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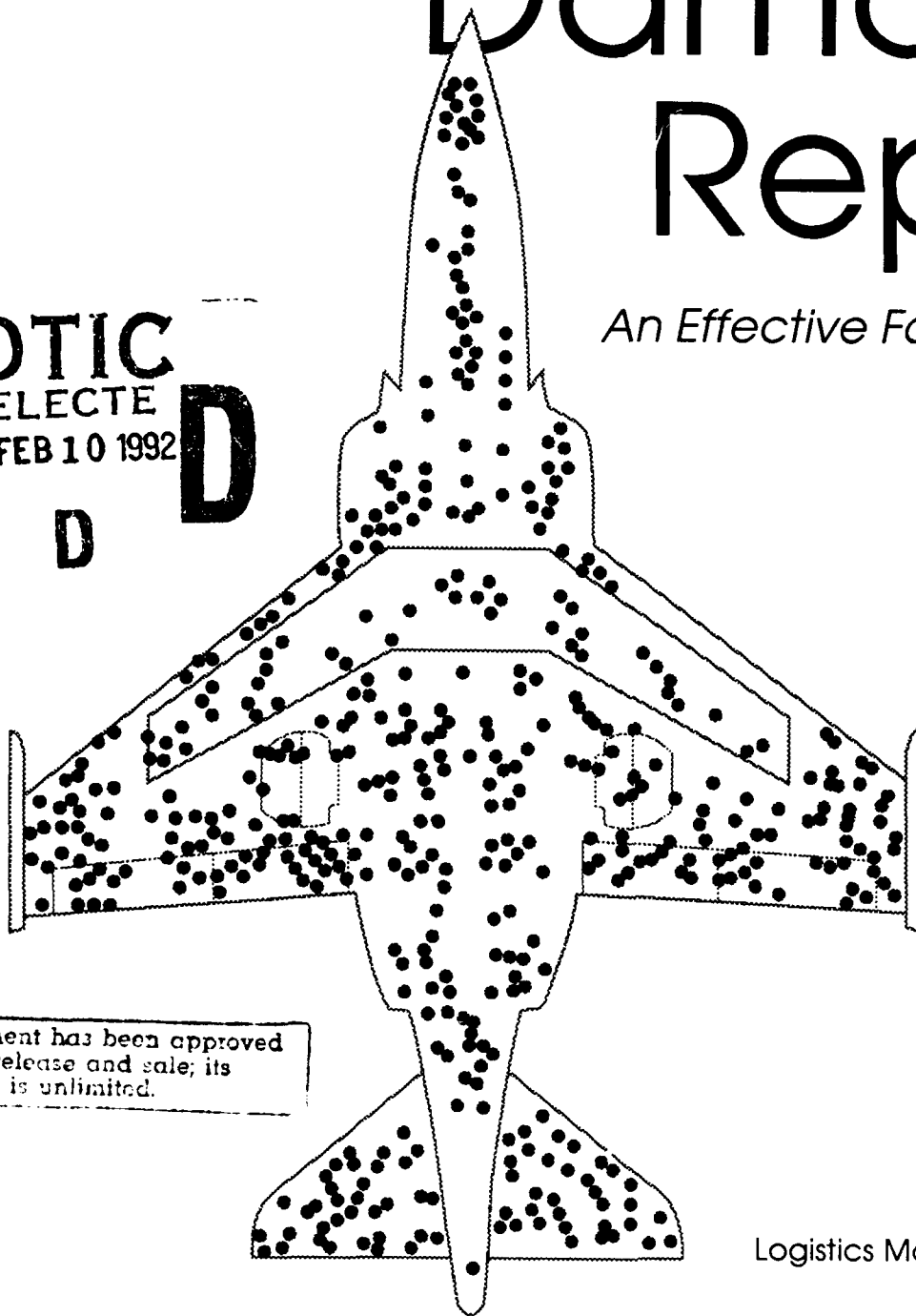
Battle Damage Repair

An Effective Force Multiplier

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Donald W. Sull
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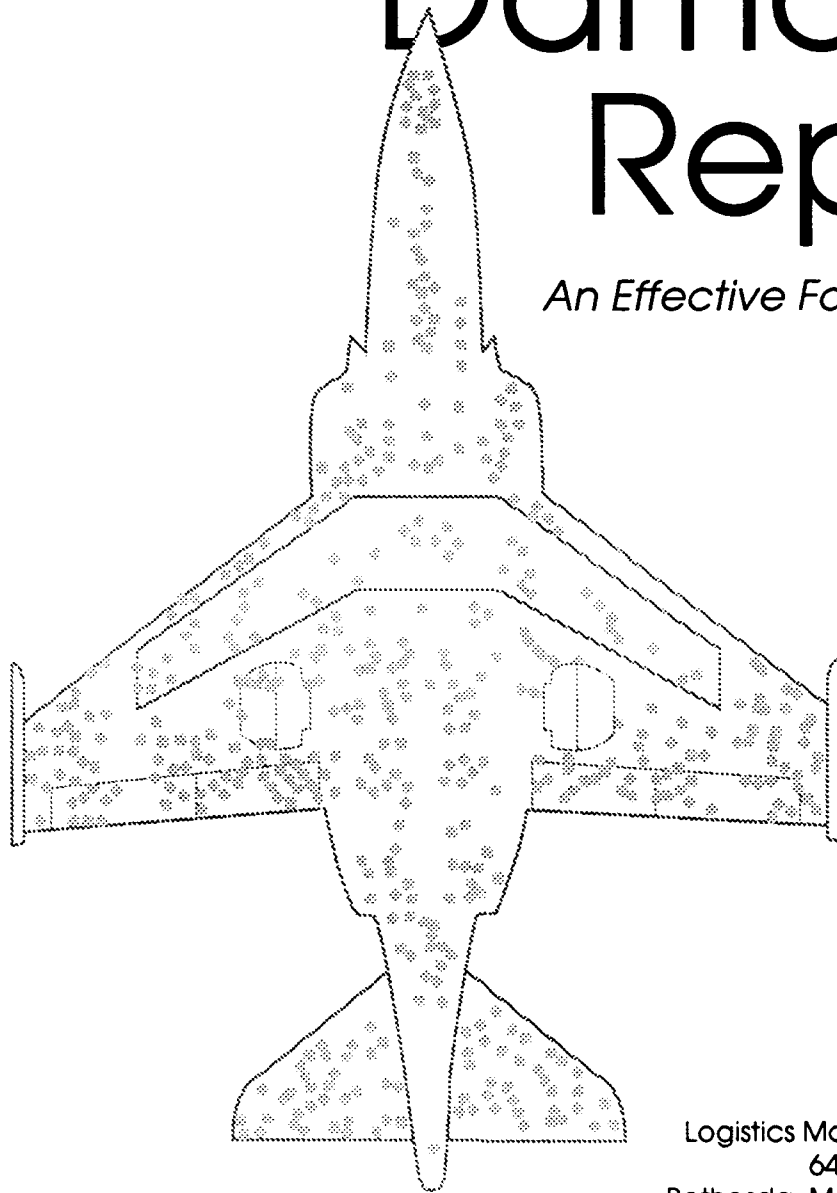
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Preface

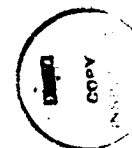
This paper was prepared by the Logistics Management Institute (LMI) as an Independent Research & Development project. It presents a summary of our views on a wide range of policy issues related to battle damage repair (BDR). It draws upon previous LMI study projects and analyses undertaken for the Department of Defense in support of the Director of Defense Research and Engineering and the Joint Tactical Coordinating Group on Aircraft Survivability. It also draws on reviews of other BDR works and on early unclassified reports of BDR experience during Operation Desert Storm.

Proper treatment of BDR can help extract the most combat effectiveness from our shrinking forces and defense dollars. Significant improvement in combat effectiveness is required and is possible. This paper contributes to the interchange of ideas on how best to achieve those improvements.

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Battle Damage Repair, An Effective Force Multiplier

Historically, the ability to repair battle damaged weapon systems effectively and rapidly has been a significant – and sometimes decisive – factor in combat. In recent history, Israel's ability to keep its aircraft and tanks combat capable after sustaining combat damage was the key to winning the Yom Kippur War in 1973. Without effective, rapid repairs, the Israeli Air Force would have been out of business by the eighth day of the conflict. The Israeli army suffered damage to 75 percent of its tank force but was able to return most (80 percent) of the damaged tanks to battle within 24 hours. More recently, the U.S. Air Force performed extensive battle damage repair (BDR) on its A-10 aircraft during Operation Desert Storm to maintain high sortie rates.

WHAT IS BATTLE DAMAGE REPAIR?

Simply stated, if a ship, tank, or aircraft sustains significant damage in battle, it must be repaired before continuing combat operations. In more precise military terms, BDR is the restoration of a useful level of combat capability to a damaged weapon system within a tactically reasonable time. If the damage sustained is not catastrophic, the following steps are necessary to perform BDR:

- Assess the damage, i.e., perform "triage" on the equipment to determine its disposition and to schedule its repair sequencing.
- Perform the repairs.
- Check out the repaired system to ensure proper operation.

Inherent in the concept of BDR is the assumption that some portion of damaged weapon systems will survive. For tactical air missions, the historical relationship between damaged and lost aircraft is that for every aircraft lost, on average three to five aircraft return with damage requiring repair before the next sortie. This relationship can vary by aircraft type, mission, and threat. Analyses of likely future

engagements show that in some scenarios (i.e., tough aircraft, close air support missions, unsophisticated threats), the rates can be as high as 15 or 20 damaged aircraft to 1 lost. Recent experience tends to substantiate these ratios. Similar relationships seem to hold for helicopters and tanks; that is, many more weapons can be expected to be damaged than are destroyed.

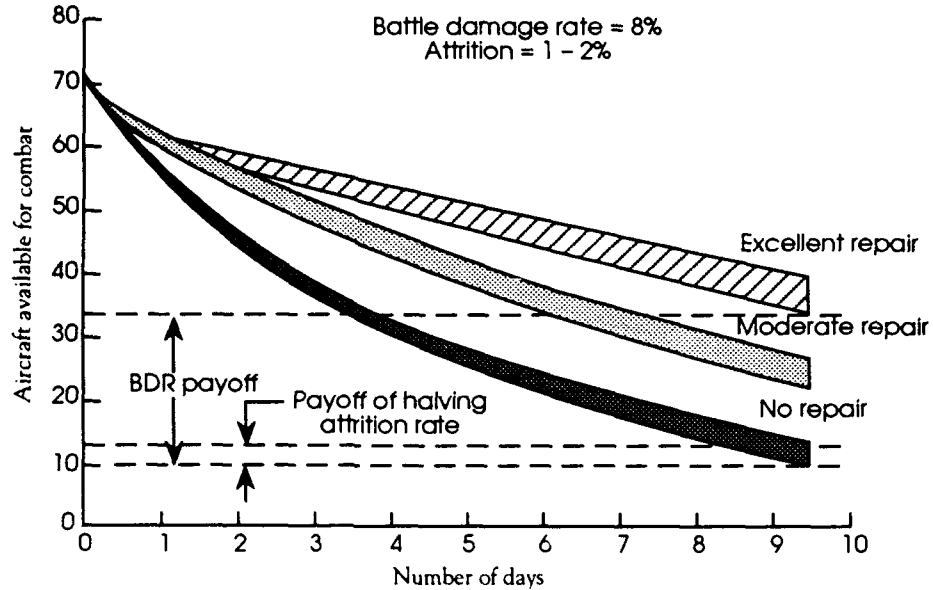
. . . BDR is the restoration of a useful level of combat capability to a damaged weapon system within a tactically reasonable time.

Another element of an effective BDR strategy is that repair during combat operations does not necessarily have to restore 100 percent performance or life expectancy to the system. The primary objective is to make the weapon useful for continuing combat. For example, a typical aircraft BDR goal might be to achieve at least 100 additional flight hours or if that is not possible, allow a one-time flight to a facility at which more extensive repairs can be performed. As a comparison, a tactical aircraft airframe design life is on the order of 6,000 to 8,000 hours.

SIGNIFICANCE OF BATTLE DAMAGE REPAIR

Effective BDR can have an extraordinary impact on sustaining warfighting capability. Figure 1 summarizes the results of an LMI study on aircraft availability conducted to compare relative effects of further reducing attrition rates from current levels and implementing BDR capabilities¹. The results of the study are somewhat surprising: in a multisortie/multiday conflict, BDR can have more impact on force levels than does attrition. The figure shows calculations for a wing of 72 aircraft operating over a 10-day period. A 2 percent attrition rate was selected as the baseline since it is a typical planning factor used for tactical aircraft. A 4-to-1 damage-to-loss ratio (8 percent damage rate) was selected because it, too, is a typical value for tactical aircraft. Available aircraft were flown three sorties a day for the first 3 days and two sorties a day thereafter.

¹Srull, Donald W., Edward D. Simms, Jr., and Raymond A. Schaible, "Battle Damage Repair of Tactical Weapons: An Assessment," LMI Report RE801R1, August 1989.



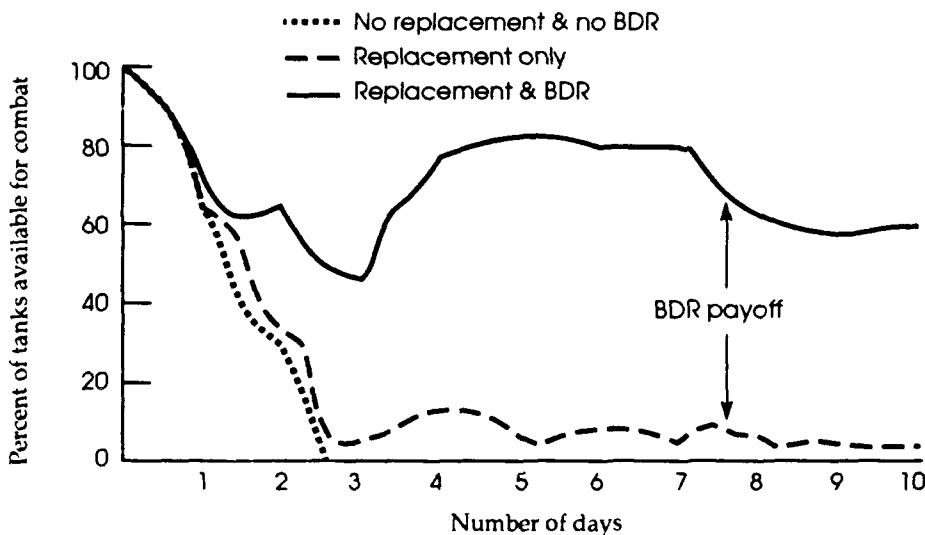
Source: Logistics Management Institute Aircraft Availability Study.

Figure 1 - Effective Attrition

The three bands in Figure 1 represent three postulated BDR capabilities. The lowest band is "no repair" (i.e., all damaged aircraft are effectively lost). The center band is developed under the assumption that 50 percent of the damaged aircraft are repaired within 24 hours; the remaining damaged aircraft are assumed to be lost. The upper band represents what is defined as excellent BDR capability in which 50 percent of damaged aircraft are repaired within 24 hours and another 30 percent repaired in 48 hours; the remaining 20 percent of damaged aircraft are effectively lost. The lower bound of each band represents the baseline 2 percent attrition rate; the upper bound represents survivability enhancement to achieve a 1 percent attrition rate.

Observe that, given the 2 percent baseline attrition rate, 3.5 times as many aircraft will be available at the end of 10 days if we can implement an excellent repair capability (BDR payoff) as compared to the "no repair" condition. On the other hand, halving the attrition rate from 2 percent to 1 percent only adds about 1.3 times as many available aircraft.

The above illustration is not unique to the air warfare arena. In our review of BDR of tactical systems, LMI also looked at studies of ground vehicle BDR. Figure 2 summarizes results of a large-scale tank battle simulation (600 tanks on each side). As can be seen, without BDR capability or tank replacement, the force will be reduced to zero in less than 3 days. By relying solely on replacement of damaged tanks from on-hand supply, we can maintain tank availability only at about 5 percent to 10 percent of initial strength. However, if battlefield damage and breakdowns can be repaired in the field, tank availability at the end of 10 days can be maintained at 60 percent to 80 percent of the original force. Other studies by the U.S. Army Materiel Systems Analysis Activity at Aberdeen Proving Ground, Md., indicate that up to 86 percent of the battlefield breakdowns (combat damage, reliability failures, and damage caused by wartime usage in the field) of U.S. Army Abrams tanks could be repaired in the field (by the crew or technicians) if effective BDR were implemented.



Source: U.S. Army Materiel Systems Analysis Activity

Figure 2 - Tank Availability

These examples point out the dramatic warfighting capability payoff for BDR. However, realizing that payoff is a significant challenge.

THE BDR CHALLENGE

Armies have always had to deal with the problem of repairing (or replacing) damaged equipment. It is the classic, "For want of a nail . . . the war was lost." Historically, the problem was addressed by the quartermaster supplying more nails, horseshoes, a hammer, and a blacksmith, or by stocking more shod horses. In other words, the problem of whether to repair or replace damaged equipment was left to the maintenance and logistics organizations to solve as best they could.

BDR must address field repair of items such as composite structures, exotic armors, "smart" skins and structures, pilot/crew associate systems, and stealth materials and devices.

Despite the evolution to modern warfare and the availability of sophisticated equipment, logisticians have not progressed far toward developing new approaches for solving this classic problem for two reasons. First, BDR is essentially invisible during peacetime. Second, BDR does not have the high profile or the glamour of piloting or commanding sophisticated weapon systems. The result is that BDR has received little recognition and almost no emphasis either as a specific design consideration or as an essential wartime supportability factor. That generalization has a few noteworthy exceptions (e.g., the A-10 aircraft design concept), but for the most part, battle damage repairability of weapon systems has been left to the considerable ingenuity of equipment maintainers and logisticians. While their efforts have been heroic and amazingly effective considering the available resources, a reasonable amount of preplanning and additional resources, including improved system design, training, and spares strategies, could undoubtedly have produced a significantly more effective BDR capability.

Battle damage repair technical manuals, for example, which should give instructions on how to expeditiously repair combat damage in the field, have not been published for many weapon systems. Furthermore, since battle damage repairs often emphasize speed of repair and restoration of capabilities with quick fixes, BDR techniques are to be used only under wartime conditions. Training for BDR is seriously restricted in some cases, both in the number of personnel trained and in the extent of training offered because the

Services do not want repair technicians and system operators to use BDR techniques in peacetime.

We must change the way we specify system requirements, design equipment, train technicians, develop spare and repair part lists, and apply advanced technology.

Stocking of spares and repair parts as war reserve materiel is supposed to account for wartime utilization. However, stocks are calculated in large measure on the basis of multiples of peacetime failure rates (reliability) to account for faster operating tempos and more operational hours in combat. Unfortunately, that approach does not account for battle damage that may be sustained by parts that have very low or no peacetime failure rates (e.g., fuel and hydraulic lines, wiring bundles, fuel tanks, and structural members). The result is that war reserve stocks do not contain proper spares for BDR, and too often makeshift fixes become the order of the day. Critical time is lost; repairs are inefficient; or, in many cases, the weapon system cannot be repaired at all even though it sustains what would seem to be repairable damage if proper spares were available.

ADVANCED TECHNOLOGIES POSE ADDITIONAL CHALLENGES

Beyond the current problems posed by fielded systems, new-generation weapons, both ours and the enemy's, present additional challenges. As we aggressively incorporate advanced technologies into our weapon systems, BDR must address field repair of items such as advanced composite structures, exotic armors, "smart" skins and structures, pilot/crew associate systems, and stealth materiel and devices. As the enemy incorporates advanced technologies, BDR must address new damage mechanisms associated with low-power lasers on sensors and night vision devices, high-power lasers inducing both immediate and latent damage effects, high-power microwaves inflicting electromagnetic and thermal damage, and hypervelocity projectiles with unique penetration and damage capabilities.

ADDRESSING THE BDR PROBLEM

How can our BDR capability best be improved? We must change the way we specify system requirements, design equipment, train technicians, develop spare and repair part lists, and apply advanced technologies if we are to handle BDR more efficiently in future conflicts. These actions are particularly critical in light of planned Department of Defense reductions of forces and weapon systems. As the total number of weapons declines, the relative military value of each weapon will grow.

. . . battle damage . . . may be sustained by parts that have low or no peacetime failure rates . . .

The key to success is an integrated, two-pronged approach. First, BDR should be explicitly addressed in every phase of the system acquisition process. Second, steps should be taken to establish BDR as a recognized design discipline.

BDR in the System Acquisition Process

Battle damage repairability should be specified and tracked as a valid system design parameter. It should be a visible part of the system design decision trade space. BDR should be quantified in such a manner that combat capability implications of design decisions reflect the payoff or penalty associated with these decisions. Parameters such as effective attrition, time to repair for various threat damage levels, return-to-combat rate of damaged systems, repair backlog, and logistics resource demand could be used as system requirements and to compare design alternatives during tradeoff studies.

Initially, DoD may realize some quick and simple payoffs. For example, if BDR had been an explicit design consideration during the development of the F-15 and F-16 aircraft and the M1 main battle tank, individual electrical wires and wire bundles may have been marked at frequent intervals to facilitate BDR when cable bundles were severed. Without marked wires, repair is much more difficult, time consuming, and error prone as shown in Figure 3. Under peacetime conditions - when cables seldom fail - the effect is relatively minor, but under wartime conditions, the result can be much more serious - much less fighting time for the damaged system.

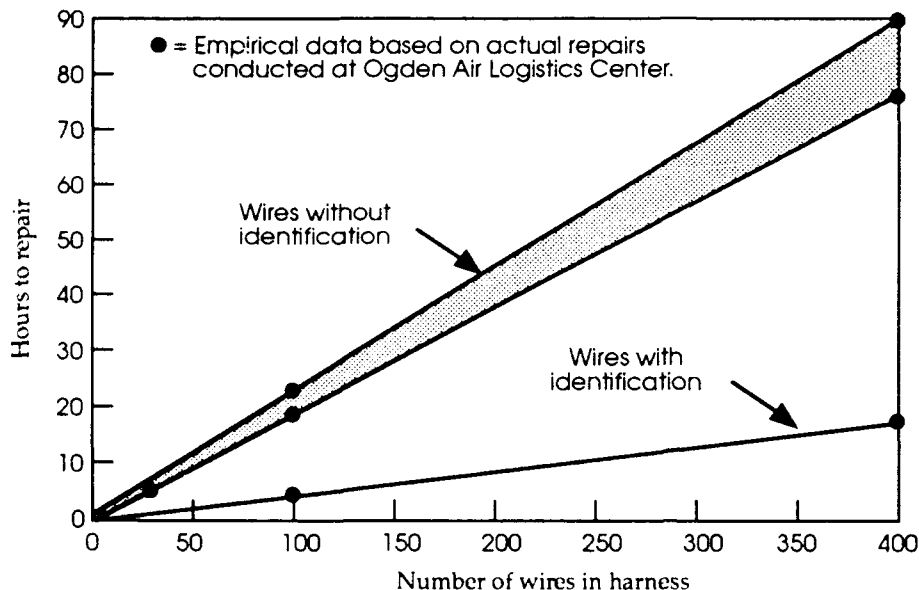


Figure 3 - Effect of Wire Identification on Damage Repair Time

BDR As a Design Discipline

The second element in developing a successful BDR capability is to establish BDR as a design discipline similar to survivability, reliability, or maintainability. Creating this new design discipline requires development of a complete set of "tools of the trade" for BDR engineering. Necessary actions include the following:

- Conduct research and development to establish a technology base for the diagnosis and repair of advanced systems and for the use of advanced technology to assess and repair fielded systems.
- Formulate engineering design guidance to assist systems designers in the development of weapon systems that are inherently easy to repair. Table 1 presents some sample "rules of thumb" that might be included in BDR design guidelines.
- Identify analysis methods to evaluate the battle damage repairability of weapon systems and for use while performing tradeoff comparisons of alternative design and system support options.
- Establish data bases to facilitate design and analysis of BDR.

TABLE 1

BATTLE DAMAGE REPAIR DESIGN RULES OF THUMB

- Build in redundancies in such a way that, if necessary, repair of survivable damage can be deferred and the system can still perform useful combat.
- Design the system so that combat-critical components are accessible for ease of repair and/or replacement in the field.
- Design the system for easy assessment of damage (e.g., take advantage of built-in-test equipment and "smart" systems that can self-diagnose damage, make critical components accessible for inspection, etc.).
- Limit the size and weight of line replaceable units (LRUs) for ease of removal and replacement under stressful combat conditions.
- Incorporate modularity and interchangeability to ease combat maintenance and cannibalization.
- Code and/or mark parts to facilitate assessment, repair, and testing (mark electrical wires and cables!).
- Select materials that require a minimum of special equipment, processes, or clean environmental conditions to perform repairs.

Fortunately, we do not have to start from scratch on many of these problems. In actuality, BDR can be viewed as an extension of the relatively mature disciplines of survivability and integrated logistics support. Survivability analysis needs to be extended to account in greater detail for damaged but surviving systems to provide data on expected battle damage against various threats. Integrated logistics support needs to be extended to plan for the unique failure/damage modes encountered in combat.

CONCLUSIONS AND RECOMMENDATIONS

Effective BDR is a force multiplier and is often decisive in combat. Unfortunately, BDR capability has received little attention in the development of most weapon systems and in the resources allocated to support fielded systems.

For new systems under development BDR should be addressed in every phase of the acquisition process including program and milestone reviews.

For both new systems under development and currently fielded systems, DoD should (1) ensure that war reserve spares include the materials (and tools) necessary to repair combat damage, (2) develop repair procedures and manuals for BDR, and (3) train sufficient numbers of repair technician teams in BDR techniques.

Improving BDR should receive appropriate priority within DoD. The emphasis on survivability, reliability, and maintainability over the past 20 years is paying dividends. Without commensurate progress in BDR, however, the full benefits will not be realized when it really matters – during combat. A commitment to improve DoD's BDR capability will produce significant dividends, allowing us to use our smaller number of weapons more effectively in combat.

RELATED MATERIAL

Battle Damage Repair of Tactical Weapons: An Assessment. Donald W. Srull, Edward D. Simms, Jr., and Raymond A. Schaible, LMI Report RE801R1. August 1989.

Aircraft Availability Study. Edward D. Simms, Jr.. LMI study results included in LMI Report RE801R1.

Battle Damage Assessment and Repair Guidelines for the System Acquisition Process. Donald W. Srull, et al. LMI Report, to be published.

The Impact of Liquid Propellant on Battlefield Damage Assessment and Repair for the Advanced Field Artillery System. John T. Durgala, Jr.. LMI Report AR008TR2. May 1991.

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