USAF CONDITION-BASED MAINTENANCE PLUS (CBM^{+}) INITIATIVE

AFLMA Report (LM200301800)

Capt Timothy Smith

Team Members

Maj David Lyle Capt Steve Oliver
MSgt Brian Millett

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14. ABSTRACT

In Nov 02, the Deputy Under Secretary of Defense for Logistics and Material Readiness (DUSD/L&MR) issued interim policy directing the military services to implement CBM$^+$ initiatives. These Service CBM$^+$ initiatives should improve maintenance agility and responsiveness, increase operational availability, and reduce life-cycle total ownership costs. In response to this policy, HQ USAF/ILI directed the AFLMA to perform a comprehensive study for USAF CBM$^+$ implementation. The objectives of the study are: 1) define CBM$^+$ for USAF use; 2) identify an enabling baseline of CBM$^+$ technologies/concepts; 3) catalogue selected CBM$^+$ initiatives within the Air Force; 4) provide recommendations for implementing Air Force CBM$^+$ policy.

15. SUBJECT TERMS
Condition-Based Maintenance (CBM), Condition-Based Maintenance Plus (CBM$^+$), USAF Maintenance Concept, Prognostics, Diagnostics, Portable Maintenance Aids, Data Analysis, Interactive Electronic Technical Manuals

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Executive Summary

PROBLEM STATEMENT:

DoD policy directs the military services to implement the tenets of CBM$^+$ in weapon systems maintenance and logistics support programs where cost effective. Therefore, existing Air Force policies, processes, procedures, information systems and logistics concepts must be evaluated and integrated into an Air Force strategy for implementing the CBM$^+$ policy.

BACKGROUND:

The Deputy Under Secretary of Defense for Logistics and Materiel Readiness (DUSD/L&MR) issued interim policy directing the services to implement CBM$^+$ initiatives in November 2002. Service CBM$^+$ initiatives have the potential to improve maintenance agility and responsiveness, increase operational availability, and reduce life-cycle total ownership costs.

OBJECTIVES:

There are four objectives for this study:

1. Identify/establish an Air Force CBM$^+$ definition.

2. Create an Air Force-specific baseline of CBM$^+$-enabling technologies/concepts.

3. Investigate selected legacy and future weapon systems, cataloging existing and future CBM$^+$ initiatives.

4. Provide recommendations for implementing Air Force CBM$^+$ policy.

ANALYSIS/RESULTS:

Our research uncovered numerous definitions for CBM and CBM$^+$ from academia, commercial research agencies, commercial industry, and the DoD. We found that the DoD definition presented in the DUSD/L&MR policy letter to be sufficient, with minor modification, for Air Force use. We suggest adding verbiage to the DoD definition emphasizing the need for CBM$^+$ implementation consideration throughout the acquisition life cycle. This emphasis should be reinforced in the appropriate AF regulatory guidance.

We compared CBM$^+$-enabling technologies and concepts outlined by the Maintenance Technology Senior Steering Group (MTSSG) and the DUSD/L&MR. We found their listings to be very similar and have concluded that these technologies and concepts cover

the gamut of current CBM$^+$ processes. We also concluded that these technologies and concepts, with minor revision are acceptable for use as an AF-specific baseline for CBM$^+$.

Our team chose three fielded weapons systems (B-1, C-17, and F-16) and one future weapons system (F/A-22) for cataloging existing and future CBM$^+$ initiatives. Although no one system fully employed all the proposed CBM$^+$ technologies and concepts, the C-17, and F-16 represented the greatest CBM$^+$ integration on legacy systems. It also became clear to us this integration took place in the absence of a structured process to ensure CBM$^+$ technologies and concepts are formally considered for implementation throughout the life cycle of the weapon system. We chose the F/A-22 as our future system because it will be operational shortly and incorporates technological advancements most likely adaptable to our legacy systems.

Given the lack of a structured process, the study team reviewed 19 directives we deemed applicable to CBM$^+$. We developed and vetted proposed changes to the Air Force Instructions (AFIs) through the appropriate OPRs at HQ USAF/XORD, SAF/AQXA and AFMC/DRXP. We have identified specific paragraphs within each instruction and directive for possible revision in this report.

ASSUMPTIONS AND CONSTRAINTS:

It was not feasible to study all DoD and Air Force policies, processes, procedures, information systems and logistic concepts that were remotely applicable to the implementation of CBM$^+$ within the Air Force.

The range of weapon systems (F-16, B-1, C-17, F/A-22) used in cataloging CBM$^+$ initiatives are considered a representative sample by the study team, but these systems do not necessarily reflect the full depth of CBM$^+$ implementation within the AF.

We believe the proposed AF definition, the identified enabling technologies and concepts (recommended as the AF baseline), and our recommended policy changes meet the DoD mandate to implement CBM$^+$.

CONCLUSIONS:

A slightly modified version of the existing DoD CBM$^+$ definition is proposed for Air Force implementation because it describes the concept fully, and it also clearly communicates the requirement that the CBM$^+$ concept is integrated throughout the life of AF weapon systems. The definition can and should be applied to both aircraft and missile weapon systems. The proposed AF definition is as follows:

Condition-Based Maintenance (CBM) can be defined as a set of maintenance processes and capabilities derived from real-time assessment of weapon system condition obtained from embedded sensors and/or external tests and measurements using portable equipment. The goal of CBM is to perform maintenance only upon evidence of need.

CBM$^+$ expands on these basic concepts, encompassing other technologies, processes, and procedures that enable improved maintenance and logistics practices. These future and existing technologies, processes, and procedures will be addressed during the capabilities planning, acquisition, sustainment, and disposal of a weapon system.

The 10 enabling technologies and concepts identified below constitute an acceptable initial AF baseline for achieving the DoD vision for CBM$^+$ implementation. The proposed technologies and concepts are:

Technologies	Concepts
- Prognostics	- Reliability Centered Maintenance
- Diagnostics	- Joint Total Asset Visibility
- Portable Maintenance Aids	
- Interactive Electronic Technical Manuals	
- Interactive Training	
- Data Analysis	
- Integrated Information Systems	
- Automatic Identification Technology	

Although the Air Force implements, to varying degrees, many of the technologies and concepts that constitute the proposed AF CBM$^+$ baseline, it lacks formal guidance needed to achieve synergies in CBM$^+$ implementation.

RECOMMENDATIONS:

Address/insert the proposed AF CBM$^+$ definition and technology/concept baseline in AFI 21-101, Aerospace Equipment Maintenance Management, and AFI 63-107, Integrated Product Support Planning and Assessment.

OPR: HQ USAF/ILM

Advocate to SAF/AQX integration of the CBM$^+$ concept into AFPD 63-2, Automatic Test Systems and Equipment; AFPD 63-14, Aircraft Information Programs; AFI 63-123, Evolutionary Acquisition for C2 Systems; and AFI 63-201, Automatic Test Systems and Equipment Acquisition.

OPR: HQ USAF/ILI and HQ USAF/ILM

Advocate to HQ USAF/XOR integration of the CBM$^+$ concept into AFI 10-601, Mission Needs and Operational Requirements Guidance and Procedures; AFI 10-602, Determining Mission Capability and Supportability Requirements; and AFI 10-1901, AF Battlelab Responsibilities, Processes, and Documentation.

OPR: HQ USAF/ILI

Recommend HQ USAF/ILM be assigned responsibility for CBM$^+$ implementation within the AF maintenance community.

OPR: HQ USAF/IL

Recommend HQ USAF/XOR be assigned responsibility for CBM$^+$ implementation within the capabilities planning process.

OPR: HQ USAF/XO

Recommend SAF/AQX be assigned responsibility for CBM$^+$ implementation within the acquisition community.

OPR: SAF/AQ

Recommend HQ USAF/ILI be assigned responsibility for CBM$^+$ implementation and oversight within the Air Force and should report to the Air Force Requirements and Operational Capabilities Council (AFROCC) and the MTSSG.

OPR: HQ USAF/IL

Recommend HQ USAF/ILI form and chair an AF-level working group along with HQ USAF/ILM, HQ USAF/XOR, and SAF/AQX ILI. The group will be responsible for tracking and reporting the annual status of AF CBM+ implementation to the AFROCC and the MTSSG.

OPR: HQ USAF/IL

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Chapter 1

Introduction

Background

The Deputy Under Secretary of Defense for Logistics and Materiel Readiness (DUSD/L&MR) issued an interim policy letter directing the services to implement CBM^+ initiatives in November 2002. This policy directs that tenets of CBM^+ be implemented in weapon systems maintenance and logistics support programs where the services deemed cost effective.

The Director, Directorate of Innovation and Transformation (HQ USAF/ILI), Deputy Chief of Staff, Installations and Logistics (DCS/IL), responded to this DUSD/L&MR policy by requesting that Air Force Logistics Management Agency (AFLMA) perform a comprehensive study on Air Force CBM^+ implementation as a basis for establishing an Air Force policy for CBM^+.

Problem Statement

Per DoD policy, the military services are directed to implement tenets of CBM^+ into weapon systems maintenance and logistics support programs where implementation is cost effective. To accomplish this, existing Air Force policies, processes, procedures, information systems and logistic concepts must be evaluated and then integrated into an Air Force strategy for implementing CBM^+ policy.

Objectives

The objectives of this study are to:

1. Identify/establish an Air Force CBM^+ definition.

2. Create an Air Force-specific baseline of CBM^+ enabling concepts/technologies.

3. Investigate selected legacy and future weapon systems, cataloging existing and future CBM^+ initiatives.

4. Provide recommendations for implementing Air Force CBM^+ policy.

Scope

The existing DoD CBM$^+$ definition was slightly modified directing program managers to address CBM$^+$ technologies during the AF acquisition process.

The study focused on the B-1, C-17, F-16 and F/A-22. However, the CBM+ definition, concept and technologies can be applied to any weapon system to include missile systems.

Limitations and Constraints

Our research on CBM$^+$ was quite extensive; however, we were unable to study every DoD and Air Force policy, process, procedure, information system and logistic concept that might be applicable to the implementation of CBM$^+$ within the Air Force.

The range of weapons systems used to catalog CBM$^+$ initiatives are considered a representative sample by the study team, but these systems do not necessarily reflect the full depth of CBM$^+$ implementation within the AF.

Chapter 2

Research and Analysis

Methodology

The case study methodology was determined the best method for this study because information concerning CBM$^+$ in the DoD and the Air Force is limited.[1] The first three steps of this methodology were used completing the following objectives: creating an AF CBM$^+$ definition, identifying AF-specific technologies and concepts, and cataloging CBM$^+$ initiatives. Steps five and six were used to develop and vet the proposed CBM$^+$ policy recommendations.

Step 1: Review applicable literature for candidate definitions, technologies, and current weapons system initiatives.

Step 2: Consult with authors and experts identified from the most relevant literature.

Step 3: Consolidate the best definitions, technologies/concepts, and initiatives from the candidates found during the literature review process.

Step 4: Validate a proposed AF definition, AF CBM$^+$ technologies/concept baseline, and representative initiatives with the subject matter experts.

Step 5: Review DoD, Air Force Policy Directives (AFPD), and Air Force Instructions (AFI) that impact CBM$^+$ implementation during any part of the weapon systems total life cycle, identifying level of impact and suggesting changes to instructions as required to integrate the concept.

Step 6: Validate CBM$^+$ implementation recommendations with applicable subject matter experts from HQ USAF/XOR, SAF/AQ and Air Force Material Command (AFMC).

The team conducted extensive face-to-face and telephone interviews, extensive internet research, as well as thorough research of regulations affecting CBM$^+$. We also corresponded via e-mail to ensure the CBM$^+$ experts agreed with the findings of this study.

We identified in our recommendations offices of responsibility for the AFPDs/AFIs we feel need changing.

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[1] Yin, Robert K. *Case Study Research: Designs and Methods.* Beverly Hills CA: SAGE Publications, 1984.

Research

The data gathered while completing this study fall into one of four categories, each of which correspond to the four study objectives.

Objective 1: Define CBM$^+$

We examined numerous definitions for CBM from commercial industry, academia, commercial research agencies, and the DoD during our research. CBM$^+$ is a term that is unique to the DoD.

We found various CBM concepts have been in use within commercial industry for over a decade. All commercial CBM applications we reviewed were highly specialized for a given purpose. No existing commercial CBM definition was sufficient for us to build upon.

Our research led us to Pennsylvania State University's Advanced Research Laboratory. The university established itself as a leader for CBM mechanical systems research. Penn State made numerous advancements in diagnostics, prognostics, advanced materials and decision support research. However, we found the Penn State CBM definition too generalized to meet the specific needs of our study.

The Logistics Management Institute (LMI) defined CBM in their report "Assessment of Condition-Based Maintenance in the Department of Defense" in August of 2000. They defined CBM as "a set of maintenance actions based on real-time, or near real-time, assessment of equipment condition, which is obtained from embedded sensors and/or external tests and measurements taken by portable equipment."[2] LMI cited what they consider to be the most succinct purpose statement for CBM in this report. Their statement was, "the purpose of CBM strategy is to perform maintenance only when there is objective evidence of need, while ensuring safety equipment reliability and reduction of total ownership cost."[3] We built an initial CBM$^+$ definition using the LMI work because of its focus on advanced technology. However, upon further review we decided that the LMI CBM definition to be too limited for our purposes because it focused on CBM technologies without relation to integration of logistics information systems technologies and enhanced business processes.

The DUSD/L&MR released the "Future Logistics Enterprise (FLE), The Way Ahead" in June 2002. The FLE cited an integrated set of six initiatives to achieve end-to-end customer service within the DoD logistics operations. Within the FLE the CBM$^+$ concept was first introduced. The FLE defined CBM$^+$ as, "the integrated application of a collection of advanced engineering, maintenance and information technologies to improve maintenance and logistics practices."[4]

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[2] S.C. Butcher, Logistics Management Institute, *Assessment of Condition Based Maintenance in the Department of Defense*, p. 6, Aug 2000.
[3] Ibid.
[4] DoD Initiative, *Future Logistics Enterprises The Way Ahead*, 26 Apr 2002

CBM$^+$ was further defined in the November 2002 DoD CBM$^+$ interim policy letter. It stated, "Condition-Based Maintenance (CBM) can be defined as a set of maintenance processes and capabilities derived, in large part, from real-time assessment of weapon system condition obtained from embedded sensors and/or external tests and measurements using portable equipment. The goal of CBM is to perform maintenance only upon evidence of need. CBM$^+$ expands on the basic concepts of encompassing other technologies, processes, and procedures that enable improved maintenance and logistics practices."[5] Our discussions with the experts led us to conclude that the DoD definition points the Air Force in the direction it needs to go, with little modification.

Although we found the DoD definition presented in the DUSD/L&MR policy letter sufficient, the team felt the Air Force needed to add a sentence institutionalizing CBM$^+$. This sentence should emphasize the need to "build" and "maintain" CBM$^+$ as part of the natural process for acquiring, fielding and disposing weapons systems.

We examined numerous definitions for CBM from commercial industry, academia, commercial research agencies, and the DoD during our research. We determined that a slightly modified version of the DoD CBM$^+$ definition is acceptable for Air Force use because it not only describes the concept fully, it also clearly communicates the requirement that the concept is integrated throughout the life of our weapons systems.

Objective 2: Identify Enabling Technologies/Concepts

Our second objective was to identify a common set of enabling technologies and concepts that work together to help the AF achieve the goals of CBM$^+$. The DoD CBM$^+$ interim policy letter outlined six characteristics of CBM$^+$. Mr. Grover Dunn, HQ USAF/ILI, identified 11 CBM$^+$ technologies/concepts for the DoD Maintenance Technologies Senior Steering Group (MTSSG). We used the MTSSG list as our starting point because we viewed DoD's CBM$^+$ characteristics as inherent to each MTSSG technology.

The six characteristics of CBM$^+$ outlined in the DoD interim policy letter are listed below:[6]

- Hardware - embedded sensors; integrated data bus
- Software - decision support and analysis capabilities, on and off equipment
- Design - open system architecture; integration of maintenance and logistics information systems; interface with operational systems
- Processes - reliability centered maintenance program development; a balance of reactive, preventive, and predictive maintenance processes
- Tools - IETMs (digitized data); Automatic Identification Technology; portable maintenance aids; embedded, data-based, interactive training
- Functionality - fault detection; fault isolation; fault prediction

[5] DoD Interim Policy, *Condition Based Maintenance Plus*, 25 Nov 2002
[6] ibid.

The MTSSG identified 11 "technologies/concepts" of CBM$^+$ encapsulating the characteristics underpinning CBM$^+$ in the DoD interim policy letter. We reduced the number of technologies and concepts to 10 by eliminating Serial Item Management as a separate CBM$^+$ technology. We consider it synonymous with Serial Number Tracking and therefore a component of AIT.[7] Our proposed technology and concepts listing is as follows:

Technologies

- Prognostics
- Diagnostics
- Portable Maintenance Aids (PMAs)
- Interactive Electronic Technical Manuals (IETMs)
- Interactive Training
- Data Analysis
- Integrated Information Systems
- Automatic Identification Technology (AIT)

Concepts

- Reliability Centered Maintenance (RCM)
- Joint Total Asset Visibility

The eight technologies and two concepts listed above are consistent with the proposed CBM$^+$ definition and represent the essential elements needed to build a complete construct given current state of technology.

CBM$^+$ --The Big Picture

To this point we have identified a proposed definition for CBM$^+$. We also identified a listing of eight technologies and two maintenance concepts that are enablers, or the "how-to," for CBM$^+$. However, we have not enumerated how these enablers work in unison to create the DoD vision of CBM$^+$.

The CBM$^+$ vision is smarter aircraft: aircraft with embedded sensors such as prognostics and diagnostics providing enhanced system health monitoring, condition-driven maintenance, advanced fault detection and isolation, and life parameter prediction.

The CBM$^+$ vision is Integrated Information Systems: systems that provide configuration management, asset visibility, as well as, trend analysis available to any valid user via the World Wide Web.

The CBM$^+$ vision is electronic portable or point-of-maintenance aids. PMAs will provide common access to aircraft data, interactive training, and parts availability. Interactive Technical Manuals will provide maintainers instantaneous technical information and diagnostic interpretation capability.

[7] Personal correspondence with Mr. J.J. Klarer, USAF AIT PMO,06 June 2002.

Advanced inspection methods and tools are also a part of the CBM$^+$ vision. Inspection methods within the CBM$^+$ environment will ultimately enhance asset life and reduce maintenance cost.

All these things, working in unison, will improve logistic responsiveness and reduce the logistics footprint and weapon system total ownership costs.

We must note, within most of our legacy systems, these technologies will be stand-alone devices only capable of limited CBM$^+$ application. However, each CBM$^+$ application will enhance the overall weapon system maintainability. As our CBM$^+$ technology infrastructure grows, these technologies and concepts will interact with each other, will perform as a network, and will make the CBM$^+$ vision possible for our future weapons systems.

The diagram below (Figure 1) illustrates a conceptual analogy of the interaction of each CBM$^+$ technology.

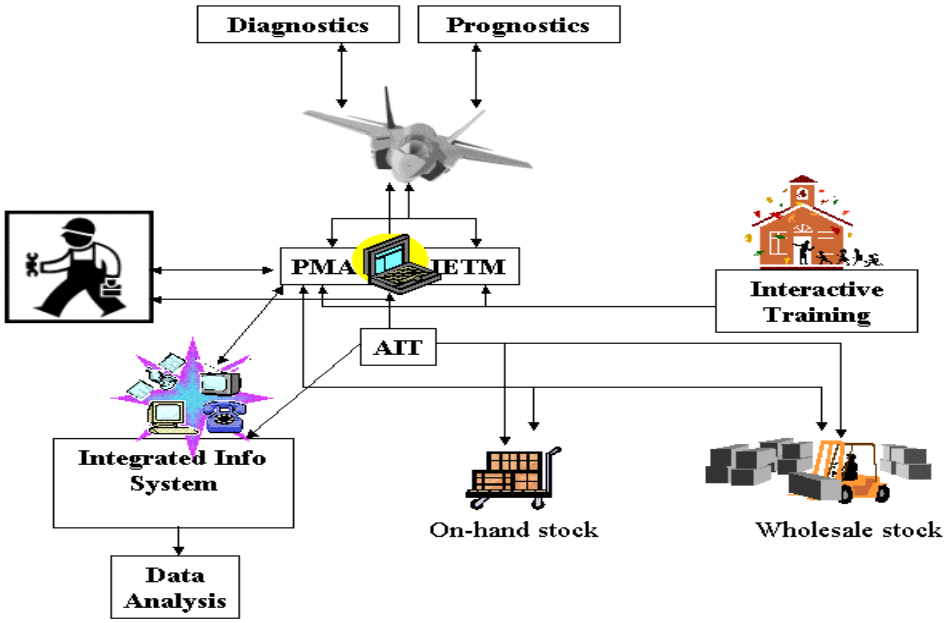

Figure 1. CBM$^+$ Technologies Conceptual Analogy

The following paragraphs briefly define each of the eight CBM$^+$ technologies and the two CBM$^+$-enabling concepts and their relationships to the overall vision. Detailed definitions for each technology and concept are found in Appendix A of this report.

Prognostics is defined as, "the capability to provide early detection and isolation of precursor and/or incipient fault condition to a component or sub-element failure condition, and to have the technology and means to manage and predict the progression

of this fault condition to component failure."[8] The aforementioned characteristics are key in meeting the goal set forth in the DoD Interim Policy on CBM$^+$. The goal is to perform maintenance only upon evidence of need. This is done, in part, through the use of embedding these prognostic capabilities within specific parts on the aircraft.

Within the CBM$^+$ concept, data gathered from embedded prognostics can be downloaded and interpreted via a Portable Maintenance Aid (PMA). The PMA feeds information about insipient failures to decision-makers.

Diagnostics is "the process of identifying the cause of a malfunction (fault), by observing its effects at various monitoring (test) points in a system."[9] This technology also plays a significant role in meeting the goal of CBM$^+$; embedding advanced diagnostics capable of identifying specific faults within the aircraft and then having the fault data directly relayed to the PMA and to the maintainer.

On-board diagnostic information is downloaded via PMA or Interactive Electronic Technical Manuals (IETM). The diagnostics do a lot of the troubleshooting so the technician can focus on the repair.

Portable Maintenance Aids (PMAs) are mobile computing devices used at the point of maintenance. They act as the primary interface between the mechanic and on-board diagnostics and prognostics. "These devices are often used for technical data display, diagnostic fault isolation, repair mentoring, materiel management, maintenance documentation, health monitoring, prognostics, and operational data upload/download."[10] In addition, PMAs on future aircraft will allow the maintainer to interact with the logistics chain for parts availability/supportability. Most PMAs in the future will interface with integrated information systems.

Interactive Electronic Technical Manuals (IETMs) tailor technical information into instructions for a specific repair under a specific set of input conditions. The instructions adapt to the technicians inputs about his/her observations. The interactive nature of the IETM provides diagnostic interpretation for legacy aircraft as well as computer-based training at the job-site. This gives the maintainer the correct instructions for the task at hand when needed. All of these capabilities are enablers of the CBM$^+$ concept.

Note: It is important to mention that within the DoD we have numerous classes (types) of IETMs. Some IETMs are very basic and only have the ability to reproduce electronically indexed page images while other IETMs have advanced abilities, which include diagnostic interpretation, and interactive training capabilities found in PMAs. (See appendix A for a detailed description of IETMs classes).

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[8] Hess et al, "A USN development strategy and demonstration results for propulsion and mechanical systems diagnostics, prognostics and health management," *Proceedings of the 2001 IEEE Aerospace Conference*, Big Sky, Montana, March 10-17, 2001

[9] S. Deb, et al, Multi-Signal Flow Graphs: *A Novel Approach for System Testability Analysis and Fault Diagnosis*, IEEE AES Systems Magazine, May 1995

[10] G.W Bapst, et al, Logistics Management Institute, *Portable Maintenance Aids*, p iii, Jul 2001.

Interactive Training PMAs and IETMs are used to conduct training at the aircraft within a CBM$^+$ environment. This ability provides a better-informed, better-equipped maintainer ready to perform the required maintenance when called upon.

"Data Analysis entails the failure rate (or probability) determination for basic events from available sources of failure information and knowledge."[11] In the CBM$^+$ context, data analysis is an assimilation of real-time and historical data into information usable for decision making. The data stored is within a common integrated information system accessible to all maintenance personnel. Armed with this information, we enhance our knowledge of parts/system performance, which, in-turn, increases system reliability. The combination of real-time and historical data provides the maintainer with maintenance management tools for *predicting* fleet health.

Integrated Information Systems are a **"**seamless composite of logistics functions and capabilities, accessible to any valid user at any time via an enterprise-wide architecture framework chartered to provide integrated solutions to meet the logistics communities operations needs. This includes modernizing and transitioning logistics information systems from legacy stovepipes to a fully integrated and compliant logistics systems environment."[12] For future weapon systems, the aforementioned PMA will send maintenance data to integrated information system. The information will be used for a multitude of functions such as data analysis, parts availability, and automatic identification of parts.

An example of this technology is the Enterprise Data Warehouse (EDW). By integrating logistical data into one source, we provide a single source for all combat support, to include analytical and historical information. The Integrated Information System is a technology that enables improved maintenance and logistics practices.

Figure 2 on the following page provides a pictorial illustration of the interface and interaction of PMAs, Maintenance Support Systems and Integrated Information systems.

[11] Idaho National Engineering and Environmental Laboratory, *An Overview of Probabilistic Risk Assessment Concepts* (Slide 11) http://saphire.inel.gov/pdf/risk_analysis_concepts.pdf
[12] Mr.Glenn Bright, HQ SSG/ILI USAF, *Logistics Systems Integration Brief* (Slide 3) 26 February 2003

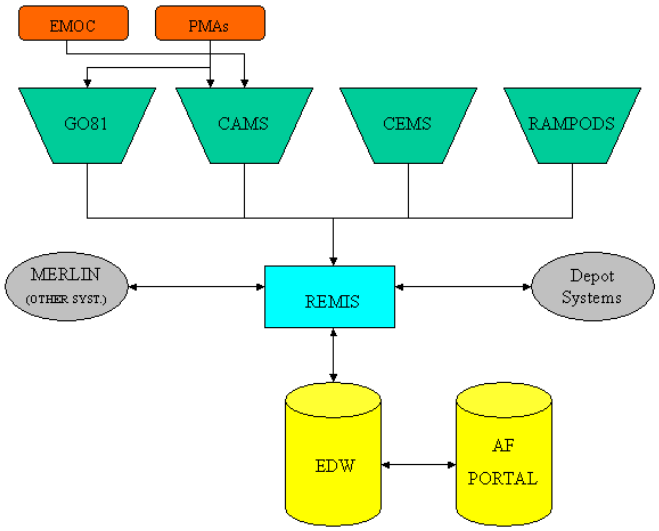


Figure 2. Integrated Info System Maintenance Support Systems, PMA Interaction

Automatic Identification Technology is defined within the DoD as the "proper mix of technologies that allow each user to efficiently and effectively capture, aggregate, and transfer data and information, and, as a consequence, integrate with Automated Information Systems (AISs) using the optimum technology for their particular application."[13] What this means is cradle-to-grave tracking throughout the Air Force logistics systems of reparables, selected consumables, engines, equipment and other designated property to provide asset and item information and status.

CBM$^+$ Concepts

The MTSSG enumerated two current management concepts they deemed critical to CBM$^+$ implementation that we have included in our proposed listing. These concepts are Reliability-Centered Maintenance and Joint Total Asset Visibility.

The goal of the **Reliability-Centered Maintenance** (RCM) program is to optimize engine expected time on wing (ETOW) through a disciplined analysis and planned maintenance approach. "The definition of RCM is a disciplined, structured process to identify cost effective and technically sound engine maintenance policies. These policies could affect field or depot maintenance, supply, training, engineering, operator procedures, and technical data."[14] Through the careful application of inspection and scheduled maintenance requirements, critical failures that can be anticipated will be minimized resulting in the highest probability of warfighting capability for legacy and future aircraft.

[13] *Defense Total Asset Visibility Implementation Plan*, 1996
[14] Hugh Gardenier, 2Lt, USAF, RCM Program Office, WPAFB, OH

Not all RCM initiatives are truly CBM$^+$. However, the advanced management tools developed through the RCM program are CBM$^+$. These tools are detailed in appendix B of this report.

Joint Total Asset Visibility (JTAV) is "the capability to provide users with timely and accurate information on the location, movement, status, and identity of units, personnel, equipment and supplies. It also facilitates the capability to act upon that information to improve overall performance of DoD's logistics practices."[15] The JTAV concept improves supply/maintenance planning and responsiveness, thereby increasing operational availability, improving maintenance and logistics practices. Within CBM$^+$ a maintainer would change a part only upon evidence of need. To delay any down time for that aircraft the maintainer would have to know when he would receive that part. JTAV allows the maintainer to do just that.

[15] *DoD Joint Total Asset Visibility Plan*, p. 4, March 6, 2001, http://www.defenselink.mil/acq/jtav/jtavpmp.pdf

Objective 3: Catalog Initiatives

During our research we cataloged CBM$^+$ initiatives within each of the eight identified technologies. First, we identified weapon system-specific initiatives (Table 1). The B-1 Bomber Central Integrated Test System (CITS) is an example of a weapon system-specific initiative. Second, we identified those technology initiatives not common to any specific weapon system (Table 2). One example of this is the Air Force Common Viewer (AFCV). The AFCV is a Class 3 IETM and is used to view technical orders for any weapon system and accessible to all Air Force personnel via a common web browser. Finally, we identified CBM$^+$ tools employed within the Reliability-Centered Maintenance and Joint Total Asset Visibility concepts (Table 3).

All initiatives and tools are explained in Appendix B of this report. One note to add, this listing in no way encompasses "all" on-going and future CBM$^+$ initiatives; it only provides a snapshot of the weapon systems we examined during this study.

Although many of the listed systems and concepts predate the CBM$^+$ concept itself, these technologies and concepts enable improved maintenance and logistics practices.

CBM$^+$ Technologies	*Weapon Systems Specific Initiatives*			
	B-1	*C-17*	*F-16*	*F/A-22*
Automatic Information Technology		SNT Test	DRILS	
Interactive Electronic Technical Manuals	Class III IETM	Class II IETM	Class III IETM	IMIS
Diagnostics	CITS	AFFIP/MMP	MFL/PFL	IMIS/DTC/ MWS
		SEC	EDNA	
Prognostics[16]	See Note 16	See Note 16	See Note 16	See Note 16
Data Analysis			DRILS	IMIS
Portable Maintenance Aids		SEC	EDNA	Honeywell Data Trak
Integrated Information System				
Interactive Training				MTS

Table 1. Weapon Systems Specific CBM$^+$ Initiatives

[16]. The aircraft listed above did not have any embedded prognostic capabilities. However, the JSF PHM is described in detail in appendix B. The JSF PHM was considered the most prevalent CBM$^+$ initiative reviewed during the study

CBM+ Technologies	*Non-Weapon System Specific Initiatives*				
Automatic Information Technology	SNT	POMX			
Interactive Electronic Technical Manuals	AFCV				
Diagnostics	ASIP	ENSIP			
Prognostics	A/C. Electrical Pwr. Syst. Prognostics Health Mgmt.	In-line Health Monitoring for Acft. Hyd. Pumps	Engine Bearing Health	Probabilistic Life Modeling	ASIP ENSIP
Data Analysis	REMIS	ASIP	ENSIP		
Portable Maintenance Aids	POMX				
Integrated Information System	AF Portal	EDW			
Interactive Training					

Table 2. Non-Weapon System Specific Initiatives

CBM+ Concepts	*JTAV and RCM CBM+ Tools*	
JTAV	GTN	Tracker
RCM	RCM Calculator	Weibull Tool

Table 3. RCM/JTAV CBM+ Tools

Objective 4: Recommend Implementation Policy

The proposed AF CBM+ definition emphasizes consideration of technologies, processes, and procedures throughout the life of a weapon system. Numerous governing directives and Air Force Instructions impact the management of Air Force weapon systems from cradle to grave. Based on the knowledge gained while completing the first three objectives, the study team reviewed every directive we thought applicable to CBM+. Personnel from HQ USAF/XORD, SAF/AQXA and AFMC/DRXP validated the list of applicable instructions. Table 4 lists the directives reviewed.

Capability Planning Instructions	*Acquisition Instructions*	*Maintenance Instructions*
CJCSI 3170.01	DoDI 5000.2	AFI 21-132
CJCSI 3170.01C	AFPD 63-2	AFI 21-101
AFPD 10-6	AFPD 63-6	[17]AFI 63-107
AFPD 10-601	AFPD 63-10	
AFI 10-602	AFPD 63-14	
AFI 10-1401	AFI 63-101	
AFI 10-1901	AFI 63-123	
	AFI 63-201	
	AFI 63-1001	
	AFI 63-1101	

Table 4. Governing Directives Reviewed

We determined the regulations needed to incorporate CBM+, as well as, where within the regulation the guidance should reside, and then vetted these recommendations through the appropriate OPRs. A detailed listing of all recommended policy changes reside in Appendix C.

[17] Although this is a 63 series (acquisition) AFI the POC was identified as HQ USAF/ILMM

Analysis

After reviewing all potential definitions, the team proposed the following definition and goal for CBM^+ within the Air Force.

Condition-Based Maintenance (CBM) can be defined as a set of maintenance processes and capabilities derived from real-time assessment of weapon system condition obtained from embedded sensors and/or external tests and measurements using portable equipment. The goal of CBM is to perform maintenance only upon evidence of need.

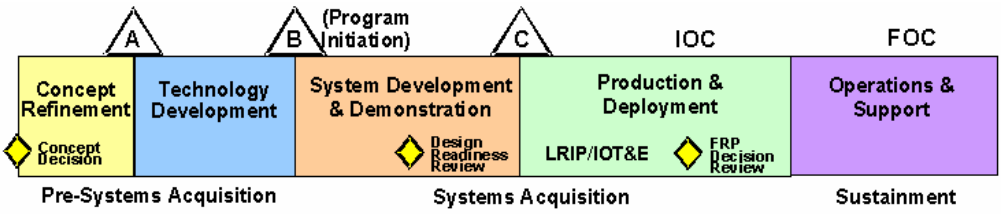
CBM^+ expands on these basic concepts, encompassing other technologies, processes, and procedures that enable improved maintenance and logistics practices. These future and existing technologies, processes and procedures will be addressed during the capabilities planning, acquisition, sustainment and disposal of a weapon system.

Our CBM^+ proposed definition is the same as the DoD definition, with one exception. The proposed Air Force definition highlights the importance of including CBM^+ considerations into the total life cycle of all weapon system (to include missile systems). For CBM^+ to be successful, these considerations must take place.

The enabling technologies and concepts identified by the MTSSG and the DUSD/L&MR were the only CBM^+ technology/concept listings available. After consulting with functional experts, we have validated the MTSSG's and DUSD/L&MR listings, finding that these technologies are, at a minimum, necessary to achieve the CBM^+ vision. However, we reduced the listing of technologies/concepts from 11 to 10. The MTSSG listing included Serial Item Management (SIM) as a technology. From our research, we concluded SIM is a part of AIT--or in other words, one of the functions of AIT. As Figure 1 illustrates, these technology categories presently cover the entire CBM^+ process.

By cataloging CBM^+ initiatives within the Air Force, we concluded the Air Force has numerous CBM^+ initiatives. However, the Air Force lacks a formalized process to ensure CBM^+ is considered through the life cycle of a weapon system.

The recommended procedural changes ensure these technologies and maintenance concepts (or new ones as technology matures) can be incorporated into the Air Force. For details of the recommended changes refer to Appendix C. Figure 3 (on the following page) illustrates Air Force Instructions affected by the implementation of the concept, as well as, points of contact/offices of responsibility and actions that must be taken along the Evolutionary Acquisition Timeline for successful implementation of CBM^+.



Stage of Development	Capabilities Planning	Acquisition Planning	Formal Acquisition and Initial Development	Initial production of new systems and growth capabilities	Concept Application
POC/OCR	HQ USAF/XOR	SAF AQX	Program Single Manager and HQ/AFMC	Program/Single Manager and HQ/AFMC	HQ USAF/ILM and applicable MAJCOM
Associated Publications	AFI 10-601 AFI 10-602 AFI 10-1901	AFI 63-107 AFPD 63-2 AFPD 63-14 AFI 63-123 AFI 63-201 DoDI 5000.2	AFI 63-107 AFPD 63-2 AFPD 63-14 AFI 63-123 AFI 63-201 DoDI 5000.2	AFI 63-107 AFPD 63-2 AFPD 63-14 AFI 63-123 AFI 63-201 DoDI 5000.2	AFI 21-101 AFI 63-107
Stage of CBM+ Integration	**PLAN**	**DESIGN**	**BUILD**	**BUY**	**UTILIZE**
Action required by POC/OCR	Ensure consideration of CBM+ concepts into capabilities planning process.	Ensure integration of CBM+ concepts into acquisition planning and design. Research applicable technologies that incorporate CBM+ concepts.	Ensure application of CBM+ concepts incorporated in design phase during construction of test units.	Verify inclusion of CBM+ concepts previously identified and effectiveness of those CBM+ concepts when utilized. (IOT&E)	1) Implement tenets of CBM+ identified in AFI 21-101 2) Ensure compliance with CBM+ concepts within specific systems/programs 3) Provide feedback to Program/Single Manager

This is the proposed application of CBM+ outlined against the Evolutionary Acquisition Process Timeline (time line ref. DoDI 5000.2 May 2003).

Figure 3. CBM$^+$ and the Evolutionary Acquisition Process Timeline

CBM$^+$ technologies must be considered within the planning phase of the evolutionary acquisition process (see action required in the planning stage of Figure 3). Therefore, there must be a process making the acquisition and logistic communities aware of the technologies currently in work by the science and technology (S&T) community. From our research, we discovered AFMC has institutionalized a process for transitioning advanced technologies from the lab environment to the acquisition and logistics communities. This process involves an Advanced Technology Council (ATC). The technologies available for transition are addressed in one (or more) of seven major ATCs (AETC, ACC, AFC2ISR, AFSOC, AMC, AFMC, AFSPC). Technologies presented at the ATC are the product of lab S&T efforts. Prior to presentation at the ATC, a "champion" and "transition agent" are identified. The champion is the primary user of the technology (the depot, MAJCOM, or program office), and the transition agent is usually the Aeronautical System Center (ASC) Aeronautical Enterprise Office's Aging Aircraft Program Office. Before the ATC meets, the transition agent, champion and lab create a roadmap for implementation that include a full story for each technology on how, when, and with what funding this technology will be handed from the lab to the transition agent, and ultimately to the customer for implementation. When the ATC commissions or re-commissions the technology, commitment is indicated to the transition and implementation plan. [18]

[18] Maj. J. Specht, HQ AFMC/DRXI, personal correspondence/e-mail, 23 Sept 2003

Summary

After comparing the DoD definition for CBM^+ with definitions available from commercial sources and academia, we concluded that the DoD definition, along with a single additional sentence to add emphasis on the entire life-cycle management of a weapon system, is the best definition available for Air Force use.

The enabling technologies identified were based on a list previously reviewed by the DoD's senior maintenance technology leaders, the MTSSG. Similar technologies and concepts were also identified as "characteristics" that underpin CBM^+ in a DoD interim policy letter. Based on the similarities in the ideas presented in these two documents, we concluded the MTSSG's list of technologies, after minor revision, was the most complete listing of enabling technologies. Our review of the entire CBM process convinced us these technology categories presently cover the entire CBM^+ process.

We concluded the Air Force lacks CBM^+ policy implementation guidance in the areas of capabilities planning (formerly requirement determination), acquisition, and maintenance. Although the Air Force has numerous CBM^+-like initiatives (i.e. IMIS, Honeywell DataTrak), there is no "formal" process for implementation of the CBM^+ concept or its oversight. We vetted our findings on Air Force policy through senior policy writers in each of the affected areas, and they concurred with our findings.

However, we did find that the current DoDI 5000.2 (Operation of the Defense Acquisition System) provides limited guidance for CBM^+ implementation and oversight. Paragraph 3.9.2.4 states, "Program Managers shall optimize operational readiness through affordable, integrated, embedded diagnostics and prognostics, and embedded training and testing, serial item management; automatic identification technology (AIT), and interactive technology refreshment."

We also found that many of the affected AFIs/AFPDs are currently being rewritten to coincide with instructions issued in DoDI 5000.2. We feel this provides the perfect opportunity for the AF to incorporate CBM^+ into Air Force instructions.

The ATC process represents an acceptable process for transitioning those approved technologies (to include CBM+ technologies) from the labs to the acquisition and logistic communities. However, chairs of the ATC must ensure participation from the MAJCOMs; and the MAJCOMs and ASC must ensure appropriate participation from their programs (future and legacy).

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Chapter 3

Conclusions and Recommendations

Conclusions

1. The current DoD definition for CBM$^+$ should be modified to include total life-cycle considerations. This captures the importance of the entire weapon system life cycle.

2. The ten enabling technologies and concepts identified in Chapter 2 represent a complete baseline necessary to achieve the DoD's vision for CBM$^+$ at this time.

3. The Air Force already has numerous CBM$^+$ initiatives, covering each of the ten enabling technologies and concepts.

4. Current Air Force policy that could affect CBM$^+$ implementation needs to be revised to institutionalize CBM$^+$.

5. The ATC process represents an acceptable form of interaction between the AF S&T and logistic communities.

Recommendations

1. Incorporate the AFLMA-proposed definition and technology/concept baseline for CBM$^+$ into these instructions/directives (See Appendix C for details):

   - AFI 21-101, Aerospace Equipment Maintenance Management, 01 Oct 02 (AF/ILMM)

   - AFI 63-107, Integrated Product Support Planning and Assessment, 29 May 01 (AF/ILMM)

OPR: HQ USAF/ILM

2. Advocate to SAF/AQX implementation of the CBM$^+$ concept into the following acquisition instructions/directives (See Appendix C):

   - AFPD 63-2, Automatic Test Systems and Equipment, 19 Jul 94 (SAF/AQKL)

   - AFPD 63-14, Aircraft Information Programs, 6 Feb 2001 (AFSC/SEF)

   - AFI 63-123, Evolutionary Acquisition for C2 Systems, 1 Apr 2000 (SAF/AQII)

- AFI 63-201, Automatic Test Systems and Equipment Acquisition, 21 Jul 94 (SA-ALC/ADA)

OPR: HQ USAF/ILI

3. Advocate to HQ USAF/XOR incorporation of the CBM^+ concept into the following capabilities planning instructions/directives (See Appendix C for details):

   - AFI 10-601, Mission Needs and Operational Requirements Guidance and Procedures, 13 Aug 99 (AF/DXOR)

   - AFI 10-602, Determining Mission Capability and Supportability Requirements, 30 Sep 02 (AF/ILMY)

   - AFI 10-1901, AF Battlelab Responsibilities, Processes, and Documentation, 1 Oct 97 (XORBB)

OPR: HQ USAF/ILI

4. Recommend HQ USAF/ILM be assigned responsibility for CBM^+ implementation within the maintenance community.

OPR: HQ USAF/IL

5. Recommend HQ USAF/XOR be assigned responsibility for CBM^+ implementation within the capabilities planning process.

OPR: HQ USAF/XO

6. Recommend SAF/AQX be assigned responsibility for CBM^+ implementation within the acquisition community.

OPR: SAF/AQ

7. Recommend HQ USAF/ILI be assigned responsibility for CBM^+ implementation and oversight within the Air Force. ILI should report CBM^+ status to the Air Force Requirements and Operational Capabilities Council (AFROCC) and the Maintenance Technology Senior Steering Group (MTSSG) at least annually.

OPR: HQ USAF/IL

8. Recommend HQ USAF/ILI form and chair an AF-level working group along with HQ USAF/ILM, HQ USAF/XOR, and SAF/AQX ILI. The group will be responsible for tracking and reporting the annual status of AF CBM+ implementation to the AFROCC and the MTSSG.

OPR: HQ USAF/IL

Appendix A

CBM$^+$ Enabling Technologies/Concepts - Definitions

Prognostics

The US Navy prognostic health management demonstration provides a clear and concise definition usable by the Air Force. They define prognostics as: "The capability to provide early detection and isolation of precursor and/or incipient fault condition to a component or sub-element failure condition, and to have the technology and means to manage and predict the progression of this fault condition to component failure."[19]

Diagnostics

In our research, multiple commercial definitions were found. However, we concluded there is no Air Force-approved definition for diagnostics. Boeing's Integrated Vehicle Management Team provided the most detailed definition. They defined diagnostics as, "the process of identifying the cause of a malfunction (fault), by observing its effects at various monitoring (test) points in a system."[20]

Portable Maintenance Aids (PMAs)

A July 2001 Logistics Management Institute study provided a detailed working definition of the PMA: "PMAs can be most succinctly defined as mobile computing devices that are used at the point of maintenance. Within the DoD maintenance community, these devices are often used for technical data display, diagnostic fault isolation, repair mentoring, materiel management, maintenance documentation, health monitoring, prognostics, and operational data upload/download."[21]

Interactive Electronic Technical Manuals (IETMs)

The term IETM describes a concept for production of complex technical documentation. There are five classes of IETMs reflecting capabilities and levels of technical sophistication. We believe that Class 3, Linear Structured IETMs, Class 4, Hierarchically Structured IETMs, and Class 5, Integrated Data-base IETIS, are highly adaptable to CBM$^+$ application due to their interactive nature. (Note: While preparing this report, the Classes of IETMs were under reclassification within the DoD. During this study we will use the class descriptions provided from the 1994 Naval Carderock Division, DoD Classes of IETMs.)

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[19] Hess et al, "A USN development strategy and demonstration results for propulsion and mechanical systems diagnostics, prognostics and health management," *Proceedings of the 2001 IEEE Aerospace Conference*, Big Sky, Montana, March 10-17, 2001

[20] S. Deb, et al, Multi-Signal Flow Graphs: *A Novel Approach for System Testability Analysis and Fault Diagnosis*, IEEE AES Systems Magazine, May 1995

[21] G.W Bapst, et al, Logistics Management Institute, *Portable Maintenance Aids*, p iii, Jul 2001.

The paragraphs below provide a general description of how IETMs work. An IETM is interactive if the presentation of information is dynamic and if the rendering of information is adjusted to respond to current conditions and users. The interaction between information users and the software that displays the information is the final, critical piece that defines an IETM.

The storage medium for these data types in an IETM is electronic (digital). The Defense Department initiated the Continuous Acquisition and Life cycle Support (CALS) program to improve the electronic interchange of digital technical data among the military services. This initiative, which predated much of the technology now used on the Web, defines a set of standard formats for storage and delivery of information. The main point of the standards is to make sure the information will be accessible over a long term, regardless of changing technology.

An IETM is a technical manual, meaning its primary purpose is to support the diagnostics, maintenance, and repair of complex technical systems. The information package supporting these operations includes descriptive, procedural, and parts data.[22]

The DoD has six accepted Classes of Electronic Technical Manuals. Class 0, Non-Electronically-Indexed Page Images, are systems of digitized page images that are intended for electronic archival filing or print-on-demand. Class 1, Electronically Indexed Page Images, are systems of digitized page images intended for full-page display and allow navigation by means of an automated intelligent index to the page images for user access. Class 2, Electronic Scrolling Documents, are systems for interactive display of ASCII encoded documents using an intelligent index and hypertext tags inserted into a tagged document file. We do not consider these classes as applicable to CBM^{+} because they are not by nature interactive.

Class 3, Linear Structured IETMs, are interactive display of technical information that is SGML-tagged using MIL-D-87269 tags to the maximum extent possible and using a hypertext presentation system for display in accordance with MIL-M-87268. It is based on a linear SGML document file and not a hierarchically based Data Base. Navigation is based on author-developed constructs employing prompted dialog boxes and content-driven logical NEXT function.

Class 4, Hierarchically Structured IETMs is an interactive electronic display of technical information specifically authored into and maintained in a non-redundant relational or object-oriented hierarchical database. This source data is subsequently packaged (i.e., "view-packaged") as a run-time database for interactive presentation in accordance with the DoD IETM Specifications (MIL-M-87268, MIL-D-87269, and MILQ-87270).

Class 5, Integrated Database IETIS. The Integrated Electronic Technical Information System (IETIS) for interactive presentation of Class 4 IETMs integrated in with the data

[22]Paraphrased from: Antech Systems, *IETM Research*, http://www.antechsystems.com/Ietmdef.htm 22 Apr 2003

for other processes including Expert-System rules for the display of information and other user-applications such as diagnostics or computer-managed training.[23]

Interactive Training

Interactive training was defined best from the Defense Automated Visual Information System/Defense Instructional Technology Information (DAVIS/DITIS) information glossary. "Interactive Media Instruction (IMI) includes computer-controlled courseware that relies on student input to determine the pace, sequence, and content of instructional delivery. Examples of delivery media are compact disc and interactive videodisc."[24]

Data Analysis

Our research found the definition from the Idaho National Engineering and Environmental Laboratory details the best definition for data analysis. "Data analysis entails the failure rate (or probability) determination for basic events from available sources of failure information and knowledge."[25]

Integrated Information Systems

Mr. Glen Bright, from the Innovation and Transformation Office at the Standard Systems Group, presented a usable definition in February 2003: "A seamless composite of logistics functions and capabilities, accessible to any valid user at any time via an enterprise-wide architecture framework. It is chartered to provide integrated solutions to meet the logistics community's operations needs. Also, it includes modernizing and transitioning logistics information systems from legacy stovepipes to a fully integrated and AF-compliant logistics systems environment."[26]

Automatic Identification Technology (AIT)

AIT is defined within the DoD as the "proper mix of technologies that allows each user to efficiently and effectively capture, aggregate, and transfer data and information, and, as a consequence, integrate with Automated Information Systems (AIS) using the optimum technology for their particular application. AIT will facilitate data collection and flow to all AISs to better achieve full Total Asset Visibility, enhance and streamline business processes and war fighting capability."[27]

"AIT devices include, but are not limited to: bar-code symbologies, magnetic stripe cards, integrated circuit cards (e.g., smart cards), optical memory cards, non-contact carrier devices (active and passive radio frequency hardware), contact carrier devices ("button memory"), magnetic storage media, machine vision, optical character

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[23] Paraphrased from: Eric L. Jorgensen, *DoD Classes of Electronic Technical Manuals*, Carderock Division, Naval Surface

[24] The Defense Automated Visual Information System/Defense Instructional Technology Information System - http://dodimagery.afis.osd.mil/dodimagery/davis/

[25] Idaho National Engineering and Environmental Laboratory, *An Overview of Probabilistic Risk Assessment Concepts* (Slide 11) http://saphire.inel.gov/pdf/risk_analysis_concepts.pdf

[26] Mr.Glenn Bright, HQ SSG/ILI USAF, *Logistics Systems Integration Brief* (Slide 3) 26 February 03

[27] *Defense Total Asset Visibility Implementation Plan*, 1996

recognition, voice recognition, and satellite tracking equipment. Because AIT is, by definition, a technological automation enabler, the only constant is change. As both the supporting and supported technologies evolve, the integration support requirements will become more challenging. The effective management of AIT will draw heavily on the collective expertise of the logistics functional, technical and acquisition communities."[28]

Reliability-Centered Maintenance (RCM)

According to AFMC Instruction 21-103, RCM programs ensure maintenance practices support the safest and most reliable operation capable. Through careful application of inspection and scheduled maintenance requirements, critical failures that can be anticipated will be minimized and the highest probability of war fighting capability will be achieved. Maj. Jesse Vickers and 2Lt Hugh Gardenier from the RCM Program Office provided an acceptable RCM definition. They described RCM as, "a disciplined, structured process to identify cost effective and technically sound engine maintenance policies. These policies could affect field or depot maintenance, supply, training, engineering, operator procedures, and technical data."[29]

Joint Total Asset Visibility

The DoD Joint Total Asset Visibility Plan provided a very clear definition for JTAV; "The capability to provide users with timely and accurate information on the location, movement, status, and identity of units, personnel, equipment and supplies. It also facilitates the capability to act upon that information to improve overall performance of DoD's logistics practices."[30]

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[28] Ibid

[29] Maj Jesse Vickers/2Lt Hugh Gardenier, RCM Program Office, WPAFB, OH

[30] *DoD Joint Total Asset Visibility Plan*, p. 4, March 6, 2001, http://www.defenselink.mil/acq/jtav/jtavpmp.pdf

Appendix B

CBM$^+$ Enabling Technologies – Initiative Examples

Prognostics

In recent years, prognostic capabilities have begun to emerge in "future" Air Force weapon systems. In our research, no DoD-"fielded" weapon system prognostic capabilities were found. However, the Joint Strike Fighter Prognostic Health Management System (PHM) was highlighted as an "emerging" example of a true prognostic-capable aircraft embodying the full intent of CBM$^+$. No other weapon system researched in this report compared to the technological enhancements within the JSF. As the JSF progresses, it should represent the DoD model of CBM$^+$ integration.

The Air Force Research Laboratory (AFRL) has made significant strides in providing the future prognostic technology requirements for legacy and future weapon systems. The study team reviewed numerous on-going efforts at AFRL. The efforts all indicated sharp advances in the future for aircraft maintenance prognostic capability. In the following paragraphs we explain four of these efforts.

Weapon System Specific Prognostic Initiatives

JSF Prognostic Health Management (PHM)

The PHM will provide continuous monitoring of the operation, health, and safety of the JSF. The PHM will detect a degraded performance from any component or subsystem; it will then isolate the fault, predict the failure time, and then schedule the necessary maintenance tasks to be completed. Maintenance actions are forwarded to the logistics chain before the aircraft returns to base via data links. The following advanced technologies are all part of the JSF PHM: performance trending and monitoring, auto calibration and gain trending, enhanced sensor technology, operational loads and usage monitoring, cross-comparison (redundancy modeling), capacity trending, enhanced information management, and automated testing. Figure 4 illustrates how these techniques are applied to the JSF PHM. Figure 5 illustrates the PHM architecture for the air vehicle on-board health assessment, the health management reporting and recording, and then the autonomic logistics and the off-board PHM used by JSF maintainers.

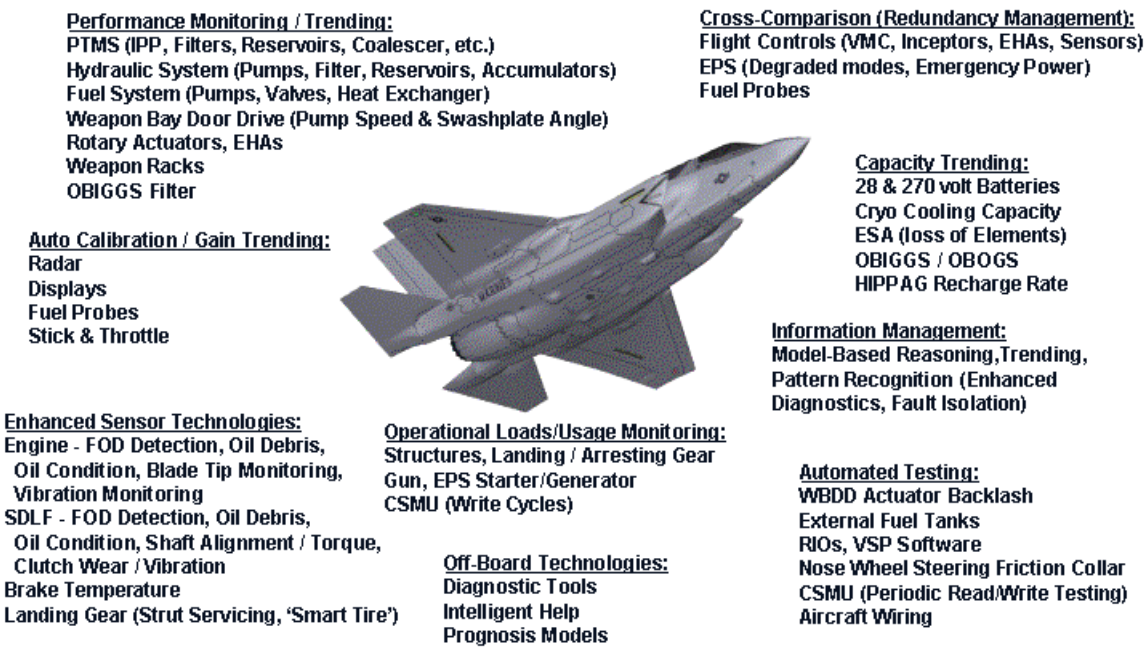

Figure 4. JSF Applied PHM Technologies[31]

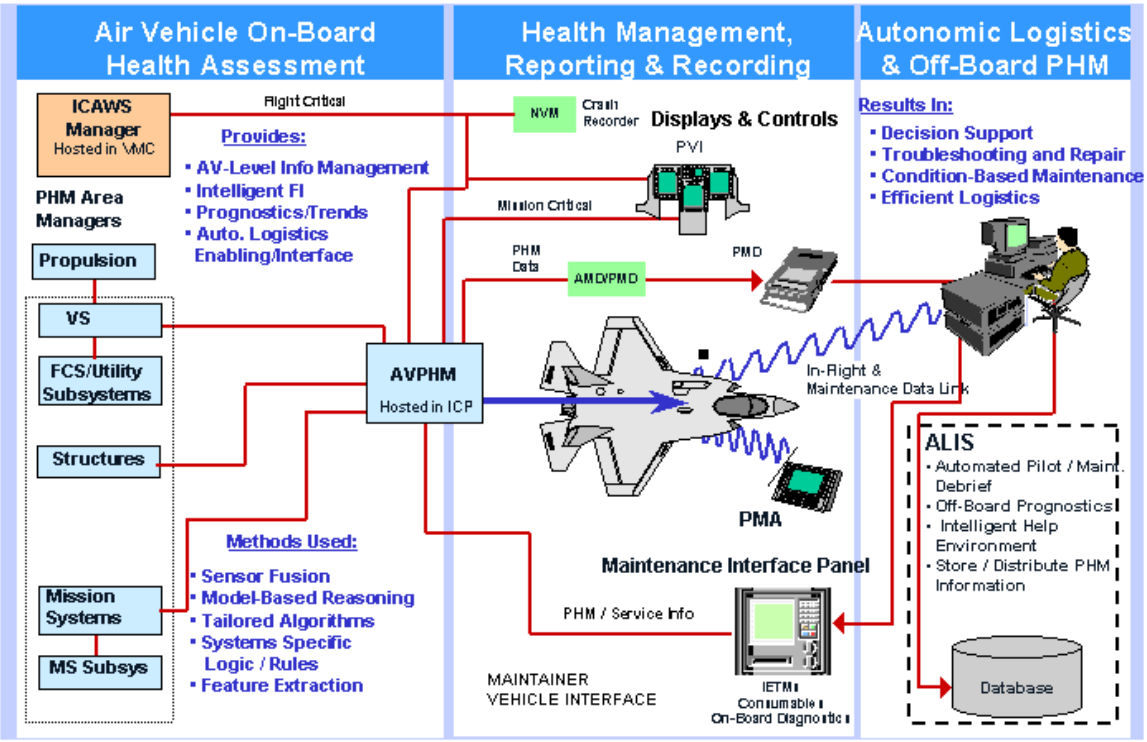

Figure 5. PHM Architecture Overview[32].

[31] 1Lt D. Burnette, JSF PHM Overview Brief, August 2003

Non-Weapon System Specific Prognostic Initiatives

While gathering information for this study, we interviewed numerous propulsion and materials engineers at the AFRL. While at AFRL, we viewed numerous advanced aircraft prognostic efforts applicable to CBM$^+$. We included four prognostic initiatives we feel best illustrate the implementation of the technologies in our proposed baseline. These efforts are the Aircraft Electric Power System Prognostics Health Management (AEPS-PHM), the In-line Health Monitoring System for Aircraft Hydraulic Pumps, Engine Bearing Health and Aircraft Engine Probabilistic Life Modeling.

Aircraft Electric Power System Prognostics Health Management (AEPS-PHM)

The USAF, Boeing and Smith Industries joined forces to develop an AEPS-PHM system for use in Boeing's X-45 Unmanned Combat Aerial Vehicle (UCAV). They are developing a PHM system possessing three important features at the aircraft level. The first level will provide the ability to predict the useful life remaining and the imminent failure of a sample aircraft electrical load. The second is to develop a method of identifying arcing faults within the wiring system before they have the chance to do serious damage to other systems and/or adjacent structure. Finally, the program will develop an electrical generation monitoring system capable of predicting and diagnosing potential generator failures. The Boeing system also will affect the way maintenance is performed by providing the maintainer a more complete picture of overall system health. By allowing the system to automatically notify depot-level distribution centers of the pending needs of the vehicle the logistics supply chain will be automatically altered. Once in place, these systems will reduce aircraft down time due to unscheduled maintenance and reduce the time spent waiting on parts. Thus, aiding in the CBM$^+$ Joint Total Asset Visibility concept.[33]

In-line Health Monitoring System for Aircraft Hydraulic Pumps

AFRL's ongoing development of the Pump Health Monitoring System (PHMS) is a direct result of a series of endurance pump tests to determine whether certain pump performance parameters developed unique characteristics that measure when the pump was nearing failure. They found that a pump with approximately 10% of its remaining useful life exhibited unique characteristics preceding its failure. The demonstration used a bench-top health monitoring system consisting of pressure, flow, temperature, and the necessary electronics. In the CBM$^+$ context, the health of the hydraulic pumps will be indicated by LEDs and/or stored in read-only memory that could be accessed by the maintenance staff. Replacing the pumps at predetermined intervals or after catastrophic failure will not be necessary. Instead, the pumps will be replaced for cause, leading to significant improvement in aircraft readiness, reliability and maintainability.[34]

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[32] Ibid

[33] Mr. Brett Jordan, Electrical Engineer, Air Force Research Laboratory/PRPE. Personal Correspondence. 7 May 2003

[34] Mr. Shashi Sharma, Senior Materials Research Engineer, Air Force Research Laboratory/MLBT. Personal Correspondence. 9 May 2003.

Engine-Bearing Health

Another AFRL initiative is predicting engine-bearing life by recording, tracking, and processing high frequency vibration and acoustic data. "Low frequency vibration signatures provide indicators of rotational defects and near-term failure, while high frequency data (100Khz) contains information correlated with longer-term failures. Data fusion techniques take both indicators in evolving robust, accurate bearing failure prediction. In the current effort, new high-frequency sensors will be evaluated and used to collect acoustic data for use in advanced bearing prognostic algorithms. At the end of the program, a prototype bearing prediction system (hardware) will be delivered to the Air Force."[35]

Engine Probabilistic Life Modeling

Mr. Ken Semega, AFRL, explained the intent of life modeling as an "approach to predict turbine engine component life to extract life indicators for critical components, such as the high compressor and turbine, from engine fleet maintenance data. A key element of the approach relies on a new technique that maps and compresses engine performance indicators (data). In the current effort, the advanced algorithms will be compared with a neural network approach and a conventional statistical regression. The best technique will be coded in the "C" programming language and evaluated on engine diagnostic hardware."[36]

USAF Structural Integrity Program (ASIP)

ASIP is an organized and disciplined approach for ensuring the structural integrity of an airframe. Airframe data is gathered and diagnosed to predict incipient airframe deficiencies (this data is not interpreted in real-time). See data analysis initiatives (page 39) for full description of the prognostic capabilities of the ASIP program.

USAF Engine Structural Integrity Program (ENSIP)

Just as with the ASIP, ENSIP is also an organized and disciplined approach to the structural design, analysis, development, production, and life management of gas turbine engines (this data is not interpreted in real-time). See data analysis initiatives (page 40) for full description of prognostic capabilities of the ENSIP program.

Diagnostics

Our fielded and future systems are replete with diagnostic capabilities, and the most sophisticated of them have direct CBM$^+$ applicability. The F/A-22 has a robust diagnostic system that illustrates the current state of CBM$^+$-concept integration. This section will discuss weapon-specific initiatives such as the F-16's Pilot Fault Listing (PFL), Maintenance Fault Listing (MFL), as well as the Enhanced Diagnostic Aide (EDNA), The B-1B's Central Integrated Test System (CITS), the C-17's Aircraft Fault-Function Indicator Panel (AFFIP)/Maintenance Management Panel (MMP) and Support

[35] Mr. Ken Semega, Electronics Engineer Controls and EHM Technology, Air Force Research Laboratory/PRTA. Personal Correspondence. 9 May 2003
[36] Ibid

Equipment Computer. The F/A-22's Integrated Maintenance Information System (IMIS) Data Transfer Card (DTC) is also discussed. Non-weapon-specific diagnostic initiatives detailed are the USAF Aircraft Structural Integrity Program (ASIP) and the USAF Engine Structural Integrity Program (ENSIP).

Weapon System Specific Diagnostic Initiatives

F-16 Pilot Fault Listing (PFL) and Maintenance Fault Listing (MFL)

The Block 50 F-16 has two distinct diagnostic fault reporting systems--the Pilot Fault List (PFL) and Maintenance Fault List (MFL). The PFL indicates system failures or system conditions affecting flight of the aircraft. The primary display of fault codes is the Pilots Fault List Display (PFLD). If the condition is severe enough to warrant immediate attention, faults display instantly along with associated warning indications, visual and/or audio. The MFL system will display failure data in flight or on the ground for maintenance tests. The primary display is the Multi Function Display (MFD). It is the same reporting system used for failure indications after initiation of built-in tests of line replaceable units (LRUs). The MFL displays data on 34 different aircraft systems as of production tape five. To aid the maintainer in troubleshooting, the MFL identifies the suspect LRUs and shop replaceable units (SRUs) within the system, the subsystem component or signal that failed and the time and number of occurrences of specific failures. Failure data can be displayed in the Heads-Up Display (HUD) if desired or as a backup in case of MFD failure.

F-16 Enhanced Diagnostic Aide (EDNA)

The F-16 also uses an enhanced diagnostic aide for their engines, avionics, anti-skid brake system, and weapons and flight control systems. The EDNA performs numerous functions to include diagnostic testing of the EDNA Memory Loader Verifier (MLV). The EDNA MLV is "the" F-16 flightline support tool (also considered a portable maintenance aid) used to transfer unclassified and classified Operational Flight Programs (OFP) into LRUs. The most common LRUs that are programmed on the flight line using the EDNA are the electronic counter-measure pods and the air launcher interface computers in the weapons systems. The EDNA consists of two pieces of support equipment--the EDNA and the EDNA Interface Cable Set. The EDNA uses a Pentium II PC with standard and programmable interfaces. The EDNA Operating Program (OP) formats and uploads the LRU OFPs onto the aircraft. The software analyzes the response and provides information back to the operator. The EDNA can also monitor sensors through the Crash Survivable Flight Data Recorder (CSFDR) system. The EDNA has the capability to download specific flight data information from the CSFDR and Analog/Digital Flight Control Systems. It also performs diagnostic functions on the CSFDR Anti-Skid Brake System and the ALR-56M Electronic Warfare Systems.[37]

[37] Ms. Michele Butler, Program Manager EDNA/Viper MLV, OO-ALC/LGFAA. Personal Correspondence, 30 April 2003

B-1B Central Integrated Test System (CITS)

The B-1B is equipped with its own diagnostic test system: the Central Integrated Test System. CITS performs on-board automated diagnostic testing on 36 different aircraft systems. According to Gary Parrish at the B-1B program office, the CITS receives circuit parameter data on any of 36 aircraft systems and processes the data to determine if a fault has occurred. Faults are identified to the subsystem level, line replaceable unit level, or the shop replaceable unit level. The CITS displays fault information visually and via hard copy. A maintenance recorder records the fault and parameter information in digital format for further analysis. Annunciator lights are also provided on the defensive system's operator annunciator panel and the offensive system's operator annunciator panel to call attention to any subsystem fault detected by CITS in flight. One note to add, the CITS system was an initial consideration at the capabilities planning phase of acquisition. [38]

C-17 Aircraft Fault-Function Indicator Panel (AFFIP)/Maintenance Monitor Panel (MMP)

The C-17 is equipped with AFFIP fault reporting system. AFFIP displays the results of diagnostic built-in tests (BIT) placed throughout the aircraft. These tests identify system, subsystem and Line Replaceable Units (LRUs) faults. System and subsystem controllers report BIT faults to the AFFIP. Identified faults are then displayed in the cockpit on the display screen placarded Maintenance Management Panel (MMP) (the AFFIP and the MMP are the same system; they just have different names). Detected faults are presented to maintainers on the MMP as six digit alphanumeric fault codes. The maintainer then uses the Fault Reporting Manual to identify the specific system, subsystem or LRU where the fault occurred. The system is used to aid troubleshooting.

C-17 Support Equipment Computer (SEC)

The C-17 community recognized the need for an updated way to perform diagnostic analysis on their weapon system. The SEC was their answer. The SEC is a Panasonic Toughbook 28 laptop computer using Microsoft 2000 as its operating system. Currently, the SEC can download and interpret diagnostic data from the Standard Flight Data Recorder (SFDR). As early as January 2004, the SEC will serve as an Environmental Control System Tests Set (ECSTS). The ECSTS will perform diagnostic analysis of the Bleed Air System, Air-Conditioning System, Ice Protection, Avionic Cooling System Sensor, as well as valve and overall system performance of the ECS. One note to add, the ECSTS will not only provide LRU fault codes, it will also define specific anomalies within the system. C-17 maintainers will use the SEC for Multi Bus Fault Isolation beginning in March of 2004. The SEC will provide an easy-to-use automated tester of the 1553 data bus. The tester will check for open or shorted bus circuits and will facilitate troubleshooting of intermittent bus faults. In the future, the SEC will be capable of operational flight program loading.[39]

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[38] Mr.Gary M. Parish, Lead Electronics Engineer, B-1 Avionics and Software Section, OO-ALC/PSBEA. Personal Correspondence. 6 May 2003

F/A-22 Integrated Maintenance Information System (IMIS) and Data Transfer Cartridge (DTC)

The F/A-22 diagnostic system was the most robust diagnostic system viewed by the study team. The F/A-22 is equipped with the Integrated Maintenance Information System (IMIS). Diagnostic capability of the IMIS lies within the Data Transfer Cartridge (DTC). The IMIS DTC is installed in the cockpit and records discrepancies occurring in flight. After a flight the pilot brings the DTC to debrief, and the DTC is then loaded into the IMIS Maintenance Support Workstation (MSW) computer for analysis. The MSW then identifies specific faults or part failures occurring during the mission. The computer then recommends a specific course of action based on the cause of the failure. The MSW also interfaces with the Honeywell Data Track portable maintenance aid informing the maintainer of the identified faults and course of action for repair. The MSW then orders the required parts and then schedules the work in the Core Automated Maintenance System.[40] (A more detailed description of the F/A-22 IMIS system will follow in the portable maintenance aid and the integrated information system sections of this report.)

Figure 6 identifies the DTC, IMIS, and Maintenance Workstation Interfaces and information relays.

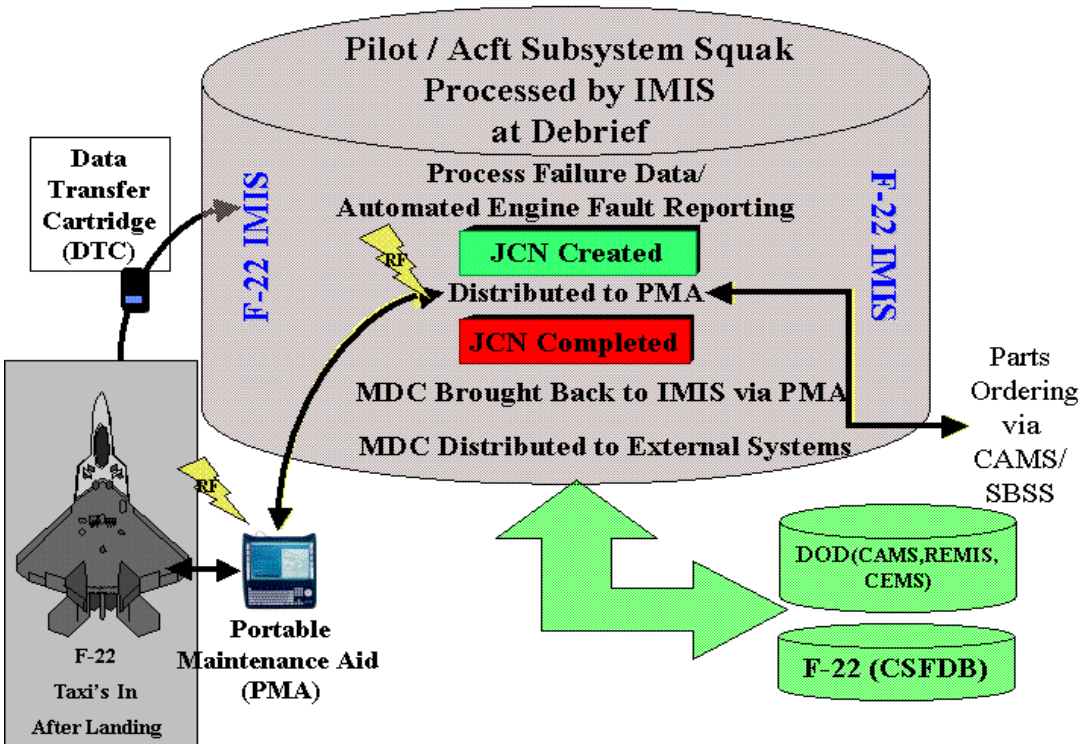

Figure 6. F/A-22 Data Transfer Card and MWS Concept of Operation

[39] Mr. Rob Freund, Mr. Gary McFarland, C-17 SPO/Source Document C-17 SEC CONOPS, 14 Aug 2003
[40] MSgt W. K. Douglas, Program Manager, F/A-22 IMIS, WPAFB, OH. Personal Interview 14 Aug 2003

Non-Weapon System Specific Diagnostic Initiatives

USAF Structural Integrity Program (ASIP)

See data analysis initiatives (page 39) for full description of diagnostic capabilities of the ASIP program.

USAF Engine Structural Integrity Program (ENSIP)

See data analysis initiatives (page 40) for full description of diagnostic capabilities of the ENSIP program

Portable Maintenance Aids (PMAs) Initiatives

The Air Force is rapidly integrating the use of mobile computing devices into day-to-day maintenance activities. Numerous weapon systems currently use Portable Maintenance Aids (PMAs) in some form or fashion in the following areas: technical data display, diagnostic fault isolation, repair mentoring, materiel management, maintenance documentation, health monitoring, operational data upload/download, and in the future prognostic review. We reviewed three weapon system-specific devices for CBM^{+} applicability: the F/A-22 Honeywell Data Trak, the F-16 EDNA Memory Loader Verifier (MLV) and the C-17 Support Equipment Computer (SEC). We also reviewed one non-weapon specific initiative, the AF Point of Maintenance (POMX) PMA.

PMAs come in many forms and fashions. However, most PMAs are ruggedized laptop-type devices. Figure 7 illustrates the Honeywell Data Trak PMA.

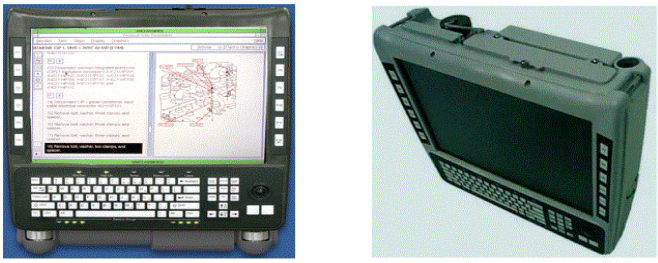

Figure 7. Honeywell Data Trak PMA

Weapon System Specific PMA Initiatives

F/A-22 PMA

The F/A-22 PMA combines a Honeywell frame and an IBM ThinkPad's internal hardware. The PMA, built by Allied Signal, weighs approximately 12 pounds and runs on nickel metal hydride batteries. It has a keypad and function keys to support data entry. It provides a direct communications link between the aircraft—including installed components—and logistics support systems. Functions of the Data Trak include: technical order data display in the form of Class V IETMs, fault isolation (built-in test) and repair mentoring, parts query and ordering, maintenance documentation and analysis, health monitoring, OFP upload and flight data download, and even command door/surface movements and starting/stopping auxiliary power unit. In the future, it will have the ability to aid in rigging the flight controls.

Next year (2004), the F/A-22 will upgrade from the Data Trak Model 20 to a Data Trak Model 30. The upgrade will result in a 300 percent increase in processor speed (933MHz), 290 percent increase in Random Access Memory (512 MB expandable to 1.0 GB), additional input/output capabilities allowing for enhanced bar code readers and printer options, as well as Solaris compatibility.[41]

F-16 EDNA Memory Loader Verifier (MLV)

The heart of the EDNA is the Memory Loader Verifier. As previously mentioned, the MLV transfers OFPs into LRUs. This allows the technician to custom format and upload LRU OFPs for aircraft/mission-specific needs. Sixteen different countries use the EDNA as their primary F-16 flightline MLV.[42] Although this PMA performs aircraft diagnostics and flight programming, it does not perform many of the other CBM$^+$ technology functions such as interactive training, technical data display or repair mentoring.

C-17 Support Equipment Computer

In the future, the SEC will provide operational flight plan (OFP) loading in addition to the diagnostic capabilities discussed earlier. Currently, OPFs are loaded at the depot, intermediate, and organizational levels at Main Operating Bases (MOBs) under the Contractor Logistics Support (CLS) concept, with limited organic capability. The SPO has developed and is executing a three-phase plan providing full organic O-level and I-level loading capability increasing mission capable rates by decreasing aircraft downtime due to the reliance on the contractor for this high frequency maintenance action.[43] As with the F-16 EDNA MLV, it does not perform many of the other CBM$^+$ technology functions such as interactive training, technical data display or repair mentoring. The SEC performance attributes include; 800 MHz Pentium III processor, 30 GB removable hard-drive, 1.44 MB floppy-drive: 24X DVD/CD-RW, 256 MB RAM (expandable to

[41] MSgt W. K. Douglas, Program Manager, F/A-22 IMIS, WPAFB, OH. Personal Interview 14 Aug 2003

[42] Ms. Michele Butler, Program Manager, F-16 EDNA/Viper MLV, OO-ALC. Personal Correspondence. 1 May 2003

[43] Concept of Operations for the C-17 Support Equipment Computer and Personal Interview at C-17 SPO, WPAFB OH, 13 Aug 2003

512 MB), MS Win 2000 operating system, AC 100V-240V 50/60 Hz Auto sensing AC adapter, 2.3" x 9.5" x 11.8" dimensions, and 3' drop specifications.

Non-Weapon System Specific PMA Initiatives

Point of Maintenance (POMX)

The Point of Maintenance (POMX) PMA is an Air Force effort to build a common PMA useable by legacy weapon systems. The POMX will electronically capture maintenance data at the point and time of origin (e.g., at the aircraft) while the work is being performed and transfer the information to the system of record (i.e., CAMS). This will be accomplished via use of E-Tools connected to a wired/wireless LAN via radio frequency (RF) technology. The Air Force Automatic Identification Technology Program Management Office (AF AIT PMO) developed a POMX front-end to the Core Automated Maintenance System (CAMS). The POMX has four primary capabilities: (1) open/close work orders; (2) order parts; (3) use barcode scanning to automate data input; and (4) digital display of technical orders at the site of the maintenance actions being performed.[44] The 16th SOW at Hurlburt Field, Florida, recently demonstrated this capability; and the 12th Logistics Group is currently installing the POMX at Randolph AFB TX.[45]

Interactive Electronic Technical Manuals (IETMs) Initiatives

The following paragraphs describe IETM initiatives for the B1-B, F-16, F/A-22 and the Air Force Common Viewer (AFCV).

Weapon System Specific IETM Initiatives

B1-B Class III IETM

For the past five years the B1-B Technical Publication Program Office has worked to digitize organizational-level (O-level) EK-coded (EK is a B1-B designator) technical orders to the SGML format, ensuring they were CALS compliant. Sixty-four percent of the O level T.O.s are currently in the SGML format. The B1-B System Program Office was also responsible for developing and fielding an Electronic Technical Order (ETO). The MultiDoc Pro Standard Generalized Markup Language (SGML) browser allows users to navigate, search and zoom in on graphics in the ETO. Five percent of B1-Bs T.Os are delivered in a Class III ETO format. The B1-B's program vision is to bring all of their T.Os into a Class III format and then begin the upgrade to a Class IV in 2004 and eventually reach a Class V format.[46] The class IV and V IETMs will progress the B-1's program to a truly CBM+-type IETM capable of interactive technologies such as accessing supply data, maintenance forms, and diagnostic capabilities. The B-1 program

[44] HQ Standard System Group Home Page https://web2.ssg.gunter.af.mil/ilm/portal/portal_maintenance.html
[45] 2Lt Angela Jimdar, HQ AETC Public Affairs, 25 July 2003.
[46] Paraphrased from: Mr. Thomas Hrubik, B-1B Tinker Support Lead, Personal Interview (E-mail) 21 August 2003

office is working to tie their efforts with the on-going efforts of the Air Force Common Viewer.

F-16 Class III IETM

The F-16 depot is also in the process of digitizing F-16 technical orders to the SGML format for a Type 1, Class III IETM. The SGML format Digital Support Suites from MSG/MMF are used to convert the F-16 data. The F-16 team is reauthoring the data from 27 independent databases into a single composite database in order to take advantage of the common data existing between the different versions of F-16. The output from the composite database will amount to approximately 1.4 million pages. Not only will the USAF use the new digitized tech data, F-16 owners from Belgium, Denmark, the Netherlands, Norway, Bahrain, Egypt, Greece, Israel, Jordan, Korea, Portugal, Singapore, Thailand, Turkey, Taiwan and Venezuela will also have access to the common digitized data. The USAF F-16 users plan to use the Air Force Common Viewer for data viewing.[47]

C-17 Class II IETM

The C-17 SPO has introduced the Digital Technical Order System (DTOS) into their weapon system. This class II IETM is a DVD for use by any user via a common laptop or computer. The DTOS DVD is interactive and updated regularly to reflect the most current tech data. Currently, maintainers use both the DTOS DVD and paper technical orders. The AMC Director of Plans and Programs, Maj Gen Essex, requested AMC perform a life-cycle cost analysis for an upgraded Class IV IETM. After completion of the cost analysis, HQ AMC will make the decision whether to proceed. Boeing has digitized approximately 90 percent of the C-17s technical orders to a SGML format. This makes the Class IV IETM transitions an easier process. The C-17 IETM conversion plan follows Technical Manual Specification and Standards compliance IAW MIL-PRF 87269e or S1000 and associated AF Digital Support Suites.[48]

F/A-22 Integrated Maintenance Information System (IMIS) IETM

The F/A-22 Integrated Maintenance Information System (IMIS) is made up of three interrelated parts: (1) the PMA/IETM, (2) the maintenance server unit, and (3) the maintenance support workstation. The F/A-22 IMIS uses the PMA to perform Class 5 IETM functions. The F/A-22 IMIS integrates tail number- specific tech order data, maintenance forms, and the aircraft itself to provide the maintainer a single source of maintenance information. The PMA/IETM is a ruggedized computer that serves as the primary maintenance interface with the aircraft and its systems. One of the biggest advances the PMA offers to the F/A-22 maintainer is the use of tail number-specific IETMs. These IETMs are interactive and offer the user "branches" of information depending on situations encountered during the maintenance action. The three-dimensional graphics used in designing the aircraft were also used in the IETM.

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[47] Mr. J. Brian Landrum (OO-ALC/YPVS), F-16 ITOD Project Manager

[48] Mr. Mike Millsap, Technical Publications Manager, HJ Ford Contractor, C-17 SPO, Personal Interview 14 Aug 2003

However, they were translated to a simplified two-dimensional drawing for ease of use and technical clarity.[49]

Non-Weapon System Specific PMA Initiatives

The Air Force Common Viewer (AFCV)

The AFCV is considered a Class 3 IETM. It satisfies the requirement for viewing SGML technical order (TO) data via a common web browser that can be used across the Air Force by all weapons systems. The AFCV viewing solution is non-proprietary, and non-weapon system specific. The AFCV is composed of commercial-off-the-shelf (COTS) software products and packages. These COTS components are integrated by three primary functional components: (1) AFCV Publishing Service, (2) AFCV Document Server, and (3) AFCV Viewing Service. The primary COTS software packages are the Ixasoft® and TextML® Server and "Standalone" Databases, Itedo® IsoView© ActiveX Browser Plug-in, James Clark's SP SGML Parser, and the Microsoft® Internet Explorer© 5.5/6.0 web browser user interface environment.[50]

Interactive Training Initiatives

Weapon System Specific Interactive Training Initiatives

F/A-22 Maintenance Training System (MTS)

Although the Air Force has used some form of interactive maintenance training for many years, the F/A-22 MTS is by far the most comprehensive effort to date. The MTS links training on realistic system mock ups, interactive classroom training and flight line on-the-job training to the IMIS via the PMA.

Patterned after the legendary Link Aircraft mock-ups, the MTS will utilize seven full-scale, partial-airplane mock-ups built by Link and United Scale Model, as well as a trainer engine built by Pratt & Whitney. Pratt also produces portions of the engine maintenance courseware. These eight devices include the fuel system, on-airplane structures repair, armament, landing gear and auxiliary power supply, aft fuselage, cockpit and forward fuselage, seat and canopy, and engines. Each operational base will have three trainers: engine; combined landing gear and auxiliary power system; and combined cockpit, forward fuselage, seat and canopy. The MTS further employs smaller- scale laboratory and backshop settings, where component-level work will be trained using a range of expendable parts and serviceable (but not flight-worthy) components. This plane-in-a-box concept allows hands-on maintenance practice in a realistic interactive environment.

What makes this initiative true CBM^{+} is the full integration of the F/A-22's IMIS. The more complex trainers having onboard diagnostics, like their real airplane counterpart

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[49] Global Security Organization- http://www.globalsecurity.org/military/systems/aircraft/f-22-sys-supt.htm - 24 Apr 2003

[50] Capt. Yancy Douget, Program Manager/AFCV, Mr. Steve Holloway, Product Manager, Global Product Data Division, Business Information Systems SPO. Personal Correspondence - 7 April 2003

functions will download to IMIS to emulate the transfer and dissemination of real airplane maintenance data.

Trainees and operational flight-line mechanics will carry the IMIS PMA between the flight-line aircraft or training mock-ups and transportable IMIS consoles.

Classroom instruction will employ digitally mastered, multi-media computer-based training (CBT) that merges video and audio, sophisticated graphics (derived from actual F/A-22 engineering computer-aided design source material); digital photography; and lesson syllabi scripted by subject matter experts (SMEs).

The SMEs will use state-of-the-art instructional system design methods, processes and tools developed for the Boeing 777 aircraft-training program. Students on individual PC-based workstations "walk" through self-paced or instructor-led study lessons and tests that incorporate interactive graphics, video, and carefully scripted audio. During instructor-led computer-based maintenance training, the instructor uses a console to project courseware material, send courseware to selected workstations, and to monitor student activity.

During pilot training, students spend time both in multi-media academic lectures and weapons and tactics trainer classrooms where instructors can project training-mission information and graphically demonstrate procedures. Students then practice on their own cockpit consoles and panels.[51]

Non-Weapon System Specific Interactive Training Initiatives

There were no non-weapon system specific interactive training initiatives cataloged.

[51] Drew Warne-Smith, Equipment, Training, and Support News (ETS), Preparing a potent Force, Winter 2002. http://www.link.com/raptor/f-22_raptor.htm

Data Analysis Initiatives

It seems we collect data in the AF on everything from erasers to airplanes. However, data is only useful if you can clearly analyze it and use it to improve logistic operations. The following paragraphs detail a CBM$^+$-type data analysis tool used at Hill AFB for F-16 depot maintenance decision support. Also, two AF data analysis tools used for airframe and engine decision support are explained. Finally, we wrap it up with explaining the Air Forces' maintenance data information system, REMIS.

Weapon System Specific Data Analysis Initiatives

Depot Repair Information Local Server (DRILS)

The goal of DRILS is to reduce F-16 avionics support costs. Through DRILS, maintainers and maintenance managers can rank LRUs and SRUs by identifying bad actors and those parts giving maintainers the most trouble at the lowest possible level. In addition, DRILS can serially track parts consumption, as well as quantify no-fault-founds costs (one of the F-16 highest support costs). DRILS uses a variety of AIT applications to input and analyze maintenance data. These technologies include bar coding, contact memory buttons and passive RF identification. The inputted data enters a local server and then provides maintainers instantaneous feedback instead of the data entering into a black hole. DRILS is web-based, agile information server accessible with no client setup.

According to Mr. Fred Smullin, Chief Software Architect, Total Quality Systems, Team DRILS, "DRILS is designed to: (1) Provide streamlined, dependable, serialized maintenance data documentation at the point of maintenance. (2) Provide immediate benefit from entering the data. (3) Capture data at the lowest possible level of repair (chip and resistor) to obtain information on what the true failure modes are. DRILS does this by capturing data by serial number and analyzing the trends over time to determine what the predominate failure modes are. This allows users to effectively focus resources on those failure modes that provide the greatest return on investment. (4) Use part consumption, rather than part order, data to give supply chain managers and repair facilities true indications of what parts are being consumed and in what frequency. This data can be used to maintain accurate repair costs as well as forecasting future parts requirements based on anticipated workload. (5) DRILS is web-based and designed to be deployed worldwide quickly and inexpensively."[52]

Non-Weapon System Specific Data Analysis Initiatives

USAF Aircraft Structural Integrity Program (ASIP)

ASIP is nothing new to the Air Force. Actually, it has existed for over 25 years. Nonetheless, ASIP continues to play a significant role in advancing the reliability of our future and legacy aircraft. Although ASIP is not a true CBM$^+$ effort, as technology advances, sensors could be added to weapon systems making ASIP information real-time

[52] Mr. Fred Smullin, Chief Software Architect, Total Quality Systems, Team DRILS. Personal Correspondence. 10 Apr 2003

providing maintainers and engineers instantaneous data for decision support. The following paragraphs explain the objectives and tasks of the ASIP program.

The ASIP program has four key objectives. The first objective is to establish, evaluate, and substantiate the structural integrity of aircraft to include airframe strength, rigidity, damage tolerance and durability, and the economic life of the airframe.

The second objective is designed to acquire, evaluate and then apply operational usage data providing a continual update of the structural integrity of operational aircraft. Data is gathered from sensors at various test points on the aircraft, which monitor airframe stresses. The Crash Survivability Flight Data Recorder (CSFDR) collects and stores the data from these sensors. CFSDR data is downloaded by base-level maintainers and sent electronically to ASIP managers located at the Oklahoma City Air Logistics Center for interpretation. Engineers then interpret ASIP data diagnosing and predicting incipient airframe deficiencies.

The third objective states the ASIP program will provide quantitative information for decisions on force structure planning, inspection and modification priorities, and related operational and support decisions.

Lastly, the ASIP program provides a basis for improving structural criteria and methods of design, evaluation, and substantiating for future aircraft systems and modifications.

The ASIP program is composed of two major efforts encompassing five core tasks. The first effort is full-scale development of a particular weapon system's structural integrity program and encompasses tasks 1, 2, and 3 (task 1 is design information, task 2 is design of analysis and development tests and task 3 is full scale testing). These tasks establish, evaluate, and substantiate the structural integrity for design. The second effort is force management and encompasses tasks 4 and 5 (tasks 4 is management of an aircraft's historical data package and task 5 is force management of a specific aircraft throughout it's life cycle, i.e., data collection, maintenance times, TCTO's etc.). Force management provides continual assessment of the in-service structural integrity of individual aircraft.[53]

USAF Engine Structural Integrity Program (ENSIP)

ENSIP is defined as an organized and disciplined approach to the structural design, analysis, development, production, and life management of gas turbine engines. ENSIP is a derivative of the first integrity program ASIP. As with ASIP, ENSIP is not a true CBM+ effort. However, if in the future we incorporate advanced technology like the AFRL's Engine Probabilistic Life Modeling prognostic effort, we will provide maintainers with real-time information and have a higher probability to predict engine catastrophic failures.

ENSIP closely follows the ASIP philosophy and format. Currently, ENSIP is organized into five major tasks, beginning with the initial planning phase and concluding with guidance on production and fleet management. To gain a better understanding of ENSIP, figure 8 illustrates areas of analysis addressed during an engine's life cycle.

[53] Mr. Archie Woods, Aeronautical Systems Center F-16 SPO/YPVF, Personal Interview, 12 August 03

As with ASIP, engineers use the gathered data to diagnose and predict negative fleet health trends. Over the program's life ENSIP has reduced (nearly eliminated) engine disk burst (catastrophic engine disk failure) events and in turn increased mission readiness.[54]

Task I	**Task II**	**Task III**	**Task IV**	**Task V**
Design Information	Design Analysis & Materials Characterization	Component & Core Engine Testing	Engine Ground & Flight Test	Production Quality Control & Engine Life Management
ENSIP Master Plan Design Service Life Design Criteria Classify Hardware	Design Duty Cycle Materials & Processes Design Data Characterization Structural & Thermal Analysis	Strength Damage Tolerance Durability Thermal Survey Vibratory Survey	Environmental Verification Durability Damage Tolerance Flight test Strain Survey Update Critical Part Lives	Production Engine Analysis Structural MX Plan DADTA Control Program Lead the Fleet Program Individual Engine Tracking Update T.O.'s

Figure 8. ENSIP Task

Reliability Maintainability Information System (REMIS)

REMIS was implemented in 1985 as a replacement/update for the AF Equipment Maintenance Database. REMIS data is now accessible via the Electronic Data Warehouse. Since REMIS' inception it has served as the Air Forces' maintenance database. REMIS is the approved source for weapon system data to support reports to the DoD and Congress. It is a centralized source for aircraft, engines, missiles, trainers, parts, automated test equipment, communication-electronics, selected support equipment, munitions, and PMEL. REMIS provides near real-time on-line reliability and maintainability data. REMIS data is updated almost hourly from other AF and contractor

[54] Mr. Vince Spanel, Aeronautical Systems Center/EN, Personal Interview, 12 August 03

information systems. Figure 2 on page 10 of this report illustrates REMIS' interaction with other information systems.

REMIS is divided into four functional areas, Equipment Inventory, Multiple Status, Utilization Reporting Subsystem (EIMSURS), Product Performance Subsystem (PPS), Generic Configuration Status Accounting Subsystem (GCSAS) and the Core programs.

EIMSURS provides detailed summary and historical data for aerospace vehicles, automated test equipment, selected missiles, selected support equipment, and communication-electronic equipment. These reports include inventory for a possessing base, status reporting to include fully mission capable or down for maintenance or supply and sortie, landings, and flying hour utilization. AF Air Vehicle Distribution Offices use EIMSURS data to monitor inventory, utilization, and configuration of assigned inventory. Planners use EIMSURS data to track the inventory, assign new equipment to the inventory, and allocate flying hours.

PPS collects and provides on-and-off equipment maintenance collection data and general support information to include R&M data, debrief data, and TCTO data. Maintenance analysts use this data to spot negative trends on a particular piece of equipment or component. Planners at the Air Logistics Centers use PPS data to compute and track repair requirements and to track TCTO accomplishment.

GCSAS functions include weapon system configuration status and accounting, as well as TCTO tracking and reporting. MAJCOMs manage modifications, report TCTO status, perform calculations and analysis, justify new modifications, and investigate trends.

The Core Subsystem supplies the other subsystems the support they need to process EIMSURS, PPS, and GCSAS data (i.e., log-on, navigation, security, query capability etc.).[55]

Integrated Information Systems Initiatives

Two integrated information systems initiatives implementing CBM$^+$ are the maintenance portion of the Air Force Portal and the Enterprise Data Warehouse (EDW). Within a CBM$^+$ environment the maintainer will enter maintenance transactions at the point of maintenance via a PMA. That data is then transferred to an integrated information system and stored in various maintenance information systems. The Air Force Portal and EDW provide a gateway and clearinghouse for that information. The information will be accessible to all Air Force personnel. The maintainer may access the data for updating maintenance transactions. Maintenance supervision may access the data for data analysis and trend reporting. Air Force leadership may use the data as a decision-making tool. Detailed descriptions of these two integrated information systems are provided in the following paragraphs.

[55] REMIS information provided by AFCSM 25-524, Vol I, 1 August 1999

Non-Weapon System Specific Integrated Information System Initiatives

Air Force Portal (Maintenance Content)

The Standard Systems Group Home Page describes the to-be state of the portal in this fashion: "The portal will be the single-source gateway to all applications. Instead of having to access maintenance information systems separately, the user will be able to log on to the Air Force portal through a common browser (e.g., Internet Explorer or Netscape) to gain access to all the maintenance information systems. The Air Force portal is a collection of data tools and gadgets that will save maintainers and decision maker's critical man-hours, because the portal shows with a simple click aggregated maintenance information that normally took hours to gather. In the future, maintainers will be able to not only access but also input data into their respective MIS; and a maintenance "Community of Interest" will afford members a single place to find the latest updates on training, policy, TCTOs or items of general interest related to the maintenance community. The Air Force is helping to create a new paradigm for maintainers on the flightline by bringing new technology to aid in data collection and identifying policies and procedures that need to be changed or updated to maintain pace with the technology explosion, for mid-managers by allowing them to reduce the amount of time needed to collect data and build reports, and for senior leaders by giving them an area of consolidated data tools to ask new questions and make better decisions."[56]

Enterprise Data Warehouse (EDW)

The Enterprise Data Warehouse (EDW) is moving toward the Air Force vision to provide a single source for all combat support analytical and historical information. In a nutshell, the EDW will provide one-stop shopping for maintainers and maintenance managers for aircraft maintenance and decision support. Within a CBM$^+$ environment, maintainers will interface with a particular information systems via a common PMA or PC directly to the EDW. Currently REMIS data, and some CEMS data, are accessible through the EDW. In the future other information systems such as CAMS and GO-81 will be accessible on the EDW. These efforts will reduce duplication of data location, improve data accuracy and improve decision support. Efforts are underway to allow users of historical air vehicle data to access the data via the portal. The EDW is constantly being updated and integrated. Further information and updates can be found by visiting the EDW program office website at https://www.ilspo.wpafb.af.mil/edw/.[57]

[56] HQ Standard System Group Home Page/ Air Force Portal https://web2.ssg.gunter.af.mil/ilm/portal/portal_maintenance.html

[57] HQ Standard System Group Home Page/ EDW https://web2.ssg.gunter.af.mil/ilm/edw/edw.html and personal interview with Mr. Mike Riley, EDW Program Office, 27 Aug 03

Automatic Identification Technology (AIT) Initiatives

Automatic Identification Technology (AIT) Initiatives exist in various forms and fashions within the Air Force. However, they all have one common goal, enhancing and streamlining business processes and our warfighting capability. The following paragraphs describe the C-17 Bar Coding Test, the Depot Repair Information Local Server (DRILS) and the Air Force's newest AIT initiative Serial Number Tracking (SNT) and Product Marking.

Weapon System Specific AIT Initiatives

C-17 Bar Coding Test

The C-17 System Program Office implemented a test to serially track selected Line Replaceable Units (LRUs) in their fleet through the use of bar coding. The goal of the effort was to improve data introduction and the tracking of configuration end items (CEI). By introducing more accurate data, fleet managers are often better able to manage fleet readiness for LRUs. A second advantage of bar coding is the ability to identify and track bad actors, repeat and recurring discrepancies, and identify those CEIs causing the most trouble. The test targeted 37 avionics LRUs constituting 94 components per aircraft. The bar code consisted of three parts. The first part is the cage code or manufacturer ID, the second part was the serial number, and the third was the part number. The part number portion was detachable in case the part number changed or required updating. Figure 9 provides a pictorial illustration of the actual tag.

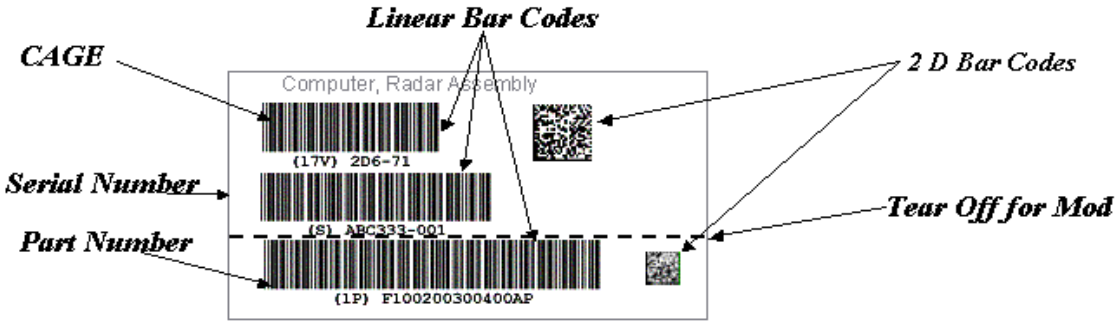

Figure 9. C-17 Bar Code Test Tag

The test took place in the back shops of Charleston AFB SC and Mchord AFB WA. The bar-coded tags were installed on the LRUs during routine maintenance. Once the bar codes were installed, maintainers could perform automated configuration management checks of the LRUs via the scanner and bar codes. In the past, this task took hours. All information was manually entered into the information system and prone to transposition errors. With bar coding technology, the maintainer can open the avionics rack, scan the bar codes, and then download the hand-held device to the docking station for complete configuration data. The eventual goal of the test is for the automated transfer of configuration data into the GO-81 maintenance information system and eventually the

Electronic Data Warehouse. Another goal of the project is to integrate the C-17 serial tracking capability into the AF AIT Office Air Force Point of Maintenance Initiative. The AF AIT Office procured the current proof of concept bar coding and scanning equipment used in the test.[58]

Depot Repair Information Local Server (DRILS)

We concluded DRILS fit into two separate CBM$^+$ technology initiatives because of its AIT capabilities and Data Analysis capabilities. As described earlier, DRILS provides serialized maintenance data documentation at the point of maintenance. Serially tracking particular component and sub-components provides significant data useable by maintenance managers. The DRILS data provides accurate replacement parts requirements thus, reducing the awaiting parts time, which, in turn, reduces MICAPs. The data can immediately identify "bad actor" parts and then recall bad parts installed on items. In the past, this took days if not weeks to perform. The data can also be used to track TCTOs, investigate deficiency reports, and identify track and correct no-fault founds.

Figure 10 illustrates the integration among information systems at the depot and then to other information systems such as REMIS (DRILS pushes selected data to REMIS).

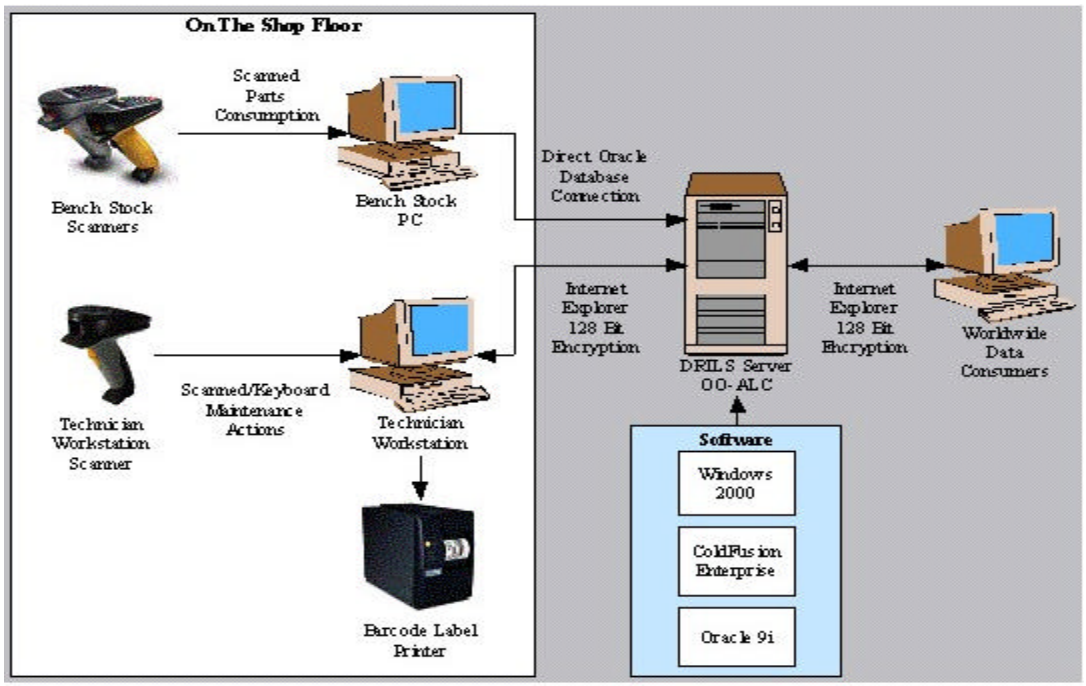

Figure 10. DRILS AIT Integration[59]

[58] Mr. Stanley Smigiel, Contractor, HJ Ford, C-17 SPO. Personal Interview 13 Aug 2003.
[59] Illustration provided by Mr. Fred Smullin, Chief Software Architect, Total Quality Systems, Team DRILS. 10 Apr 2003

Non-Weapon System Specific AIT Initiatives

Air Force Serial Number Tracking (SNT) and Product Marking

Numerous serial number tracking and product marking initiatives exist throughout the Air Force. As seen in the previous paragraphs, the C-17 has initiated bar coding test on specific LRUs and serially tracking of parts at the depot is an initiative of DRILS.

Precision Measurement Equipment Laboratory (PMEL) personnel have serially tracked their equipment through the use of bar codes for over fifteen years. They use the bar code technology to identify calibration dates, maintenance, work unit codes, and serial and part numbers. This information is stored on a local server. As early as Jan 2004, the stored information will be incorporated into the PMEL Automated Management System (PAMS). The information stored in PAMS will provide a direct source of data for the Air Force Metrology Laboratory to adjust calibration dates and make other management decisions for PMEL equipment.[60]

In response to the numerous aircraft maintenance SNT initiatives, the Air Force has formed an IPT responsible for creating guidance for AF-wide SNT and product marking. The conceptual objectives of this IPT are to: "(1) identify items suitable for SNT, (2) protocols and standards for marking of the items, (3) identify modification requirements of information systems, (4) identify system architecture requirements, and (5) modification of business processes."[61] The identified benefits of the Air Force SNT and product marking include identification of poor performing items, configuration management, and a decreased premature disposal of items, reliability improvement, and enhanced management of specific warranty requirements. The IPT plans to implement tenants of SNT by early 2004 throughout the Air Force.

Reliability Centered Maintenance (RCM) CBM$^+$ Tools

Earlier in this report we identified RCM as a key maintenance concept applicable to CBM$^+$. The following paragraphs describe advanced tools used by RCM managers to increase engine time on wing and engine reliability. These initiatives are the RCM calculator and Weibull Analysis.

The RCM Calculator

The RCM Calculator is a web-based tool used to help engine maintenance personnel better align aircraft engines and their parts with engines and parts having similar usage times and/or life limits. By aligning similar engines and parts the number of scheduled engine removals can be reduced. While using the calculator, users identify which bases' engines and/ or engine parts they wish to look at for alignment. The calculator then identifies and aligns the modules within the bases selected. This calculation provides the greatest percent alignment and therefore the fewest number of scheduled engine removals. The calculations are only suggestions for improving percent alignment.

[60] MSgt. Danny Vessells, HQ SSG/ILMM. Personal Interview, 20 Aug 2003
[61] Material Management and Policy Division of Directorate of Logistics Readiness DCS Installations and Logistics Hq USAF, Air Force Concept for Serial Number Tracking and Product Marking, 27 Feb 03

Maintenance personnel are not required to perform any of the suggested changes due to extenuating mission, cost, or supply factors. [62]

Weibull Analysis

Not all engine removals are scheduled due to the fact engines and/or engine parts do not all fail at the same time or in the same way. Weibull Analysis is a statistical tool used by engineers to determine if a part is failing either randomly or wearing out with relatively limited failure data. This tool helps engineers determine if a part needs to be modified, replaced, or kept as-is and the engine left to fly to failure. Weibull analysis provides a predictive maintenance tool and gives insight into the health of the engine fleet. The TF39 Predictor tool is an example of a Weibull analysis tool. TF39 engineers use the predictor tool to predict how long engines will remain on wing and align engines and components with similar Expected Time on Wing (ETOW). Aligning ETOW reduces the number of unscheduled engine removals and further increases engine Time on Wing. Furthermore, unscheduled engine removals account for the majority of engine removals; and, by reducing these types, a further reduction in cost per engine flying hour can be realized.[63]

Joint Total Asset Visibility Initiatives (JTAV) CBM$^+$ Tools

The following paragraphs detail two tools used in achieving JTAV. The first initiative is the U.S. Transportation Command's (USTRANSCOM) Global Transportation Network (GTN). GTN provides DoD users the ability to track passenger and cargo movements. Air Force Material Command introduced the second identified initiative, the Tracker Data System. Air Force supply personnel use this program for asset visibility of parts within the supply system.

Global Transportation Network (GTN)

According to information gathered from the GTN home page, the USTRANSCOM GTN provides customers the capability to access and employ transportation and deployment information. GTN is an automated command and control information system that provides an integrated system of in-transit visibility information and command and control capabilities. GTN collects and integrates transportation information from selected transportation systems. The information gathered from GTN provides its customers with information to support transportation planning and decision-making during peace and war. GTN is available to any valid user via the World Wide Web.[64]

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[62] 2Lt Hugh Gardenier, RCM Program Office, Personal Interview 11 August 2003
[63] Ibid
[64] US Transportation Command Global Transportation Network Home page
https://www.gtn.transcom.mil/public/home/aboutGtn/index.jsp

TRACKER Data System

TRACKER was best described within the User's Manual for the Tracker Data System. It described TRACKER as part of the D087 series of programs, specifically, D087T. It provides users with information from its data warehouse, which is filled by numerous data systems used by the DoD. TRACKER is accessible to users via the Internet. Tracker is a data-mining and display tool for the Oracle database.

The TRACKER database is aligned and presented in such a way that it focuses on flight line base level users providing them with the information on their requisitions.

TRACKER works by acquiring copies of the transactions transmitted between the computer systems used to acquire, store, repair, and move assets for the US Air Force. These transactions are in military standard formats as defined in MILSTRIP, MILSTRAP, MILSCAP, MILSBILS and MILSTAMP. TRACKER aligns these transactions according to key data and allows queries to be made via those keys. Additionally, TRACKER pulls useful data from other data warehouses, such as WSMIS-SAV and D043, and displays it with the MILS transactions.[65]

[65] Air Force Material Command, *User's Manual for the Tracker Data System*, September 2002, p. 3 https://tracker.wpafb.af.mil/tracker_manual_v3_0.doc

Appendix C

Recommended Policy Changes

Capability Planning AFIs/AFPDs Recommended for Change

- AFI 10-601, Mission Needs and Operational Requirements Guidance and Procedures, 13 Aug 99 (AF/DXOR)
  Note: This AFI is currently under revision (estimated completion date for interim guidance will be available Fall 2003)
    - Several places for changes in the draft version impacting CBM^+
        - 1.4.6. Technology Transition Activities – add emphasis on technology that enhances sustainment through CBM^+ in addition to the existing emphasis on technology that enhances operational capabilities.
        - 3.3.14.4 Directs AFMC to provide assistance and guidance to address early determination of sustainment posturing. Add emphasis on the 10 CBM^+ technologies/concepts.
        - Add 3.3.18 directing AF/ILI to report to the AFROCC and the MTSSG on CBM^+ implementation and responsibilities for AF CBM^+ oversight and implementation.
        - Terms – need to add definition of CBM^+.

    The new AFROCC Charter (March 2003) is referred to in paragraph 3.5. AF/IL is a designated member and his/her involvement should ensure capability requirements documents give proper weight to CBM^+ plans (as directed in paragraph 3.2 of this charter). However, IL needs to make sure ILI gets a seat in the room or has thoroughly briefed IL on CBM^+ issues that may need to be addressed.
- AFI 10-602, Determining Mission Capability and Supportability Requirements, 30 Sep 02 (AF/ILMY)
    - Current AFI should be revised to update CBM^+ implementation.
    - Para 2.1.2. Requirement Developer Direction. Either draft a new sub-paragraph, or modify existing sub-paragraphs to address CBM^+ technologies/concepts.
    - Terms –add CBM^+ definition
    - Attachment 2, Acquisition Logistics. Modify to include CBM^+ technologies/concepts in "many" paragraphs. These changes will require input from CBM^+ functional experts.

- AFI 10-1901, AF Battlelab Responsibilities, Processes, and Documentation, 1 Oct 97 (XORBB)
    - Para 2.2, Battlelab Planning Cell (BPC) describes one function of the BPC is to focus on logistics concepts--could also be expanded to emphasize CBM^+ technology/concepts.

Acquisition AFIs/AFPDs Recommended for Change

- AFPD 63-2, Automatic Test Systems and Equipment, 19 Jul 94 (SAF/AQKL)
    - Para 2 should be expanded to include CBM^+-like goals for AIT and technology.
- AFI 63-201, Automatic Test Systems and Equipment Acquisition, 21 Jul 94 (SA-ALC/ADA)
    - Section B, paragraph 2, should emphasize consideration of state-of-the- art CBM^+ technologies related to prognostics and diagnostics.
- AFPD 63-14, Aircraft Information Programs, 6 Feb 2001 (AFSC/SEF)

  Para 2 and 2.1 should be modified to add emphasis on CBM^+ applications where feasible.
- AFI 63-123, Evolutionary Acquisition for C2 Systems, 1 Apr 2000 (SAF/AQII)

  Para 5.5, update to state that MAJCOMs propose and advocate CBM^+ technology.

Maintenance AFIs Recommended for Change

- AFI 21-101, Aerospace Equipment Maintenance Management, 01 Oct 02 (AF/ILMM)
    - Paragraph 1.4, introduce CBM^+ concept, definition, and goal for future aircraft.
    - Paragraph 1.5, introduce CBM^+ concept.
    - Paragraph 1.9, consider CBM^+ initiatives for any proposed modifications.
- AFI 63-107, Integrated Product Support Planning and Assessment, 29 May 01 (AF/ILMM)
    - Many paragraphs marked for potential changes in existing document.
    - Paragraph 1.4, introduce CBM^+ definition, concept, and functions.
    - Paragraph 1.5, add paragraph emphasizing preference for CBM^+ technologies.
    - Paragraph 2.3, direct AF/IL to be responsible for advancing CBM^+ concepts and functions.
    - Paragraph 2.9, direct AFMC to facilitate technologies that enhance CBM^+ concept where applicable.
    - Paragraph 2.10, direct Single Managers to ensure CBM^+ concept and functions are considered in the Product Support Management Plan.

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Appendix D

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Mr. Brett Jordan, Electrical Engineer, Air Force Research Laboratory/PRPE

Mr. Shashi Sharma, Senior Materials Research Engineer, Air Force Research Laboratory/MLBT

Mr. Ken Semega, Electronics Engineer Controls and EHM Technology, Air Force Research Laboratory/PRTA

Ms. Michele Butler, Program Manager EDNA/Viper MLV, OO-ALC/LGFAA

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Appendix E

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