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**EMMA : THE EXPERT SYSTEM FOR
MUNITION MAINTENANCE**

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ABSTRACT

EMMA (Expert Missile Maintenance Aid) is the result of research sponsored by the Air Force Armament Laboratory, Air Force Systems Command at Eglin Air Force Base (AFB), Florida. It is a first attempt to enhance maintenance of a tactical munition at the field and depot level by using artificial intelligence (AI) techniques. The ultimate goal of EMMA is to help a novice maintenance technician isolate and diagnose electronic, electromechanical, and mechanical equipment faults to the board/chassis level more quickly and consistently than the best human expert using the best currently available automatic test equipment (ATE). To this end, EMMA augments existing ATE with an expert system that captures the knowledge of design and maintenance experts.

This paper describes the EMMA program. It addresses such issues as how the field-level expert system prototypes were evaluated as well as the results of the evaluations. Additionally, current work on the depot-level prototypes is discussed as well as issues related to using DOD-STD-2167 to document the development of expert systems. This paper will briefly address several study tasks performed during EMMA. The paper concludes with a discussion of future plans for a follow-on program and other areas of concern.

INTRODUCTION

Weapon systems of today are undoubtedly benefiting from technology advances and justifiably so. Munitions are becoming more sophisticated and "smarter" as a result of this technology. Electronically sophisticated munitions are quickly infiltrating the Department of Defense arsenal of weapons. Simple bombs are becoming relics of the past.

However, some shortcomings can be associated with incorporating new technology into current and future weapon sys-

tems. Munition maintenance will surely suffer as a consequence of this technology. The technology advances that have improved the effectiveness of munitions are simultaneously complicating the maintenance of these munitions by increasing the functionality of the munition typically making the munition harder to maintain. Munition test equipment and associated software do not adequately diagnose faults. Automatic test equipment (ATE) is plagued by high false alarm rates. Guidance and control sections returned to the depot are currently experiencing approximately 28 to 44% retest OKs. Many faults, as many as one out of every four, cannot be detected by ATE. Sequential testing is typically how ATE performs diagnostic testing. This limits the diagnostic capabilities of the test equipment. Additionally, ATE cannot diagnose beyond multiple linked components.

Another aspect of munition maintenance that must be addressed when dealing with munition reliability is the personnel shortage. The current shortage of skilled munition maintenance technicians is a serious problem. Demographic projections indicate that this dilemma will not subside in the near future. Since experienced technicians are able to diagnose a fault quicker and more reliably than a novice, the knowledge acquire by the experienced technician (expert) throughout the years should be captured so that this knowledge can be used by novice technicians during future diagnostic sessions.

Artificial intelligence (AI) technology is one approach to increasing the reliability and maintainability of existing and future weapon systems. One popular and heavily cited definition of artificial intelligence is provided by Dr. Elaine Rich, University of Texas at Austin. She defines AI as follows: "Artificial intelligence is the study of how computers do things at which, at the moment, people are better" (Rich, 1983:1). A subset of AI is a field called expert

systems. This area of AI has emerged recently with the greatest amount of success (Hayes-Roth et al., 1983:xi). Donald Waterman defines expert systems as "sophisticated computer programs that manipulate knowledge to solve problems efficiently and effectively in a narrow problem area" (Waterman, 1986:xvii).

The Air Force has recognized the importance of increasing munition reliability. In a joint memorandum, General Gabriel, former Air Force Chief of Staff, and Verne Orr, former Secretary of the Air Force stated, "For too long, the reliability and maintainability of our weapon systems have been secondary considerations in the acquisition process. It is time to change this practice"

EMMA

EMMA (Expert Missile Maintenance Aid) is the result of research sponsored by the Air Force Armament Laboratory, Air Force Systems Command at Eglin AFB, Florida and is a first attempt to enhance Air Force tactical munition maintenance by applying artificial intelligence/expert system technology to ATE. The objective of EMMA is to develop an automated smart munition test system that augments existing ATE. The ultimate goal of EMMA is to help a novice munition technician isolate and diagnose electronic, electromechanical, and mechanical equipment faults to the board/chassis level more quickly and consistently than the best human expert using the best currently available ATE.

EMMA is a thirty month effort split into two phases. Phase 1 began in September 1986 and concluded 10 months later in July 1987. This phase addressed the field-level maintenance of tactical munitions and ultimately resulted in two field-level expert system prototypes. Phase 2 began in August 1987 and is scheduled to conclude in April 1989, 20 months later. Phase 2 focuses on depot-level maintenance and will produce two depot-level expert system prototypes. Since depot-level diagnostic activities are more in-depth and detailed than the field, this phase is expected to be more difficult and of greater complexity. This accounts for the greater time allotted to this phase. The prototypes from both phases are targeted towards the maintenance technicians. Since EMMA is constrained by schedule and money, the number of tests developed under this effort is limited, yet sufficient to demonstrate concept feasibility of using expert systems for munition maintenance.

EMMA draws on many different types of knowledge and information to perform the diagnosis of the faulty munition. The EMMA knowledge base consists of maintenance rules or Technical Orders (TOs),

maintenance technician practices (heuristics), Unit Under Test (UUT) design, existing test equipment capabilities, failure rates, and test costs. This knowledge is gleaned from various sources including TOs, schematics of the UUT and the test equipment, knowledge acquisition interviews with munition maintenance experts and the experts that designed the munition and test equipment. Figure 1 depicts how this knowledge is brought to bear on the problem of diagnosing the faulty munition. First, the symptoms are derived from the test equipment and technician observations. This information is supplied to the expert system via a sophisticated, user-friendly interface. The expert system then employs the knowledge stored in the knowledge bases and derives a repair strategy which is displayed to the technician using the EMMA computer.

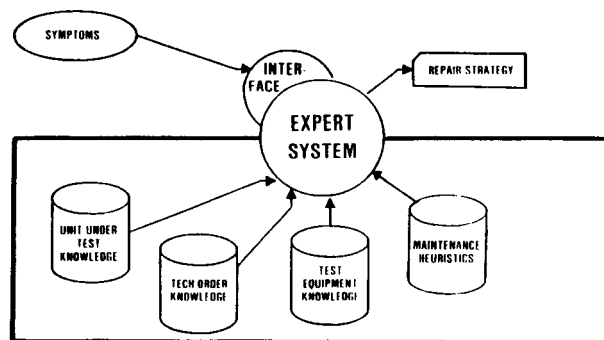


Figure 1. EMMA Expert System

EMMA is a dual contract effort performed by Raytheon Company, Missile Systems Division in Bedford Massachusetts, and Rockwell International Corporation, Autonetics Sensors and Aircraft Systems Division in Anaheim, California. Both contractors will develop a phase 1 and phase 2 EMMA prototype resulting in a total of four prototypes. Both contractors were allowed to select their candidate vehicle for the EMMA program within specified limits. Raytheon selected the AIM-7F Sparrow missile as their candidate munition. Rockwell chose the GBU-15 modular glide bomb.

THE AIM-7F FIELD-LEVEL EMMA PROTOTYPE

The Raytheon field-level (phase 1) EMMA prototype was designed to enhance the field-level maintenance of the AIM-7F missile by augmenting the missile's test set. All references to the word "EMMA" in this section refer to the Raytheon AIM-7F version of EMMA. The field-level test set for the AIM-7F is the AN/DSM-162 test set. EMMA is hosted on a Symbolics 3670 LISP machine running the expert system shell ART (Automated Reasoning Tool). ART pro-

vides a production language that is primarily rule-based. Consequently, EMMA was developed using the rule-based approach. The Symbolics computer is connected to the AN/DSM-162 test set via an RS-232 cable. Figure 2 illustrates the major components of the EMMA system and how they are interconnected.

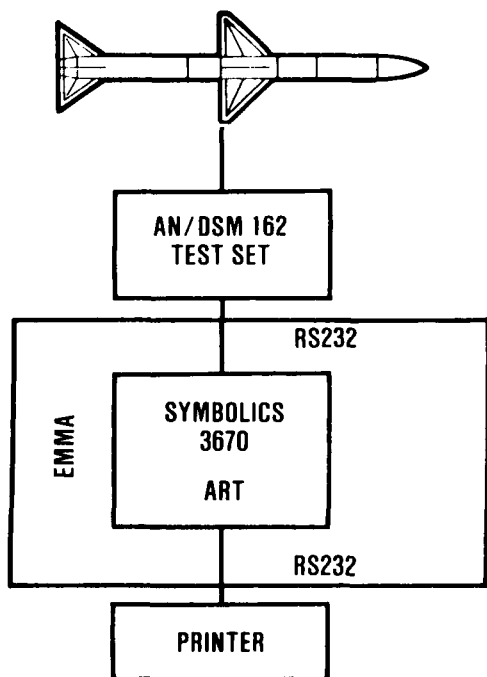


Figure 2. AIM-7F Field-level EMMA Prototype

The RS-232 cable allows EMMA to operate in three modes -- automatic, semi-automatic, and manual. The distinguishing characteristics of these modes is the level of automation EMMA is allowed during the diagnostic session. The automatic mode uses the RS-232 interface to allow EMMA to direct the diagnostic testing and resequencing of tests. EMMA automatically accepts data from the test set via the RS-232 cable, performs the fault isolation, and directs the test set to perform additional test, if required, until the fault is detected or all tests pass. If a fault is detected during automatic operation, the user may switch to semi-automatic mode for closer control over the testing and the ability to query after each test segment.

The semi-automatic mode operates similar to the automatic mode with one exception. This mode stops execution of EMMA at the completion of each unique test segment. This allows the technician to query EMMA recommendations using the explanation capability. Another advantage of the automatic modes (semi and full) is

data integrity. Since EMMA passes the data between the test set and the Symbolics computer via the RS-232 cable, the data are more likely to remain valid as opposed to transferring data via a technician who could inadvertently introduce errors.

The last mode is manual. This mode is provided in case an RS-232 connection is not possible. As the name implies, all activities between the test set and the Symbolics computer must be performed manually by the technician. EMMA will direct the technician to perform the appropriate actions to the test set and wait for the response. The technician enters the responses from the test set into EMMA.

As with most expert systems, EMMA is able to explain its reasoning process to the user (technician). EMMA explains its fault detection and resequencing logic. In other words, EMMA explains a detected fault and why a certain test is being recommended. Two levels of explanation are available depending upon the experience of the technician. The technician may request an explanation during any phase of the diagnostic process. This allows the technician to query EMMA during a consultation which heightens the technician's understanding of what EMMA is doing while simultaneously providing the technician with a valuable training aid.

One of the most critical aspects of any software system is its user-friendliness. If the system is difficult to use and the user does not use it, it has failed. EMMA uses windows to relay information to the technician and accepts information via menus. Using a mouse, the technician is able to enter data quickly and accurately without having to learn cryptic commands. The majority of the data entered into EMMA by the technician is done using the mouse; however, some keyboard input is required. Figure 3 shows the screen of a Symbolics computer running EMMA.

THE GBU-15 FIELD-LEVEL EMMA PROTOTYPE

The Rockwell field-level (phase 1) EMMA prototype was designed to enhance the field-level maintenance of the GBU-15 glide bomb by augmenting the field-level test set -- GJM-55. All references to the word "EMMA" in this section refer to the Rockwell GBU-15 version of EMMA unless stated otherwise. EMMA is hosted on a IBM PC/AT compatible computer running the expert system shell M.l. Although, the M.l language is primarily rule-based, EMMA was developed using an object oriented approach. The rules of the knowledge base reference objects and object attributes. This EMMA did not support the capability for an automatic mode due to hardware

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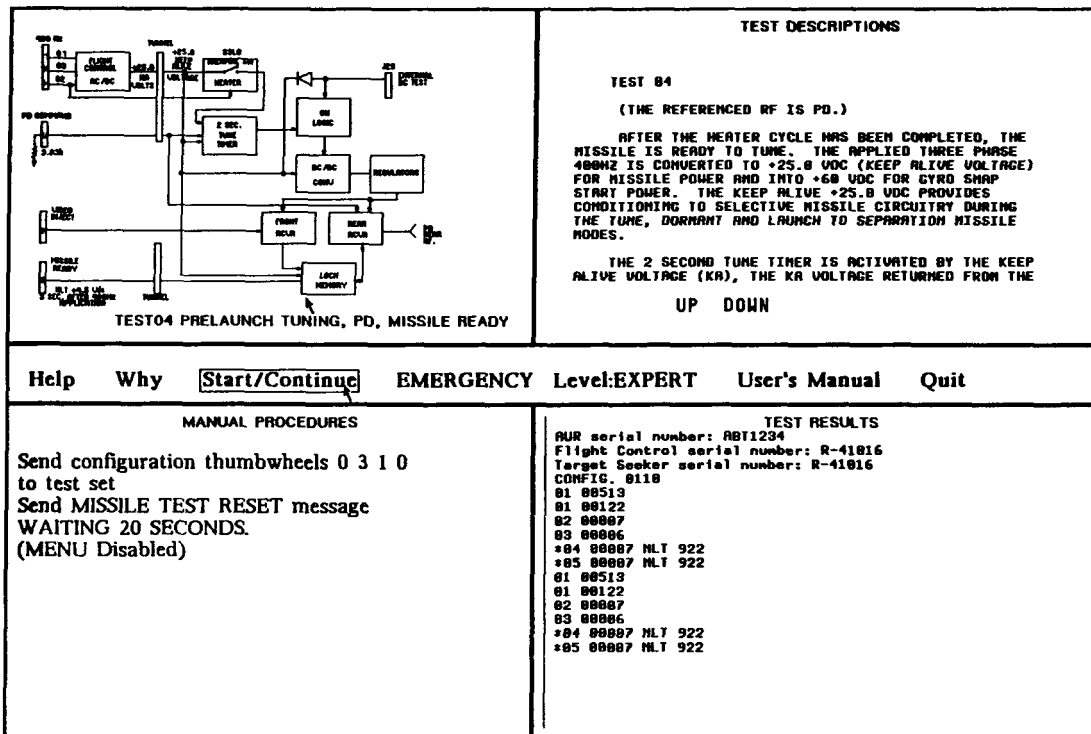


Figure 3. AIM-7F EMMA Screen

limitations thereby leaving only the manual mode (i.e., no connecting cable). Figure 4 illustrates the major components of the EMMA system and how they are interconnected.

Uncertainty is addressed in this version of EMMA. When EMMA asks the technician for information, the technician may enter "unknown" as a response. EMMA will accommodate this response by adapting its reasoning process using uncertainty. Uncertainty is handled using a MYCIN-like representation. When a recommendation is displayed to the technician, the certainty of the recommendation is also displayed to indicate the belief of the recommendation.

The GBU-15 EMMA also possesses explanation capabilities. The technician may ask EMMA for an explanation or help at any time. EMMA will respond with either an explanation of the reasoning process or information that will guide the technician through the consultation. The explanation capability can handle queries regarding the reason a certain conclusion was reached or why EMMA is asking for information. As with the AIM-7F EMMA, the GBU-15 EMMA has two levels of explanation to accommodate the needs of different technicians. The same training benefits exist in the GBU-15 EMMA as the AIM-7F EMMA.

EMMA exploits the use of pull-down menus and function keys on the computer to

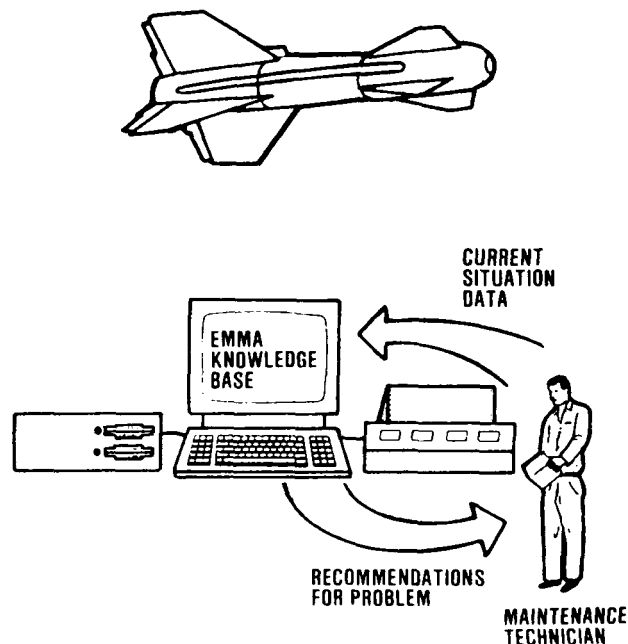


Figure 4. GBU-15 Field-level EMMA prototype

make it as user friendly as possible. The majority of technician interaction with EMMA is performed using the keyboard. The technician typically responds to EMMA questions and requests with short answers thereby reducing the probability of erroneous data being entered. Figure 5 shows the screen of the computer running EMMA.

EVALUATION OF THE EMMA PROTOTYPES

Meaningful evaluation of expert systems has been an often discussed but seldom achieved topic within recent years. More often than not quantitative metrics are simply not available or meaningful as an evaluation measure. Since an expert system encapsulates the knowledge of a given expert in a given field, the effective evaluation of the expert system may be difficult at best. Validation must be used to justify the representation levels of expert systems (O'Keefe et al., 1987).

Validation is typically considered a part of evaluation, and evaluation is concerned with determining the comprehensive value of an expert system (O'Keefe et al., 1987). Validation should not be confused with verification. "Validation refers to building the right system (that is, substantiating that a system performs with an acceptable level of accuracy), whereas verification refers to building the system 'right' (that is, substantiating that a system correctly implements its specifications)" (O'Keefe et al., 1987). Validation and verification will be addressed in this paper as they apply to EMMA.

Verification of EMMA

A unique aspect of the verification of the EMMA program is that it uses DOD-STD-2167, the Defense System Software Development standard, to develop the expert system prototypes. This is one of the first attempts to apply this standard to the development of an expert system. DOD-STD-2167 traditionally employs top-down development of large software systems. Expert systems on the other hand are developed using a development methodology that is less rigidly defined which typically entails an iterative approach to software development. Additionally, expert systems are usually created by a relatively small team.

The EMMA program has shown that expert systems can be developed using DOD-STD-2167 software development requirements. With some careful tailoring of some of the documents, this standard can be effectively used to document the program and provide the program manager valuable insight into the contractor's software development, testing, and evaluation efforts. The tailored documents were altered to accommodate the iterative nature of expert system development.

Since verification must determine whether an expert system correctly implements its specifications, testing must occur in order to validate this requirement. Again, DOD-STD-2167 proved to be adequate for verification testing once extended. Using the testing procedures called out in this standard, the correct

EMMA CONFIG NO: 33 TEST NO: 0096 NOGO: INV/M6 A1

<u>SRU</u>	<u>COMPONENT</u>	<u>CABLE</u>	<u>CERTAINTY</u>
INV/CONV			60%
CONTROL UNIT (HARNESS)	UUT INPUT CABLE	053A20(BLU)	40%

RECOMMENDATION:

CHECK THE INPUT CABLE OF THE UNIT UNDER TEST. IF OK, THEN R&R INV/CONV

JUSTIFICATION:

A RELATED TEST WITH A DIFFERENT INPUT CHANNEL PASSED AND THE PARAMETERS THAT FAILED WERE APPROXIMATELY ZERO; THUS THE INPUT CABLES OF THE UNIT UNDER TEST COULD BE THE CAUSE. A MORE LIKELY FAILURE IS THE INV/CONV BECAUSE THE +28 VDC ELECTRONICS IS COMPLEX AND COULD CAUSE ZERO FAILURES AS INDICATED

Figure 5. GBU-15 EMMA Screen

implementations of the specifications for EMMA were verified. Two levels of testing occurred to accomplish this task. First, informal testing took place. This testing verified the integrity of the individual computer software units before the units were integrated into the system and tested as a system. Informal testing was performed by the knowledge engineer. Since expert system development is iterative in nature, informal testing essentially occurs throughout development. The knowledge engineer and the expert verify the expert system and identify potential corrections and enhancements. Based on these recommendations, the knowledge engineer was able to incorporate the recommendations. Second, formal testing occurred. An independent team performed the formal testing by exercising EMMA using test plans and test descriptions generated using DOD-STD-2167.

Validation of EMMA

The validation of EMMA will be addressed in this paper in two areas. First, the performance validation of EMMA will be discussed (i.e., how well EMMA performed). Second, the human factors aspect of validation will be addressed. Both areas are extremely important to the success of an expert system. The following paragraphs will present the validation of the two EMMA prototypes. The validation methodology will be discussed followed by the results of the validation.

As with most expert systems, the ultimate measure of success is determined when the system is used by the end users (in this case the field-level munition technician). This is the approach taken with the EMMA program. Both contractors took their respective prototypes to Air Force bases in which their selected munition is used and a field-level maintenance capability exists. This allowed the prototypes to be evaluated in an actual field test environment.

After considering several alternatives, both contractors decided to use a toggle switch box to insert faults into a known good missile. This approach was necessary since it was feared that the maintenance squadrons in the field might not have a sufficient number of faulty munitions during the evaluation period. These faults were induced by the user by simply toggling one of the switches which in turn would disturb one or more signals within the munition. The faults were defined by the domain expert such that the faults would adequately exercise the various characteristics of the EMMA prototypes which included the resequencing logic, the explanation capability, and the fault isolation logic. To verify the expert was not trying to select only the

faults EMMA could handle best, the maintenance experts agreed the selected faults were representative of faults they commonly experience.

The AIM-7F EMMA Evaluation. Raytheon took their field level AIM-7F prototype to the 325th Equipment Maintenance Squadron (EMS) at Tyndall AFB, Florida for an evaluation period that began on 8 June 1987 and concluded on 12 June 1987.

The argument could be made that EMMA should accurately diagnose all the induced faults since the expert system and the faults were derived from the same source -- the domain expert. In order to demonstrate the robustness of EMMA, an additional evaluation methodology was used. Two faulted missiles were saved by the EMS prior to the evaluation. These missiles had previously failed testing using the AN/DSM-162 test set. However, the fault data for these missiles were not released by the EMS personnel until after the EMMA evaluation. A third missile became available during the EMMA evaluation by failing a flight line test during prelaunch tuning. This missile was an excellent exercise for the EMMA prototype since it was not previously tested by the AN/DSM-162 test set. Its fault was unknown to everyone present at the evaluation. All three missiles (sometimes referred to as "mystery missiles" due to their unknown past) contained faults unknown to EMMA or the domain expert thereby exercising EMMA in an unpredictable manner.

Four munition maintenance technicians from the EMS at Tyndall were used for the evaluation. Two technicians were classified as novice with little experience with the AN/DSM-162 test set and its associated operating procedures. The other two technicians were classified as experts with a substantial background in using the AN/DSM-162 test set. Two teams of two technicians were created consisting of one expert and one novice. One team (hereafter referred to as the EMMA team) received extensive training on the operation of EMMA. The other team (hereafter referred to as the non-EMMA team) was not trained on the EMMA system and served as a baseline for the evaluation.

Twelve faults were inserted into a known good missile using the toggle switch box. The faults were diagnosed by the EMMA team using the EMMA system and the non-EMMA team using just the AN/DSM-162 test set and the applicable TO. Performance of the two teams was based on the level of expertise of the operator, duration of test, and the ability to diagnose the fault accurately.

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The results of this evaluation exercise were very promising. There were three significant results derived from the evaluation. First, the EMMA system operated by the EMMA team was able to consistently diagnose the fault quicker than the non-EMMA team using just the AN/DSM-162 and the TO regardless of the experience level of the EMMA operator. A time savings of 20% was seen with the novice using EMMA over the expert using the AN/DSM-162. Second, novice technicians using the EMMA system significantly outperformed (better fault diagnoses) novice technicians using just the AN/DSM-162 and performed 33% better than expert technicians using just the AN/DSM-162. Finally, EMMA's explanation capabilities significantly enhanced the abilities of the EMMA team to determine the reason behind each fault.

Once EMMA's abilities were exercised using the induced faults, EMMA was pitted against the mystery missiles again with excellent results. The EMMA team using EMMA correctly isolated the faults in all three missiles. Only after EMMA diagnosed the faults was the previous testing data on the missiles released. EMMA's diagnosis was consistent with this data.

User acceptance of EMMA was outstanding. In fact, the technicians accepted EMMA's diagnosis of the missile from the flight line and said they would have, if allowed, sent the missile to the depot with no further testing using the AN/DSM-162 test set. This exemplifies EMMA's acceptance by the EMS maintenance personnel at Tyndall AFB. The technicians found the system to be very user-friendly. The mouse and the use of menus made the system easier to use than the bulky and cumbersome TOs. Also, the explanation capability proved to be an effective training mechanism.

The GBU-15 EMMA Evaluation. Rockwell evaluated their GBU-15 EMMA at the 4th Equipment Maintenance Squadron located at Seymour Johnson AFB, North Carolina during the period of 22 June through 29 June 1987.

Four maintenance technicians were used in the evaluation of the EMMA prototype. Two technicians were considered experts with several years of experience with the GBU-15 test environment. The remaining two technicians were considered novices with less than 6 months of experience. Another important distinction between the expert and novice technicians is the fact that the expert technicians owned personal computers and therefore were familiar with how computers operate whereas the novice technicians did not own computers and had never used a computer before the EMMA evaluation. All four technicians were trained on how to use the

EMMA system. After this brief training, the technicians felt very comfortable using the system.

Twenty-two simulated faults were induced into the known good munition with the intent of evaluating EMMA's capabilities to handle the following five areas: resolution of ambiguities between major shop replaceable units (SRU), referencing lower configuration testing to facilitate further component resolution, distinguishing between a cable failure and a circuit card assembly (CCA) gain failure, resolution of ambiguities between CCA's, and recognizing operator errors or test set problems. Six of the twenty-two induced faults were in the all-up-round (AUR) configuration (i.e., the test was performed while the GBU-15 munition was completely intact). The remaining sixteen faults were in the control module stand alone configuration. EMMA was able to handle these five areas by analyzing additional test parameters as well as instituting and analyzing tests related to the failed test.

The diagnostic results of the induced faults showed substantial time savings in fault isolation and increased diagnostic capabilities. While the munition was in the control module stand alone configuration, a time savings of 40% was seen over conventional testing with the GJM-55. When the munition was in the AUR configuration, EMMA was able to provide up to 74% time savings. This is due to EMMA's capability to resolve failures while the munition is in the AUR configuration thereby saving the technician from having to perform testing in stand alone configuration.

The GJM-55 test set, in some situations, will recommend more than one suspected failure. This group of failures is called an ambiguity group since the test set cannot resolve any further than this group. This is another of EMMA's capabilities that demonstrated promising performance as seen by the results that follow. EMMA also considered the possibility of a cable harness failure or the test set is failing. Based on these capabilities EMMA was able to significantly improve fault isolation. The results of the twenty-two simulated faults demonstrate this improvement. EMMA added a wiring harness check to 50% of all tests. EMMA deleted a CCA from an ambiguity group 40% of the time thereby reducing the number of CCA to be considered during testing. EMMA added a CCA to an ambiguity group 30% of the time to insure all potential CCA's are considered during the testing. This indicates that the test set sometimes did not consider all potential CCA's. Finally, EMMA exchanged one suspect CCA in an ambiguity group for another CCA 10% of the

time. The ability to manipulate the ambiguity group to benefit fault isolation was demonstrated by EMMA and proved to be an effective fault isolation technique. These results directly support the time savings previously mentioned.

The GBU-15 EMMA prototype also received accolades for its user friendliness. The technicians used EMMA with comfort and found several items to be particularly laudable. Among these items was the understandability of EMMA. The explanation capability provided easy to understand responses. Another aspect they found beneficial was the addition of the internal wiring harness check as one of the reasons for a fault since this check is relatively "inexpensive" to perform and can prevent unnecessary and potentially costly future testing. The training potential of EMMA was also mentioned as one of its major assets with the shortage of skilled technicians in the munition maintenance field.

EMMA PHASE 2

Both contractors are currently in phase 2 of the EMMA program. As previously mentioned, phase 2 focuses on the maintenance of tactical munitions at the depot level. More specifically, Raytheon is focusing on the depot-level maintenance of the AIM-7F. Rockwell is using the GBU-15 as its depot-level maintenance munition. Phase 2 is a natural extension of phase 1 since field-level faults are sent to the depot for repair. The prototypes developed during the phase 2 effort will be more detailed extensions of the phase 1 prototypes with one exception; the phase 2 prototypes will augment the depot-level test sets. The depot test set for the AIM-7F is the AN/DPM-22 test set. The GBU-15 depot-level test set is CATS (Calculator Automatic Test Station).

The depot-level prototypes will be implemented on the same computer hardware using the same expert system shells as the field-level prototypes. However, one difference between the field and depot prototypes for both contractors is the interface between the test set and the EMMA computer. The Raytheon interface will only support one-way communication from the test set to the EMMA computer due to test set limitations. This is different than the two-way communication of the field prototype. Rockwell is using a two-way communication interface between the test set and the EMMA computer whereas the field prototype interface was manual. Both prototypes will again incorporate an explanation capability for the technicians.

The evaluation of the depot prototypes will follow the same methodology used in phase 1. Each prototype will be evaluated at the actual depot location by actual depot technicians. Once again, both evaluations are scheduled to last five days and are scheduled to occur in February 1989. The AIM-7F prototype will be evaluated at the Naval Aviation Depot (NAVAVNDEP) in Alameda, California. The GBU-15 prototype will be evaluated at Rockwell's Missile Systems Division in Atlanta, Georgia since an organic depot capability currently does not exist.

FOLLOW-ON PROGRAMS TO EMMA -- EMMA 2

A follow-on program will be initiated in early 1990 -- EMMA 2. The primary thrust of EMMA 2 is to develop an expert system that is capable of diagnosing a family of tactical munitions at the depot level. The current EMMA is limited to one munition per prototype. EMMA 2 would attempt to expand the current prototype capabilities to include multiple munitions from the same family (e.g., AIM family, GBU family, surface-to-air family, etc.). EMMA 2 would draw on the best features of all prototypes developed in the two phases of EMMA to derive a robust system.

OTHER ISSUES/OBSERVATIONS

The following paragraphs present other areas of interest to the EMMA program.

Studies

As part of the phase 1 effort, five studies were conducted to address areas of concern that could be incorporated into the depot-level prototypes and potentially in future maintenance expert systems. These studies included the reuse of munition test programs, the use of the Ada language for expert system development and ATE test programs, the applicability of the Modular Automatic Test Equipment (MATE) standard to EMMA, the applicability of the Warner Robins Reliability Asset Monitor (RAM) database to EMMA and future maintenance expert systems, and the security issues of expert systems. A complete discussion of the results of these studies is beyond the scope of this paper. Therefore, the interested reader is referred to the two final reports of phase 1 (Elerin et al., 1987; Davis, 1987). These final reports are split into two volumes; the second volume contains a complete discussion of the results of these studies.

Current Maintenance Philosophy

The current munition maintenance philosophy of the Tactical Air Command (TAC) for field maintenance is that of fault detection (go/nogo testing). If a fault does occur in the field, the suspected

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faulty section of the missile is sent to the depot for repair. One of the driving factors of this philosophy is the shortage of skilled maintenance technicians in field-level maintenance.

Since training these technicians is costly, TAC decided to eliminate an Air Force Specialty Code (AFSC) for munition maintenance. The deleted AFSC, 316X1L, was an electronics munition maintenance specialist. With this specialist no longer available, munition, not electronic munition, specialist are diagnosing today's munitions. This tends to create problems. The munition specialists are typically not adequately trained to diagnose the electronically-sophisticated munitions of today.

EMMA is capable of providing the necessary training of munition maintenance technicians. Using the explanation capabilities of EMMA, a technician can quickly become skilled at diagnosing the munition. Since EMMA's knowledge is gleaned from diagnostic and design experts, the novice munition technician using EMMA will effectively be performing as if he has an expert maintenance technician, the designer of the test set, the munition designer, and an instructor looking over his shoulder during the diagnosis. Another aspect of EMMA that should reduce overall maintenance costs is its ability to diagnose to a greater component level than existing test sets used by today's technicians. This should significantly reduce the costs associated with shipping faulty munitions to the depot, since more faults can be isolated at the field.

The munition depots are currently responsible for the majority of munition repairs. The field has very limited repair capabilities. This results in increased costs for overall maintenance of a munition system. The obvious cost is transportation of the munition between the field and the depot. However, the less tangible and potentially more significant cost is that of having the munition out of the inventory. This effectively reduces the number of missiles available for exercises or conflict.

Future Maintenance Systems

EMMA prototypes have proved the feasibility of applying AI to munition maintenance. In future weapon systems, maintenance expert systems should evolve with the weapon system instead of after the fact. This would allow the expert system to capture knowledge about the weapon as it is developed. Furthermore, the expert system should be incorporated directly into the ATE instead of augmenting the ATE with a separate computer system. This should make weapon systems of the future

more supportable by considering the maintenance aspect early in the weapon life cycle.

SUMMARY

Tactical munition maintenance of today has problems. EMMA is an attempt to relieve some of these problems by applying artificial intelligence/expert system technology. The results of EMMA indicate that this approach to munition maintenance has significant potential for future tactical maintenance systems.

Corporate knowledge retention is one of the premium benefits of EMMA. Since EMMA is updated easily and it never "forgets" knowledge, EMMA is an excellent tool for storing corporate knowledge as technicians come and go. Also, EMMA provides consistent, high quality diagnosis since it never has a "bad" day as contrasted with technicians. Rapid fault isolation and efficient manpower utilization are two more benefits of using EMMA. These benefits provided by EMMA will result in substantial mission payoffs. Weapon system downtime will be decreased as well as personnel requirements and training time. However, the most significant payoff is the increase in the reliability of munition maintenance procedures.

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