represented by a separate block that is sized according to the proportion of workload attributed to that subsystem. As shown, Fire Control is the primary cause of avionics maintenance for the F-16, contributing 42 percent of the workload. In theory, elimination of the Fire Control failures could eliminate 42 percent of the weapon system down time for avionics and this could be a major contribution to improved readiness.

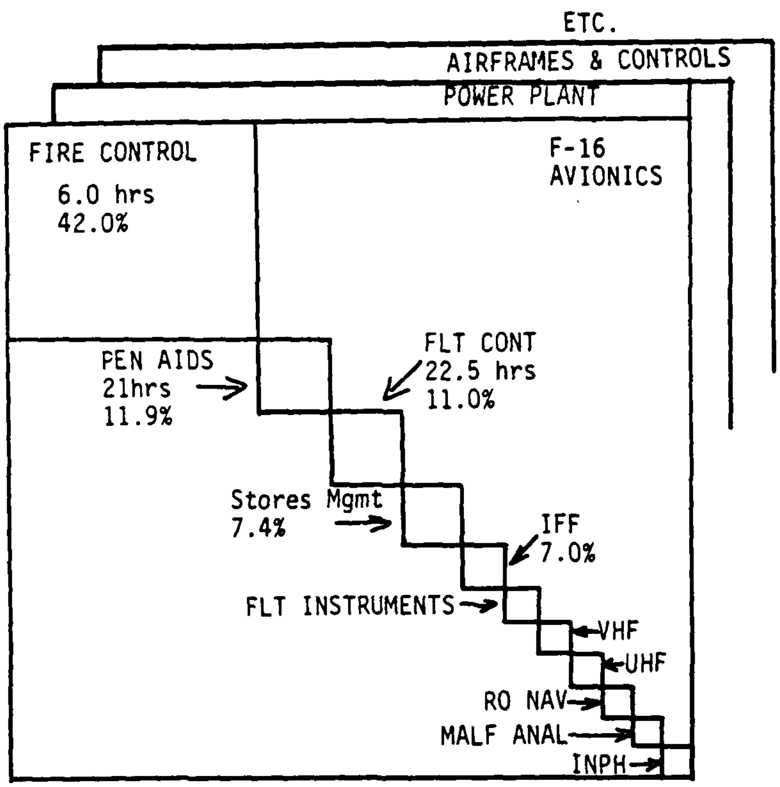

FIGURE B-5. Avionics Subsystem Reliability

123/1-21

The next level or indenture in the investigation is a breakout of the Fire Control system. Now we are down to the "black box" level of the WUC structure and are approaching the level where subsystem design can have an effect. Figure B-6 provides the data and a graphic representation of the Fire Control system where radar is the primary cause of maintenance.

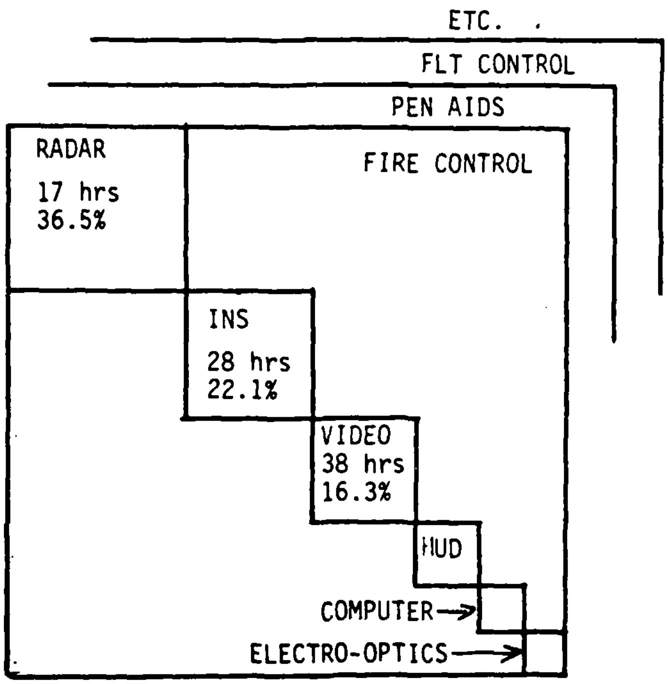

FIGURE B-6. Fire Control Reliability

123/1-22

Within the radar subsystem, there are nine line replaceable units (LRU) which contribute to subsystem reliability. Additionally, maintenance actions coded to "radar set" and not associated to a specific LRU, also contribute to subsystem reliability. This last set of maintenance data, as shown in Table B-6, accounts for 49 percent of the total maintenance actions performed on radar.

TABLE B-6. F-16 RADAR MDCS STATISTICS

WUC	NOMENCLATURE	MAINT ACTS	MTBM	PERCENT TOTAL	PERCENT @ LRU
74AOO	Radar Set	1330	35	49	----
74AAO	Antenna	302	153	11	23
74ABO	LPRF	337	137	13	25
74ACO	Transmitter	217	213	8	16
74ADO	DSP	164	282	6	12
74AFO	Radar Computer	197	234	7	15
74AHO	Control Panel	47	1777	2	4
74AJO	Rack Assy.	21	23095	0.9	1.9
74AKO	Coax. Xmit.	1	46190	0.1	0.1
74ALO	Waveguide	44	2200	2	3

These data, however, cannot be incorporated within the hierarchical structure. Thus, Figure B-7, the graphic display of radar maintenance at the LRU level, only accounts for 51 percent of the radar reliability. This fact becomes extremely important when analyzing the effects of component level technological impacts upon overall reliability and maintainability characteristics.

123/1-23

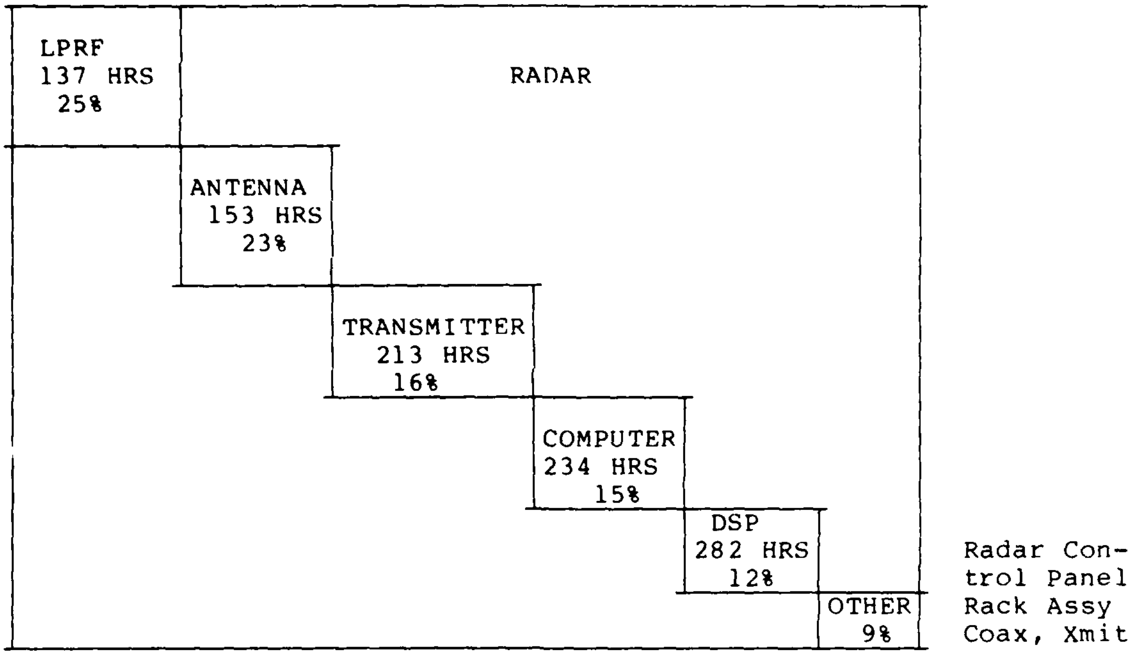

FIGURE B-7. Radar Maintenance at LRU Level

This hierarchy has thus far been traced down into the weapon system's detail to determine which subsystem "black boxes" are the main causes of problems. However, the identity of the specific component parts which cause the "black box" failures must still be determined. Data at this point in the WUC hierarchy often lack an adequate description of what is being done by the maintenance specialist. In the case of the F-16 radar, data that reflect which components were replaced within the "black boxes" were available due to a "reliability improvement warranty" (RIW) program. While this data does not provide a complete picture of the radar repair requirement, it does allow some insight into what type components fail most. The RIW program was employed on the Fire Control Radar and includes the antenna, low power RF, transmitter, digital signal processor, and computer. Data at this level becomes the baseline for the bottoms-up analysis of technology impact.

123/1-24

A common assumption has been that VHSIC will revolutionize avionics and have an enormous effect on weapon system readiness. With this assumption in mind, we looked at how VHSIC will impact the F-16 Fire Control Radar.

The first step in such analysis is to establish the baseline. Using the RIW data for the Digital Signal Processor (the LRU which has the highest potential for incorporation of VHSIC technology) we constructed the final block in the WUC hierarchy structure. As shown in Figure B-8, microelectronic devices (MED) account for 74 percent of the component replacements in the DSP.

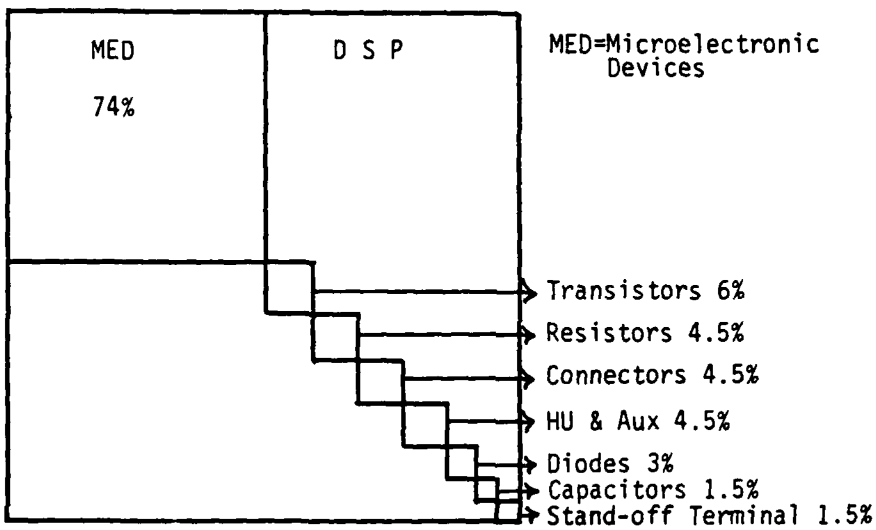

FIGURE B-8. DSP Reliability

With a breakout of data such as this, we can more readily assess the impact of a given technology and evaluate the potential impact of technological advances because of the one-to-one relationship. For example, a MED breakthrough would have a leverage on DSP reliability improvement. It could conceivably eliminate 74 percent

123/1-25

of the DSP failures. As we progress back up through the hierarchy, however, we may find very little effect on the overall subsystem or weapon system.

To illustrate this point, assume that perfect reliability could be achieved for MEDs. Thus, a MED failure would never occur and 74 percent of the current DSP maintenance action would not exist. Table B-7 provides a bottoms-up analysis of how the technological breakthrough would impact the avionics subsystem. As can be seen, an improvement factor of 3.8 at the LRU level translates to only a 1.01 improvement for the entire avionics suite.

TABLE B-7. IMPACT OF NO MED FAILURES ON AVIONICS

SUBSYSTEM/ COMPONENT	CURRENT MTBM	PERFORMANCE #FAIL	IMPROVED MTBM	PERFORMANCE #FAIL	IMPROVEMENT FACTOR
MED	381.7	121	inf	0	inf
DSP	282.0	164	1074.0	43	3.8
Radar	17.0	2717	17.8	2596	1.05
Fire Cont	6.0	7698	6.1	7577	1.02
Avionics	2.5	18476	2.52	18355	1.01

This illustrates a major theme of the findings of this study; that is, very little impact can be made by only improving one subsystem or by applying only limited technology insertions. Rather, a broad full-court press is needed to accomplish meaningful readiness improvements through R&M changes.

123/1-26

4. System Hierarchical View (Tank)

Another example of how the hierarchy approach could be used is illustrated by data extracted from an Army Sample Data Collection (SDC) report on the M-1 tank. In this assessment, the hierarchy structure is coupled with the idea of FEGs. The data collected represent 3325 unscheduled maintenance actions (UMA) performed on 182 M-1 tanks which reported a total mileage of 26,258 miles. The mobility and non-mobility subsystems have been aggregated into the Propulsion, Structures and Electronics functional element groups used earlier. Figure B-9 illustrates the distribution of tank subsystems into FEGs.

PROPULSION	STRUCTURES	ELECTRONICS
Engine	Suspension	Fire Control
Track	Gun/Turret Drive	Mobility Electronics
Transmission	Gun Mount Recoil	Non-mobility Elect
Mobility, Other	GFE Non-Mobility, Other	

FIGURE B-9. Tank FEG Structural Breakout

Figure B-10 depicts the distribution of UMA by FEG for the M-1 tank and Figure B-11 displays the distribution of UMA across the five functional subsystems of the Propulsion FEG. Finally, Figure B-12 shows the distribution of components affected by UMA within the track subsystem of the Propulsion FEG.

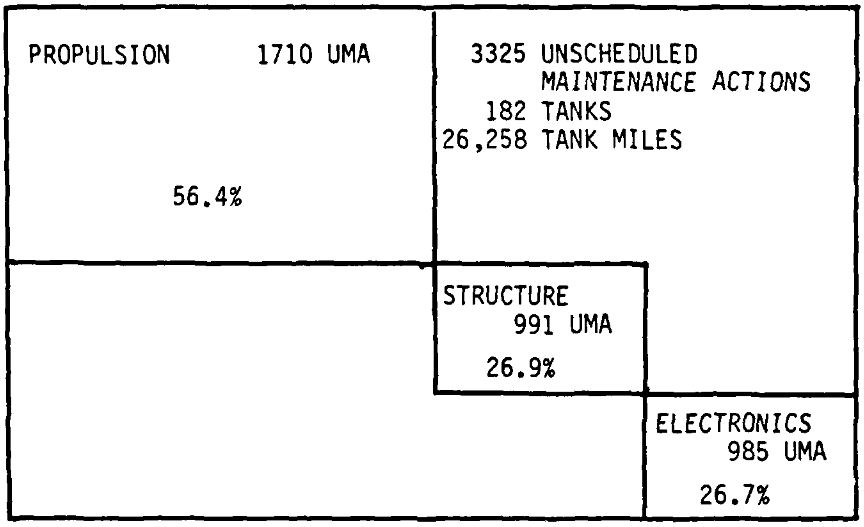

FIGURE B-10. M-1 Tank Unscheduled Maintenance Action Distribution

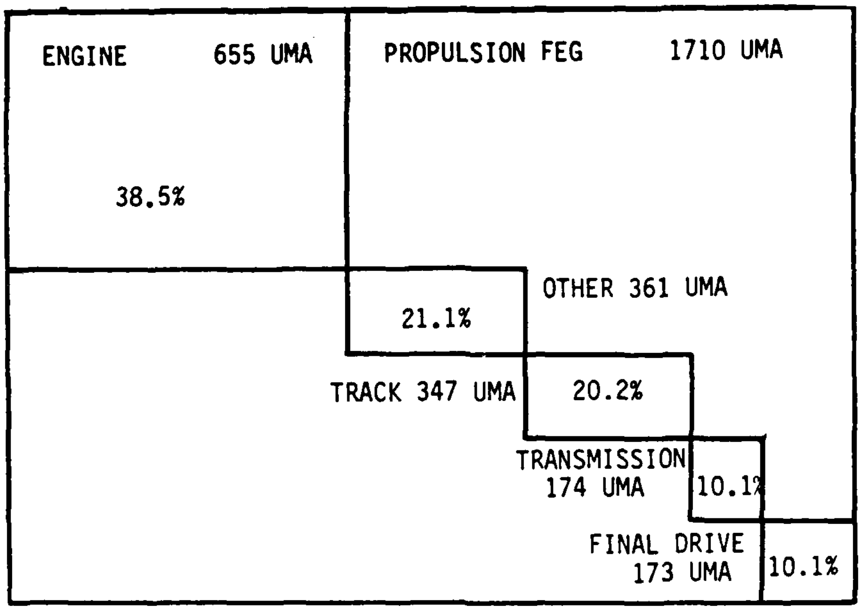

FIGURE B-11. M-1 Tank Propulsion Functional Element Group (FEG)

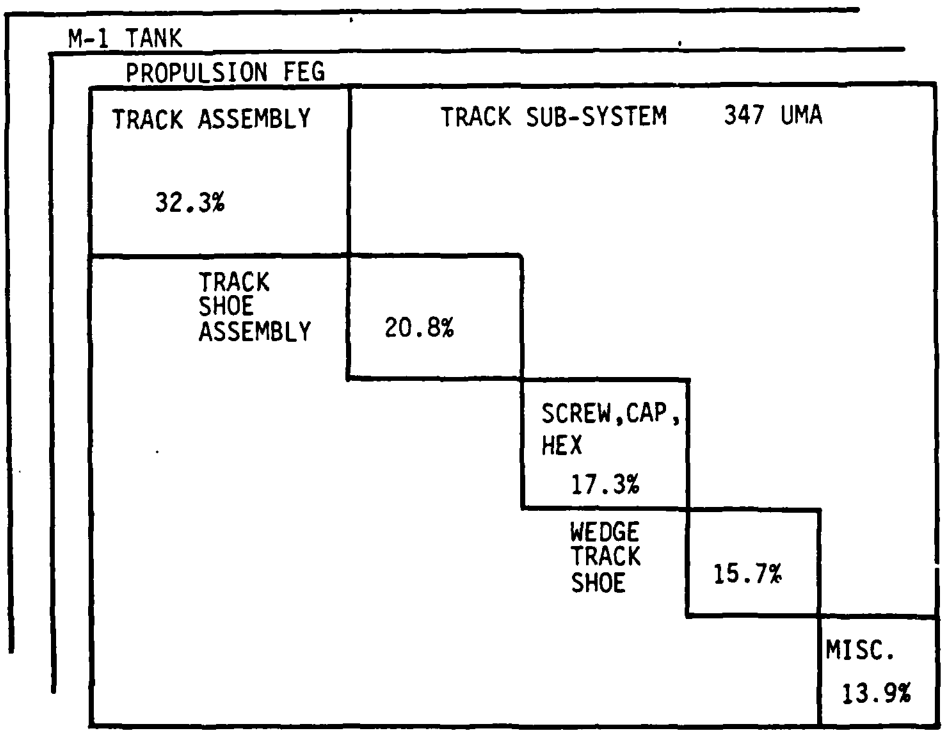

FIGURE B-12. M-1 Tank Subsystem Component Distribution

123/1-29

A breakout of this nature allows for the analysis of a tank in the same manner as the analysis of aircraft. The same could be done for ships, communications equipment or any other class of weaponry.

C. OTHER ANALYSES

As mentioned earlier, not all the analyses accomplished in the assessment of technologies used the same methodology. In fact, the component part breakdown was something of a departure from how data were collected and analyzed for the preceding WUC structured assessments. Although an attempt was made to use this model structure for each technology, it was often inadequate due to an absence of data at the component level. The premise remained, however, that identification of the lowest, most directly influenced, characteristic or component of a subsystem was crucial because a truer picture of the potential impact could be gained through use of the bottoms-up approach to assessment.

1. Weapon System Improvement Needs

The task order for the IDA R&M study uses the term "quantum impact" in defining the desired effect of technologies on readiness. Since "quantum" was undefined, it seemed necessary to determine what improvements in readiness are actually required. In the context of the study, quantum became defined as the measure of needed improvement based upon the "Year 2000" analyses.

Data collection and analysis for determination of need was accomplished by compiling available data estimates of future weapon system reliability requirements and comparing these estimates to current weapon system achieved reliability. A first cut of such data, using Navy projections and current F-16 experience resulted in the data of Table B-8. While there were recognized inconsistencies in this data set, the analysis did provide an initial baseline of need, which was for an overall improvement factor of 6.2. Figure B-13, a graphic display of the improvement needs annotated in Table B-8, gave us a feel for what quantum meant. It has to be realized that this was just an initial attempt to determine the bounds in which we must conduct analyses. The individual WUC figures used here represent a single opinion of how to achieve the 4.5 flight-hour requirement of the Navy study and there is nothing optimal about this assessment.

TABLE B-8. IMPROVEMENT NEEDS BY WUC

WUC	NEED	CURRENT	IMPROVE-MENT	WUC	NEED	CURRENT	IMPROVE-MENT
11	25.8	6	4.3	51	77.2	43	1.8
12	161.6	18	9.0	63	193.3	64	3.0
13	47.3	10	4.7	64	923.2	213	4.3
14	90.7	13	7.0	65	526.3	35	15.0
23	53.9	5	10.8	71	841.3	90	9.3
24	195.8	11	17.8	74	136.2	6	22.7
41	113.1	36	3.1	75	300.7	11	27.3
42	75.8	20	3.8	91	631.0	409	1.5
44	62.8	25	2.5	93	41634.0	8255	5.0
45	98.0	45	2.2	96	14155.6	1179	12.0
46	105.0	12	8.8	97	68696.1	266	258.3
47	361.7	70	5.2				
49	146.6	297	---				
				SYSTEM TOTAL	4.5	0.73	6.2

After this initial assessment, additional analyses were performed to further scope the potential of technology. We realized that weapon systems of the future will have more stringent R&M requirements if the threat projected in the "Year 2000" type analyses is to be countered. To put these requirements in perspective, and in a quantitative framework, fighter aircraft were used as a surrogate for weapons in general. The rationale for such a

123/1-31

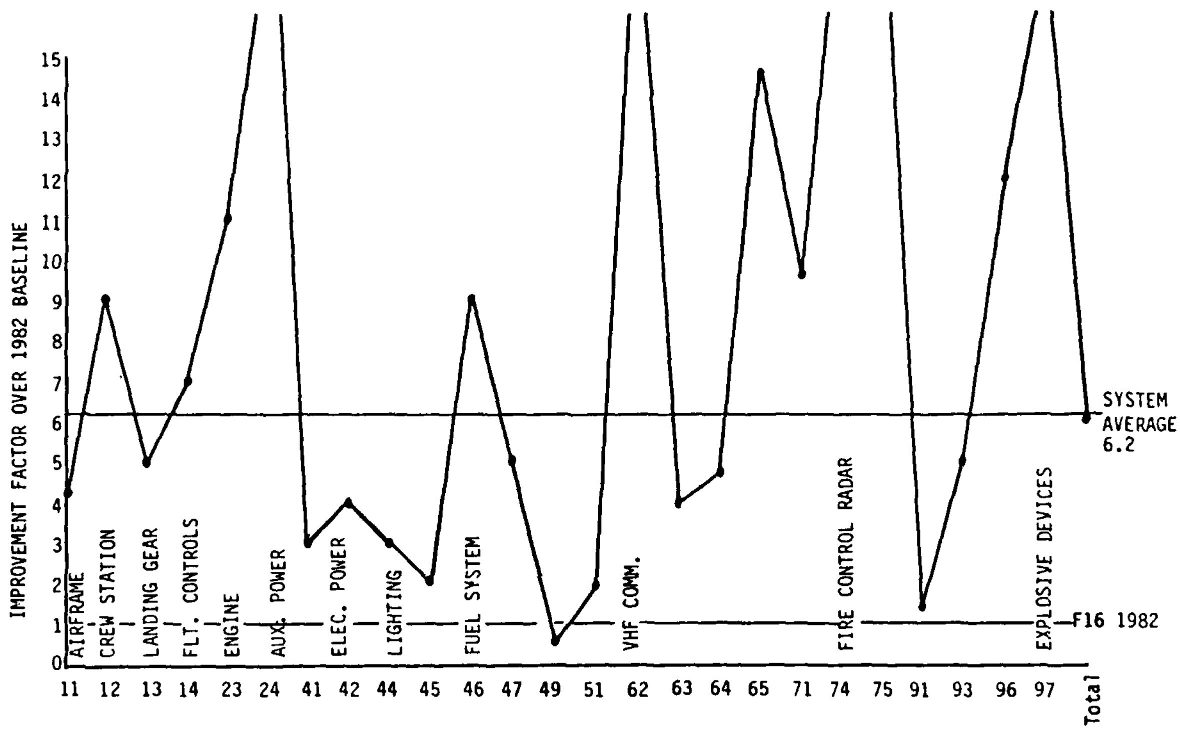

FIGURE B-13. Improvement Needs By WUC

123/1-32

decision was quite simplistic--data were available and fighter aircraft were perceived to be complex, pushing the state-ofthe-art. If an aircraft engine or radar system can be improved through advances in technology, that improvement should be translatable to ground and sea systems.

The data used to determine potential future weapon system need consisted of a Navy study which identified subsystem level MTBF requirements for a notional fighter aircraft, and an Air Force assessment of Advanced Tactical Fighter (ATF). Comparison of these data require extreme caution in that there are differences in weapon system complexity and the definitions of reliability parameters. Additionally, each Service, based upon its unique experience, has a different opinion about what is a required and achievable improvement in reliability at the subsystem level. However, the overall weapon system requirement is fairly consistent as shown in the data of Table B-9. Subsystem reliability requirements projected by each Service yield fighter aircraft with projected MTBF/MTBM of 4.5 and 4.9 flying hours. Because of the differences in these data at the subsystem level, the point estimates of need are not statistically comparable but do identify the Service's perceived goals. To enable evaluation of need, rather than use these point estimates directly, the subsystem level reliability projections were stratified by optimistic, pessimistic and average. Such stratification, also detailed in Table B-9, provided a range of 3.6 to 5.9 flying hours of continuous operations with no maintenance other than servicing as the goal for future fighter aircraft.

Having established a range as the goal for future needs, a similar range to describe present fighter aircraft reliability was needed. Based upon the fact that Navy and Air Force data were used to estimate future needs, current weapon systems in the inventory of each Service were used to develop estimates of present reliability.

The Navy's F-18 and Air Force's F-16 were selected as the platforms upon which to establish a quantitative baseline for current reliability. Selection of these was based upon availability of data

TABLE B-9. NAVY AND AIR FORCE PROJECTED NEEDS

WUC	NOMENCLATURE	NAVY MTBF	AF MTBF	OPTIMISTIC MTBF	AVG MTBF	PESSIMISTIC MTBF
11	Airframe	25.8	31.0	31	28.4	25.8
12	Cockpit	161.6	127.0	161.6	144.3	127.0
13	Landing Gear	47.3	42.0	47.3	44.65	42.0
14	Flt Controls	90.7	75.0	90.7	82.85	75.0
23	Engine	95.4	28.0	95.4	61.7	28.0
24	Auxiliary Pwr	195.8	126.0	195.4	160.9	126.0
29	Prop Inst's	123.8	N/A	123.8	123.8	123.0
41	Env Cont Sys	113.1	88.0	113.1	100.6	88.0
42	Electrical Sys	75.8	402.0	402.0	239.9	75.8
44	Lighting Sys	62.8	173.0	173.0	117.9	62.8
45	Hyd/Pneumatic	98.0	60.0	98.0	79.0	60.0
46	Fuel Sys	105.0	141.0	141.0	123.0	106.0
47	Liq Oxy Sys	361.7	394.0	394.0	377.9	361.7
49	Utilities	146.6	1500.0	1500.0	823.3	146.6
51	Instruments	77.2	236.0	236.0	156.6	77.2
55/58	Malf Recorder	4333.0	8500.00	8500.0	641.65	4333.0
56	Flt Reference	314.0	N/A	314.0	314.0	314.0
57	Integ Guid/Flt Cont	385.6	N/A	385.6	385.6	386.6
62-71	Comm Group	84.9	196.0	196.0	140.5	84.9
72	Radar Nav	839.8	419.0	839.8	629.4	419.0
73	Bomb Nav	322.5	N/A	322.5	322.5	322.5
74	Wpn Control	136.2	108.0	136.2	122.1	108.0
75	Wpn Delivery	300.7	83.0	300.7	191.9	83.0
76	ECM	219.5	215.0	215.0	217.3	219.5
91	Emergency Equip	631.0	N/A	631.0	631.0	631.0
96	Personnel Equip	1455.6	N/A	14155.6	14155.6	14155.6
97	Explosive Dev	68696.1	N/A	68696.1	68696.1	68696.1
	TOTALS	4.5	4.9	5.9	5.0	3.6

123/1-34

and recognition that these were the weapon systems used by each Service wh... extrapolating for future needs. A quantitative comparison of the reliability characteristics for these aircraft would be difficult due to obvious differences in complexity and maturity. Both systems are the newest for their respective services but the F-18 is more complex and has not yet reached maturity. The objective of analysis, however, is not to compare systems but to approximate current weapon system reliability. Therefore, use of these two systems seemed reasonable since they represent a broad spectrum of complexity and state-of-the-art technology.

Using the same procedure as used for estimations of future needs, the data of Table B-10 were extracted from the Service's maintenance data collection systems. Once again, there is reason for scrutiny. The F-18 data came from the 3M data system via the Navy's Sea-Based Air Logistics study, while the F-16 data were extracted from D056B (one format of Air Force MDCS) for the period of 1 October 1982 through 31 March 1983. Although the F-18 data are annotated as MTBF and the F-16 data are inherent MTBM, through discussions with Navy and Air Force logistics analysts, it was determined that these terms were consistent.

As in the projection analysis, data were stratified by optimistic, pessimistic, and average to provide a model of current achieved reliability. Under these assumptions a baseline weapon system of 1.2 to 2.6 flying hours was established.

With future needs and current achievements established, it was possible to determine more precisely the improvement factor which would allow attainment of the goal. Again, the method of analysis remained the same by stratifying the needed improvement. Once the improvement factors were identified as shown in Table B-11, the most stringent was selected for use in determining the overall improvement required. As illustrated in Table B-11, the overall range of improvement needs is bounded by improvement factors of 1.31 and 31.3. This translates to the fact that some systems require

TABLE B-10. NAVY F-18 AND AIR FORCE F-16 FAILURE DATA

WUC	NOMENCLATURE	NAVY MTBF	AF MTBF	OPTIMISTIC MTBF	AVG MTBF	PESSIMISTIC MTBF
11	Airframe	8.6	101.0	101.0	54.8	8.6
12	Cockpit	80.6	86.0	86.0	83.3	80.6
13	Landing Gear	13.2	24.0	24.0	18.6	13.2
14	Flt Controls	18.8	34.0	34.	26.4	18.8
23	Engine	84.4	16.0	84.4	50.2	16.0
24	Auxiliary Pwr	96.5	48.0	96.5	72.3	48.0
29	Prop Inst's	42.6	N/A	42.6	42.6	42.6
41	Env Cont Sys	30.4	111.0	111.0	70.7	30.4
42	Electrical Sys	21.3	68.0	68.0	44.7	21.3
44	Lighting Sys	40.5	39.0	40.5	39.8	39.0
45	Hyd/Pneumatic	81.3	128.0	128.0	104.7	81.3
46	Fuel Sys	23.0	45.0	45.0	34.0	23.0
47	Liq Oxy Sys	168.8	217.0	217.0	192.9	168.8
49	Utilities	137.2	2251.0	2251.0	1194.1	137.2
51	Instruments	105.8	96.0	105.8	100.9	96.0
55/58	Malf Recorder	143.9	1651.0	1651.0	897.5	143.9
56	Flt Reference	186.8	N/A	186.8	186.8	186.8
57	Integ Guid/Flt Cont	81.3	N/A	81.3	81.3	81.3
62-71	Comm Group	37.7	24.8	37.7	31.3	24.8
72	Radar Nav	258.2	N/A	258.2	258.2	258.2
73	Bomb Nav	49.9	N/A	49.9	49.9	49.9
74	Wpn Control	8.4	19.0	19.0	13.7	8.4
75	Wpn Delivery	27.3	40.0	40.0	33.7	27.3
76	ECM	219.5	53.0	219.5	136.3	53.0
91	Emergency Equip	731.7	4503.0	4503.0	2617.4	731.7
96	Personnel Equip	4390.0	1981.0	4390.0	3185.5	1981.0
97	Explosive Dev	2195.0	2752.0	2752.0	2473.5	2195.0
	TOTALS	1.4	2.5	2.6	2.5	1.2

123/1-36

TABLE B-11. IMPROVEMENT FACTOR ESTIMATION

WUC	NEED	PESSIMISTIC CURRENT	IMPROVEMENT FACTOR	NEED	OPTIMISTIC CURRENT	IMPROVEMENT FACTOR	GREATEST IMPROVEMENT FACTOR
11	25.8	8.6	3.0	31	101	-3.25	3.0
12	127.0	80.6	1.58	161.6	86	1.88	1.88
13	42	13.2	3.18	47.3	24	1.97	3.18
14	75	18.8	3.99	90.7	34	2.67	3.99
23	28	16	1.75	95.4	84.4	1.13	1.75
24	126	48	2.63	195.8	96.5	2.03	2.63
29	123.8	42.6	2.91	123.8	42.6	2.91	2.91
41	88	30.4	2.89	113.1	111	1.02	2.89
42	75.8	21.3	3.56	402.0	68	5.91	5.91
44	62.8	39	1.61	173	40.5	4.27	4.27
45	60	81.3	-1.36	98	128	-1.31	-1.31
46	105	23	4.57	141	45	3.13	4.57
47	361.7	168.8	2.14	394	217	1.82	2.14
49	146.6	137.2	1.07	1500	2251	-1.50	1.07
51	77.2	96	-1.24	236	105.8	2.25	2.25
55	4333	143.9	30.11	8500	1651	5.15	30.11
56	314	186.8	1.68	314	186.8	1.68	1.68
57	385.6	81.3	4.74	385.6	81.3	4.74	4.74
62-71	84.9	20.8	4.08	196.0	37.7	5.20	5.20
72	419	258.2	1.62	839	258.2	3.25	3.25
73	322.5	49.9	6.46	322.5	49.9	6.46	6.46
74	108	8.4	12.86	136.2	19	7.17	12.86
75	83	27.3	3.04	300.7	40	7.52	7.52
76	215	53	4.06	215	219.5	-1.02	4.06
91	631	731.7	-1.16	631	4503	-7.14	-1.16
96	14155.6	1981	7.15	14155.6	4390	3.22	7.15
97	68696.1	2195	31.30	68696.1	2752	24.96	31.30

little improvement while others require a considerable increase in reliability. However, if we look across the board at subsystem improvement, increasing subsystem reliability by a factor of 5.715 seems necessary. This figure substantiates our initial estimate of a factor of 6 being needed. Again, however, it does not incorporate any optimization and in reality would provide a weapon system that far exceeds the goal as shown by the computations of Table B-12, which applies the 5.715 factor to the F-16, resulting in a 13.96 flying hour aircraft.

Results of analysis such as this solidified our feeling that a generic, averaging approach to technology impact was not as beneficial as the direct approach used by FEGs and WUC hierarchies. The analysis was not wasted, however, because it did provide insight into the problems to be encountered in assessing technology impacts.

TABLE B-12. APPLYING GROWTH FACTOR TO THE F-16

Using average factor growth would result in the following:

WUC	MTBF
11	577.22
12	491.49
13	137.16
14	194.31
23	91.44
24	274.32
41	634.37
42	388.62
44	222.89
45	731.52
46	257.18
47	1240.16
49	12864.47
51	548.64
55	9435.47
62	668.66
63	697.23
64	2886.08
65	331.47
71	1331.60
74	108.59
75	228.60
76	302.90
91	25734.65
96	11321.42
97	15727.68
TOTAL =	13.96

123/1-39

D. INDIVIDUAL TECHNOLOGY ASSESSMENTS

With future needs identified, the technology gap estimated, and the relationship of technology to weapon subsystem functional groups established, the assessment of technology impact on readiness began. As specific technology/weapon system relationships were addressed, special data collection and analysis efforts were expended. Following is a discussion of those specific attempts to unravel data and accomplish assessment of technology impact on readiness.

1. Electronics

The electronic portion of weapon systems has received considerable attention of late. Among the opinions and hypotheses expressed are:

1. Electronics are leading contributors to maintenance.
2. Integrated circuitry accounts for less than 2 percent of avionic failures.
3. Cables and connectors account for 60% of avionic failures.
4. Forty percent of electronic failures are related to power supplies.
5. VHSIC will greatly increase the reliability of avionics.

Some of these seemed conflicting; thus additional data collection was conducted in an attempt to substantiate or refute each statement.

a. Electronic (Avionics) Failure. All indications are that airborne system electronics (avionics) contribute at least 30% of the total maintenance actions. This, of course, is variable dependent upon the complexity and quantity of components in any given installation. A quick look at three weapon systems provided the

123/1-40

failure data of Figure B-14. Further, top 10 maintenance drivers (Table B-13) show that radars are high on the list. For this reason, radar subsystem data are used here as a surrogate for avionics.

WEAPON SYS	ELECTRONIC FAILURES AS % OF TOTAL
F-16	30
F-18	34
E-3A	52

FIGURE B-14. Electronic Failures as Percent of Total Failures

TABLE B-13. TOP 10 MAINTENANCE DRIVERS

F-16		F-18		E-3A	
SUBSYSTEM	% MAINT	SUBSYSTEM	% MAINT	SUBSYSTEM	% MAINT
Engine	15	Weap Cont	17	Radar	10.6
Fire Cont	12	Airframe	16	Computers	10.2
Airframe	12	Landing Gear	11	ECS	6.5
Landing Gear	7	Flt Cont	7	Airframe	6.3
Flt Cont	7	Electrical	7	Flt Cont	5.7
Weap Del	7	Fuel Sys	6	Landing Gear	5.2
Aux Pwr	7	Weap Del	5	Propulsion	5.2
Fuel Sys	6	ECS	5	UHF	4.3
Crew Sta	4	Lighting	3	Intercom	4.2
Pen Aids	4	Propulsion Inst	3	Electrical	3.7
% TOT MAINT	81		80		61.9

123/1-41

b. Integrated Circuitry. Data does not support the hypothesis that integrated circuits (IC) account for only 2 percent of avionic failures. A piece part count of radar components for the F-15 (APG-63), F-16 (APG-66) and F-18 (APG-65) radars showed that ICs comprise 38 percent, 48.5 percent, and 39.5 percent of the respective subsystems. The reliability improvement warranty (RIW) for the F-16 APG-66 provided additional data which indicate that 62 percent of the radar actions involved solid state device replacement. None of these data can be used to provide a point estimate of IC contribution to avionic failure but the numbers are high enough to invalidate an estimate as low as 2 percent. A better estimate may be bounded by F-18 APG-65 digital failures (a function of ICs) at 10.3 percent (extracted from 3M data) as the lower bound and the F-16 APG-66 IC failures, computed strictly as a function of piece part count, of 22.3 percent (RIW) as the upper bound.

c. Cables and Connectors. Upon hearing the claim that cables and connectors (C&C) contribute to 60 percent of avionics maintenance, investigation into this area was initiated. The E-3A, which has a considerable quantity of cables and connectors, had only 1.12 percent of the total maintenance actions coded against C&C. Since electronics account for approximately 50 percent of the total maintenance actions, C&C would be about 2.24 percent of the electronics failures. These data seemed to indicate that the influence of C&Cs was not very great. Due to the difficulty of identifying maintenance actions attributable to cables and connectors, an interview of avionics specialists was conducted within the Air Force to get estimates of the contribution of C&C to avionics maintenance. Results of this interview technique are displayed in Figure B-15. The fact that estimates increase for older aircraft seems to indicate that C&C actions may be time-dependent.

An additional data point, a PAVE PILLER briefing, estimates that up to 40 percent of avionics maintenance actions are related to cables and connectors.

WEAPON SYS	IOC	% C&C OF TOTAL AVIONIC FAILS
F-16	1981	5-15
F-15	1975	10-20
F-111	1967	40-50

FIGURE B-15. Expert Opinion of Potential Effect of Cables and Connectors

None of these data are conclusive nor can a point estimate be established for the impact of cables and connectors. It does seem, however, that the problems involving cables and connectors are not as great as 60 percent, but may, over time reach such proportions.

d. Power Supplies. Once again, due to a high estimate of the contribution of power supplies to avionics maintenance (40 percent), additional information was desired. In this area, due to the way data are coded, it was difficult to identify specifically power supply related failures. It was, however, determined that 2.43 percent of the E-3A radar and approximately 13 percent of the F-18 radar failures were power supplies. These data alone are not sufficient to dispute the 40 percent figure, but it does make it suspect.

e. VHSIC. The dependency issue discussed in Appendix C emphasizes the interaction of VLSI/VHSIC technology with the other technologies. Although large scale integrated circuit technology will result in improved reliability, it will only impact digital circuitry. PAVE PILLAR studies estimate a 36 percent reduction in avionics system maintenance actions (which equates to an improvement factor of 1.56) due to VHSIC and a 90 percent reduction in cables and connectors via multiplexed architecture. Using these impact estimates on F-16 and F-18 data results in the improvement shown by Figure B-16, which does not achieve the established goal of between 3.6 and 5.9 MTBF in flying hours.

F-16 Avionics MTBF = 6.77 Total ACFT MTBF = 2.5	F-18 Avionics MTBF = 4.09 Total ACFT MTBF = 1.4
6.77 x 1.56 = 10.63 MTBF = 10.63 Total MTBF = 2.9 16% increase	4.09 x 1.56 = 6.4 MTBF = 6.4 Total MTBF = 1.6 14% increase

FIGURE B-16. Effect of VHSIC and Reduced C&C on F-16 and F-18

123/1-44

f. <u>Electronic Impacts</u>. It is obvious that no one technology will provide the reliability improvements needed for future weapon systems. The ATF goal is an MTBF of 21.88 hours. Historical data as displayed in Table B-14 show an upward trend in avionics in MTBF. In fact, the improvement in avionics MTBF over the last 17 years is a factor of 6.76 with at least five weapon systems in the line of progression. If the improvement is looked at between each weapon system, it can be seen that there is also growth in the improvement factor. It is conceivable that the next generation avionics suite will achieve the ATF goal, but a 2.8 improvement factor is a real challenge.

TABLE B-14. AVIONICS SYSTEM GROWTH OVER THE YEARS

IOC	Weapon System	MTBF	Growth Factor
1964	F-4C	1.7	
			1
1967	F-111A	1.7	
			1.4
1970	F-111E	2.4	
			1.6
1975	F-15A	3.8	
			1.5
1979	F-15C	5.8	
			2.0
1981	F-16A	11.5	
			2.3
19??	ATF	26.45	

Improved reliability is a definite requirement, but from an operational viewpoint, improved diagnostics may have a greater impact on electronic subsystems maintenance. Current field experience reflects a high rate of Cannot Not Duplicate (CND) and Re-Test OK (RTOK) maintenance actions. Approximately 40 percent of avionics maintenance actions at the organizational and intermediate levels are in this category.

Evaluation of this area becomes a bit difficult since most of the data used in the assessment of technologies have been based upon inherent failures. Diagnostic problems do not show up in this data, so total maintenance actions must be used to determine CND and RTOK impacts. As an example, the inherent MTBM used for the F-16 fire control system has been 19 hours. Actual field experience, however, shows a total MTBM of 6.2 hours. Most of the difference (59 percent) is due to CND actions.

Total elimination of CND and RTOK may not be possible, but to achieve future needs, diagnostics must improve considerably. The Artificial Intelligence Working Group reported an expected CND rate of 0-20 percent and a RTOK rate of 10-17 percent if AI is properly implemented. This type improvement would eliminate a substantial portion of today's avionics maintenance activity.

2. Propulsion

The mechanical systems condition monitoring (MSCM) group reported that substantial cost savings and improved readiness could be realized through implementation of MSCM techniques. Dealing within the area of flyable weapon systems, MSCM has potential to reduce engine removals by 20 percent for helicopters and 40 percent for fighter aircraft.

A logical extrapolation from the 40 percent reduction in fighter aircraft engine removals is that there would be similar reductions across the entire engine maintenance requirement. With this assumption and the F-16 as an example, a 20.0-hour engine would be achieved. While this is still short of the Air Force requirement for ATF, it is a step in the right direction.

3. Structures

Composite materials and nondestructive evaluation impact system structures. It has been reported that corrosion alone cost the DoD $8 billion/year and composite materials could reduce this substantially. Analysis of F-16 data shows that 2 percent of the airframe maintenance actions are corrosion-related, but 29.5 percent of the F-15 variable inlet ramp maintenance actions are for corrosion. With these minimal data, not much can be surmised about the effects of corrosion, especially since the F-15 and F-16 employ composite materials in their airframe structure.

A close look at F-15 airframe maintenance data provides some insight as to the distribution of maintenance causes. As shown in Table B-15, 85 percent of the airframe maintenance actions could be attributed to cause. These data imply that 22 percent of the maintenance actions are design-related in that the work was done to facilitate other maintenance (FOM).

TABLE B-15. F-15 DISTRIBUTION OF AIRFRAME MAINTENANCE ACTIONS

HOW MALFUNCTIONED	PERCENT OF FAILURES
FOM	22%
Hardware	49%
Corrosion	2%
Broken	3%
Worn	5%
Dirty	4%
TOTAL	85%

While some of this is unavoidable (removal of panels to access subsystem components), the percentage could be reduced through design efforts. The 49 percent maintenance actions attributed to hardware addresses the replacement of nuts, bolts, screws, etc. This could be reduced by use of composite materials and nondestructive evaluation. Composite materials generally require fewer and less exotic fasteners and NDE techniques can ensure close tolerance hole drilling, which eliminates many causes of hardware failure.

Figure B-17 shows that helicopter structural maintenance actions are distributed similar to aircraft. Thus, composites and NDE impacts will apply equally to both type systems.

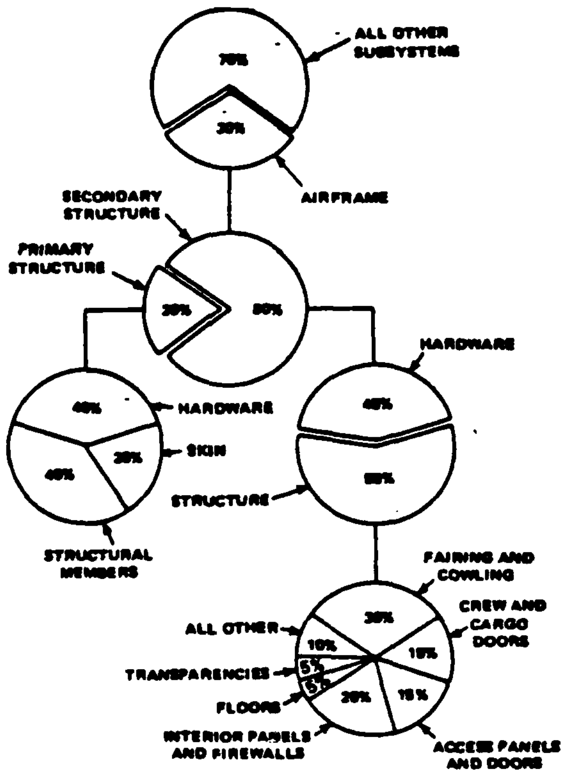

FIGURE B-17. Events for Current Inventory Helicopters

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123/17-2

APPENDIX C

INTERDEPENDENCE OF TECHNOLOGY

APPENDIX C

INTERDEPENDENCE OF TECHNOLOGY

A. OVERVIEW

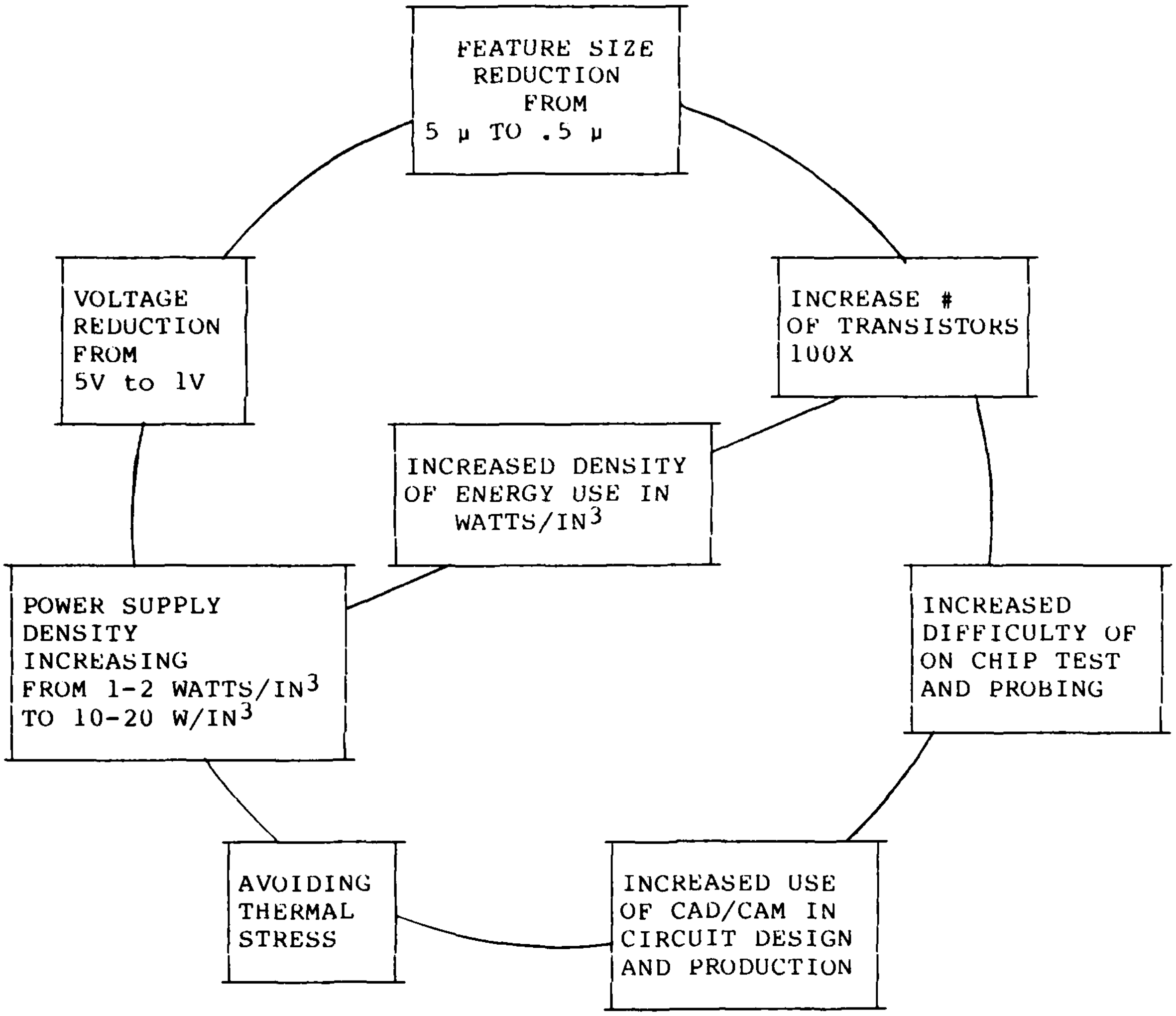
There has been steady progress in the improvement of subsystem and component reliability over the past two decades. During this same period, system capability has increased significantly. All indications are that this steady progress will continue into the future. The questions raised in this study are related to whether there is a gap between "what will be" and "what is needed" by the end of the century. Appendix B demonstrates that there is a gap between our perceived needs and our expectations, especially if our practice as a community continues as in the past. The

proper use of todays technologies, the proper anticipation of new challenges, and the direction of new solutions all come into focus when the ripple effect of technologies are considered. There is a sizable part of the gap that can be overcome by the recognition of these interdependencies and acting on the insight that is thereby provided. This is only another way of saying that a "full court" press is the type of approach that is being advocated, with a reach across all elements of design and manufacture. Understanding the problem is the first step to achieving consistency and program integrity which will become the basis of the solution.

Six such circles are included in this discussion, each demonstrates one circle of dependency:

1. Shrinking size
2. Increasing speed
3. EMI/RF
4. On-condition monitoring
5. Economics
6. Man-machine interface

SHRINKING SIZE



125/1-11

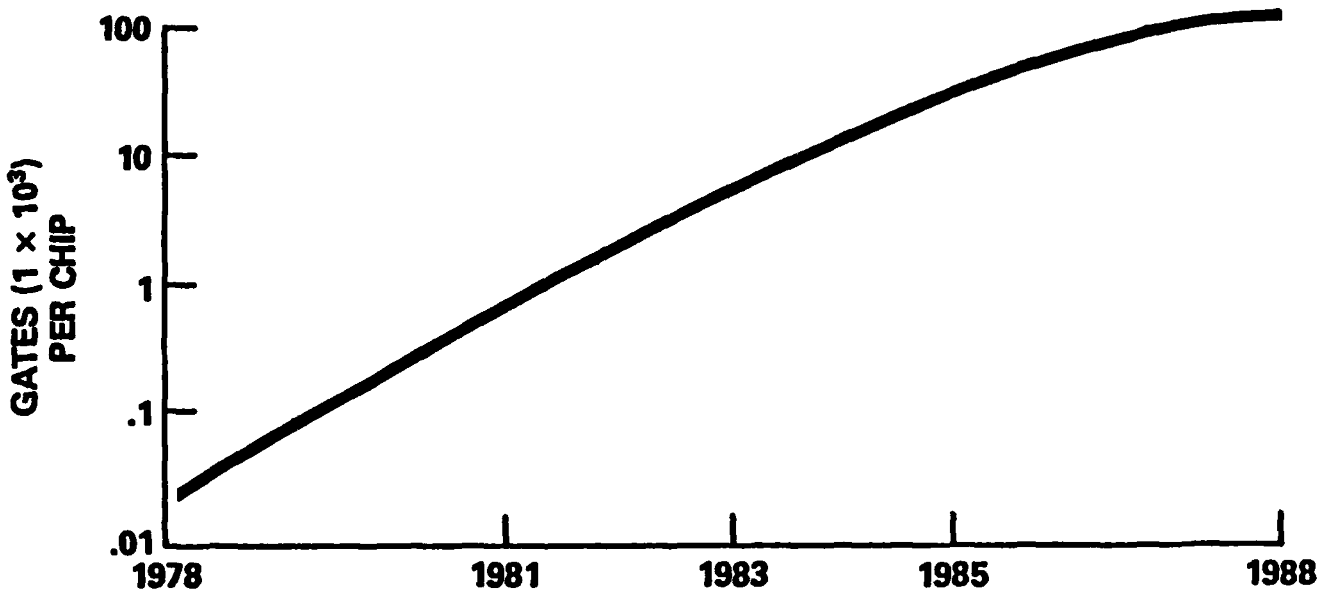
B. SHRINKING SIZE

The feature size in the design of electronic circuits has been reducing rapidly over several decades and the trend line appears steady into the rest of this century. The technology of the late 1970s can be characterized loosely as 5 μ technology and that of the mid to late 1980s as 0.5 μ technology (Figure C-1). This ten-fold reduction in linear dimension results in a 100 times increase in the number of transistors in a given-sized area of microelectronics. The power consumed per transistor is also reducing; however, the density of energy in watts/cubic inch is increasing due to the ratios involved. We know that junction temperatures are a very important parameter in the failure rates of electronics and that junction temperature problems are going to escalate as power densities increase.*

A second phenomenon that spins out of the increased density of elements is the loss of ability to probe the circuit after packaging to determine the physical state of the circuit. The inability to effectively "reach inside" the circuit requires an early consideration of testability in circuit design. There are numerous techniques and logical constructs for overcoming this barrier but the challenge has yet to be met with confidence. There appears to be a major role for CAD/CAM concepts and artificial intelligence as means to overcoming these barriers.

There is another element in this circle which stems from the fact that the traditional 5-volt logic levels are rapidly falling to 1 volt with the advent of these new circuits. The ability to deliver power conditioned to 1-volt logic levels at the watts/cubic inch densities that appear required does not exist as general practice at this time. Therefore, not only will an entirely new logic level be required but a new family of power supplies will need to be developed and matured. These phenomena must be addressed in balanced fashion to ensure that the full benefit of shrinking size of microelectronics is obtained.

* μ = one micron = one millionth of a meter.



SEMI-CONDUCTOR TECH.	ECL/SSI	ECL/MSI	2 μm CMOS	1.25 μm VHSIC	0.5 μm VHSIC
GATES PER CHIP	10-50	400	6K	30K	100K
CLOCK RATE (MHz)	10	20-40	30-40	40	100
NO. OF BOARDS	60	24	6	1	4-6 CHIPS
SIZE (FT^3)	8	.86	.2	.1	.01
POWER	3 KW	1.6 KW	300 W	50 W	3 W

SOURCE: INTERNATIONAL MICRO ELECTRONICS CONFERENCE, FEBRUARY 1981, C. BROOKS & MICHAEL LUCAS

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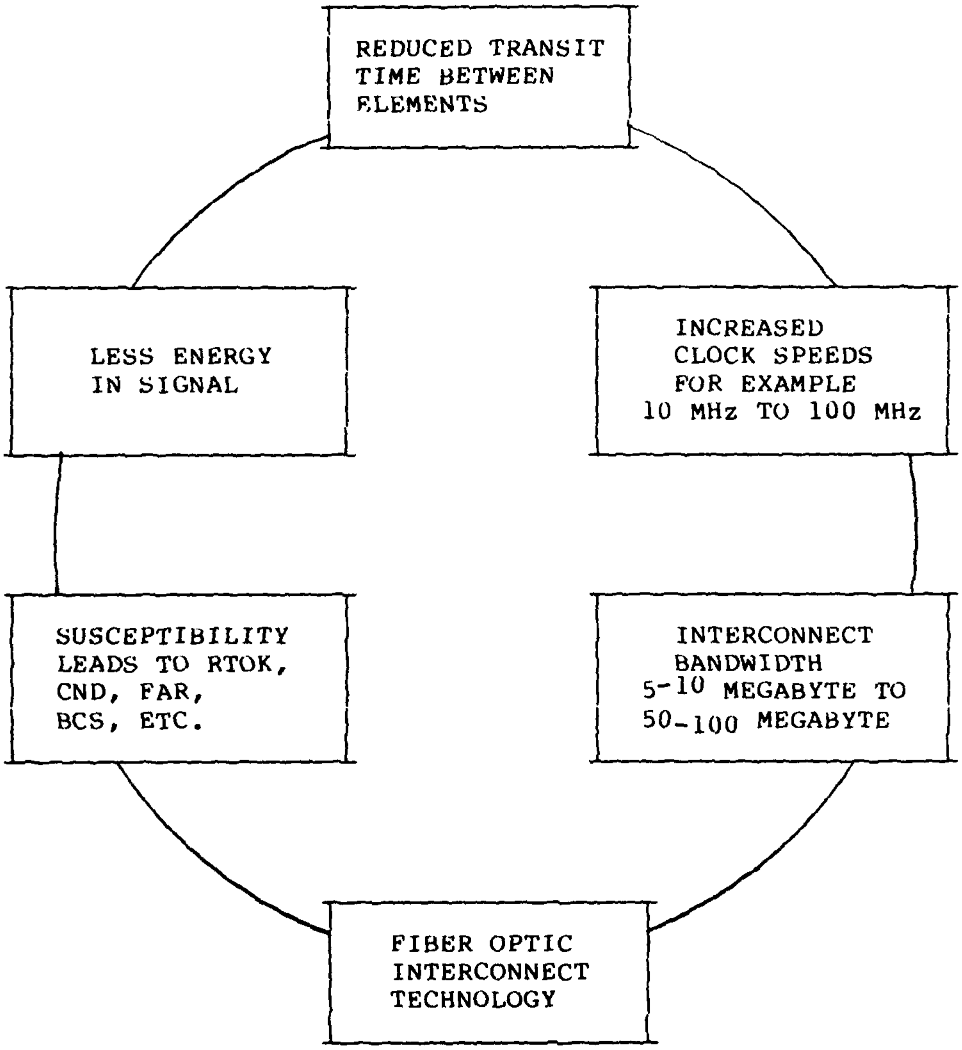
FIGURE C-1. Technology Evaluation

INCREASING SPEED



125/1-12

C. INCREASING SPEED

One of the principal reasons that circuits are becoming more dense is because it is necessary to reduce the transit time between elements in order to increase the speed of processing. As a result the clock speeds of microelectronics will increase from the 10 MHz* range to the 100 MHz range in the next decade. This increase in clock frequency translates to an interconnect transfer rate of 5-10 megabytes/second to 50-100 megabytes/second. The importance of these larger numbers is that they surpass the bandwidth of the twisted pair and coaxial technologies in use today. The best developed, if not the only, alternative which exists today is fiber optic technology.

This circle of dependency closes when we realize that the two-pronged impact of increased frequency and reduced voltage in these new circuits combine to significantly reduce the energy contained in the signal being processed. The energy in the ambient noise is not reducing in a commensurate manner. The utilization of present interconnect technology is seen, therefore, to lead to more interference from existing ambient backgrounds. The outcome appears predictable, namely an increase in intermittent failure that does not result in any corrective action under present maintenance concepts. Retest OK, Cannot Duplicate, false alarm rate and bench checked serviceable are only a few of the new terms surfacing to describe these phenomena. These phenomena have already surfaced as major problems in existing systems.

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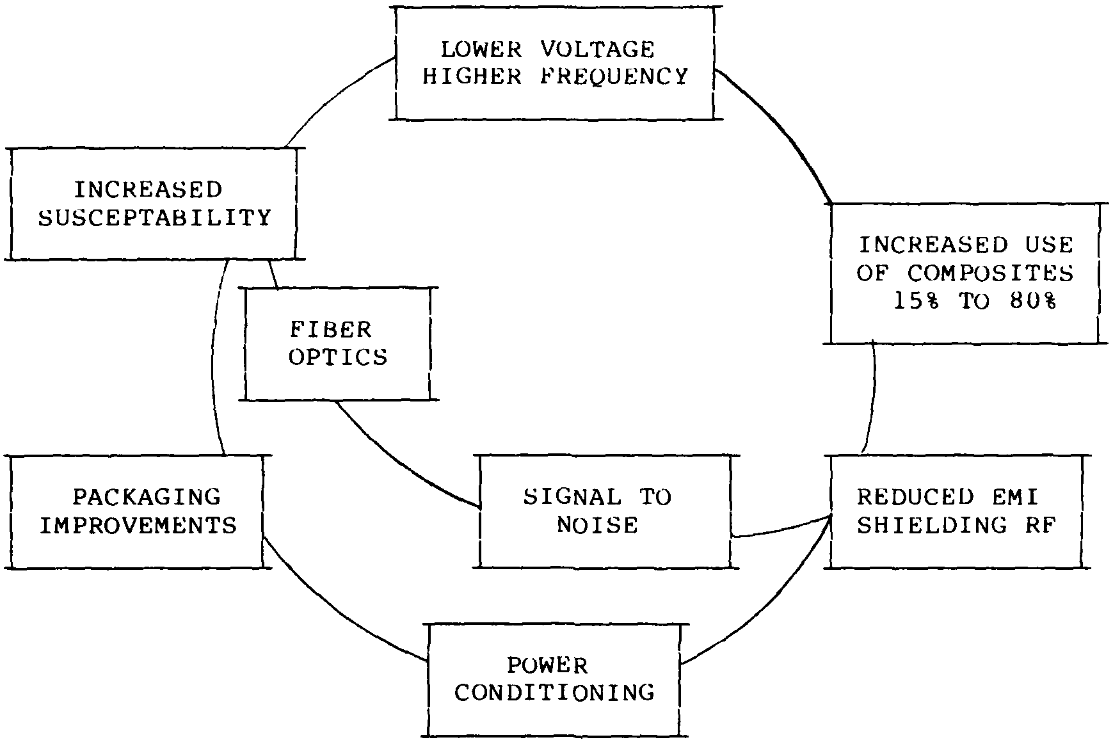
*1 MHz = 1 million cycles per second

EMI/RFI



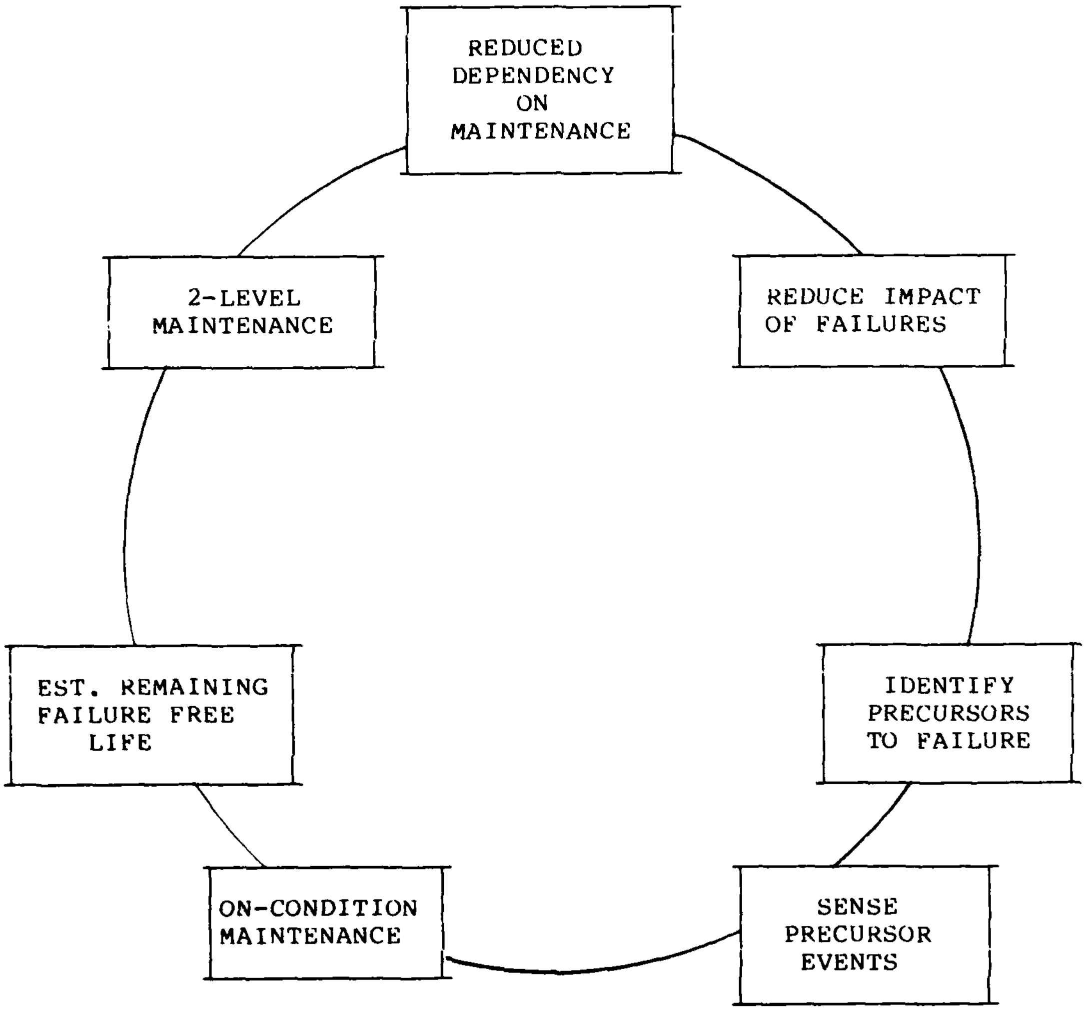
125/1-13

D. EMI/RFI

The previous circle of dependency discussed one aspect of the combined effects of lower logic voltage and higher frequency, namely the impact of existing ambient environments on the reduced signal levels. This circle links this aspect with the reduced shielding of electronics due to the increased use of composite materials in military structures (from 15 percent in the late 1970s to nearly 80 percent by the end of the decade). The reduced shielding results from the displacement of metal structures by composites. Electromagnetic and radio frequency waves travel through composites with ease compared to the previous metal structures. As a result, they have much greater interference on electronics, for both power and signal aspects. There are a number of solutions to this type of problem, but these all make the tasks of signal-to-noise management and power conditioning very difficult compared to previous systems.

Packaging improvements and the increased use of fiber optics offer means to attack the problem. In addition to the obvious problem of transparency created by composites, there is the problem of static electricity. The previous metallic structure also provided a common "ground" conductor for the electric current. This has been taken away and replaced by an insulator when composites are used. The system becomes more susceptible to lightning strikes or static electricity buildup as a result. These factors are challenges enough in themselves without the speed/power issue. The EMI/RF circle exacerbates the problem and enhances the challenges raised by the other circle of dependency.

ON-CONDITION MONITORING



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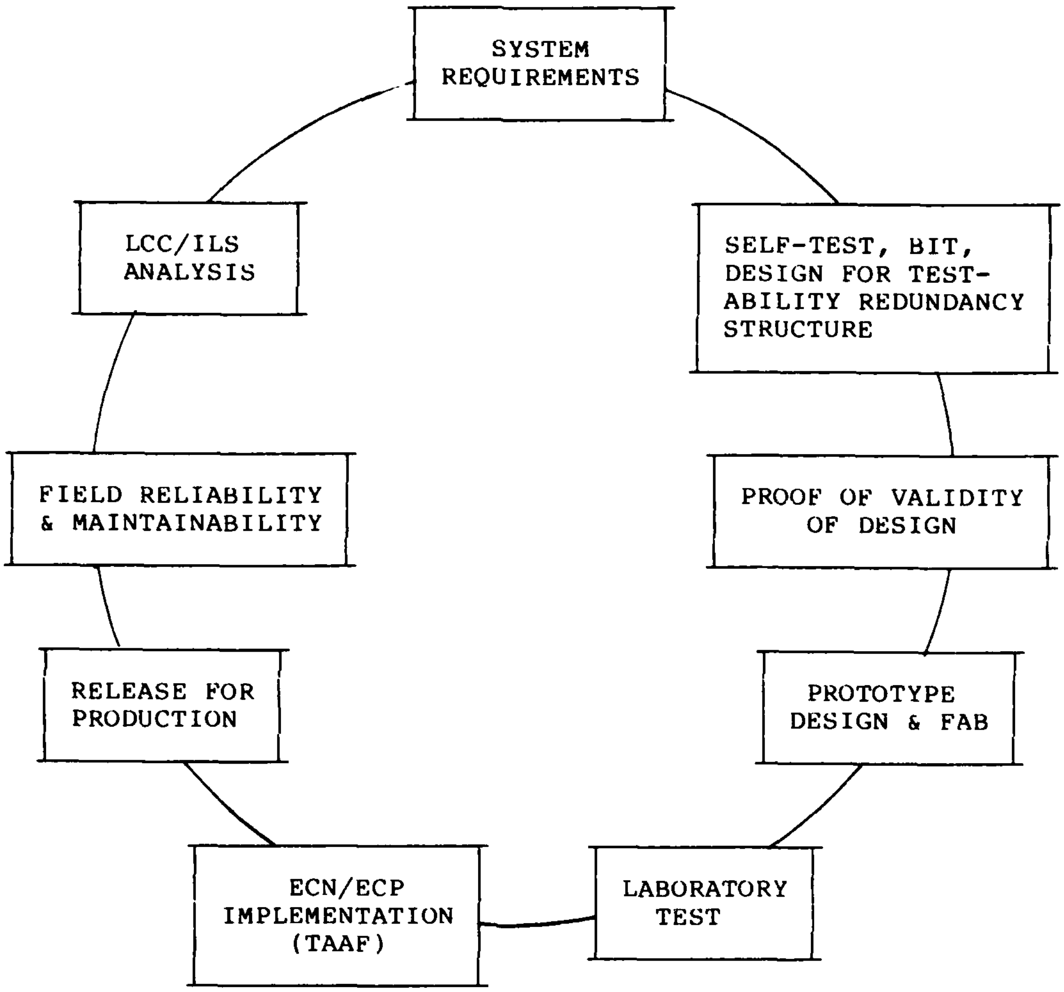
E. ON-CONDITION MONITORING

The scenarios of the Year 2000 stress the reduced dependency on maintenance that is implied in the austere bases and remote operations of the future. This can be accomplished by reducing the impact of failures on system performance. The technique for doing this either provides for redundancy (avoiding single point failures so failures "on mission" do not cause mission abort) or by identifying precursors to failure so that there is a very low probability of failure during the next assigned mission. To achieve these low probabilities of failure, it is necessary to sense the precursor events so that catastrophic events can be avoided. The propulsion technologies are leading the way in this new technique, but even they have a long way to go to achieve on-condition maintenance as a standard of military operations. It appears possible for similar techniques to be developed for structures and electronics. Once "on-condition" capability is achieved, it is possible to consider going even further into estimates of remaining failure-free life. In this latter case, it would be possible for an operational commander safely to order one sortie (or more) before scheduling the vehicle back to a depot for maintenance. When such a capability is achieved, then the long sought-after 2-level maintenance concept will begin to have a demonstrable impact on operations.

ECONOMICS



125/1-15

F. ECONOMICS

The economic leverage that proper requirements and design have on life-cycle costs or system logistics costs has been recognized for over a decade in concept and in policy. The ability to achieve consistent priorities within the several years of the program acquisition cycle is another matter. The reprogramming action where financial and other resources are reallocated, all too often damage the integrity of well thought-out test plans and fault-tolerant system structures.

The difficulty centers around the fact that tremendous savings due to certain design features can always be analytically demonstrated for the out years, but this proof has not been sufficient in the past. Therefore, if things remain as they are in reprogramming environments, the outcome is inevitable: budget driven reprogramming will occur and the desired design features will suffer.

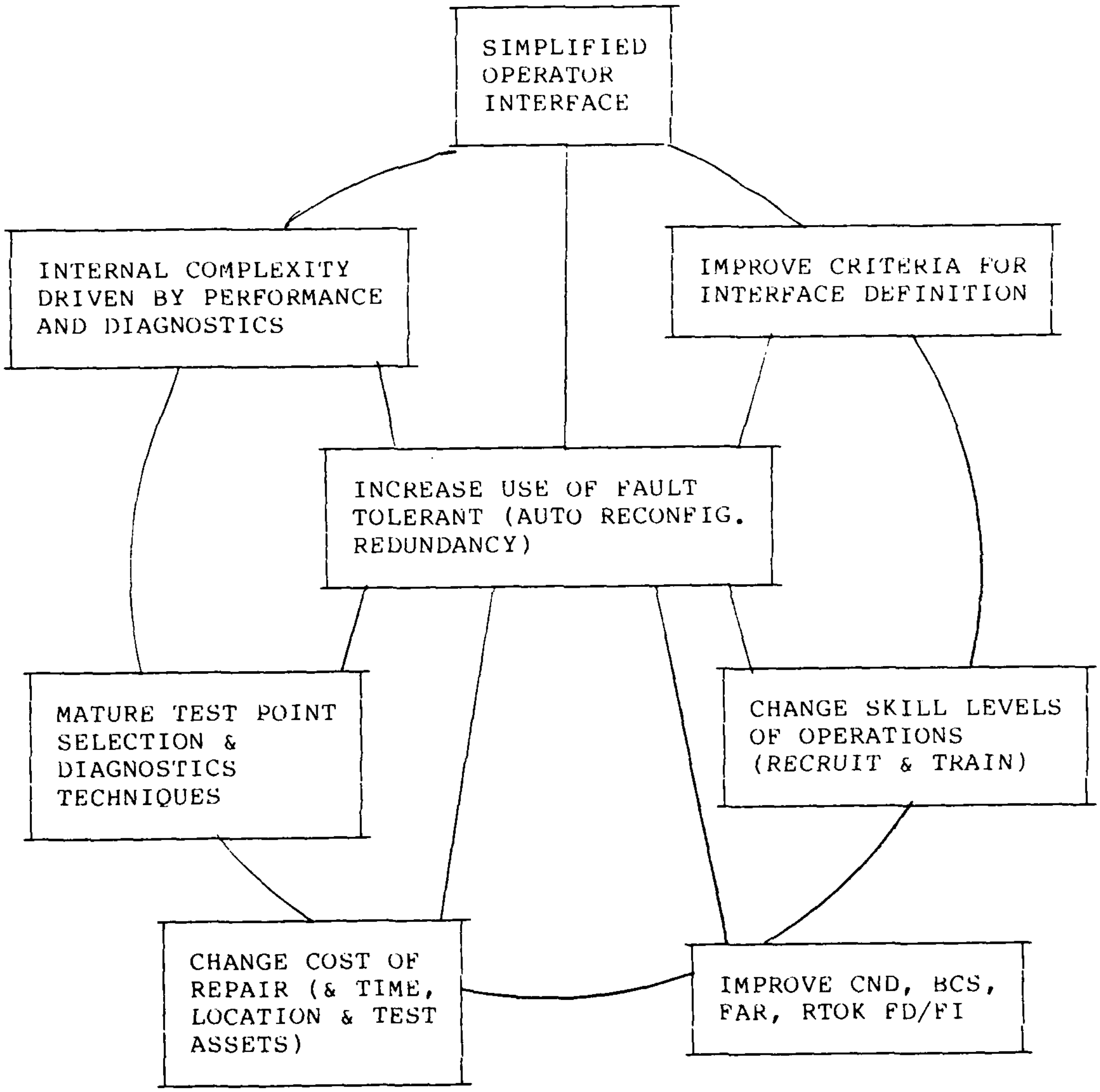
We are now learning that the desired design features save money in the acquisition cycle. Somehow we have lost sight of the fact that the early attainment of technical performance requirements also requires redesign, testing and feasibility demonstrations, all of which can have their costs reduced by the very same design and engineering disciplines required for high reliability and improved maintainability as identified in the Testing Technology Working Group Report, IDA Record Document D-41. The simple statement that "quality is free" derives from the knowledge that doing it right the first time is the least expensive approach. The problem is that doing it right the first time in today's world creates a number of cost increases over the cost estimating numbers of today. At issue, essentially, is how the costs of these desired design features can become part of the baseline budgeting process.

One solution to the problem is to develop more data on the premise that doing it right the first time saves money "straight away." In other words, it will be recovered through efficiencies in the next phases of concept formulation, engineering design, advanced design, etc. Another part of the solution is to recognize that many of the past programs were being taxed to mature technologies which should have been matured "off line" before being incorporated in procurement. In a way, options presented in the past to system designers and program managers were immature technologies with unknown payoff and risk.

We still have significant deficiencies in our ability to specify the hierarchy of requirements so we can achieve the best performance from our engineering community and to define the cost necessary to support the effort. As a result the self-test, built-in-test, design for testability and the design structure are often not matured early in design. The evidence in this study is very indirect, but it appears that the irony of avoiding reprogramming these early costs is that these early design considerations can lead to savings in the design and manufacturing phase directly. Thus, the reprogramming actions justified to save funds due to budgetary pressure in a specific year may actually increase costs in short term (e.g., within the validation of design or in the design fabrication and laboratory testing of prototype).

In like manner, the management of the engineering change process whether by the contractor or the program office is a challenge. All too often, engineering changes of significant economic impact are defined and justified only to get trapped in a queue of unfunded requests. Thus, even when good designs and test plans are achieved, the fixes that are proposed as a result are often not implemented due to time or financial constraints. Thus, systems are often released for production without adequate attention given to many meritorious early recommendations only to demonstrate less than desired field reliability and maintainability performance.

MAN-MACHINE INTERFACE



125/1-16

No PAGE 17

G. MAN-MACHINE INTERFACE

The microprocessor electronics revolution clearly holds forth the potential for embedded system complexity and thus to simplify both operator and maintainer tasks (Ref. IDA Record Document D-35, Manpower, Personnel and Training Working Group Report). Yet, the benefits of this capability are slow and painful to surface. The establishment of human performance criteria upon which to base the evaluation of initial design appears to lack the sensitivity to choose between designs optimized for different skill levels. The best time to establish this interface, however, is early in the design phase when the structure of the system, including its subsystem and component interfaces, are being determined. At this time in the process, the structure of equipment modules, the test mechanization, the fault tolerance strategy and several other features are being defined and are ripe to be structured to accommodate the human related criteria. At this point in time, the downstream effectiveness of diagnostics, the false alarm rate, and the effectiveness of maintenance are defined. At this same point, the stage is set for two-level maintenance and other desirable features.

All of these considerations, in the long haul, define the recruitment strategy for enlisted and officer corps, the nature of basic technical training and the ability to support the fielded inventory with the volunteers that eventually respond to the Service opportunity. We know general demographic trends and patterns, all of which appear to be working at cross purposes to the requirements that will result if traditional techniques continue to be applied.

A significant amount of operator/maintainer efforts are expended in activities that do not find faults or lead to corrective action. The fault detection/fault isolation rates are dependent on the design of the system and the capability of the personnel assigned. These diagnostic activities are significant contributors to the cost of support of military systems. There are significant advances in test point selection and diagnostic techniques, as well as the use of redundancy, all of which contribute to and benefit from the increasing internal complexity of modern systems. The key to the solution is to ensure that proven techniques are applied in a reasonable manner and the early design process is adequately structured and funded. The key point here is that standards of excellence which represent the best that can be achieved within our community should be applied across the board. Unfortunately, this is not the case at present and there are wide swings in the tolerated levels of performance.

H. SUMMARY

The preceding circles of dependency are drawn from all 16 technology working group reports. They are presented more to stimulate thought and to increase awareness of the incredible complexity involved in trying to bring about a quantum change in reliability and maintainability.

The management challenge posed by the complexity is to find some hand-holds which could pull everything else into line. The approach proposed is to establish technological performance targets that unequivocally draw the attention of the system to their importance and if pursued will draw a number of other factors into the right perspective. Four such targets are presented:

(1) The need to establish an alternative to the existing interconnect technology to cope with the 100 MHz clock frequencies of the I/C's of the 1990's.

(2) The need to provide reliable, efficient power supplies for electronics capable of delivering the 1-volt high amperage DC power required by VLSI/VHSIC with power densities in the 10-20 w/in^3 range.

(3) The need to establish high confidence estimates of "failure free" windows of performance for critical military subsystems. This requirement is an extension of the ability of health monitoring systems to capture incipient failures and extends the concept to allow weapons systems to continue battle action prior to cycling the unit back to a repair facility.

(4) The need to grasp all the implications of the increased use of composite materials in the structure of military platforms. This need is brought about by the constantly increasing content in military systems of composite materials.