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JOINT DoD/INDUSTRY STUDY ON OPPORTUNITIES IN INTEGRATED DIAGNOSTICS

Herbert R. Brown
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January 1990

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Weapons Support Improvement Group (WSIG)
Office of the Assistant Secretary of Defense for
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IDA

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13. ABSTRACT *(Maximum 200 words)*

IDA Paper P-2300, Joint DoD/Industry Study on Opportunities in Integrated Diagnostics, documents a study which identified DoD opportunities in integrated diagnostics. The objectives of the study were to (1) provide a forum to present and discuss advanced industrial and DoD integrated diagnostics applications, (2) establish a consensus on the specific integrated diagnostics applications that have the potential of addressing DoD's systems maintenance problems, and (3) address the research, feasibility, and implementation issues. The study included two workshop meetings hosted by the Institute for Defense Analyses (IDA). The participants represented the areas of DoD maintainers, DoD research & development/acquisition managers, defense industry, and commercial industry.

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PREFACE

The IDA Paper P-2300, *Joint DoD/Industry Study on Opportunities in Integrated Diagnostics*, is intended to partially fulfill the objective of Task Order T-B5-490, Integrated Diagnostics for Weapons and Support Systems. It documents the workshop case studies and findings, and IDA's analyses and recommendations. The Opportunities in Integrated Diagnostic workshops were hosted by IDA for OASD (P & L) on 21 & 22 June and 3 August, 1989 in Alexandria, Virginia.

The workshop participants were asked to consider some examples of commercial applications of integrated diagnostics, and then to (1) identify key attributes and implementation approaches used, (2) observe which attributes and implementation approaches might be useful to address DoD weapons system maintenance problems, (3) recommend how DoD might validate these approaches, and (4) consider potential obstacles for DoD application of these diagnostic improvement opportunities.

A draft of this paper was provided to all of the workshop participants for review and comment. We would like to thank the workshop participants for contributing their energy and talents to this effort. The participants are listed in Appendix A. The draft version of this report was reviewed within the Computer and Software Engineering Division (CSED) on September 19, 1989, by R. Wexelblat, T. Mayfield, J. Linn, R. Winner, and J. Pennell. We thank Lew Dimler and Betty Pinna for the excellent organization of the workshops, Betty Pinna for typesetting and Katydean Price for editing the report. Finally, we would like to thank Chris Fisher and Marty Meth of OASD (P&L) WSIG for their guidance and support.

EXECUTIVE SUMMARY

Introduction

This study was requested by the Weapon Support Improvement Group (WSIG) of the Office of the Assistant Secretary of Defense for Production and Logistics (OASD(P&L)), and is intended to identify an approach to take advantage of opportunities for improved diagnostic capability already demonstrated in selected commercial industries. This report documents the study results which includes the opportunities identified in the June and August, 1989 workshop case studies and findings, and IDA's subsequent analyses and recommendations.

Workshop General Observation

The workshop observed that companies have successfully developed and implemented diagnostic elements (e.g., built-in-test, test equipment, technical information and training) as an integrated capability, and thereby have improved diagnostic accuracy, reduced warranty and maintenance costs, and increased system availability. The case studies illustrated dramatic improvements in maintenance productivity and operating efficiency: (1) The General Motors (GM) Computerized Automotive Maintenance System (CAMS) demonstrated 33% improvement in maintenance shop productivity within 3 weeks of usage, (2) the AT&T 5ESS electronic switching system automated maintenance performance exceeds the system requirements of less than 3 minutes of down time per year, and (3) the General Electric Ground-based [aircraft] Engine Monitoring (GEM) system on-wing (Lufthansa) maintenance performance analyses reduces maintenance overhaul budgets by 5% and reduces fuel consumption by an estimated 0.5%.

DoD Diagnostic Needs

Current DoD weapon systems field maintenance environments require large logistics infrastructures consisting of many different technical specialists, complex test equipment, and voluminous technical information. This translates to vulnerable and burdensome forward support. Maintenance depots operate with imprecise operational performance and diagnostic technical information from other maintenance activities. Field and depot maintenance workloads are a direct function of diagnostic accuracy. A number of assessments on weapon systems support have documented the difficulty in performing accurate diagnostics on DoD systems (the range of maintenance actions resulting in the removal of items with no evidence of failure frequently varies between twenty and fifty percent).

Future DoD requirements call for increased mobility, small deployments with increased sustainability and the potential for increased vulnerability. These operational needs can be addressed by reducing the forward burden of spares and diagnostic equipment. Improved diagnostic accuracy will reduce the burden of diagnostic equipment and spares as will the requirements for the many technical specialists.

Summary of Recommendations

The workshop case studies highlighted a number of key attributes that facilitated successful application of integrated diagnostics. The resulting payoffs demonstrated in the commercial implementations are lower costs to organizations (warranty), quicker repair response times (customer satisfaction), improved repair accuracy (more up-time), and enhanced feedback to design for next generation (future support cost avoidance and more rapid diagnostic maturity). Interestingly, the key attributes that facilitated the application in the commercial cases often contrast with the perception of current DoD practices and guidelines. The following recommendations are based on this observation and are divided into three areas: near term actions to identify new opportunities by focusing on contrasting commercial and DoD diagnostic practices, long term actions to develop a planning framework that will assist DoD in the implementation of applicable integrated diagnostics concepts, and recommendations resulting from the general workshop consensus.

a. Near Term Actions: The Services collect huge amounts of information relating to systems performance, use, and maintenance for a variety of reasons that are not directly tied to diagnostic needs. DoD should initiate a broad based study effort to investigate DoD's practices and compare them with what was identified in the commercial cases:

(1) Identify what information relating to maintenance is collected, assess how it is used, identify additional data opportunities, and assess how DoD should capture and analyze data.

(2) Assess how maintenance diagnostic responsibilities are assigned and performed within organizational structures.

(3) Identify the types and capabilities of information links among various diagnostics elements.

(4) Examine approaches to data collection that make the work load associated with the collection process transparent to maintenance personnel and identify opportunities to further the application of integrated diagnostics concepts.

b. Long Term Actions: Based on the results of the near term actions, investigate implementation and environmental issues that relate to the uniqueness of DoD type missions:

(1) Assess the usefulness of applying the capability of using data that is rapidly fed-back from maintenance to influence design and system evolution and assess how DoD might go about implementing such a concept.

(2) Develop a planning framework that considers the uniqueness of DoD's needs and facilitates the implementation of integrated diagnostics concepts.

c. General Workshop Consensus: The workshop participants concluded that the integration of diagnostics elements provides a unique opportunity for DoD to significantly enhance the maintenance and availability of today's systems and unanimously recommended that DoD undertake the initiatives to demonstrate and communicate opportunities in integrated diagnostics:

(1) Accomplish demonstrations on fielded systems to further evaluate as well as learn of application opportunities for integrated diagnostic concept payoffs.

(2) Expand efforts to increase the awareness and understanding of integrated diagnostics opportunities by presenting information to senior level using and maintenance communities.

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1. INTRODUCTION

1.1 PURPOSE

A study was conducted under Task Order T-B5-490 for the Weapon Support Improvement Group (WSIG), Office of the Assistant Secretary of Defense for Production and Logistics (OASD(P&L)) to identify DoD opportunities in integrated diagnostics. The objectives of the study were to (1) provide a forum to present and discuss advanced industrial and DoD integrated diagnostics applications, (2) establish a consensus on the specific integrated diagnostics applications that have the potential of addressing DoD's systems maintenance problems, and (3) address the research, feasibility, and implementation issues.

1.2 WORKSHOP ORGANIZATION

This study included two workshop meetings hosted by IDA. The workshop participants were carefully selected for their in-depth technical background and personal experience. These participants represented (in almost equal proportions) the following areas: (1) DoD maintainers, (2) DoD R&D/acquisition managers, (3) Defense industry, and (4) commercial industry. Appendix A provides a list of workshop participants.

The first workshop was conducted on June 21-22, 1989. Mr. Martin Meth, Director WSIG, led off the discussions with an introductory presentation (contained in Appendix B) highlighting the concept and DoD strategy for integrated diagnostics. Industry and DoD case studies followed and were intended to focus the participants' attention on potential opportunities to apply and accelerate the use of integrated diagnostics in systems applications.

The workshop participants were asked to consider some examples of commercial applications of integrated diagnostics, and then to (1) identify key attributes and implementation approaches used, (2) observe which attributes and implementation approaches might be useful to address DoD weapons system maintenance problems, (3) recommend how DoD might validate these approaches, and (4) consider potential obstacles for DoD application of these diagnostic improvement opportunities. The participants also were divided into four working groups and were asked to focus on these questions from the perspectives of the following communities:

a. Users and supporters

b. Acquisition and system development

c. Engineering technical data and standards

d. Research and development

The second workshop was conducted on August 3, 1989. This workshop was specifically intended to review a preliminary draft of this workshop paper and to continue the consensus building from the first workshop.

2. BACKGROUND

2.1 INTRODUCTION

Diagnostics is the practice of investigating the cause or nature of specific problems that inhibit normal system operation. Today's system diagnostic capability is developed and provided through engineering design, testing, technical information, and trained personnel. The diagnostic elements that support this capability include built-in-test (BIT), automatic and manual test equipment, integration support facilities based on elements of weapons systems and external support equipment, and limited condition monitoring. The diagnostic technical information is provided to the maintainers in the form of technical manuals and to a lesser extent through limited capability information delivery systems.

2.2 ACQUISITION AND SUPPORT ISSUES

Maintenance depots operate with little feedback of maintenance data to allow system wide improvement of the diagnostic process. Across DoD, maintainers compensate for diagnostic accuracy problems with trial-and-error component replacement techniques. A DoD Task Force on Productivity in Support Operations (1986) discovered that the range of avionics maintenance actions resulting in removal of items with no evidence of failure varied between twenty and fifty percent.

DoD's current approach for acquiring and using diagnostic capabilities is not focused only on the operational objectives of the weapon system, but also many other objectives which create the following conditions:

a. Diagnostic specifications are not clearly derived from operational objectives.

b. Separate diagnostic element specifications are often prepared and put on contract by different organizations.

c. Separate maintenance organizations independently control the use of diagnostic capabilities.

2.3 INTEGRATED DIAGNOSTIC CONCEPT

Integrated diagnostics concept requires the design and development of these diagnostic elements as a "package" for system maintenance. This differs from the current

DoD practice of specifying and buying isolated diagnostic elements. The concept of acquiring diagnostics capability as a package evolved out of initiatives from the Automatic Test Committee and Logistics Management Committee of the National Security Industrial Association (NSIA). The primary focus of this effort was to improve maintenance quality through discipline in diagnostics design and development.

NSIA's involvement spans the last four years and includes three NSIA-sponsored conferences that defined the problems and advanced the integrated diagnostics initiative. The NSIA approach has been to get specialists involved by forming an Integrated Diagnostics Working Group with representatives from 200 companies along with DoD counterparts in each of the various task areas. Out of these efforts evolved an NSIA Model Statement of Work (SOW) for integrated diagnostics which places the responsibility for diagnostic capabilities, performance, and integration on the contractor. The primary goal of the Model SOW is to deliver a system where the individual diagnostic elements are specifically designed to complement each other.

NSIA also sponsored a series of three DoD and Industry "Executive Roundtables" in 1988. In attendance were 40 executives from 20 companies (including 11 vice presidents, 10 directors and 5 program managers) as well as 12 Flag Officers and Senior Executive Service (SES) members from DoD. The Roundtable participants agreed that the new acquisition approach is better than the current method of acquiring diagnostics, that the NSIA Model SOW is a good starting point, and that DoD and Industry should begin to apply the concept now.

2.4 LONG TERM OBJECTIVES AND NEAR TERM STRATEGY

This workshop, as well as the joint DoD and Industry participation in the NSIA meetings, are part of an OASD(P&L) WSIG strategy to achieve three long-term objectives: (1) to improve the accuracy of maintenance actions, (2) to make diagnostic technology improvement transparent to the weapon system maintainer, and (3) to significantly reduce the logistics "deployment tail" (manuals, test equipment, spare parts, manpower specialization, etc.).

In addition to the acquisition aspect of the WSIG strategy, a second part of this strategy is to stimulate the fielding of mature technology solutions in weapon systems by demonstrating the feasibility of already developed laboratory diagnostics technology programs. Towards this end, a new FY-90 Research and Development program element (603708D), Integrated Diagnostics Technology Demonstration Program, was established by the Defense Resources Board.

The objective of the Technology Demonstration Program is to prove the feasibility of implementing integrated diagnostics concepts and to measure potential improvements by conducting large-scale field demonstrations on operational weapon systems. Several laboratory diagnostic research projects were selected based on the following criteria:

a. Each project demonstrates DoD research that is ready for application.

b. The project proposes a lead weapon system to demonstrate the generic diagnostic technology and is managed by the program manager.

c. The demonstration project has the feasibility of fostering cross-Service applications of the demonstrated diagnostic technology.

d. The proposed diagnostic technology demonstrations must have user commitment to implement weapon system diagnostic improvements.

3. CASE STUDIES

A review of commercial product maintenance practices in preparation for this study revealed that faced with increasing product complexity, companies began to identify and address their diagnostic needs as an intentionally integrated "package" of capability. For this workshop, case histories and studies (predominantly from the commercial sector) were selected to illustrate (1) why and how industry was doing this, (2) what the implications might be in terms of DoD's maintenance environment, and (3) how they might relate to DoD integrated diagnostics initiatives already underway.

A broad spectrum of case studies was selected and included examples from the automotive, aviation, communications, computer, and power industries. The presentations were selected as examples of one or more of the following integrated diagnostics approaches:

- Diagnostic elements developed as a package and designed to work together.
- Effective use of engineering diagnostic information through the application of transparent to maintainer operational and support information capture, analysis, update, and feedback for improved diagnostic system performance.
- New computer-aided engineering (CAE) design and analysis tools that support diagnostic system effectiveness concurrent with product design..
- New on-board condition monitoring sensors to improve accuracy and timeliness of maintenance actions.

The objective of the presentations was to provide examples of diagnostic capabilities that have been developed and applied in an integrated diagnostic approach. The presentations were intended to show how these approaches were exploited, what technologies were applied, and provide some insight as to the potential benefits for the users and maintainers. These perspectives set the stage for addressing the following areas during the working group sessions: (1) identify key attributes and implementation approaches used, (2) observe which attributes and implementation approaches might be useful to address DoD weapons system maintenance problems, (3) recommend how DoD might validate these approaches, and (4) consider potential obstacles for DoD application of these diagnostic improvement opportunities.

3.1 CASE STUDY ATTRIBUTES

The following summarizes the typical attributes of the eight case studies. These attributes have been grouped under the general categories of Diagnostics Requirements, Organizational Accountability, Implementation Characteristics, and Operational Characteristics. Summaries of the individual case studies as well as a listing of the system attributes and general factors that influenced the diagnostic successes in the respective cast studies are located in Appendix C.

3.1.1 Diagnostic Requirements

Each of the case studies presented was initiated and justified based on high-level, diagnostic-related support and system performance requirements. These requirements were traceable to areas in which diagnostics enhancements could lead to a positive improvement (i.e., cost of repair, system availability, warranty impacts, spares burden, technical manuals and training, etc.). Common diagnostic requirement characteristics include the following:

- Diagnostic performance requirements were defined in operational terms (as opposed to specification requirements like false alarm rates) and the implementation of these requirements was left to the equipment design organization.

- Requirements, which were established by one corporation and then passed on to another to develop the diagnostics capability, took the form of broadly stated measurable maintenance and support metrics or functional capabilities. (i.e., reduced volume for technical manuals, higher levels of availability, level of repair).

- Requirements that were established internally by the corporation (or from within the corporation's own operations organization) generally were focused on the cost and/or burden of providing committed services or product performance needs over some sustained period of system life. These needs were determined from market analyses, warranties, availability, overhead, or cost containment requirements.

3.1.2 Organizational Accountability

In the majority of the case studies, a single organization was responsible for the diagnostic system throughout its life cycle from concept definition through the design evolution, installation, and support of field applications. Typically the organizations exhibited the following characteristics:

- A single organization was tied to, and held authority and responsibility for, the delivered and evolving maintenance capabilities.

- A single organization had dedicated resources (dollars, people, and facilities) to improve diagnostic capability across organizational and functional domains.

- A single organization was committed to improve and evolve the integrated diagnostic capabilities beyond the initial installation and fielding of the host system.

3.1.3 Implementation Characteristics

The case studies highlighted a number of common key integrated diagnostic implementation characteristics. These implementation characteristics including methodologies and approaches very often crossed over diagnostic element boundaries and depended on analyses of maintenance information for the integrated diagnostics system maturation and evolution. Typically the key implementation characteristics include the following:

- The diagnostic system designers were not restricted by the classical maintenance and support boundaries and developed diagnostic capabilities that were integrated across functional lines (i.e., BIT, fault logging, data capture, data and trend analysis, prognostics, presentation of maintenance instructions, training, etc.).

- The implementation approaches mitigated the potential of human error by making transparent to the maintainer the maintenance information collection, and providing improved tools for automating analysis and presenting information to the maintainer.

- The diagnostic system decision used BIT and/or functional (on-board equipment) sensors to record system performance and operational status.

- The diagnostic system design established an implementation environment that called for conducting maintenance information analyses off-equipment at a centralized location.

- The diagnostic approach used flexible, intelligent electronic presentation technologies to select and display maintenance and support information.

- The system designers implemented diagnostic elements with existing enabling technologies as opposed to pushing state-of-the-art technologies.

- Implementations focused on a closed loop maintenance information feedback capability, generally through a centralized organization, to evolve and rapidly mature diagnostics.

- The information feedback approach stimulated the user to input data on system performance.

- System designers used methods and tools which allowed concurrent assessment of diagnostic characteristics during design cycle.

3.1.4 Operational Characteristics

The case studies summarized a common set of key operating characteristics that were essential to maintenance acceptance, diagnostic accuracy, and system supportability.

- The integrated diagnostics systems made extensive use of centralized analyses facilities that permitted the rapid analysis and update of critical maintenance information and ensured early and continued design feedback data essential for maintenance maturation.

- Acceptance by the maintenance community was enhanced by simplified maintenance information input techniques (e.g., no numerical codes, transparent data collection, and interactive electronic maintenance and support instructions).

- The integrated diagnostic systems typically provided automated configuration management of product and support tools.

- The maintainer was provided a flexible interface and set of functions, which allowed the maintainer to improvise effective maintenance solutions within bounded limits.

4. COMPARISONS OF TYPICAL CASE STUDY ATTRIBUTES AND DOD PRACTICES

The following tables compared the typical diagnostic related attributes found in the case studies with typical diagnostics related DoD practices. Tables 1 through 4 highlight these observations. Table 1 compares how the diagnostic requirements are typically defined and translated into system applications. Table 2 addresses the typical differences in the organizational accountability for developing and evolving the system diagnostic elements over the product life cycle. Table 3 focuses on the typical diagnostics related implementation characteristics found in the case studies and observed in DoD practices. Table 4 summarizes the key operating characteristics found in the case studies and compares them with the observed typical DoD operationally related maintenance and support practices.

Table 1. Definition and Translation of System Diagnostics Requirements

Typical Case Study Attributes	Observations of Typical DoD Practices
Started with High-Level Diagnostic Related System Performance Requirements (e.g., availability, cost of warranty spares) • Requirements are stated in operational terms and implementation is left to designer. • Requirements are determined by customer needs or by the system developer needs to provide a competitive service.	DoD Typically States Very General Diagnostics Goals in Strategic Plans (e.g., R&M 2000 to reduce burden by 50%) and Over Specifies Solutions in Contracts • DoD often specifies requirements, by reference to standards that over constrain designer's solution while striving for related system compatibility. • DoD contractors are often not contractually bound to deliver maintenance and supportability performance. • Acquisition of diagnostic requirements are often delayed until after production delivery. • Operational diagnostic needs are seldom translated into contractual terms.

Table 2. Organizational Accountability for Developing and Evolving Diagnostics Over Product Life Cycle

Typical Case Study Attributes	Observations of Typical DoD Practices
Single Organization Accountable for Diagnostic Capability Throughout Product Life Cycle • Held authority and responsibility for diagnostic performance in the field. • Implemented an improved diagnostic system across organizational boundaries. • Evolved diagnostic system beyond initial installation.	Accountability for Diagnostics Distributed Across Functional Elements • DoD maintenance responsibilities fragmented across multiple functional organizations. • Diagnostic elements usually acquired and managed separately. • Developer involvement in diagnostics maturation often end with delivery. • Multiple contractors usually developed discrete diagnostic elements and DoD then took over management.

Table 3. Typical Diagnostics-Related Implementation Characteristics

Typical Case Study Attributes	Observations of Typical DoD Practices
Key Implementation Characteristics of Integrated Diagnostic Systems • System designers not restricted by classical maintenance boundaries. • System designers used advanced CAE tools to support concurrent analysis of expected diagnostic performance. • Mitigated human error by automating maintenance collection. • Set out to build a closed loop diagnostic system. • Used existing technology. • Capitalized on existing functional sensors and built-in-test hardware. • Recorded malfunctions on-equipment. • Analyzed malfunctions off-equipment. • Used intelligent electronic display of maintenance information. • Transparently captured maintenance history information. • Minimized on-equipment software changes.	*DoD Implementation Characteristics* • DoD has antiquated, error prone, maintenance collection and feedback capabilities that are not well integrated across functional elements. • DoD and it's contractors lack the integration of CAE tools across weapon system design to support concurrent analysis of diagnostic performance during design. • DoD lacks centralized data analyses centers focusing on diagnostic accuracy. • Routine update of maintenance and diagnostic data is slow. • Design feedback is limited and slow. • DoD maintenance and support functions are paper intensive. • DoD focuses on discrete diagnostic elements.

Table 4. Summary of Key Diagnostics-Related Operating Characteristics

Typical Case Study Attributes	Observations of Typical DoD Practices
Key Operating Characteristics of Integrated Diagnostic System • Central analysis facility for rapid analysis and update of diagnostic information. • Simplified maintainer input. • Automated configuration management of product and support tools. • Flexible systems allow maintenance personnel to improvise solutions within bounded structure. • Integrated supporting communications systems.	DoD Generally Delegates the Operation and Up-Date of Discrete Diagnostic Elements to Multiple Organizations (technical manuals, test equipment, on-board sensors & BIT, training) • DoD maintenance data collection techniques are paper intensive and often originate from verbal inputs. • DoD configuration management and maintenance data traceability to configuration items are significantly less capable than the case study examples. • DoD captures much logistics data but it is often analyzed in multiple organizations and is not well integrated across functions. • DoD diagnostic capabilities must be tolerant of potential communications shutdowns during wartime conditions.

5. RECOMMENDATIONS

The workshop discussions clearly illustrated that today's systems (both commercial and military) are faced with increasing maintenance and support burdens. These increased burdens carry with them an increased need for effective diagnostics. This need is tied directly to customer requirements for sustained product quality and cost effective maintenance. Payoffs demonstrated in the commercial implementations of integrated diagnostics are lower costs to organizations (warranty), quicker repair response times (customer satisfaction), repair accuracy (more up-time), and enhanced feedback to design for next generation (future support cost avoidance and more rapid diagnostic maturity).

The workshop cases studies highlighted a number of key attributes (See Section 4) that facilitated successful application of integrated diagnostics concepts in commercial cases. Interestingly, these key attributes often contrast with the perception of current DoD practices and guidelines. The following recommendations are based on these observations and are divided into three areas: near term actions to identify new opportunities by focusing on contrasting commercial and DoD diagnostic practices, long term actions to develop a planning framework that will assist DoD in the implementation of applicable integrated diagnostics concepts, and recommendations resulting from the general workshop consensus.

5.1 NEAR TERM ACTIONS

At present the Services collect huge amounts of information relating to systems performance, use, and maintenance for a variety of reasons that are not directly tied to system diagnostic needs. Specific near term actions are needed to identify what data is collected and how this information is used, assess if this information may be used to enhance diagnostics performance, identify if other information is needed, and assess how the DoD maintenance data collection practices compare with the commercial cases studied.

a. DoD should initiate a broad based study effort to identify what information relating to maintenance actions is collected within DoD operational organizations. The study should assess how this information is used to address diagnostic needs as well as identify opportunities where DoD could better apply available information. The study also should focus on what additional data would be useful and how DoD should capture, analyze and apply this information. Finally, the study should compare these current DoD maintenance data collection practices with what was seen in the commercial cases.

b. DoD should identify how maintenance responsibilities (across the spectrum from development of a system capability, to performing maintenance, to modifying and managing a fielded capability) are assigned and carried out in today's DoD organizational structures. The study should assess what are the limitations of these organizational structures, and compare these structures to what was seen in the commercial cases.

c. DoD should assess the types and capabilities of information links among various DoD diagnostic elements (at all maintenance levels) and compare these information links with what was seen in the commercial cases. The study also should identify specific diagnostic payoff and improvement opportunities that would result from enhanced information links.

d. DoD should examine the various approaches to maintenance data collection that make the work load and burden associated with data collection virtually transparent to the maintenance personnel. The near term study should assess this transparency issue as applied in DoD and as compared to approaches used in commercial cases. The study should identify particular problems and needs related to applying maintenance data collection transparency to DoD systems.

5.2 LONG TERM ACTIONS

Based on the results of the near term actions and in order for DoD to realize the full potential of the integrated diagnostics concept, there are several implementation and environment issues that relate to the uniqueness of the DoD type missions that must be addressed.

a. Several of the commercial cases demonstrated that there was benefit in using data that was rapidly fed-back from maintenance to influence design and system evolution. As a result, these commercial enterprises developed a link to accomplish this feed-back rapidly. DoD should assess the usefulness of this idea and assess how DoD might go about implementing such a concept.

b. Since DoD has its own missions and needs which are different than those found in commercial cases and since DoD has a large and varied scale of maintenance activities to manage, DoD should develop a planning framework to facilitate the implementation of integrated diagnostics concepts.

5.3 GENERAL WORKSHOP CENSENSUS

a. The workshop participants expressed concern that 90 percent of the DoD systems in the field today would still be operational (and in critical deterrent roles) in 20 years and observed that opportunities to improve diagnostic performance of existing DoD systems abound. Their concern was further exacerbated by the perception that the user communities are not cognizant of the opportunities and benefits associated with integrated diagnostics.

   Therefore, based on the results of the workshop, the participants concluded that the integration of diagnostic elements provides a unique opportunity for DoD to significantly enhance the maintenance and availability of today's complex weapon systems and unanimously recommended that DoD undertake initiatives to demonstrate and communicate the opportunities in integrated diagnostics.

   (1) DoD should accomplish demonstrations on fielded weapon systems to further evaluate various integrated diagnostics concept payoffs and to better understand the technology applications most useful for improving maintenance.

   (2) DoD should expand its efforts to increase the awareness and understanding of integrated diagnostics opportunities, and document demonstrated benefits by presenting information to senior level using and maintenance communities.

LIST OF ACRONYMS

AI	Artificial Intelligence
ASR	Air Surveillance Radar
BIT	Built-In-Test
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CALS	Computer Aided Acquisition and Logistics Support
CAMS	Computerized Automative Maintenance System
CSED	Computer and Software Engineering Division
DLH	Lufthansa German Airlines
DoD	Department of Defense
ED/FI	Error Detect, Fault Isolate
EMS	Engine Monitoring System
ESS	Electronic Switching System
FAA	Federal Aviation Administration
FMEA	Failure, Mode, and Effects Analyses
FRU	Field Replaceable Unit
GEM	Ground-based Engine Monitoring
GFE	Government Furnished Equipment
GM	General Motors

IDA	Institute for Defense Analyses
KLM	Royal Dutch Airlines
LRU	Line Replaceable Unit
LSA	Logistics Support Analysis
LSI	Large Scale Integration
LSSD	Level Shift Scan Design
MAM	Maintenance Assist Module
NSIA	National Security Industrial Association
OASD(P&L)	Office of the Assistant Secretary of Defense for Production and Logistics
OEM	Original Equipment Manufacture
R&D	Research and Development
SAS	Scandinavian Air System
SERD	Support Equipment Requirements Document
SOW	Statement of Work
TCM	Thermal Conduction Module
WSIG	Weapon Support Improvement Group
XMAN	Expert Maintenance

APPENDIX A

WORKSHOP PARTICIPANTS & INVITED SPEAKERS

Integrated Diagnostic Workshop Attendees
21-22 June 1989

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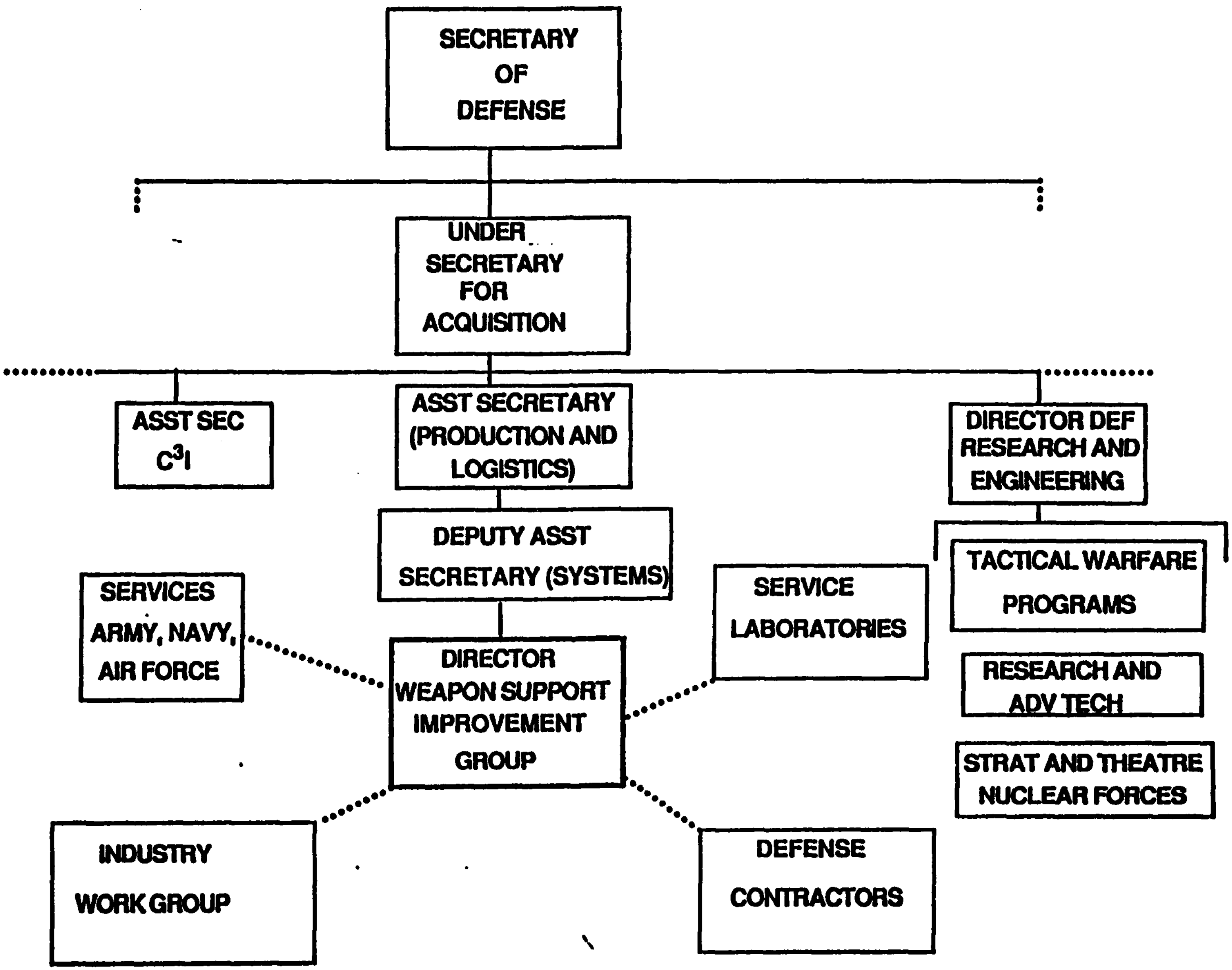
APPENDIX B

OPPORTUNITIES IN INTEGRATED DIAGNOSTICS PRESENTATION CHARTS

OPPORTUNITIES IN INTEGRATED DIAGNOSTICS

MARTIN A. METH
OFFICE OF THE SECRETARY OF DEFENSE
U. S. DEPARTMENT OF DEFENSE
JUNE 21-22, 1989

WEAPON SUPPORT IMPROVEMENT GROUP (WSIG)



WHAT CONSTITUTES THE DIAGNOSTIC CAPABILITY ?

(DIAGNOSTIC ELEMENTS)

DESIGN
- STATUS MONITORING
- BUILT–IN–TEST (BIT)

TESTING
- TEST EQUIPMENT
- MAINTENANCE AIDS (EXPERT SYSTEMS)

TECHNICAL INFORMATION
- TECHNICAL MANUALS
- INFORMATION SYSTEMS

TRAINED PERSONNEL
- SKILLS
- KNOWLEDGE
- MOTIVATION

INTEGRATED DIAGNOSTICS: BACKGROUND

- INITIATED BY INDUSTRY IN 1983 TO IMPROVE MAINTENANCE QUALITY THROUGH DISCIPLINE IN DIAGNOSTICS DESIGN AND DEVELOPMENT
  - NATIONAL SECURITY INDUSTRIAL ASSOCIATION (NSIA) SPONSORED 3 CONFERENCES TO DEFINE PROBLEM AND ADVANCE INITIATIVE
  - NSIA INTEGRATED DIAGNOSTICS WORKING GROUP: REPRESENTS 200 COMPANIES WITH DOD COUNTERPARTS ACTIVE IN ALL TASKS, REPORTS TO DOD ON PROGRESS
  - 3 DOD/INDUSTRY EXECUTIVE ROUNDTABLES HELD IN 1988: 40 EXECUTIVES/20 COMPANIES (INCLUDING 11 VICE PRESIDENTS) AND 12 FLAG OFFICERS/SES
  - NSIA BRIEFED TO USD(A), DR. COSTELLO, APRIL 14, 1989
    - USD(A) ENDORSED CONCEPT, TASKED SERVICE ACQUISITION EXECUTIVES FOR IMPLEMENTATION STEPS

LONG - TERM STRATEGY

TODAY:

- SKILL-INTENSIVE MAINTENANCE ACTIONS RESULTING FROM DESIGN LIMITATIONS
- FRACTIONATED ACQUISITION OF DIAGNOSTIC ELEMENTS RESULTING IN LARGE, COMPLEX DIAGNOSTIC EQUIPMENT WITH PERFORMANCE VOIDS AND OVERLAPS

OBJECTIVES:

- IMPROVED DIAGNOSTICS ACCURACY
- LOWER SKILL REQUIREMENTS FOR WEAPON SYSTEM MAINTAINER
- SIGNIFICANT REDUCTION IN LOGISTICS DEPLOYMENT TAIL

LONG - TERM STRATEGY (CONTINUED)

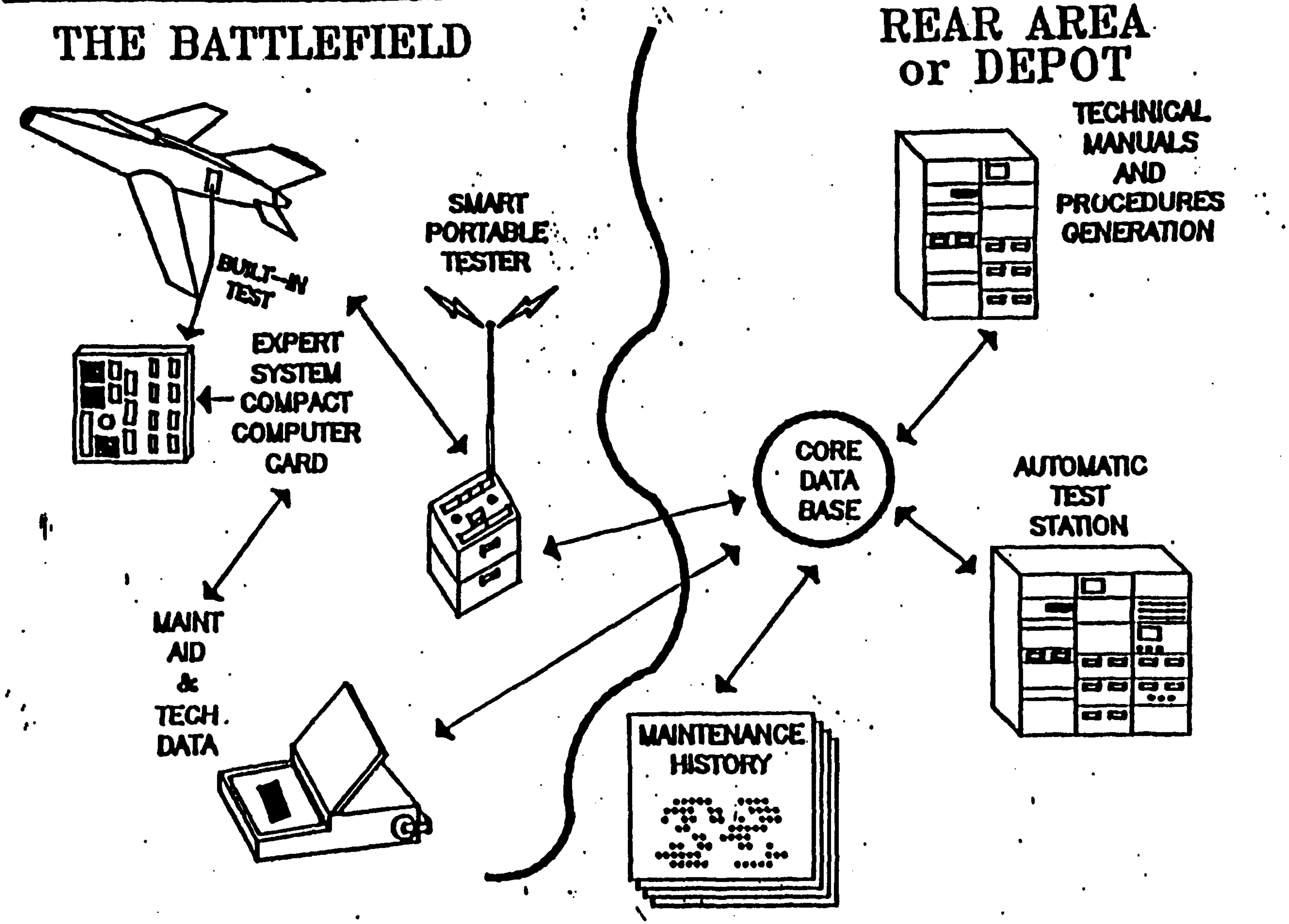
HOW: AN INTEGRATED DIAGNOSTIC APPROACH BUILT AROUND:

- DIAGNOSTIC ELEMENTS DESIGNED TO WORK TOGETHER
- CAPTURE DIAGNOSTICS INFORMATION; RAPID ANALYSIS AND UPDATE
- NEW CAE DESIGN/ANALYSIS TOOLS
- NEW ON-BOARD CONDITION MONITORING SENSORS

ASD(P&L) NEAR TERM STEPS

- ACQUISITION
  - SINGLE CONTRACTOR RESPONSIBLE FOR DELIVERING "DIAGNOSTICS PACKAGE"
  - INDUSTRY ENDORSED MODEL STATEMENT OF WORK TO USD(A)
  - SERVICE ACQUISITION EXECUTIVES DEFINING IMPLEMENTATION STEPS
- TECHNOLOGY
  - PROVIDE FUNDING FOR RAPID TRANSITION OF PROMISING TECHNOLOGY PRODUCTS FROM LABORATORIES TO WEAPON SYSTEMS
    - OSD(P&L)WSIG PROGRAM ELEMENT 63708D, INTEGRATED DIAGNOSTICS DEMONSTRATION PROGRAM
- AWARENESS
  - HOLD WORKSHOP TO BUILD INDUSTRY AND USER CONSENSUS FOR NEW MAINTENANCE "PACKAGE" APPROACH

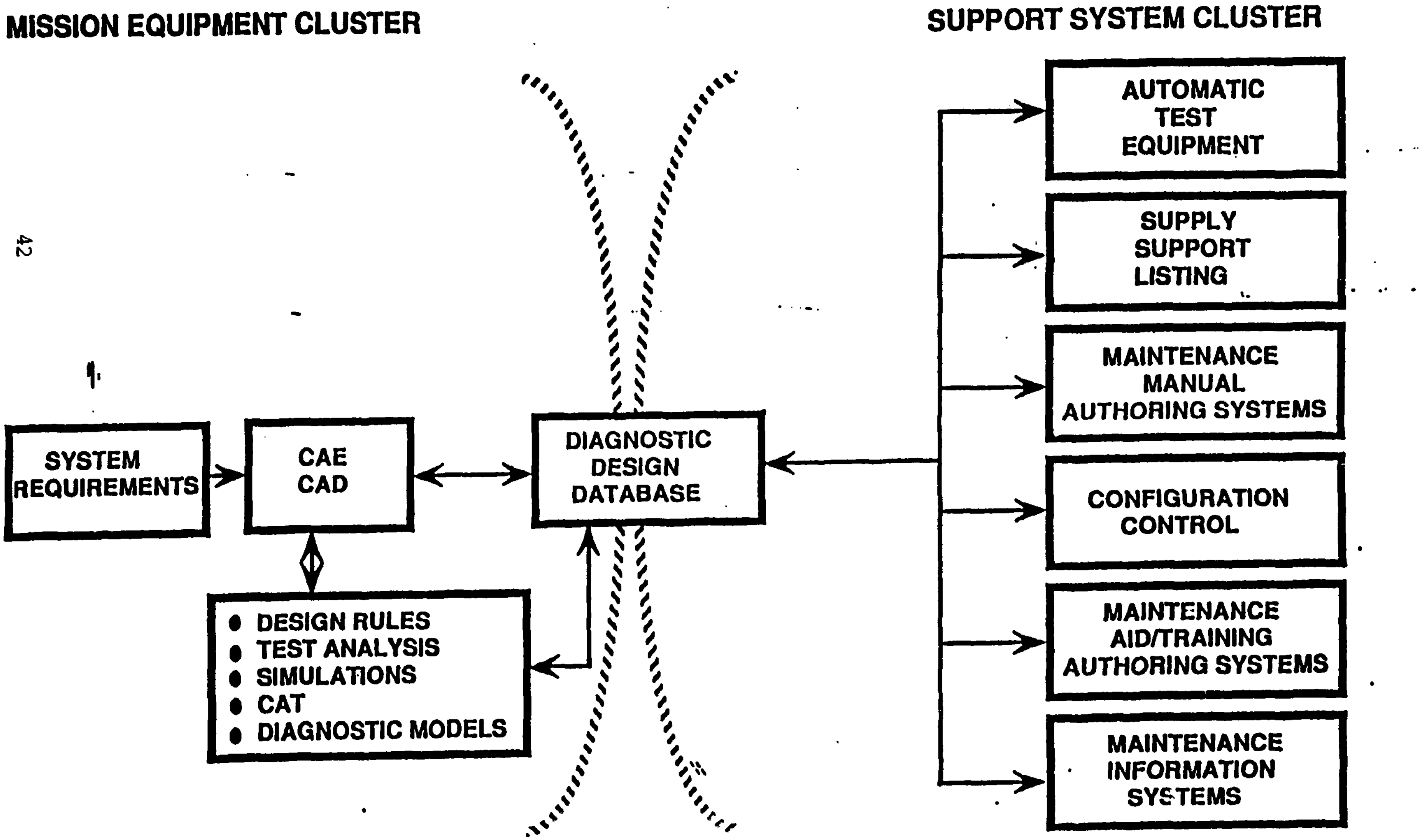
A FUTURE CONFIGURATION



OPPORTUNITIES

DIAGNOSTIC IMPROVEMENT AREA	WEAPON SYSTEM SUPPORT IMPACT	NEW TECHNOLOGICAL BUILDING BLOCKS
DEPLOYMENT BURDEN	REDUCE/ELIMINATE WEIGHT AND VOLUME (ATE, TECH INFO, SPARES)	ELECTRONIC DATA TRANSFER AND PRESENTATION
READINESS	RAPID, ACCURATE ASSESSMENT OF SYSTEM HEALTH (LONG TERM: BATTLE DAMAGE REPAIR)	INTEGRATED DIAGNOSTICS SYSTEM
MANPOWER #S & SKILLS	REDUCE TRAINING, APTITUDES, NUMBERS	PORTABLE MAINTENANCE AIDS
		RAPID CAPABILITY TO UPDATE MAINTENANCE KNOWLEDGE BY EXPERT SYSTEMS
		NEW SENSOR CAPABILITIES
		IMPROVED FAULT TREE LOGIC

FRAMEWORK FOR AUTOMATION OF DIAGNOSTICS DESIGN



WORKSHOP PARTICIPANTS

- FUNCTIONS REPRESENTED:
  - DOD MAINTAINERS - 24%
  - DOD R&D/ACQUISITION MANAGERS - 24%
  - DOD INDUSTRY - 24%
  - COMMERCIAL INDUSTRY - 28%
- MANY COMMODITY TYPES REPRESENTED (AIRCRAFT, SHIPS, HELICOPTERS, MISSILES, ATE, C^3)
- SPECIAL REPRESENTATION FROM ATA, ATF, AND LHX, THE EMERGING LEAD PROGRAMS CURRENTLY IMPLEMENTING ASPECTS OF INTEGRATED DIAGNOSTICS

WORKSHOP FOCUS

- DEVELOP APPROACHES FOR INCORPORATING INTEGRATED DIAGNOSTICS INTO SERVICE MAINTENANCE ENVIRONMENTS
  - FEASIBILITY OF INTEGRATING MAINTENANCE FUNCTIONS AND INFORMATION ACROSS TRADITIONAL MAINTENANCE "LEVELS"
- IDENTIFY IMPROVEMENTS IN SPECIFICATION AND ACQUISITION OF INTEGRATED SET OF DIAGNOSTIC HARDWARE/SOFTWARE
  - INTEGRATING VARIOUS VENDORS
  - WHAT TECHNOLOGY OR DESIGN "TOOLS" NEED TO BE DEVELOPED IMMEDIATELY
- IDENTIFY OTHER STEPS NEEDED TO ACCELERATE INTEGRATED DIAGNOSTICS IMPLEMENTATION

APPENDIX C

SUMMARIES OF CASE STUDIES

The following sections contain summaries of each of the case history presentations as well as a listing of system attributes and general factors that influenced the diagnostic successes described in the respective case study. The case studies are documented in the order they were presented in the workshop.

1. PRESENTATION TITLE: THE GENERAL MOTORS (GM) COMPUTERIZED AUTOMATIVE MAINTENANCE SYSTEM (CAMS)

1.1 Summary

Mr. Jon Beresia, Director, Product Engineering of the Service Technology Group, General Motors Corporation, described the GM-CAMS system as an advanced vehicle service system. It provides a nationwide connection of terminals, networks and GM factory computers. It also provides dealer service departments with similar test and diagnostic capabilities used in assembly plants, and is designed with diagnostic capabilities for electronic system and powertrain drivability in late model GM vehicles.

Mr. Beresia highlighted the combined market and technology forces which led to the development of the GM-CAMS. In general, the recent market forces in the automobile industry are being strongly influenced by the perceived maintenance and supportability of the vehicle. Yet at this same time two other technology driven forces are active making the service mechanic's job more difficult. The more restrictive emission controls and the application of microcomputer-based control systems in the engines and transmissions are making the vehicles more complex.

The technology in the complex electrical and mechanical systems of today's vehicle are advancing faster than the mechanic's expertise and training. This condition was exemplified by the fact that frequency of "trouble not found" problems on the vehicles with the more advanced technology were increasing significantly. Furthermore, the technique of trouble-shooting by removing and replacing suspected parts was becoming the accepted practice and driving up the customer's repair costs as well as impacting the parts warranty service costs for GM. GM recognized that a new diagnostic capability was needed and developed the GM-CAMS expert (rule-based) system.

The ability to service the vehicles is a function of many factors including the maintenance documentation, the training of the service technician, the test and diagnostic equipment, and the ability to update and maintain the service bulletins, campaigns (block design changes), and the various specifications for each type subsystem. Mr. Bereisa explained that the GM-CAMS system evolved into a technician's terminal that is much more than a powerful diagnostic computer—it is an integrated diagnostic tool that provides the following vehicle service capabilities:

a. Provides up-to-date, relevant service information, such as service bulletins, campaigns and vehicle specifications all of which are easily called up and viewed on the monitor.

b. Provides in-depth display and analysis of out-of-range vehicle data streams and malfunction codes.

c. Performs a quick test of entire vehicle electronic systems under key-on, part throttle and idle conditions.

d. Performs in-depth diagnosis and fault isolation of vehicle electronic systems and components down to harness wires and connector pins without the need of additional tools or "trouble tree" charts.

e. Supports difficult-to-make adjustments, such as minimum air rate or throttle position sensor, without the need for specifications or additional tools.

f. Transmits vehicle data back to GM divisional technical assistance centers for simultaneous viewing of problem vehicle performance.[1]

Mr. Bereisa observed that the GM-CAMS, with the centralized data collection and analyses capabilities, is providing an effective bridge between the maintenance technician and the system designer. The maintenance data feedback is essential for maturing both the system design as well as the diagnostics. Mr. Bereisa also indicated that GM is attempting to further extend this bridge by maintaining a single thread of diagnostic requirements that are needed throughout the design, preservation and maintenance life cycle.

Table C-1 summarizes the GM-CAMS diagnostics system attributes and factors that were assessed to influence the program success.

1. "GM-CAMS, The Technical Connection," Information pamphlet (M12727), EDS, Dec 87.

Table C-1. GM-CAMS Diagnostics System

- Addresses a clearly defined warranty parts problem.
- Problem resolution had corporate level support.
- Diagnostic system design and evolution focused on the specified problem.
- Set out to build an integrated set of diagnostics elements.
- Applies existing technology components.
- Automates configuration management of released product and support systems.
- Uses central data collection (including real time measurement data).
- Uses central analysis/refinement to mature diagnostics and product.
- System significantly improves fault isolation and diagnostics accuracy.
- Uses functional condition sensors.
- Takes advantage of functional sensor information overlap to improve diagnostics and system reliability.
- Uses automatic detection and error logging of intermittent and hard failures (transparent to operator).
- Makes use of automated (on-equipment) operational fault log.
- Uses diagnostics that self-adapt to vehicle condition and environment.
- Delivers intelligence presentation of maintenance information electronically.
- Simplifies maintenance input from technician.
- Uses software to compensate for limitations of hardware BIT extensively.

2. PRESENTATION TITLE: IBM 3090 DIAGNOSTIC SYSTEM

2.1 Summary

Dr. Nandakumar Tendolkar, Senior Engineer, Noise Detection and Recovery Design Department, IBM - Data Systems Division presented the IBM 3090 Diagnostic System. The IBM 3090 is the latest generation general purpose System/370 computer. The 3090 Processor includes a number of units: Processor, Processor Controller, a Coolant Distribution, and a Power Unit. The Processor Controller is an independent processor dedicated to maintenance and monitoring functions.

The processor is made from a very unique packaging technology called the Thermal Conduction Module (TCM), which is comprised of helium filled multi-chip large scale integration (LSI) modules. Each TCM contains 132 silicon chips. The next level of packaging is based on six to nine TCM's per board. On-line fault isolation provides for fault isolation to one field replaceable unit (or TCM board) in 95% of maintenance actions.

The maintenance strategy at the customers site is based upon a diagnostic system which fault isolates to the defective TCM board. The maintainer can then replace the identified board. Intermittent as well as hard faults are expected as fault types that the diagnostic system must detect and identify. The basic strategy of fault detection/isolation has been moved from a separate diagnostic process which may never determine or reproduce an intermittent fault to a concurrent detection and identification strategy based upon hardware error detection, error logging, and fault isolation by analysis of logged data. IBM calls this approach ED/FI (error detect, fault isolate). The Processor Controller manages the process of identifying the failed field replaceable unit (FRU). The customer engineer will change the FRU and the Processor Controller is used to verify the repair.

The maintenance processor (the Processor Controller) provides the mechanism for monitoring and supervising error recovery and fault isolation. The basic hardware is designed with Level Shift Scan Design (LSSD) built-in-test (BIT). The maintenance processor has complete control and access to this BIT and manages fault recovery as well as diagnostic actions required to verify the problem FRU. A history of all faults is maintained and when the processor detects an error that exceeds a designated threshold, the maintenance processor notifies the customer engineer which FRU to replace. The basic maintenance approach is a two-level maintenance strategy.

The maintenance processor uses a fault isolation analysis strategy based on intersection of direct error logging and fault dependency analysis to determine the failed FRU.

IBM set out on a new strategy to eliminate downtime for diagnostic testing. This new concurrent error detecting, and fault isolating strategy has allowed IBM to provide high system availability with a two level maintenance approach.

Table C-2 summarizes the IBM 3090 system attributes and factors that influenced case study success.

Table C-2. IBM 3090 System

- The 3090 system is a primary product of IBM.
- Willing to dedicate significant system resources to address diagnostic requirements (approximately 1/4 of system hardware).
- Conducted extensive design and testability analysis before committing to hardware configuration.
- Uses software to compensate for limitations of hardware BIT extensively.
- Leading edge technology selected and/or developed as needed to meet diagnostic objectives.
- Automatic detection, error logging, and isolation of intermittent and hard faults established as primary goal at design onset.
- Established a two-level maintenance goal with parts/cards fault isolation, removal and replacement objective.
- Made extensive use of diagnostics analysis tools.
- Used diagnostic software to identify and isolate intermittent faults.
- Used checking algorithms (implemented in software) to allow reconfiguration around defective redundant elements.

3. PRESENTATION TITLE: AT&T SWITCHING SYSTEMS USE OF INTEGRATED MAINTENANCE AND DIAGNOSTICS

3.1 Summary

Ms. Linda Ginzer, Head, Special Systems Development Department, AT&T Bell Laboratories, presented the AT&T #5ESS integrated diagnostic system. The #5ESS is the latest generation digital switching system developed and manufactured by AT&T. It provides local and toll switching as well as operator services to the telephone network. The switch supports 100,000 line terminations, 400,000 calls per hour, and the installed base of #5ESS is twenty-three million lines. The system has very high reliability requirements with a system downtime of less than three minutes per year, and a single line downtime of less than twenty eight minutes per year. The system availability is 99.8%. Downtime in such a high reliability system based on a fault tolerant system is 20% due to hardware, 40% due to embedded software, and 40% due to maintenance technician procedural mistakes.

The #5ESS does not have a conventional electronic computer system maintenance philosophy where errors are catastrophic, and system downtime is nuisance. Instead system downtime is a catastrophe, and errors become a nuisance. The system is based on distributed hardware, localized fault detection and recovery, and fault containment from the balance of the system. The system uses continuous self-testing of all hardware and software, and supports graceful degradation of system functions based on hardware redundancy. The system includes error reporting and on-line trouble location reporting. Generally, the system corrects faults automatically and notifies the craft (maintainer) of circuit packs to be replaced. Software error checks are based on correlation of redundant information and autonomous process checks as well as more typical data format and range checks.

The diagnostic system supports craft control of diagnostic processes to verify operation of a circuit, confirm a real-time fault recovery decision, and is also used during manufacture and installation of the system.

The craft maintenance interface actually identifies which circuit pack is suspected as faulty indicating aisle, frame, bay location as well as identification codes. Ninety percent of the diagnostic applications identify one circuit pack, and the balance are resolved to two circuit packs. Circuit packs are returned to the factory for conventional repair by replacement of faulty components.

This level of required system availability dictated that approximately fifty percent of the software be dedicated to maintenance and diagnostics. Much of the diagnostic software makes up for limitations in the capability of built-in-test hardware. A significant percentage of the operating system software is used to support real-time error detection and management. The #5ESS provides a guidepost to attainable availability goals for electronic systems and demonstrates effective two level maintenance.

Table C-3 summaries the 5ESS system attributes and factors that influenced case study success.

Table C-3. 5ESS System

- System availability of 99.8% (or 3 minute down time per year) is primary corporate objective.
- Different maintenance philosophy errors are a nuisance; however, a system failure represents a catastrophe.
- Predefined maintenance strategy to provide redundancy and prevent down time.
- Automatic detection, error logging, and isolation of intermittent and hard failures are a design requirement.
- Diagnostic elements implementation applied leading edge technology solutions when required.
- The system automates maintenance and resource allocation in real time without an operator.
- Diagnostic and fault recovery are built into the design.
- Simplified maintenance technician interface.
- The system uses extensive software to compensate for limitations of hardware BIT coverage and intelligence.

4. PRESENTATION TITLE: WESTINGHOUSE TURBINE GENERATOR ON-LINE DIAGNOSTIC SYSTEM

4.1 Summary

Dr. Robert Osborne, Manager, Diagnostic and Monitor Development, Generation Technology Systems Division, Westinghouse, described the on-line diagnostics for commercial turbines, generators and steam chemistry systems. The Westinghouse system applies artificial intelligence (AI), rule-based logic to provide continuous on-line status and problem diagnostics information (including the projection of potential future problems) to a single centralized control center.

Dr. Osborne explained that the downtime of a major unit can cost as much as a half million dollars a day. The AI diagnostics permit utilities using these systems to plan maintenance intervals with higher levels of confidence and to plan for the higher levels of availability. The diagnostic systems are continually fed information from on-line sensors that monitor the system operating conditions. The operating parameters and other data are then transmitted to the diagnostic center's centralized computers.

The computers are programmed to simulate the thinking process of the system experts and, based on the extensive rule-based logic and the real time operating data, to recommend appropriate actions. In addition to identifying recommended actions, the AI diagnostic system identifies specific equipment conditions, places conditions in a relative priority order, and identifies potential consequences of inaction.

Dr. Osborne also indicated that because the data and rules are continually exercised at the centralized diagnostic center for multiple on-line systems, the diagnostic rule based for any given situation grows faster with the experience that may be gained from a greater number of systems. He indicated that the bottom line is increased productivity because maintenance actions can be scheduled on a convenience basis rather than due to reactive necessity. Based on the estimated half million dollars per day for a major system outage and the on-line availability improvement of approximately 1.9 percent (or 7 days), they generally estimate the economic return to be 3.5 million dollars annually per application of the AI diagnostics system.

Another interesting aspect of this AI diagnostic concept is that virtually all of the installations were applied to existing turbine and generator systems. Not only does it

represent an application of the leading edge technology, it represents a stand-alone innovation to an existing system that will provide opportunities for better maintenance management and planning as well as increased productivity.

Table C-4 summarizes the GenAid diagnostic system attributes and factors that influenced case study success.

Table C-4. GenAid Diagnostic System

- Corporate need to minimize unscheduled downtime (cost approximately $.5M per day).
- Establishes an environment that permits continuing maturation of diagnostics (even with low failure rates and a small population of monitored units).
- Expert (rule base) system captures what has been/is being learned, thereby improving diagnostic capability.
- Requires prognostic view to ensure early identification of necessary maintenance action as well as consequences of inaction.
- Requirements driven by users (implemented on existing system by 3rd party).
- Uses remote central data collection, analyses, and AI maintenance prognostics.
- Central on-line analysis of multiple (similar) systems improves diagnostics algorithms and rules.
- Corporate need to minimize catastrophic (secondary damage) problems.
- Uses functional and diagnostic condition sensors.
- Takes advantage of functional and diagnostic sensor overlaps to improve diagnostic accuracy.
- Changes from on-condition maintenance strategy to prognostic based maintenance planning.

5. PRESENTATION TITLE: COMMERCIAL ENGINE INTEGRATED DIAGNOSTICS EXPERIENCE - THE GROUND BASED ENGINE MONITORING (GEM) PROGRAM

5.1 Summary

Mr. David Doel, Manager of Data Analysis Technology, General Electric Aircraft Engines, described their Ground-based Engine Monitoring (GEM) system. GEM was developed in the early 1980s by GE Aircraft Engines in cooperation with DLH (Lufthansa German Airlines), KLM (Royal Dutch Airlines) and SAS (Scandinavian Air System). The original objectives of the GEM included the following: (1) providing a single integrated engine monitoring software system, (2) reducing the personnel requirements for engine monitoring support, (3) increasing the effectiveness of engine monitoring equipment, (4) capturing history to facilitate future monitoring improvements, (5) providing a single software package to address all engine models, and (6) integrating to other airline systems.

The GEM application scenario captures on board/in-flight engine operation data as well as test cell and maintenance data. The aircraft data is sent to a centralized real-time processing center via the line station reservation system. The ground based software analyzes the engine performance data from the test cell, run-ups, and on-wing. Analytic features of the GEM include maintenance alerts, the recognition of potential performance or maintenance trends, data on the occurrence of exceeded limits of specified operating parameters, and summary data on fleet averages.

The GEM data and analyses provide early identification and resolution of field problems, and through the alerts and trend analyses, reduces personnel needs for monitoring. The fan rotor imbalance analysis alone is estimated to save $1000 per trim balance with an average of two trim runs per year per engine. On-wing maintenance performance analysis saves an estimated 5 percent of the maintenance overhaul budget. Furthermore, the controls monitoring function saves fuel and increases the engine stall margin resulting in approximately a 0.5 percent reduction in fuel consumption.

Mr. Doel indicated that the development of the GEM system was clearly a team effort, and that the development and implementation occurred in evolutionary stages. He indicated that the monitoring and analyses technologies can not develop by theory alone.

For example, new designs are via development testing, and the integrated diagnostics that evolve must be tested in service environments. This is, in large part, due to the fact that simulated tests cannot provide sufficiently large data samples that are representative of real operational conditions. Finally, it takes time to fully comprehend what the data may be implying and to establish a means of integrating the results of various data inputs.

Mr. Doel highlighted the following lessons learned from the initial development of the GEM. Initial development of monitoring systems is truly a research area and it needs the extensive testing data from field experience. He indicated that deriving up front system development and production specifications for integrated diagnostics capabilities, may be very difficult due to the iterative nature of diagnostics development. He went on to suggest that rapid prototyping environments are needed to support integrated diagnostic research. These prototyping concepts should recognize that the sensor and hardware designs are generally not easy to alter; however, the software may be designed in such a way that it may be enhanced as field experience is gained.

Mr. Doel also provided the following observations. For integrated diagnostics to progress, the designer and user communities must take some risks. He further observed that integrated diagnostics is a test of perseverance and it is often very difficult to justify the addition of specific sensors or monitors into a system design to support diagnostics. They cost more to add, they reduce reliability, and they can cause other system design and maintenance problems. Mr. Doel suggested that integrated diagnostics must be sold on faith because very often the available justification data will not support the real need.

Table C-5 summarizes the GEM system attributes and factors that influenced case study success.

Table C-5. GEM System

• Clear corporate desire to minimize unscheduled downtime. • Establishes an environment that permits continuing maturation of diagnostics. • Implements a prognostic capability to ensure early identification of necessary maintenance action as well as consequences of inaction. • Uses central data collection and analysis from all on-wing and ground maintenance actions (i.e., test cell, etc.). • Uses continuous centralized analysis of multiple systems to improve diagnostic algorithms. • Corporate need to minimize catastrophic (secondary damage) problems. • Requirement driven by customers (integrated diagnostics requirement not driven by original equipment manufacturers (OEM), however, implemented by OEM). • Changes from on-condition maintenance strategy to prognostic based maintenance planning. • Uses functional and diagnostic condition sensors. • Takes advantage of functional and diagnostic sensor overlaps to improve diagnostic accuracy.

6. PRESENTATION TITLE: THE SYSTEM CONTROL TECHNOLOGY XMAN JET ENGINE DIAGNOSTIC SYSTEM

6.1 Summary

Dr. Ronald DeHoff, Manager of the Maintenance and Logistics Systems Department, and Mr. Lawrence Miller, Manager, New Program Development, Maintenance and Logistics Department, both of Systems Control Technology, jointly presented an overview of the eXerpt MAiNtenance (XMAN) system. XMAN is an expert system which has been applied to integrated maintenance support of jet engines in both Air Force and Navy weapon systems. These aircraft engines are maintained at three operating levels, and the maintenance process generally involves moving hardware and data from the flight line through the overhaul depot. The modern aircraft engines that XMAN is being applied to have engine monitoring systems (EMS) on-board that detect abnormal engine operating data. XMAN supports the diagnostics and troubleshooting by applying a rule based integrated interface framework to the available EMS, ground maintenance and logistics data. XMAN also delivers technical order and/or manual data to the engine mechanic at the flight line, thereby greatly reducing the paperwork burden associated with maintenance management.

The main components of XMAN include a computerized knowledge or rule base, integrated data bases, and a control system. The data sources include the EMS data taken directly from the aircraft, data from both on-and off-aircraft maintenance actions, and the base logistics maintenance and support information systems. This information is used to form the historical records upon which XMAN applies the expert knowledge. This process results in identification of equipment faults, provides prognostic information as well as supporting data.

XMAN is also an automated technical manual delivery system that supplements the go/no go diagnostics and on-wing inspections. It also has time/cycle tracking as well as trends/forecasting capabilities. Furthermore, it helps keep track of the engine parts configuration and the specific engine maintenance history.

Both presenters focused on the challenges of applying an integrated diagnostic and expert system into the DoD environment. There are a number of training concerns including computer literacy as well as management, social and political factors that must be considered in any application. For example, they found that XMAN required a significant user and management acceptance period given the potential safety implications involved with a diagnostic maintenance tool for aircraft jet engines. The apparent learning period necessary to accept the automated diagnostics outputs, coupled with the need to change work habits and cultural barriers, appears to be consistent across system applications.

Table C-6 summarizes the XMAN diagnostics system attributes and factors that were assessed to influence the program success.

Table C-6. XMAN Diagnostics System

- Automates the integration of existing maintenance and operational history data bases.
- Integrates the maintenance data base information with the engine maintenance procedures and diagnostics.
    - Prognostic (interactive with maintenance technician).
    - Electronic presentation of technical manuals as needed.
    - Integrates electronic reference to technical manuals.
    - Provides support trend analyses and prognostic-based maintenance actions.
    - Data is centrally analyzed and distributed for maintenance implementation.
    - Integrated training and electronic technical manual presentation.
    - Developed and retrofited to existing system by third party developer.
    - Provides maintenance technology bridge between paper and electronic presentation.

7. PRESENTATION TITLE: THE WESTINGHOUSE REMOTE MAINTENANCE SYSTEM FOR AIR SURVEILLANCE RADAR (ASR)

7.1 Summary

Mr. Charles Alfred, Fellow Engineer, Remote Maintenance Systems Department, Electronic Systems Group, Westinghouse, described the new Federal Aviation Administration (FAA) Remote Maintenance System for Air Surveillance Radars (ASR). These radars, currently being fielded at FAA sites throughout the United States, demonstrate a growing need and concern for integrated diagnostics and remote maintenance capabilities. A primary driver for the new FAA maintenance philosophy is the anticipated budgets and funding cuts which will dictate that future maintenance and support efforts must be less costly. This condition is occurring at the same time that a significant portion of the average maintenance workforce will be approaching retirement age, thus complicating the training of a wide range of technologies necessary to support the old as well as new (state of the art) systems. Finally, the new systems will have higher reliabilities, thereby, creating a secondary problem of impacting the maintenance on-the-job training as well as extending the time necessary to gain a quality experience base.

The remote maintenance systems for the ASR will provide for monitoring and identification of needed maintenance actions from centralized sites. Then, when a maintenance problem is identified, a field technician will be dispatched to perform the required maintenance or support action. The expert diagnostics system will identify needed parts to be transported to the site as well as specific instructions to perform the corrective action. The system will also have the capability to provide limited remote maintenance by switching to alternate redundant equipment when directed from the central maintenance control facility.

This integrated diagnostics system will also help to improve the configuration and control of the FAA facilities. It will provide a common configuration and failure information data base. The centralized management and the remote monitoring will help facilitate the standardization of both the hardware and software documentation and configuration across sites.

The remote maintenance system capabilities remove the need for on site/on call personnel, provide a central control of multiple sites, and provide the opportunity for sharing of on-the-job maintenance learning and experience.

In addition to the basic system, Westinghouse has developed a remote monitoring system simulator for training. It provides the look and feel of the primary system, operational error trapping on-line help, as well as a question and answer capability via a mail facility.

Mr. Alfred highlighted the following lessons learned. Remote control and embedded training cannot be implemented without being initially specified. The remote features and capabilities should be designed with user input and specifically to meet the technician's needs. Training simulations should be developed along with the primary systems, and they need the same configuration control attention to detail as the primary system. Finally, user friendliness is essential and valuable inputs come from maintenance training organizations as well as from the maintainers.

Table C-7 summarizes the ASR diagnostics system attributes and factors that were assessed to influence the program success.

Table C-7. ASR Diagnostics System

- FAA corporate commitment to reduce maintenance manpower, spares and support equipment.
- High system availability a primary FAA objective.
- Uses ability to take full remote control of multiple sites from a centralized facility to remotely fault isolate, correct software driven faults, and replace hardware failures with redundant equipment.
- Eliminates permanent on-site maintenance staff through remote monitoring, diagnostics, redundancy and mobile field service (2-level maintenance).
- Provide simulation based training (for remote maintenance and diagnostics).
- Reduces spares through improved diagnostics accuracy.
- Reduces spares by consolidating inventories at centralized facilities (control centers).
- Uses functional condition sensors and built-in-test equipment.

8. PRESENTATION TITLE: THE IBM AN/BSY-1

8.1 Summary

Mr. Victor Scuderi, Project Manager of Integrated Diagnostics, IBM-Federal Systems, Systems Integration Division presented the AN/BSY-1 Integrated Diagnostics. The AN/BSY-1, Submarine Combat Control and Acoustics System, provides the 688 class submarine with a completely Integrated Combat Suite consisting of 117 cabinets of hardware and 4.5 million lines of software. The system relies heavily on previous subsystems.

The maintenance strategy for the submarine is based upon no on-board test, measurement, and diagnostic equipment. On board maintenance is limited to automatic reconfiguration of fix-on-incident, and modules swaps. Spare modules are pre-packed in maintenance assist module (MAM) kits. The intermediate (or "I") level maintenance uses conventional maintenance approaches. This system is unique compared to other high availability systems presented at this workshop. It contains Government Furnished Equipment (GFE) and equipment produced by many subcontractors. The system on board diagnostic system is based upon performance monitoring and fault localization.

On-line performance monitoring can detect 95% of faults in a mean time of 180 seconds. The maximum detect time is seven minutes and one false alarm is allowed per twenty-four hours. The off-line fault localization system can isolate to two modules 80% of the time and must isolate to no more than eight modules.

Built-in-test hardware structural test was available only in the new system components. The system relied upon 4.5 lines of software code to implement system functions and the maintenance strategy. About 25% of that software was dedicated to the maintenance strategy. The AN/BSY-1 reduced technical manuals through very effective on-board test and fault isolation capability. No circuit diagrams were required to be deployed. On board maintenance manual space was reduced from 28.5 to 15.7 cubic feet. Circuit training was eliminated for the maintainers.

The AN/BSY-1 represents an evolutionary approach to maintenance strategy improvement. Extensive on-board software and redundant hardware reduced the requirements for support equipment to maintenance assist module (MAM) kits only.

Table C-8 summarizes the AN/BSY-1 system attributes and factors that influenced case study success.

Table C-8. AN/BSY-1 System

- Functional space constraints dictated reductions in paper manuals, test equipment and spares.
- Design and maintenance requirement and/or strategy from the onset:
  - No special test equipment.
  - Reduce spares volume.
- Essential customer requirement for high availability.
- Eliminates requirement for circuit diagrams on submarine through improved diagnostics accuracy attained with extensive software.
- Uses checking algorithms (implemented in software) to allow reconfiguration around defective redundant elements.
- Uses software to compensate for limitations of hardware BIT extensively.

APPENDIX D

WORKSHOP REPORTS

The following sections highlight the discussions and results of the respective working groups and provides an overall workshop summary.

1. WORKING GROUP 1: USERS AND SUPPORTERS

1.1 PROBLEMS

All the systems highlighted in the case studies rely upon "data collection" to form a feedback loop. This feedback loop is essential for the integrated diagnostic system to be successful. The working group noted that DoD's experience in collecting data from flight line operations has mixed results. Hence, integrated diagnostic systems may be vulnerable because of the need for an effective feedback loop. Many of the presenters spoke of the difficulty of updating the integrated diagnostic system with on-going data collection.

A clear definition of what integrated diagnostics is must be articulated. Some users assert that the DoD has integrated diagnostic now. Common terms and understanding are essential to minimize risk of not obtaining what the DoD asks from a contractor. The consensus of the working group was that integrated diagnostics is the application of technology to system restoration that improves the process and is characterized by automation, built-in-test, expert systems, feedback loops, information delivery system and data collection.

The data collection effort cited above interplays with the fact that weapon systems evolve. If an integrated diagnostic approach requires this feedback, then configuration control is critical to maintaining a valid integrated diagnostic system. An evolving weapon system baseline may adversely impact the data collection capability as well as the integrated diagnostic accuracy.

An ingredient to successful integrated diagnostic system effectiveness is the failure modes-effects analysis (FMEA). However, several presenters noted that no matter how skillful and thorough the engineering effort to predict *a priori* failure modes and the observable effects, FMEA is only a starting point. Routine data collection and diagnostic system improvement effort is required to keep the system robust and accepted by the users. This reality introduces risk into the integrated diagnostic concept.

Adding integrated diagnostic to a weapon system could increase complexity and decrease reliability. As will be noted in recommendations below, this tradeoff must be reviewed when considering the overall issue of integrated diagnostic. Note that Lufthansa refused to add certain sensors to their engines because of the resulting decrease in reliability.

The thrust of the workshop and tenor of the presenters were to design integrated diagnostic into a system at its conception. However, declining DoD budgets may reduce the chance to use integrated diagnostic on new starts just because there will be so few.

Consequently, much of the existing equipment on the ramp, in the field, or at sea will be with us for a long time. The viability of integrated diagnostic may rest with its ability to be retrofit to all that existing equipment. Can it be retrofit or must it be part of the initial design? The results of the XMAN (see Appendix C) project may answer this question and suggest decisions on integrated diagnostic's future.

Cultural changes for the users represent potential problem areas. As the XMAN presentation indicated, the maintainers used XMAN and then promptly consulted their old paper technical data to confirm the recommended corrective action. Integrated diagnostic does not obviate the need for reliability.

1.2 WAR VERSUS PEACETIME

An integrated diagnostic system must not require a deploying war fighting unit to remain linked to some central data processing facility. A unit must be able to stand alone and fight with little or no decrease in system reliability or maintainability. The complexity of war should not be further encouraged by making successful maintenance depend on a cosmic data system that may be unusable or unavailable during war. After the initial bed down and theater status stablizes, data links can be re-established. But these diagnostics related data links should not be a necessity when using the systems to fight.

1.3 BARRIERS

The lack of a common definition for integrated diagnostics has spawned uncommon approaches and equipments. This may impede the introduction of new diagnostics capabilities, particularly if retrofit is the most productive way to gain the advantages of integrated diagnostic. Proliferation complicates and discourages.

1.4 BENEFITS

Clearly, the presenters made the case for reduced manpower to maintain systems with integrated diagnostic. The presenters also highlighted opportunities to reduce the system life cycle costs.

1.5 RECOMMENDATIONS

The workshop participants recommend that integrated diagnostics be designed into weapon systems, but only after results of some of the pilot programs and current integrated diagnostic system are analyzed and true costs and benefits derived. Having been sold "bills of goods" before, the DoD should wait for tangible results to be visible. A large number of integrated diagnostic systems are under development and/or near completion and use. The following are working group comments relative to this recommendation:

- Look for other ways to achieve improved reliability and note that systems that break infrequently may not need an expensive, high-risk, data-sensitive integrated diagnostic system.
- Analyze tradeoffs between integrated diagnostic and basic reliability improvements.
- Look at eliminating a level of maintenance, e.g., depot level maintenance.
- Look at Deming's concepts of Total Quality Management. (See Mary Walton's, The Deming Management Method, New York, Perigee Books, 1986.)
- Keep the status quo pending evidence that integrated diagnostic is not a flash in the pan.
- Proof of integrated diagnostic retrofit opportunities are needed. XMAN may be an appropriate program to watch.

2. WORKING GROUP 2: ACQUISITION AND SYSTEM DEVELOPMENT

2.1 INTRODUCTION

This section provides the results of discussion within the Working Group on Acquisition and System Development. This working group was tasked to address the following ideas and questions:

a. Differences between commercial and DoD,

b. Lessons learned, benefits and barriers, and

c. Application opportunities.

2.2 GENERAL

The working group observed that the DoD is currently experiencing an interaction between technological and social forces. Advancements in technology are allowing the rapid transition from simple monitoring systems into highly integrated diagnostic systems. However, the effective implementation of integrated diagnostic techniques also requires integration across a support infrastructure that is very functionally oriented. Currently the ability of this structure to effectively handle the interaction among the functions is poor. Although the infrastructure is moving toward greater functional integration, it is occurring at a much slower pace than desirable to keep up with technology. Section 11.3 contains a discussion of the differences between commercial and military systems, the lessons to be learned and how the DoD can apply these lessons.

2.3 DIFFERENCES

The following paragraphs highlight the basic differences between various requirements and needs of commercial and military systems.

a. Threat vs. Market Share. The major force behind the development of military systems is the current and projected threat from the weapon systems of potential adversaries. These threats are translatable into specific capabilities that must be countered. In contrast, the commercial world is largely driven by the need to capture that share of the market that is necessary to derive an acceptable profit. In the commercial environment, if a company recognizes that it cannot meet the challenges of a particular product line, the company may withdraw from that competitive environment and direct energies elsewhere.

b. Weight and Volume. Military systems frequently have more severe weight and volume constraints than commercial systems. This characteristic derives itself from the threat, the typical need for US military systems to deploy and operate over long distances, and meet a threat that is typically closer to its internal lines of communication. One of the major fall-outs of this is that commercial systems can frequently incorporate greater redundancy in order to delay required maintenance actions to a point of convenience. In the military environment, component redundancy is sometimes incorporated to reduced unscheduled combat maintenance. However in peacetime, the maintenance workforce is generally tasked to keep all redundant items in working condition. Thus, the redundancy actually adds to the peacetime workload.

c. Budget vs. Requirements. In a tight budget environment, the military Services may place emphasis on "rubber on the ramp" over effective support. This is based on the argument that selected spares and trained people can be produced faster than the aircraft, ships and ground systems during a crisis situation. Although the military users may be dissatisfied with a less effective support system, they have few, if any, alternatives. In the commercial world, the producers must maintain customer confidence and satisfaction if they are to remain in business. This tends to insure that the integrated diagnostics and other support consideration are not eroded in the overall commercial sector budget decision process.

d. Product Life. The military environment is characterized by much longer product life cycles. The military environment takes 7-10 years to develop a new weapon system while, on average, the commercial development environment is much shorter with many products only requiring 2-4 years. The operating life in the military ranges from 20 to 30 years with upgrades. In the commercial environment, the system life is variable and is driven by technology, customer expectations, and profit motivations.

2.4 LESSONS LEARNED, BENEFITS, AND BARRIERS

The following paragraphs are based on the shared experiences of the working group participants and highlighted their perception of lessons learned, the benefits, and the barriers to integrated diagnostic system implementation.

a. Lessons Learned:

(1) Funding. Integrated diagnostics and other support requirements must have adequate management commitment and funding for the life of the program.

(2) Early Design Definition. The development of an effective integrated diagnostics capability must be accomplished concurrently with the product design. It is very difficult to retrofit integrated diagnostics onto an existing product. Equally important, early emphasis must be placed on working the support infrastructure to be compatible with the integrated diagnostic approaches that are taken. This will require the in-depth involvement of the users and supporters as both the design and its integrated diagnostics features are developed.

(3) Rapid Prototyping. While early definition of integrated diagnostics requirements and solutions should be emphasized, it is also recognized that integrated diagnostics is an evolving technology that still requires a certain amount of trial and error in real world applications. It is very doubtful that a fully integrated diagnostics capability could be adequately specified prior to the start of product development. An evolutionary strategy incorporating rapid prototyping to improve realism of integrated diagnostic requirements appears to hold the most promise. Within this strategy, the users and supporter should be provided the opportunity to gain some early experience with the systems while there remains the chance to influence the design. The system should then be evolved to satisfy their needs. Finally, the system must be adequately tested prior to delivery to operation units.

(4) Local versus Central Capabilities. The architecture that provides for the best long-term use of integrated diagnostics resources appears to have a local data collection and limited information retention. However, it must provide for full automated analysis capability with all significant information flowing into a central repository. It is from a central location that the continued refinement of the diagnostic analysis and capability is accomplished.

(5) "Not Invented Here" Syndrome. The "Not Invented Here" syndrome needs to be recognized early and attacked with great vigor. The effective

implementation of integrated diagnostics will cross over many traditionally separate functional areas. An early strategy needs to be developed to anticipate social/political/organizational problem areas and to gain the support of the associated individuals.

b. Benefits

The primary benefits for DoD systems from integrated diagnostics is increased availability while decreasing the support needs. The decrease in support needs includes reduced burdens in the logistics areas such as spares, support equipment, people, and manpower specialization training.

c. Barriers

(1) Major Weapon System Dependence. It generally takes a major weapon system development to drive significant advancements in the support infrastructure. Major weapon systems are usually highly complex and have the broadest impacts on the support structure.

(2) Poor Contractor Incentives. DoD business strategies currently do not provide good contractor incentives toward integrated diagnostics. This primarily is due to the fact that there is no effective means for a contractor to share directly in the benefits accrued to the government from an effective integrated diagnostics capability. In fact, exactly the opposite occurs. If the integrated diagnostics capability is successful, then the contract will probably sell less spare items to the government. Furthermore, it also adds complexity to the system. Thus, yielding greater cost, schedule, and performance risks for the contractor.

(3) Functionally Oriented Infrastructure. As stated earlier, the effective implementation of integrated diagnostic techniques requires integration across a support structure that is very functionally oriented. Currently, the ability of this structure to effectively handle the interaction between the functional areas is poor. This is basically a social problem that effects acquisition communities as well as the operational and support communities. Although the infrastructure is moving toward greater functional integration, it is occurring at a much slower pace than desirable to keep up with technology.

(4) Quantifiable Requirements. Currently, there is a lack of quantifiable, easily measurable, integrated diagnostics requirements. Traditional measures of supportability provide for such factors as quantity of spares,

support equipment, people, skills, etc. Similarly, operational measures include items such as failure rates, fix rate, mission completion success probabilities, stories generated, etc. However, suitable measures of integration effectiveness across the traditional measures do not exist.

(5) Competition and break out. The effective implementation of integrated diagnostics requires a true systems engineering approach. This requires that the contractor have broad system design and management responsibility to ensure the achievement of a long term integrated systems approach. This strategy is in direct contrast to the prevailing government strategies of competition and break out. This strategy reduces concurrent engineering analysis through lack of investment in necessary methods, tools , and information standards.

(6) Specification and Standards. There are already too many specifications and standards within DoD. However, engineering information standards which would enable communication across contractors and Government do not exist to support concurrent diagnostic design. The success of integrated diagnostics implementation is best served by more logic and reason with less restrictive standards.

2.5 APPLICATION OPPORTUNITIES

The characteristics of good application opportunities are those that lower DoD costs while providing higher contractor profits. They should be aimed at high payoff areas that are reasonably under the control of one implementing office.

a. Rapid Prototyping. As discussed above, the evolutionary strategy incorporating rapid prototyping should be used. This strategy should provide demonstrated concepts before writing detailed specification and standards. It should be geared to proving successes on a small scale and preferably implemented on existing systems in order to show immediate benefits. The proven concepts should be used to gain broad-based support in both DoD and industry such that demonstrated integrated diagnostics concepts can be expanded in scale.

b. Industry Incentives. New approaches to incentivize contractors toward the development of effective integrated diagnostic capabilities need to be developed.

c. Industry and Government Forums. The expanded use of informal industry and government forums is encouraged. These will help promote the exchange of ideas and the development of concepts outside of competitive program office environments and outside of the traditional staff through the System Program Office to contractor relationship.

2.6 DEFINITION OF INTEGRATED DIAGNOSTICS

Working group discussions focused on the many meaning and definitions of "Integrated Diagnostics" used throughout the workshop. The participants observed that Integrated Diagnostics was used interchangeably as (1) a process and/or approach, (2) a series contractual needs or requirements, and (3) as a measure of diagnostics capabilities. The working group recommended that a consistent set of definitions and terms be developed to address each of these specific areas. The consensus of the working group was that the following NSIA definition that referred to Integrated Diagnostics was an excellent first step towards a standard definition:

> Integrated diagnostics is defined as a structured design and management process to achieve the maximum effectiveness of a weapon system's diagnostic capability by considering and integrating all related pertinent diagnostic elements. The process includes interfaces between design, engineering, testability, reliability, maintainability, human engineering, and logistic support analysis. The goal is a cost-effective capability to detect and unambiguously isolate all faults known or expected to occur in weapon systems and equipment in order to satisfy weapon system mission requirements.

3. WORKING GROUP 3: ENGINEERING TECHNICAL DATA AND STANDARDS

3.1 OVERVIEW OF GROUP DISCUSSIONS

Group 3 discussions concentrated initially on determining when to begin including integrated diagnostics. It was decided that the integrated diagnostics requirement was to be included in the Tentative Operational Requirement and certainly no later than Defense Acquisition Board (DAB) Milestone I.[2] This would assure that integrated diagnostic would be included from concept definition through development as part of the Functional, Allocated, and Production Baselines.

The working group discussed the various diagnostic elements (built-in-test, test equipment, technical information, training, etc.). Discussions focused on how the diagnostics elements could be specified and included in development specifications and baselines. The working group felt that test equipment implementation could not be standardized due to various manufacturer's unique/proprietary configurations. However, it was felt that test information interfaces could be standardized.

The working group identified a number of engineering information interfaces that need to be considered in terms of integrated diagnostics. These include drawings, specification, technical manuals, Logistics Support Analysis (LSA), Computer Aided Engineering (CAE), Computer Aided Design (CAD), and Support Equipment Requirements Document (SERD).

3.2 SUMMARY OF IDENTIFIED CONCERNS/PROBLEMS

The working groups identified the following concerns:

a. There is not a uniform understanding of integrated diagnostics in DoD, industry, and academia.

b. There will be a considerable impact on maintenance and maintenance training as a result of integrated diagnostics and it needs to be addressed.

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2. Department of Defense Directive 5000.1, Major and Non-Major Defense Acquisition Programs, September 1, 1987.

c. The effects of integrated diagnostics on equipment weight, configuration, environment, human factors, etc., need to be addressed.

d. Operators and maintainers must avoid becoming complacent and expecting equipment to be overly self-sufficient.

e. The effects on traditional life cycle support need to be addressed.

f. Engineering information interfaces are not standardized for integrated diagnostics and this inhibits design analysis across weapon systems, and subsequent analysis during operation.

3.3 WORKING GROUP FINDINGS

The working group was unanimously receptive to integrated diagnostics. Most group members could recite examples of instances where many hours were expended and good hardware was replaced in attempts to localize failures.

3.4 PRELIMINARY RECOMMENDATIONS

The working group identified the following preliminary recommendations:

a. Require integrated diagnostics early in a program, i.e., during concept definition.

b. Include integrated diagnostics as part of contract requirements, by integrating the needs into requirements (i.e., avoid separate line items.)

c. Revise and consolidate current standards to include integrated diagnostics.

d. Develop engineering information standards to support assessment of integrated diagnostics performance.

e. Maintenance and maintenance training needs must be addressed.

4. WORKING GROUP 4: RESEARCH AND DEVELOPMENT

4.1 SUMMARY OF IDENTIFIED CONCERNS/PROBLEMS

The workshop group expressed concern that there is a lack of a clear definition of integrated diagnostics. Additionally, they expressed fear that integrated diagnostics would be treated as one more great idea doomed to inertia.

4.2 WORKING GROUP FINDINGS

The working group findings and opinions are summarized in the following:

a. Is it feasible to acquire and apply integrated diagnostics?

The working group concluded that it is feasible to acquire and apply integrated diagnostic approach. However, integrated diagnostics must be required up front with clearly articulated specifications. Furthermore, new design tools may be required.

b. Is it feasible to acquire integrated diagnostics when multiple contracts are involved?

The working group concluded that it is feasible; however, the risks are probably reduced if only one contractor is involved. Furthermore, the basis for contractor source selection and award may become very important if DoD plans to acquire integrated diagnostics system as a package. The question of how to handle non-developed items would also need to be addressed.

c. What changes might be required to implement integrated diagnostics concepts on DoD systems?

A number of potential changes to acquisition and support policies and procedures may be required, including the following areas:

(1) Institutional change

(2) Basis for award

(3) Metrics and measurement techniques

(4) Testability requirements

(5) DoD policy and standards

d. Technology strategic objectives that may influence integrated diagnostics systems' success include:

(1) Attack technical barriers in integrated diagnostics (e.g. Line Replaceable Unit (LRU) fault isolation capability).

(2) Prognostics (mechanical and electrical)

(3) Electronic manuals

(4) Data collection and feedback

(5) Centralized diagnostics system

(6) Interoperable engineering information exchange and repository.

(7) Steering committee

e. The following are potential R&D related areas that might have an influence on successful integrated diagnostics system applications:

(1) OSD objectives and policies (*life cycle cost reduction*, increased availability and maximized war fighting capability)

(2) Design analysis tools (testability analyzers, fault simulators, design checkers, etc.)

(3) Methods, processes, metrics

(4) Design center for analysis

(5) Independent R&D

(6) Design requirements and specifications (reasonable)

(7) Pilot programs and prototyping

(8) Architectures

(9) End user involvement

(10) Technical base (e.g., neural networks, AI)

(11) Adaptable, reconfigurable system architecture, design, and maintenance strategy and implementation.

4.3 PRELIMINARY RECOMMENDATIONS

The working groups all agreed that tools were required; however the process of identifying specific tools requires a longer, more technically oriented meeting. Additionally, the group felt that organization methods and processes need to be developed in the area of integrated diagnostics. Furthermore, the working group felt that the workshop was an excellent forum for the exchange of ideas. The group recommends that these forums should be continued and emphasis should be placed on additional government support to continue the development of an integrated diagnostics support infrastructure.

The working group also felt that a DoD focal point for integrated diagnostics would be beneficial and recommended that OASD(P&L)/WSIG assume this role. In that capacity, they could establish a listing of who's who in integrated diagnostics as well as serve as a centralized clearinghouse that could periodically document and distribute the results of the integrated diagnostics pilot demonstration programs. The working group recommended that WSIG consider using an electronic bulletin board to facilitate the information flow.

5. WORKSHOP SUMMARY

The following observations represent a composite of the combined analyses of the case studies as well as the results of both the working group and full workshop discussion forums. These observations are divided into seven major categories: Definition of Integrated Diagnostics, System Design Approach, Commitment to Diagnostics Requirements, Data Analyses and Feedback, Contracting Policy and Approaches, Research and Development Opportunities, and Diagnostic Models and Design Tools. Summaries of individual working group discussions are located in Sections 1-4 of Appendix D.

5.1 DEFINITION OF INTEGRATED DIAGNOSTICS

Throughout the workshop, participants emphasized the need for a clear definition of integrated diagnostics. They found that the term "integrated diagnostics" was used in several different contexts and often with different meanings.

For example, the term "Integrated Diagnostics" was used (1) to represent a structured design process that integrates all related pertinent diagnostics elements, (2) to represent an acquisition approach that develops and acquires various diagnostics elements as a package, and (3) to represent a deliverable system (or subsystem) that integrates diagnostics elements.

The workshop participants could not agree on a specific definition for "Integrated Diagnostics". However, there was general consensus that integrated diagnostics includes some application of technology to improve the system restoration process and is characterized today by automation, BIT, expert systems, feedback loops, information delivery systems and data collection.

5.2 SYSTEM DESIGN APPROACH

The individual steps of the system design process leading to the development and incorporation of enhanced diagnostics capabilities were found to be virtually identical whether the process was targeted towards a new design or was focusing on an existing system application. The opportunity to deliver an effective diagnostic capability for the system undergoing the design process was a function of four factors that relate to the maturity of the target system: technology, configuration constraints, system trade-offs, and maintenance data availability.

The working groups observed that the viability of integrated diagnostics may rest with its ability to be retrofited to all that existing equipment. The case studies supported the conclusion that it is indeed viable to retrofit diagnostic capabilities into existing systems.

5.3 COMMITMENT TO DIAGNOSTIC REQUIREMENTS

Participants agreed that a strong DoD commitment to developing and enhancing the diagnostics capabilities of weapons systems is essential to improving effectiveness in terms of increased system availability and reduced maintenance burdens. Furthermore, it was viewed as essential that this commitment be sustained throughout the product life cycle.

The rationale and justification for improving the diagnostics capabilities of the new and evolving weapon systems must originate from, and be sustained based on, the operational needs and requirements of the using and maintaining communities. In order to develop a sustained commitment:

- DoD needs to better understand the basic needs and requirements for integrated diagnostics, especially those that span the product life cycle.
- DoD needs to invest in models and tools that help forecast the benefits of integrating diagnostics elements and assist in determining integrated diagnostics requirements.
- The logistics organizations and systems must facilitate developer involvement in support of the maturing diagnostics system.
- Cultural change resulting from the introduction of integrated diagnostics systems may be significant. User confidence must be acquired incrementally through verification, and integrated diagnostics implementation plans must recognize this condition.

5.4 DATA ANALYSES AND FEEDBACK

Systems with highly effective diagnostic capabilities typically employed effective maintenance data collection, centralized data analyses, and rapid feedback of critical information to both the design and maintaining communities. Attributes that characterized effective maintenance data collection included on-line data collection, limited opportunity for human error, and electronic presentation and interaction with the system maintainer.

Centralized data analysis was observed to be critical for improving diagnostic maturation. It increases the population sample for analyses, eliminates latency of maintenance data, and provides opportunities to develop statistically accurate prognostic algorithms. The workshop participants also noted that as new, more reliable systems are introduced, it will physically take longer to collect the necessary data for formulating enhancements to the design and/or diagnostic approaches unless centralized data analysis concepts are adopted.

Effective data feedback loops to the maintainers and designers are essential to successful integrated diagnostics implementation. However, the effectiveness and accuracy of field maintenance data collection for DoD systems are generally less capable than those illustrated in the case studies. DoD field units currently collect enormous amounts of data that are not being analyzed effectively. Opportunities to enhance the DoD data collection analyses and feedback abound. The workshop concluded that improvements in system diagnostics capabilities may be hampered if the DoD relies on the current field data collection capabilities.

Configuration control is essential and diagnostics is only one aspect of systems operation and maintenance that requires this essential capability. Integrated diagnostic systems with automated data collection and analysis capabilities can actually help automate and improve the configuration management and control.

5.5 CONTRACTING POLICY AND APPROACHES

New approaches for identifying integrated diagnostics needs must be incorporated into the system contractual requirements. Integrated diagnostics cannot be effectively implemented as multiple line items for discrete diagnostics elements unless there are appropriate interface specifications that include diagnostics interface needs. Importance of this aspect increases if there are multiple contracts.

The participants also felt that it is feasible to develop standards for testing and data/information interfaces, but the standards should be limited to the minimum level necessary to achieve successful implementation across a common set of weapon system platforms served by one centralized analysis center. Extensions of the CALS information standards to support integrated diagnostics will be necessary to support long term diagnostic improvement goals.

Support system environments and contracting methods must ensure the proper balance of rewards, benefits, and incentives that may be shared with contractors over the product life cycle. Without the appropriate combination of contractual requirements, incentives, and rewards, it is unlikely that contractor communities will develop a sustained commitment towards developing and delivering an effective diagnostics capability.

5.6 RESEARCH AND DEVELOPMENT OPPORTUNITIES

DoD weapon systems have unique integrated diagnostic needs, driven by operational requirements that are often not evident in commercial applications. DoD integrated diagnostics implementation opportunities could be expanded through research and development initiatives that focus on common weapon subsystem architectures and pilot demonstration programs conducted in the unique DoD operational environments.

In addition, DoD integrated diagnostics methodologies and approaches would benefit significantly from research and development initiatives targeted towards enabling integrated diagnostics technologies. The following is a list of potential R&D enabling technology opportunities developed by the participants.

- Multi-function condition sensors.
- Development of centralized data collection, analysis, and distribution facilities. capabilities and methods.
- Maintenance prognostics technologies.
- Integrated diagnostics design, synthesis, and assessment tools.
- Diagnostics models (artificial intelligence and rule based).
- Electronic presentation and authoring tools correlated with diagnostics models.
- Sets of standardized on/off equipment diagnostics interfaces.
- Extensions of CALS engineering information standards in product and test specification and description and other diagnostic interfaces.
- Integrated diagnostics architecture, design, and implementation.

5.7 DIAGNOSTIC MODELS AND DESIGN TOOLS

DoD generally bases an initial system's diagnostic and maintenance procedures on the Failure, Mode, and Effects, Analyses (FMEA) data. Unfortunately this data is not representative of the final operational system. No matter how skillful and thorough the engineering effort to predict *a priori* failure modes, the FMEA is typically inaccurate and incomplete. The FMEA is a starting point; however, new design tools and diagnostic models to support decision trade-off analyses are needed.

- The tools must support a methodology for improving diagnostics as the information available changes from design-based knowledge of the weapon system to maintenance history and experience-based knowledge.
- The models and tools must take into account that diagnostic effectiveness will improve over time, and the models must facilitate the development and evolution of appropriate strategies to accelerate this maturation process.

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