ABSTRACT

Today's military weapons systems, communications equipment, and vehicles are more sophisticated than ever before. The heart of these systems is the complicated electronic circuit and its related components. Electronics will enable our forces to respond rapidly to the intense battle tempo of future conflicts. Unfortunately, the same electronic equipment that provides this "fighting edge" is very sensitive and highly vulnerable to damage.

Previous papers at this Symposium have indicated that the bulk of our combat equipment will be disabled in the first hours of combat. However, catastrophic damage is rare and rapid forward field repair provides a means of restoring damaged equipment to the ongoing battle and of helping to sustain our forces at an effective level.

Live-firing tests have demonstrated that today our combat equipment is not designed for quick forward repair. Except for cables, connectors, and a few other external components, electronic components such as printed circuit boards must be transported to higher levels in the rear for repair. In peacetime exercises, special transportation capabilities have been developed to carry damaged equipment to this rear for repair and return it to keep front line equipment operational. In wartime, such schemes will be inadequate. There is a desperate need for a breakthrough in the design of electronic equipment which will provide for rapid forward repair and quick return to battle in wartime.

INTRODUCTION

The Air Land Battlefield 2000 (ALB) will be multi-dimensional, complex, and highly mobile. Our forces may be pitted against a threat that is numerically superior. In addition they will possess the home court advantage.

In view of this numerical superiority of the Warsaw Pack (WP) forces, the NATO community has been searching for means to increase the sustainability of our forces on the battlefield. One promising scheme combines the FIX-FORWARD concept with Battlefield Damage Assessment and Repair (BDAR), Reference 1. Our studies show that the great bulk of our combat equipment, when damaged on the battlefield, could be repaired within a short time and returned to battle. Our FIX-FORWARD and BDAR programs are established to do just that, to repair combat damaged equipment on-site or as close as possible to the "Front Line of Own Troops" (FLOT) as quickly as possible so they can be returned to combat in time to play an effective part in winning the battle.

Unfortunately, in our live-firing trials, Reference 2, we have discovered that much of our combat equipment is not designed so that it can be quickly repaired if damaged in combat. This appears not to be a consideration to which our designers have given much thought. The U.S. Army in cooperation with some of its NATO allies has developed the concept of Combat Resilience, Reference 1, namely a weapon system characteristic which provides for combat damaged weapons to be quickly restored in the field to some useful operational level with the resources available at the forward area. Combat resilience differs from the technical term "survivability" in that it places a top priority on minimum down time, does not require equipment to be restored to full mission capability, and does not prescribe required skills tools or procedures. Combat resilience requires combat equipment to be designed so BDAR procedures can be applied effectively.

The U.S. Army has issued a number of Technical Manuals documenting BDAR procedures for various weapon systems, and a number of additional manuals and kits are under development, Reference 3. The Communications and Electronics Command (CECOM) has issued TM 11-5800-215-ED, BDAR for C-E Equipment, Reference 4, but it only covers cables, connectors, antennas, and other external components. Army policy of reducing repair time has also led to the incorporation of more modular design and Built-In-Test-Equipment (BIT/BITE), but to date no progress has been made on incorporating combat resilience considerations into the design of costly functional components of electronic systems such as printed circuit boards (PCB). This is most unfortunate since the success of friendly forces will rely heavily on communications-electronic (C-E) equipment to even the odds. Whenever hostilities develop, a country or alliance attempts to execute a specific course of action, or rhythm, which must be followed to go to war. At the outset of hostilities, Command Control and Communications (C3) will have immediate problems from CONUS to the foxhole. Satellite systems are needed for instantaneous long-distance communication. Short-range communication may be more difficult to attain based on the battlefield situation. Force performance will require a high reliance on communication-electronic (C-E) equipment. Troop mobility, collection of battlefield data, and the ability to communicate are fundamental to insure that our forces will be in the right place at the right time.

THE THREAT

For the designer to configure electronic equipment for combat resilience, he must have a thorough understanding of the nature of the threat as well as the operational requirements. The modern battlefield will possess three distinct environments in which electronic devices will have to survive in order to successfully conduct the "business of war".

1) Conventional (includes recently developed/improved overpressure weapons)
2) Chemical (includes biological weapons), and
3) Nuclear.

Threat doctrine encourages creation of combined environments for the purpose of exploitation.

Let us address the different types of combat environments and damage that electronic equipment may be exposed to.

THE CONVENTIONAL ENVIRONMENT

Within the conventional environment, collateral damage to equipment will be generated by explosive projectiles (bombs, mines, grenades, etc.), small arms fire, and conventional overpressure ordnance. Damage caused by the penetration of projectiles (shrapnel, bullets, etc.) will most likely be devastating to electronic equipment performance. In the case of an antiarmor plating can result in internal spalling (splintering of the vehicle's armor resulting in a internal shrapnel effect) and overpressure. It is also possible that a near-miss will break electrical electronic connectors, printed circuit boards (PCB's), and misalign critical elements within the electronic circuitry. The development of conventional overpressure weapons has added another facet to war in the blast effects of a nuclear detonation which may be produced without the undesirable effect of battlefield contamination.

THE CHEMICAL ENVIRONMENT

The Chemical Environment recognizes the current high proficiency level of threat forces in the use of chemical agents. This is a undeniable threat to friendly forces. The expected use of chemical weapons will likely consist of three general types of agents:

1) persistent vapor or water-based harassing agents,
2) persistent agents with oily/sticky bases, and
3) biological agents.

Current filters employed in C-E equipment were designed to counter particulate dirt and dust and will be useless against the effects of chemical contamination. Perhaps future designs will address this problem, particularly in the case of electronic equipment that utilizes fan-forced open-air cooling.

Regardless of the source of contamination, decontamination procedures may introduce potentially caustic/corrosive elements onto the electronic components.

THE NUCLEAR ENVIRONMENT

The five major elements of nuclear damage are caused by:

1) blast overpressure,
2) thermal heat,
3) initial radiation (alpha, beta, and gamma),
4) electromagnetic pulse (EMP), and
5) residual radiation (fallout).

These elements have greater range, destructive potential, and overall negative effects against equipment than any other weapon. The blast element is the combined destructive forces of the explosion and overpressures and may result in collateral damage to equipment. Thermal heat causes the melting of cables, insulation, connectors, and the PCB material. Initial radiation in the form of "neutron bullets" causes microscopic physical damage to equipment. EMP causes a tremendous surge of electromagnetic energy which overloads and destroys circuitry. Residual radiation poses less damage than the other four elements, but mandates the need for decontamination prior to repair. As with chemical decontamination, removal of residual radiation may cause additional damage to the equipment. A wet resistor is not a happy resistor.

OTHER POTENTIAL HOSTILE ENVIRONMENTS

Short-term control of weather could be a key factor in future conflicts. Offensive operations in extremes of heat, cold, wind, or moisture will result in a reduction of efficiency or equipment breakdown. The threat has outpaced us in the development of chemical weapons (to include smoke). The use of chemical weaponry can pre-existing or modify existing weather conditions. For example, the use of smoke at high altitudes during a thunderstorm will intensify the storm by providing a catalyst for the condensation of water particles into raindrops, thus producing more rain.

Prolongation or alteration of temperatures can also enhance the use of other forms or weaponry (i.e. nuclear, chemical, biological). Drastic command directed temperature changes may have adverse effects on electronic equipment performance, particularly in areas of extreme heat or cold. For example, on July 7, 1987, at Greensburg, Kansas, there was an unexplained temperature increase of twenty degrees in a period of fifteen minutes. If artificially induced, such capabilities could have profound results on ill prepared military forces.

COMMON FACTORS

Within each of these environments, there remains five common factors of damage:

1) internal,
2) internal,
3) physical,
4) electrical/electronic, and
5) mechanical.

External, physical, and mechanical damage may be readily diagnosed at the operator level using human tactile sensations and observation. Further damage analysis may be accomplished by attempted operation or deliberate inspection technique as outlined in the affected equipment technical manual (TM).

Internal electronic damages present the greatest challenge. For example, in communications equipment, the loss of a single stage (tuner, gain control, amplifier, etc.) can render a radio useless. At this point, Built-In-Test/Built-In-Test-Equipment (BIT/BITE) analysis of the affected unit must become the diagnostic tools of the operator. Artificial intelligence and logic development of BIT/BITE devices must be simplified for use at the operator level.
Simplicity of the use of BIT/BITE devices will minimize training requirements and reduce the impact of personnel turnover in the ALB 2000 environment.

REFORGER 86

In the integrated battlefield C-E maintenance will have the mission of repairing equipment on a day-to-day basis at all operational levels especially the rear areas. In the European Theater, most communications and electronic equipment is repaired by the 21st Support Command and its Pirmasens communications and equipment maintenance center. 21st Support Command assumed control of three Electronic Quality Assurance Test Equipment (EQUATE) Detachments on 1 October 1985. This reorganization was conducted to develop and refine procedures required to support the corps with Printed Circuit Board (PCB) repair capabilities. To accompany this and to conduct a viable test, the CG, 21st Support Command directed that a test be conducted during the Return of Forces to Germany (REFORGER) 1986 exercise. REFORGER is NATO's annual major training exercise and provides an excellent simulation of wartime conditions.

TEST PREPARATION

To provide the required support during REFORGER, a number of steps were taken to assure efficient operation.

The 166th Maintenance Detachment (EQUATE) was relocated forward to the Faucht Army Airfield to be as close as possible to the exercise area. The 166th Detachment was assigned two missions:

- Repair of EQUATE supportable items.
- Conduct direct support exchange (IX) of non-EQUATE supportable items.

The second assignment created the problem of timely transportation of IX items to the Pirmasens Comm Maintenance Center (PCMC) for repair. To save time, an Air Line of Communication (ALOC) was established using both rotary and fixed wing aircraft.

Other concerns involved assurance that the items would not be damaged in shipping and handling, and that strict accountability was maintained. These problems were solved by the introduction of special, properly labeled shipping boxes. The boxes protected this equipment, and the labels provided a means for maintaining accountability.

TEST OBJECTIVES

The following test objectives were established:

- Evaluate EQUATE as a one stop Echelons Above Corps (EAC) repair and supply facility for PCB repair.
- Develop the rapid movement of high dollar, combat essential PCB's, modules, and Line Replaceable Units (LRU's) on the battlefield.
- Compare and measure aircraft reliability versus ground transportation.
- Evaluate the box method for packaging PCB's, modules, and LRU's for shipment.
- Compare the cost of air versus ground transportation.
- Document/refine accountability procedures to be used for forward support.
- Determine the feasibility of expanding/implanting the Air Line of Communications (ALOC) concept to an inter-theater, multi-commodity distribution system.

TEST RESULTS

Analysis of the data accumulated during the PCMC ALOC test has led to the formulation of the following conclusions:

- EQUATE is forward deployable during wartime.
- The concept of air delivery of PCB's, modules, and LRU's and other electronics components is viable and provides rapid, safe, and dependable transportation during peacetime. However, the availability of aircraft and test assets is questionable during hostilities.
- All types of aircraft (UH-1, CH-47, U-21, and C-23A) used in the ALOC test were found reliable and suitable for the transportation of electronic components.
- Air transportation costs were 32% higher than ground costs, but produced a 58% reduction in turnaround time.
- Current accountability procedures are adequate during the repair and transport of PCB's, modules, and LRU's.
- The ALOC concept is extremely fast and reliable with unlimited potential for expansion.

RECOMMENDATIONS

The following recommendations have been derived from the PCMC ALOC test:

- Relocate the EQUATE detachments from the Corps of the most forward feasible location.
- Train and equip the detachments for forward employment during wartime for a maintenance mission with augmented supply and transportation capability as required.
- Augment the detachments with the necessary personnel, storage, and transportation assets for the above mission.
- Assign additional electronic repair mission and capabilities to the unit (i.e. M-1, M-2/3).
- Maintain and enforce accountability procedures.
- Expand Intra-theater ALOC by continuing the peacetime use of air transportation to move PCB's, modules, and LRU's to PCMC and return.

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g. Develop the use of air transportation to include other high priority, high dollar value, critical items.

h. Perpetuate the use of specialized shipping containers to protect components during shipment.

The ALOC concept is readily adaptable to other high dollar/critical components. The formalization of an expanded Theater-wide ALOC, developed jointly between the U.S. Army and U.S. Air Force, is now in the final stages of negotiations. When implemented, this innovative approach to meeting support requirements on the battlefield will contribute significantly to demonstrating our resolve for the defense of Western Europe.

WARTIME VERSUS PEACETIME

REFORGER 86 has demonstrated that with some imaginative and costly innovations the present maintenance system is adequate for peacetime applications. However, REFORGER stressed the maintenance system to its very limits. Under the wartime threat described before, delivered by numerical superior WP forces in a massive surprise attack, the bulk of our combat equipment will be incapacitated in the first hours of combat. Not only will the numbers of damaged elements, but also the extent of the damage will exceed anything we have ever experienced before. Under that additional stress, the present maintenance system cannot prevail.

The WP forces are prepared for a quick breakthrough followed immediately by a rapid dash through Western Europe. To combat this threat, it is essential that we win the first critical battles and prevent the breakthrough. To cope with this threat, NATO has developed the concept of Combat Resilience and BDAR to increase the sustainability of its forces in combat. Combat Resilience is a design problem, while BDAR is a military task. Both go hand in hand, and one is not effective without the other. To date, there has been no response from the electronic design community for more combat reliant electronic systems, and this constitutes a major void in our current defense.

BATTLEFIELD DAMAGE ASSESSMENT AND REPAIR

Electronics Battlefield Damage Assessment and Repair (BDAR) is the rapid assessment and expedient repair of damaged electronic equipment to mission operational status using the available resources in the forward area. The purpose of BDAR is to maximize the time that electronic equipment can be used in the battle and even if in a degraded mode. Key elements in BDAR are the correct assessment of damage and the proper application of proven hasty repair techniques. Commanders must stress these elements during peacetime training of soldiers. Soldiers will perform in war as they have trained in peacetime.

Electronic BDAR provides a means to maintain equipment at a mission essential state until the proper unit standard repair can be performed. During wartime, electronic BDAR should provide quick-fix non-standard repair. This incorporates such techniques as EET/ERE with the KISS (Keep It Simple, Stupid) principle and allows a technical repair to be accomplished at operator level.

For effective application of BDAR, however, electronic equipment must be designed so that if damaged in combat, BDAR procedures can be applied in the forward area.

COMBAT RESILIENCE

Combat resilience is a characteristic of equipment which allows it, when damaged in combat, to be quickly restored to combat by BDAR procedures so it can be effective in winning the battle. Providing for combat resilience is a complex equipment design problem; there are many factors involved. The threat and the maintenance system have already been described. These must also be an awareness of the deficiencies of present equipment. Some of the other factors are discussed below.

DEFICIENCIES OF PRESENT EQUIPMENT

BDAR is limited by the very nature of electronic equipment. BDAR repair of external components such as cables, and antennas, are effective due to their relatively simple location and construction. BDAR repair of PCB's, black boxes and internal systems is next to impossible. These components are very susceptible to damage and once affected become totally inoperative. Presently assessment of the damage requires test equipment that is not on site and may be located many hours away.

Even when the test equipment is available it may require hours to set up and evaluate/determine the specific problem. Repair of these components require, in most cases, evacuation to a rear maintenance facility, direct exchange, or cannibalization. In a conflict with WP forces in Europe, there will be no time for these procedures.

In order to enhance BDAR capabilities for the 21st Century, we must capture the most efficient mode of restoration given current generation and design philosophies. Now, we have proliferation of sole purpose devices, which are dependent on special purpose cables, special integrating function boxes and other control mediums. These sole purpose devices, such as communications and fire control, are combined to achieve integral combat capable systems. Not all functions can be considered equal when applied to specific missions. For example, a battle tank with laser range-finding difficulties would be severely hampered in a mobile defense or offensive operation. The same tank, however, could be used in a static defense where distances could be chartered without severe degradation of capability. This, then, implies that certain components can become expendable in applying BDAR. The question of which components can aid the restoration of the other systems has not been studied in depth. In some cases it may be possible to gain usability of certain cables from sole purpose functions to multi-purpose functions by the use of gender adapters or connector overlays. This would allow a communication cable of lesser importance to restore a more critical fire control system or vice versa. To best achieve this end, it is suggested that lists of available donor systems components should be studied for applications of this nature. NASA has experienced life saving benefits from such applications by relying on a room of engineers being present to think through the given situation. We could provide necessary adapter in a compact form with miniaturized video disk or microfiche instructions without undue sacrifice of space to the operator level.

DESIGN CONSIDERATIONS

The military equipment fielded incorporates the state of the art technology. This electronic equipment will help the common soldier to survive and be more combat effective on an intense battlefield. The systems are very complicated from the design and
repair viewpoint. However, the intelligence and skills of the user are not on the same level as the equipment. Therefore, the operator has a major problem coping with malfunctioning equipment due to lack of training or knowledge. The gap between technology and the knowledge of the user should be of the utmost concern in design and is probably the most difficult to fix. Under combat conditions the problem is even more pronounced when repair or a system is crucial to survival. In wartime, maintenance personnel will not be as well trained as they are in peacetime.

Based on exercises and experience, focus should be on simplicity of design and use of more common components. Soldiers under stressful combat conditions need simple methods to assess damage and repair electronic equipment. Repair far forward is the key to a successful maintenance operation.

Some design considerations should be made but not limited to the following areas:

1) CABLES: Common Connectors
   - Common number of strands in cables
   - Common number of pins in connectors
   - Color coded wires in cables

2) Hardening of Components: Against EMP
   - Proper location in vehicles
   - Use of fiber optics

3) Standardization of Components

The commonality of components within different systems will enable the supply system to be more responsive to requests for repair parts and the quick return to operation of the component. The concept of repairing via replacement of the entire component or via part exchange needs to be expanded to the operator level. This requires a rethinking of our design philosophy on damage assessment. Today we rely on costly test equipment available only in the rear areas for fault isolation and assessment.

This system will be very difficult to support in a wartime environment. Systems of the future should be operator repairable or low cost throw-aways (disposables). This presents the designer with a formidable challenge and may require a technical breakthrough similar to the introduction of solid state technology. However, the payoff in combat capability would fully justify this effort. In the meantime, much can be accomplished via Built-In-Test Equipment (BITE) and Built-In Test (BIT). BIT will enable the operator to localize the fault to a single part or assembly which the operator could replace and return the damaged unit to the rear for storage. This system provided that adequate accessibility has been provided. The standardization of test equipment and parameters will reduce the necessary repair time and return the equipment to action in a more expedient manner.

Today more emphasis should be placed on the development of inexpensive, technologically simple, and dependable equipment is required for winning the battle. An example of this is the KL-43, developed to use the host countries telephone system. This device is capable of transmitting secret (i.e. REFORGER 86) encrypted data over telephone lines. An engineer's design new equipment, development should be in the performance/function arena, rather than placing emphasis on PCB/component size. This does not mean size is unimportant, but it cannot be the driving force for design.

Designers should also consider that while electronic equipment will not accept much damage before its efficiency is impaired or in most cases not functions at all, it is possible to restore combat effectiveness by elimination of selected components from less critical applications. Design for degraded modes of operation should be considered in the original conceptual phase.

SUPPLY AND TRANSPORTATION

The designer should also consider the repair cycle and the associated supply and transportation problems in the conceptual stages. Repair procedures generally require the evacuation of the equipment to a remote site and the loss of services of a critical weapon system. The loss might be for an indefinite time due to the transportation and repair process.

The package and environmental control of the component is mandatory for reliability and must be a high priority factor. Electronic components, to insure adequate shelf life, must be stored in a packaged mode, at a controlled temperature and ambient humidity. Technological advancement quickly makes systems obsolete commercially. With this in mind the program of manufacturing the dies and other components for the PCB's of a system, based upon the projected life cycle, and storing them, is a solid maintenance idea. It has one flaw however, and that is the storage projections are based on the Failure Mode Effects Analysis (FMEA) study and production projections and do not consider battle damage replacement requirements. The Army in trying to correct this deficiency by requiring that a Battle Damage Failure Factor (BDIF) be included in the Logistics Support Analysis (LSA).

To stock an item requires packaging and transportation. Not only must the packaging be resistant to contamination and damage caused by handling but the environmental threats cited earlier. The success of this packaging process will determine the availability of parts and operational components on the battlefield. Parts made unusable in transit, either through contamination or damage will not win the battle.

Transportation of parts normally will by the most expedient means available. Replacement parts will be transported by air and then by land. It will be a critical part indeed that will be transported to the user by aerial means only. The extended time required for land transportation will figure significantly in the combat availability of a system.

BDAR AS A MILITARY FUNCTION

Successful BDAR of combat resilient electronic equipment will be dependent upon two elements: Command emphasis and training. No matter how much design of components is stressed or technology incorporated by the engineers, it is command emphasis, training, and utilization of that training which will decide the success of BDAR. It is the responsibility of the chain of command to identify problems within BDAR and to surface BDAR issues and repair suggestions. This includes field developed fixes. As in all areas of Army life, mis-utilization of training time and assets, usually leads to failure. Without the proper training at the user and support level, BDAR will not succeed and will have a significant negative impact on the outcome of the battle. Proper training, and correct command utilization of assets will result in BDAR success.
EBDAR will provide an additional tool for the commander in his war battle effort. EBDAR will allow the operator and using unit to become a more integral part of the maintenance/repair chain. Through the use of EBDAR techniques, the user/operator will be able to bring this equipment back to a mission capable status more rapidly. There should be a significant reduction in downtime and a corresponding more effective combat time. As the battle progresses, the ingenuity of the soldier will be a key element in overcoming electronic equipment damage. Utilization of quick, simple fixes such as semaphore flags and mounting telephones on the rear of tanks, are an element of the answer. The commander will, by the proper use of EBDAR, be more in control of his destiny. The 1973 Arab-Israeli War is a recent classic example where EBDAR determined the outcome. The Israelis were able to return damaged tanks to the battle rapidly due to EBDAR techniques. In the battle for the Golan Heights, 15 battle-damaged tanks were returned by maintenance just in time for the Israelis to mount a counter attack which decide the outcome of the battle. The Israelis readily agree that this program was a decisive factor in their winning of the war. EBDAR will lead to an achievable victory, despite larger enemy forces and weapons.

CONCLUSIONS

Modern electronic equipment has become the heart of our modern, sophisticated weapon systems. However, the maintenance of electronic systems today requires a time-consuming, personnel and resources, intensive effort which could not be maintained in a major combat situation.

In view of the numerical superiority of the WP forces, the NATO nations have developed the concepts of Combat Resilience and EBDAR to improve the sustainability of their forces in combat. These are new concepts to which the designers of electronic equipment have not yet responded. Our current inability to maintain electronic equipment in combat represents a major weakness in our defense posture. It is therefore recommended that the electronics industry give serious consideration to incorporating Combat Resilience into its designs to allow the Army to institute proper EBDAR procedures in the forward area of the battlefield.

Although the possibilities of current technologies have not been fully exploited, a fully satisfactory solution providing for full EBDAR in the forward area may require technological breakthrough.

On the modern battlefield proper applications of EBDAR techniques will result in a more effective fighting force and enhanced maintenance alternatives. Electronics EBDAR will enable the commander to maximize the time that he is able to deploy an effective fighting force.

REFERENCES


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