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SURVIVABILITY PRIMER

ARMY MATERIEL SYSTEMS ANALYSIS
ACTIVITY, ABERDEEN PROVING GROUND
MARYLAND

SEPTEMBER 1976

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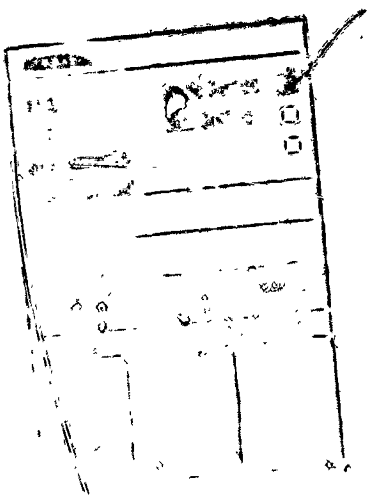

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Survivability is discussed in terms of its four main ingredients: detectability, hitability, vulnerability, and repairability. The discussion centers about methods for adding survivability value to Army materiel and personnel, mainly from the developer's rather than the user's point of view. The primer is intended for guidance to developers and is restricted to a nonnuclear combat environment.

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20. ABSTRACT (Continued)

Examples are introduced to demonstrate how personnel and materiel have been given or might be given more survivability value through various measures, without compromising the effectiveness or the performance of the system to which the personnel and materiel belong.

FOREWORD

The place and time for survivability as a military discipline is here and now. The days of inexpensive replaceable weaponry and seemingly unlimited stockpiles of military items are over. A new era is upon us, marked by expensive, sophisticated weapons.

The search for practical ways to add survivability value to our military personnel and materiel must be a continuous one. The enemy is also constantly seeking more effective combat procedures. When our forces go into battle, they must have the decisive edge derived from more effective and more survivable equipment as well as from intensive training to fully use that equipment. Once our forces realize that they themselves are the chief benefactors of survivability efforts, they will look for and find new ways to extend and apply survivability concepts.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1 Background.

Survivability is of paramount importance to our armed forces. This conclusion is based on the following observations:

- In recent wars, large quantities of materiel were damaged in short time intervals.
- There has been a proliferation of relatively cheap unsophisticated weapons capable of destroying expensive, complex weapon systems.
- Potential enemies demonstrate a numerical superiority of military personnel and materiel.
- There is a growing complexity of materiel with an accompanying greater need for highly trained personnel for its operation.
- The costs of developing, acquiring and maintaining materiel have escalated.

Survivability encompasses such older established disciplines as vulnerability reduction, maintainability, and repairability. Its overall objective is to assist our forces in accomplishing their prescribed mission effectively.

1.2 Definition of Survivability.

Faced with the absence of a formal definition of survivability in the Army dictionary, the USAMSAA proposed the following definition:

> "SURVIVABILITY IS THAT CHARACTERISTIC OF PERSONNEL AND MATERIEL WHICH ENABLES THEM TO WITHSTAND (OR AVOID) ADVERSE MILITARY ACTION OR THE EFFECTS OF NATURAL PHENOMENA WHICH ORDINARILY AND OTHERWISE WOULD RESULT IN THE LOSS OF CAPABILITY TO CONTINUE EFFECTIVE PERFORMANCE OF THE PRESCRIBED MISSION."

1.3 Goals of Survivability.

The goals of survivability are to enable our military forces to avoid or absorb all attacks and to remain capable of decisively engaging and reengaging the enemy.

In order to achieve these goals, our materiel should be:

- DIFFICULT TO DETECT AND ACQUIRE
- DIFFICULT TO HIT IF ACQUIRED
- DIFFICULT TO DAMAGE IF HIT
- EASY TO REPAIR IF DAMAGED.

Each of these elements will be discussed in the chapters that follow.

1.4 Purpose.

The primer presents:

- The basic principles and philosophies of survivability and their interaction with other system characteristics.
- An overview of materials and techniques for survivability enhancements that can be applied for proposed or existing equipment.
- Selective examples of survivability enhancement materials and techniques.

1.5 Scope.

This primer:

- Is directed primarily for guidance for designers, developers, and program managers of military systems.
- Is restricted to the nonnuclear combat environment.
- Presents an overview of the spectrum of military systems with no emphasis intended on any particular system.
- Utilizes available information on materials and techniques, primarily on Army materiel.

2. GENERAL DISCUSSION

2.1 The Distinction Between Survivability and Vulnerability.

The terms "survivability" and "vulnerability" are often used interchangeably and are easily misinterpreted. Survivability was defined in paragraph 1.2. The following definitions, extracted from DARCOM Regulation 70-53 entitled Non-Nuclear Vulnerability and Vulnerability Reduction, may serve to clear up some of the confusion.

VULNERABILITY

A QUANTITATIVE MEASURE OF THE SUSCEPTIBILITY TO DAMAGE OF A TARGET STRUCTURE OR MATERIEL TO A GIVEN MECHANISM.

VULNERABILITY REDUCTION

THE APPLICATION OF DESIGN TECHNIQUES TO MATERIEL ITEMS TO REDUCE OR ELIMINATE THE EFFECTS OF COMBAT DAMAGE MECHANISMS.

It should be noted that survivability is an element of system effectiveness in much the same way that vulnerability is an element of survivability. This is illustrated in Figure 1.

2.2 Trade-Offs.

Survivability improvements must be achieved without sacrificing the system's ability to perform its mission, and within realistic cost and resource constraints. Realistic tradeoffs are necessary between survivability and other aspects of effectiveness such as reliability, mobility, and lethality.

For example, Table 1 shows a checklist of survivability equipment under consideration for Army aircraft. Assessments of the relative effectiveness of existing, developmental, and conceptual equipment for enhancing the survivability of Army aircraft, together with the cost, weight, and reliability measures of the associated equipment, provide a basis for trade-off studies leading to procurement recommendations.

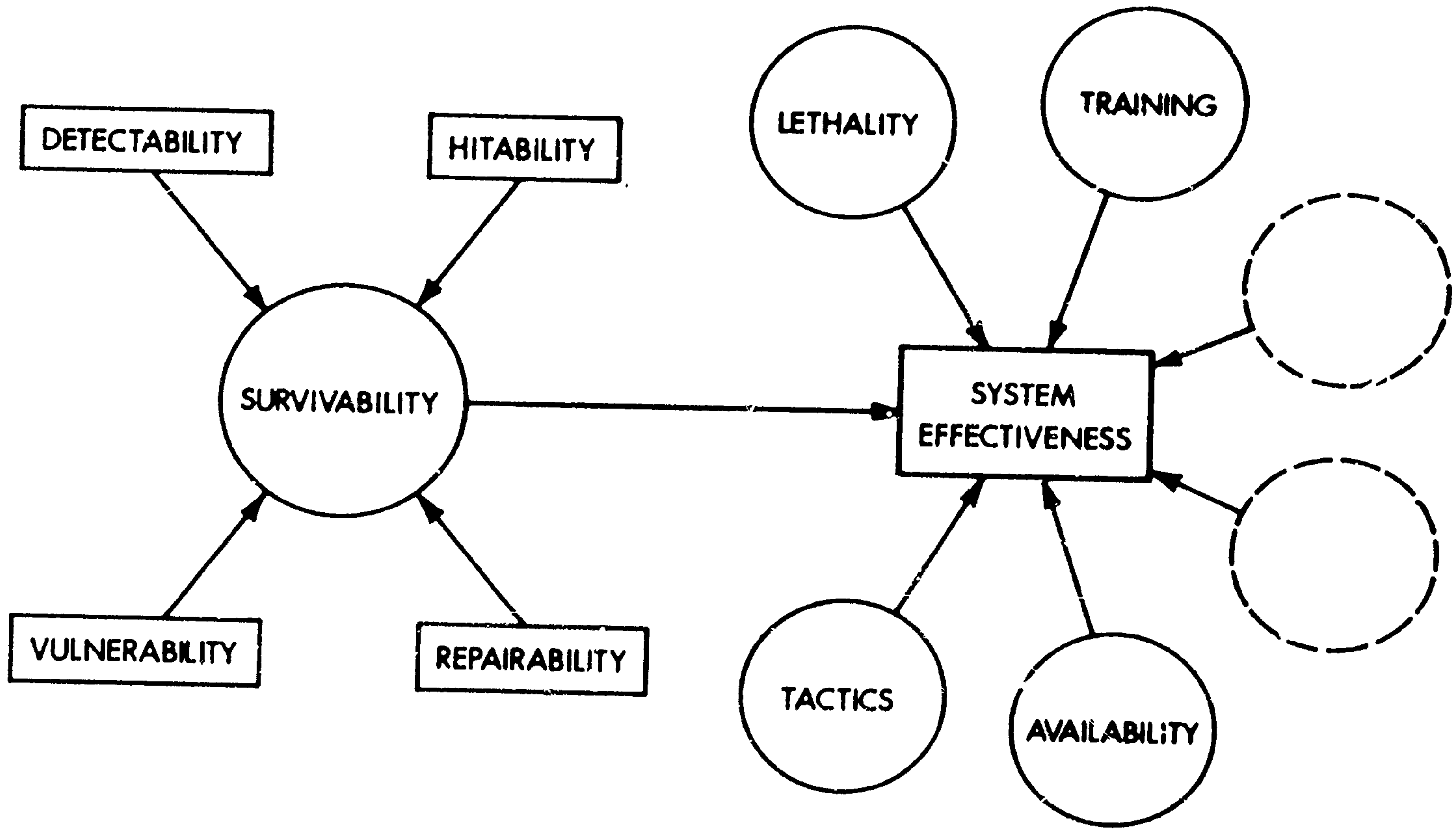

Figure 1. Relationship of Survivability to System Effectiveness.

Table 1 Summary Chart of Survivability Equipments Under Consideration for Army Aircraft

		Aircraft					
Aircraft Survivability Equipments		AH-1G/Q	OH-58A	UH-1H	CH-47C	OV-1D	RU-21
Optical Countermeasures	1. Flat Canopy	•	•				
	2. Low Reflective Paint	•	•	•	•	•	•
	3. Optical Contrast Reduction Devices	•	•	•		•	
	4. Optical Jammers	•	•	•		•	
Electronic Counter-measures	1. Radar Jammers	•	•	•		•	
	2. Radar Cross Section Reduction	•	•	•			
	3. Chaff	•	•	•		•	
Infrared Countermeasures	1. Suppressors	•	•	•	•	•	•
	2. Missile Launch Detectors and Flares	•	•	•	•	•	•
	3. Missile Approach Detectors and Flares	•	•	•	•	•	•
	4. IR Jammers	•	•	•	•	•	•
Vulnerability Reduction Designs	1. Rotor Blade, Boom, or Fin Redesign	•	•	•	•		
	2. Fuel Feed System Modification	•	•			•	
	3. Ballistically Tolerant Fuel Tanks		•	•	•	•	•
	4. Engine Fire Prevention		•				
	5. Ballistically Tolerant Rotor Drive, Supports, Controls	•	•	•	•		
	6. Fail-Safe Lube System	•	•	•	•		
	7. Control Redundancies					•	
	8. Crew Armor and/or Crew Redundancy					•	•
	9. Flight Control System Hardening	•		•			
	10. Single Engine Capability				•		

2.3 Survivability Consciousness and Efforts.

When the principles of survivability become second nature to designers, developers and users of military hardware, the pay-offs will be significant. First of all, troops and their equipment will have a better chance of surviving a combat environment and therefore will have "longer life"; this translates into more military missions with no increase in resources.

In general, a system's survivability cycle consists of five phases, as depicted in Figure 2. The analyses, methodologies, and design procedures used to derive survivable systems are normally iterative processes, with each iteration accommodating increasing levels of detail. The depth of sophistication of survivability efforts performed is determined by the degree of definition required in a particular phase. The objectives of initial analyses required during the conceptual phase are fairly general in nature, while the survivability efforts during the full-scale development phase are specific and detailed.

A typical approach for determining design parameters for optimum system survivability would consist of the determination of

- mission requirements
- potential threats
- hostile environments
- vulnerability to threats and hostile environments
- areas where survivability enhancement techniques should be utilized
- effects of these techniques on system effectiveness (including safety, availability, logistics, repairability and others)
- cost associated with these techniques.

A trade-off process is iterated until an optimum design is achieved.

To further the goals of survivability, the following steps must be taken:

- establishment of survivability guidelines,
- establishment of survivability principles,
- development of a bank of survivability specifics,

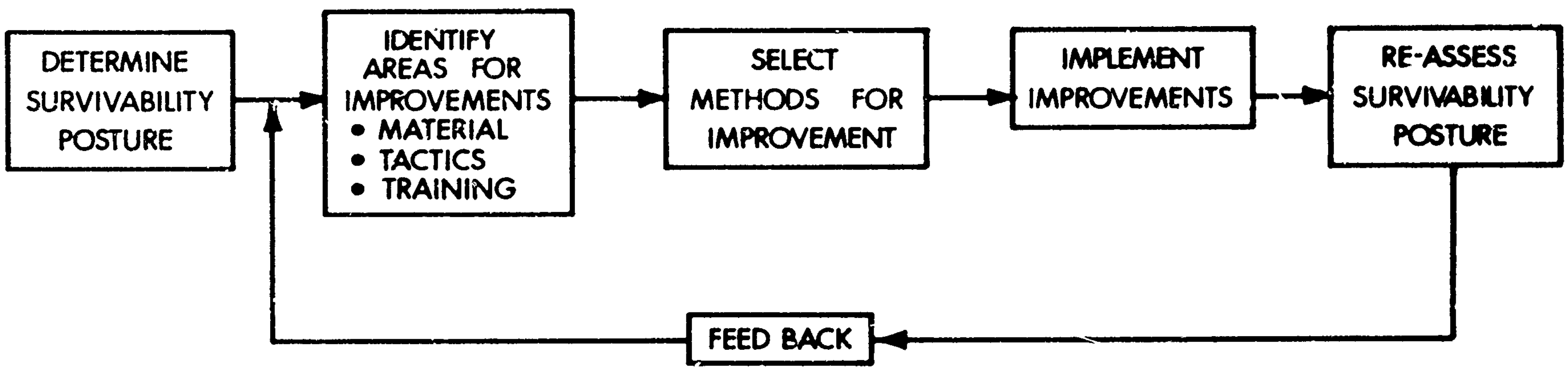

Figure 2. Survivability "Cycle".

- develop simple techniques to measure or rate basic aspects of survivability,
- ensure that survivability is "built-in",
- use statistical approach on combat data to evaluate the success of survivability measures or actions,
- ensure communications between hardware users and designers.

To show how a basic weapon system may benefit from continuous application of modifications and changes in design, Figure 3 documents the evolution of the UH-1 over a period of fifteen or more years. Thus, a variety of models of Army aircraft has ensued, each with a specific primary mission, and each with new characteristics which have enhanced the survivability of a given model over that of its predecessors.

3. DETECTABILITY

3.1 General.

Detecting and locating items of military significance have always been of the utmost importance on the battlefield. In the past, detection and location have depended greatly on the human senses of sight and hearing. On the modern battlefield, human senses have been enhanced and augmented by sophisticated equipment. Such devices will be discussed in a separate category.

Detectability is defined as:

THE CHARACTERISTIC OF A TARGET
WHICH DETERMINES HOW READILY
THE ENEMY CAN DETECT IT.

The process of detection continues with;

RECOGNITION - CLASSIFICATION BY TYPE
(VEHICLE AS OPPOSED TO FORTIFICATION)

IDENTIFICATION - CLASSIFICATION BY NAME
(TANK OR TRUCK; FRIEND OR FOE)

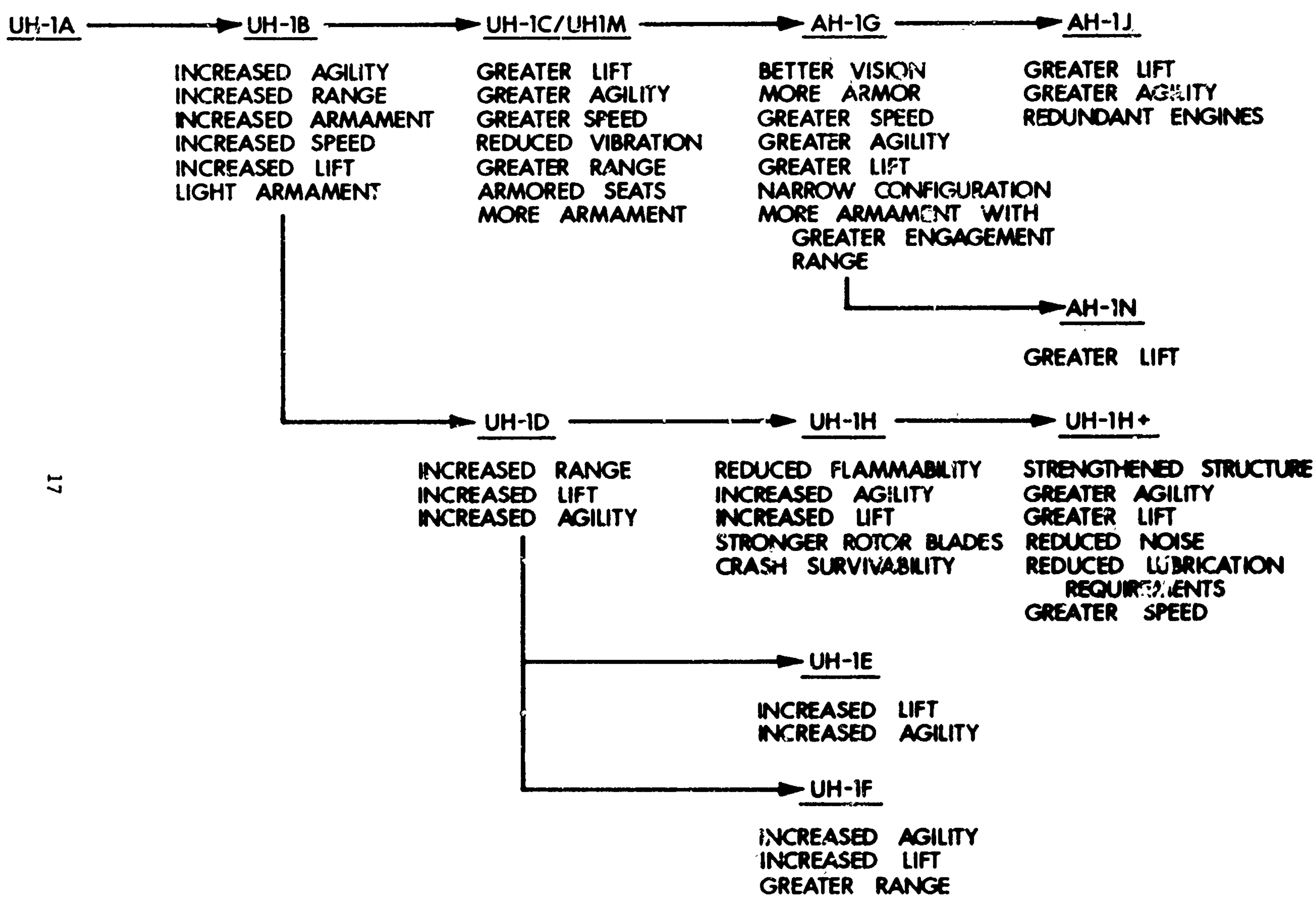

Figure 3. Evolution of UH-1 in Terms of Survivability Enhancement.

ACQUISITION - A GENERAL TERM THAT INCLUDES ALL THREE PHASES OF DETECTION, RECOGNITION, AND IDENTIFICATION THAT ARE NECESSARY TO FULLY LOCATE A TARGET.

A target is detected by its signature; be it sound, radio, microwave, infrared, visible, ultraviolet, X-ray, or other. A target may be made more difficult to detect by reducing or eliminating its signature. Five types of signatures (visual, acoustic, infrared, microwave, and radio) account for the major portion of military related research and activity. Techniques such as camouflage, reduced electromagnetic radiation, use of IR suppressors and acoustic mufflers should be considered as options for reducing signatures. To improve the survivability of our equipment, we must minimize the enemy's capability to detect and track our equipment by manual or automatic systems.

Four areas where serious surveillance threats exist are:

- Visual - materiel may be seen with the naked eye or with the eye aided by optical devices.
- Acoustical - operation of materiel or movement of personnel provides distinct signatures which can be picked up by the ear or by acoustical devices.
- Infrared/thermal - infrared radiation from equipment and personnel provides a signature for infrared and thermal detectors.
- Electronic - detectors can locate military operations by radar, by triangulation on radio transmissions, or by detections of spurious radiation from operation of equipment.

3.2 Visual Detection.

Some characteristics which usually lead to detection by optical means are:

- configuration - shape, size, silhouette
- glint - reflection, glare
- smoke/dust - exhaust plumes, dust trails
- movement - target motion relative to environment

- color - target contrast relative to environment
- flame/flash - muzzle flash, missile/rocket motors
- lights - vehicles, aircraft, flashlights

3.3 Noise (Acoustic and Seismic Vibrations).

Sources of distinctive noises include:

- engine and exhausts - diesel, gas, turbine
- propellers and rotor blades - fixed wing aircraft, helicopters
- locomotion systems - track, wheel, air cushion
- explosions and gunfire - small arms, artillery, rockets
- communications - radio, voice, teletype
- earth vibration - movement, detonations

3.4 Infrared/Thermal.

Sources of infrared/thermal signature include:

- hot metals - exhaust systems, radiators, gun barrels and tubes
- hot gases - exhaust plumes, muzzle gases
- reflectance - paints, camouflage nets

3.5 Electromagnetic.

Sources of electromagnetic signature include:

- radios - AM, FM
- radars - stationary and rotating antenna
- data processors - computers, teletypes
- spark ignition engines - vehicles, aircraft, generators
- electric motors - generators, winches
- radar cross section

Table 2 High Threat Areas - Enemy Capabilities and Our Countermeasures

Surveillance Threat	Threat	Enemy Capability	Our Countermeasures
Visual	Naked eye Conventional photographs Image intensifiers	Yes	Pattern painting Lightweight screening system(LSS) Smoke
Noise (Acoustic and Seismic vibrations)	Directional microphones Seismic sensors	Yes	More efficient mufflers Quiet operations
Infrared/thermal	Infrared photographs Infrared searchlight	Yes	Improved paint LSS Smoke
Electromagnetic	Radar Monitoring of radio transmission Detection of spurious radiation Direction finding units	Yes	LSS Jamming Remote antennas

3.6 Typical Enemy Capabilities and Our Countermeasures.

Typical enemy threats and our methods to counter those threats are listed in Table 2.

3.7 Status of Research in Detectability.

The development and deployment of sensors (equipment related to the gathering of information) have continued at a high rate. Dramatic advances have been made in this field in the last decade. Airborne surveillance has now progressed to the point where it can be carried out not only by manned aircraft but also by means of remotely piloted vehicles (RPV's) or even satellites. The latter means are particularly favored in peacetime because of their capability to operate continuously. Ground surveillance has reached new heights of sophistication through the introduction of battlefield radars, passive night vision systems, acoustic and magnetic unattended ground sensors (UGS), and other electronic and optical aids.

In the last category, the variety of active and passive sensors which may defeat traditional camouflage and the extent of their deployment are already formidable. Ten years ago, the Warsaw Pact armies were carrying out some 75 percent of their training operations at night, and employing active infrared night vision equipment on a wide scale. This has led to initial deployment of similar IR systems in the West. The first generation systems were cumbersome and not very effective; their use was easily detected by another IR sensing device because these early systems required that the target area be actively illuminated by an IR searchlight. Active IR is still in use, but is gradually being superseded by passive, and therefore undetectable, optical systems which incorporate recent technological advances to reduce system size and weight and to improve performance. The new passive sensors include image intensifiers and low light level television employing light intensification techniques. The passive operating mode has also been applied to equipment operating in the IR spectrum in order to provide thermal imaging, as exemplified by Forward Looking InfraRed (FLIR) and IR Linescan systems. These produce an image of the target from its emitted thermal radiation, independent of visible light.

Microwave radiometry also utilizes the Linescan principle, but formulates the image from the electromagnetic radiation emitted from the target area.

Few of these passive equipments rival the time-honored photographic camera however, in terms of cost, flexibility or resolution - even when employed aboard reconnaissance satellites. Though its successful use is generally dependent upon daylight and good meteorological conditions, the camera may be fitted with either conventional or special films and filters registering color or black-and-white images in the ultraviolet (UV) or near-IR bandwidths. These images can be presented in permanent form and reproduced for detailed examination.

Other passive sensor developments owe much to American involvement in Vietnam. These US-developed sensors include a wide range of seismic intrusion detectors (SIDs), magnetic and acoustic equipments, and even hand-held and helicopter-mounted "people sniffers" to detect body odor. Some of the better known and more practical equipments are: ACOUSID, an acoustic SID development from US Navy sonobuoys and dropped by aircraft; ADSID, a smaller air-delivered acoustic "implant" sensor, which may be deployed from helicopters; MINISID, a manually implanted SID; MICROSID, a small shortrange acoustic sensor carried by individual soldiers to detect enemy movement; DISID, a disposable SID; COMMIKE, an acoustic-operated command microphone dropped along tracks; and MAGIC, a magnetic detector which senses the presence of metal.

Some of these sensors, and others of different nature, are being deployed as barriers. They are also being refined and further developed to form elements of the "Electronic Battlefield." Since other nations will surely follow the US lead in this domain, the western alliance will eventually have to find effective counters (or camouflage) against its own new passive sensor technology.

New active sensors are still entering the inventory despite the attractiveness of passive systems; radars operating at the longer wavelengths are used more and more for battlefield surveillance purposes since they can penetrate clouds, fog, rain, or smoke. Groundbased battlefield surveillance radars have maximum ranges of between 5 and 20 km.

For airborne reconnaissance, side-looking airborne radar (SLAR) is being introduced more often. While the short wavelengths used display increased sensitivity to bad weather, the equipment can produce images of photographic quality, and has the potential to penetrate foliage. Another new sensor in the active category is the laser illuminator geared to a scanner to record the reflected radiation.

Faced with this array of sensors, the field commander may resort to constant mobility as a means of confusing enemy observers, but in so doing he could increase his chances of being detected by radar fitted with MTI (moving target indicator), or by unattended ground sensors. Decoy systems, including deployment of dummy vehicles or aircraft, may distract an enemy momentarily (and were, in fact, used extensively by the Egyptians during recent campaigns). However for wide-scale concealment and cover of large formations or installations, the skillful exploitation of natural features and vegetation, coupled with artful camouflage, remains the only practical resort.

Tables 3 and 4 list some of the research efforts that have been or are being implemented related to detectability. These efforts should bring about enhancement in survivability.

Table 3 Survivability Enhancement Measures That Have Been Implemented — Detectability

Item	Measure Taken	Stage of Life Cycle at Which Measure was Implemented	Benefit Observed (O) Expected (E)
UH-1H	Reduced noise	Fielded item	Reduce detection range based upon acoustics (O)
UH-1M	Low light level TV	Fielded UH-1H	Some night vision capability, low level night flight (O)
AH-1S	Flat-plate canopy	Fielded items	Reduce glint and likelihood of detection (O)
OH-58C	Flat-plate canopy	Fielded items	Reduce glint and likelihood of detection (E)

Table 4 Survivability Enhancement Measures for Consideration - Detectability

Item	Measures for Consideration	Expected Benefit
Aircraft	Smoke-screen warhead for 2.75 inch rocket	Protect aircraft from observation by enemy anti-aircraft and troops on the ground
Vehicles	Noise-reduction -- tracks, engines	Reduce distance at which vehicle may be detected by its noise
Vehicles	Signature reduction - IR, acoustic, optical, magnetic, seismic, and gases	Reduce detection probabilities
Personnel	Lightweight camouflaged clothing and equipment.	Reduce chances for detection of individual
Vehicles and aircraft	Engine advanced technology - regeneration aircraft engine; reduced noise, reduced IR signature.	Reduce signature and maintenance
Various equipment	Camouflage through reflectance of natural environment by mirrors	Reduce detectability
Various equipment	Camouflage through use of urethanes colored at local site	Reduce detectability
Aircraft and Ships	Reduced radar cross section	Reduce detectability
Materials	Coatings to increase radar absorption	Reduce detectability

4. HITABILITY

Hitability is defined as:

THE SUSCEPTIBILITY OF
A TARGET TO BEING HIT

4.1 General.

Since some targets will be detected in battle despite all measures taken to prevent detection, the survivability of those targets may be increased by making them harder to hit. Characteristics which determine the degree of difficulty of hitting a target include:

- Size and configuration - target area and configuration presented to the enemy gunner.
- Standoff - maximum distance at which a weapon can effectively engage a target.
- Agility/maneuverability - capability for sudden changes in speed, acceleration, and course.
- Suppressive fire - using one's own weapons so as to prevent the enemy from using his weapons effectively.
- Electronic Countermeasures - measure taken to avoid detection to avoid being hit after dectection occurs.
- Artillery interference - measures taken to prevent enemy artillery crews from making corrections by registration.

Often, the same efforts expended to make our equipment more difficult to detect also help to make that equipment more difficult to hit.

4.2 Size and Configuration.

Aspects of a system which may be exposed frequently to enemy direct fire weapons should be designed to have minimal and ill-defined presented areas to such weapons.

Critical components which are vital to the success of the mission often occupy a sheltered or very small region of the overall area of the target, and therefore represent a difficult portion of the target to damage. Conversely, appendages which enlarge the presented area of the target increase the chances that the target will be hit.

4.3 Standoff.

Standoff refers to the effective range of a weapon system. The effective range of a weapon is the maximum distance at which that weapon can damage a given target. If two weapon systems oppose each other, the one with the greater standoff has an obvious advantage, other things being equal. Greater standoff prevents effective enemy return fire and, therefore, is a military goal which enhances survivability.

4.4 Agility/Maneuverability.

Capabilities for mounted crews to exploit a wide variety of terrain, to move their vehicles rapidly with spurts of acceleration so as to confuse the enemy's aiming process, and to move at an irregular pace during the time of flight of incoming projectiles will improve system survivability. The ability of vehicles to traverse a wide variety of terrain provides military planner flexibility in choosing routes of approach which may not be adequately covered by the enemy weapons or which provide more opportunities for cover and concealment. With sufficient power to accelerate and maneuver quickly, the vehicles can tax the tracking capabilities of enemy weapons. Under ideal conditions, a combination of agility and maneuverability will permit vehicles to move rapidly after an enemy weapon has been fired so that the weapon is more likely to miss.

4.5 Suppressive Fire.

Suppressive fire relates to the use of weapons to keep the enemy from using his own weapons effectively. Suppressive fire may affect the enemy psychologically even when he has not received significant physical damage.

Developers should consider the design of weapons that would be particularly useful for suppressive fire. The emphasis would be on weapons that can cheaply and rapidly deliver a volume of area fire.

4.6 Electronic Countermeasures.

Electronic countermeasures (ECM) are taken to avoid detection or to avoid being hit after detection occurs. They are used to deceive the enemy concerning the exact location of materiel and to confuse hostile guidance systems.

The modern battlefield environment manifests the rapid development of technology since World War II. The presence of sophisticated ECM devices and systems influences every aspect of tactical operations. This was particularly demonstrated during the October 1973 Yom Kippur War.

4.7 Artillery Interference.

Effective delivery of artillery fire normally requires that the artillery crews make corrections for various factors. In part, this is done by registration, firing rounds and correcting for differences between expected and actual impacts or bursts. If enemy artillery crews are prevented from making these corrections, their fire will be less effective. With a method to determine the location of enemy artillery attempting to conduct registration and the means to provide effective rapid counterbattery fire, our forces will be capable of either eliminating the enemy artillery or preventing accurate registration. ECM may prevent an enemy observer from delivering messages concerning adjustment of fire. ECM can prevent observation altogether; because if the observer is located, he can be suppressed or eliminated. Measures which disturb the enemy's capability to make position surveys and collect data may result in erroneous siting data; measures which prevent his collection of accurate meteorological data may cause errors in the enemy's delivery accuracy.

4.8 Status on Research in Hitability.

The status of research efforts related to hitability is reflected in Tables 5 and 6. These efforts should result in an enhancement of survivability of military hardware.

5. VULNERABILITY REDUCTION

5.1 General.

One obvious method to enhance survivability is to minimize a target's vulnerability. Vulnerability is defined in paragraph 2.1.

Some typical damage mechanisms are:

- Blast
- Kinetic energy
- Thermal
- Nuclear radiation
- Chemical, biological
- Laser

Table 5 Survivability Enhancement Measures That Have Been Implemented - Hitability

Item	Measure Taken*	Stage of Life Cycle at Which Measure was Implemented	Benefit Observed (O) Expected (E)
UH-1H	Increased power	Fielded item	Greater agility (O)
UH-1H	Large rotor blade	Fielded item	Greater lift, greater agility (O)
AH-1G	Narrow fuselage with same engine and rotor as UH-1	Development	Greater speed and agility than UH-1C; narrower, and thus more difficult to hit (O)
UH-1C/ UH-1M	Wider chord on rotor blade and door-hinge design of rotor blade	Fielded UH-1B	Greater speed and maneuverability (O)
M551	Installed smoke grenade launchers	Development	Smoke would obscure vehicle (O)
AH-1G	Anti-solar reflective paint	Fielded item	Reduce solar radiation to lower the probability of hit from an IR-seeker (O)
AH-1G	Plume suppressors	Fielded item	Reduce IR plume intensity to lower the probability of hit from an IR-seeker (O)

*Tradeoffs between added size and increased performance have to be considered.

Table 6 Survivability Enhancement Measures for Consideration - Hitability

Item	Measures for Consideration	Expected Benefit
Aircraft	Navigation and control systems	Improved combat capability in areas of weapon location and night operations
Vehicles and aircraft	Engine advanced technology - smaller size increased power	Reduced signature, greater agility
Aircraft	Roller gear transmission	Reductions in weight, size, and number of parts
Aircraft	Improved flight control stability by integration of control system elements and displays	Greater agility, safer flight at low altitude
Artillery	Auxiliary propulsion unit for towed artillery	Increased mobility
Engines	Reduce exhaust temperature by additives to exhaust jet	Reduced IR emissions
Missile guidance	IR seeker with counter ECM capability against lasers, decoys, and signature reduction systems	Improved weapon effectiveness resulting in greater suppressive capabilities
Aircraft	Integrated Actuator Package	Reduced area should reduce probability of being hit.

Some ways of reducing the vulnerability of targets are:

- Adding protective surfaces to critical components,
- Designing redundancy and separation into critical components,
- Using temporary ballistic protection, such as nylon blankets, when enemy fire is expected or experienced,
- Using field expedients such as sandbags or logs,
- Locating critical components behind noncritical ones.

There are two classical ways to obtain vulnerability data and to assess improvements obtained by the application of vulnerability reduction techniques. One is the collection and analysis of combat damage data, and the other is the generation and analysis of data from controlled tests. When data from both sources are available, they may be used for validating purposes. Such data are also used to examine the validity of predictive mathematical models.

5.2 ABC's of Vulnerability Reduction.

To focus attention on the Army's efforts to achieve vulnerability reduction in critical military items such as aircraft and tanks, the Vulnerability Reduction Branch of the Ballistic Research Laboratories has developed a mnemonic system - an alphabetized code - of protection techniques or philosophies.

The examples which follow do not exaust the gamut of possible ideas. Indeed, in design and conceptual stages, concepts for reducing vulnerability are limited only by the imagination of designers and developers. For retrofit hardening of fielded materiel, other factors such as weight and cost produce serious constraints on practical options.

Armor. Wherever practical and within weight limitations, add armor to systems where no other technique will provide the necessary protection. The armor may be either integral or parasitic. Integral armor is used as a frame or component load-carrying element of a system. Parasitic armor is defined as protective shielding which has no load-carrying or other subsystem function. The armor may be either metallic or non-metallic depending on weight limitations, spallation characteristics and other consideratios. The choice of a specific design approach or of a specific armor depends on such factors as weight, material availability, cost, and the type of threat exposure.

Bury. Locate vulnerable components behind non-critical components which provide shielding. Place components in an area geometrically difficult to attack; for example, locate hydraulic lines underneath heavy structural beams.

Cover and Concealment. The ease of locating and effectively using indigenous material for cover and concealment on the battlefield can be greatly influenced by basic design. Those activities or items that successfully deceive an enemy as to true size, identity, or location of friendly materiel will improve survivability. Materiel must have quick move and set-up features, provide a low silhouette, and be free of unusual limitations that restrict the choice of a site or hamper operations. Manipulation of target signatures or establishment of dummy sites will reduce the effectiveness of anti-radiation missiles. Use of camouflage paints or nets should be considered.

Consider the placement of major system elements (such as engines, heavy structure, fuel tankage, and landing gear) to achieve shielding of the critical elements from the prominent hostile ballistic threat aspects. In existing systems, natural shielding usually can be achieved through relocation of relatively small critical components into areas where more natural shielding is available. Ensure that the relocation does not expose an equally or more critical component or that the relocation does not result in a higher vulnerability of other portions of the same subsystem.

Concentrate. Gather critical components in one small protected space, rather than disperse them over an area that cannot be protected or an area which may require significant additional protection. Compact grouping of critical components serves to reduce the overall vulnerable area of subsystems. Major considerations for application of this technique are accessibility and maintenance requirements. The ease of accessibility should receive attention commensurate with the frequency of servicing or replacement action.

Duplicate and Separate. Redundancy of critical functions will provide greater reliability and assure continued operation. Duplicate components should be separated so that one projectile impact does not disable or kill both parts. Redundancy of critical systems is an important consideration when other survivability enhancement techniques would impose greater penalties in performance, maintenance, safety, or reliability. Examples of redundancy are multiple engines, dual flight control systems, and duplicate armament circuits. Consider the potential of secondary threat hazards such as fire, explosion, or structural deformation to cause failure of redundant elements. The routing of redundant critical hydraulic system lines should be planned so that structural spalling from a single hit by a high velocity projectile or fragment will not cause the simultaneous failure of both systems.

Eliminate. Frequently, vulnerability may be reduced by eliminating sophisticated components that are not absolutely necessary. Simpler design will result in smaller size and greater tolerance to damage. It is axiomatic that simplicity in design leads to toughness while sophistication invariably leads to increased vulnerability.

Miniaturize. This concept would expose a smaller target for the threat and may facilitate repairs or replacements in the field.

Modular Construction. A system designed in a modular fashion provides a capability for interchangeability and quick replacement of components or modules.

5.3 New Design Capability With Brittle Materials.

Developments in ceramic materials engineering and design capability over the past decade have led to the use of ceramics in the hot-flow-path components of gas-turbine engines. Precision-formed torso armor with complex curvature offers many applications in personnel protection against small caliber projectile impact. A capacity exists to massproduce high quality, shaped ceramics.

There has appeared a new generation of high-strength, low-density, thermally shock-resistant ceramics. With these new compounds, ceramics may be utilized in gas-turbine engines to increase engine efficiency.

5.4 Survivability Principles for Tank Design.

Within dimensional constraints there are alternatives for packaging the various components and functional systems that make up a tank. Certain principles developed in design of aircraft weapon systems can significantly reduce the inherent vulnerability of tank components and systems. These principles have already been identified as the ABC's of protection, as presented by BRL. While the tank problem is dramatically different from that of the aircraft with respect to the main threat caliber of weapon, some of the lessons learned still apply. There are also ongoing efforts to investigate ammunition vulnerability and the means to reduce that vulnerability to ballistic impact. Other efforts seek to redesign track systems to provide redundancy and develop propulsion systems with smaller, more powerful engines to reduce vulnerability while increasing mobility and agility.

The survivability of a tank can be greatly enhanced through the judicious use of engineering and design techniques to make components more resistant to combat damage. Vulnerability reduction must be a consideration throughout the complete design cycle of the tank. Not only should individual subsystems be made more resistant to ballistic damage, but the interaction of one vulnerable system with another must be considered throughout the design evolution with measures taken to maximize the total survivability of the tank.

Some guidelines for reducing tank vulnerability through design and engineering techniques follow:

- Locate main gun ammunition and fuel supplies outside the crew compartment, where feasible.
- Use spall suppression liners on the interior walls and floor of the crew compartment.
- Design sighting devices, secondary armament sytems, and attachments to minimize the debris in the crew compartment following the impact of a large projectile.
- Store ammunition so as to minimize effects on crew in case of ballistic impact on ammunition. Consider ammo storage in vented, explosion-safe compartments and/or in external areas.
- Isolate the main fuel supply from the engine compartment. Consider placing fuel (1) behind the front glacis, (2) under the floor of the engine compartment in the rear of the vehicle, or (3) in sponsons on the top rear deck.
- Provide for capability to dump fuel away from crew or engine when the fuel tank is hit.
- Consider fuel additives to reduce chances for ignition.
- Consider smaller lighter engines for tank propulsion.
- Consider turbine-powered, electric generator drive systems to permit simpler, split-track suspension systems.
- Provide redundant sighting systems.
- Add screen-type devices to cause premature functioning of fuzed munitions.
- Consider skirting plates as an add-on feature.

5.5 Vulnerability Reduction of Stacked Ammunition.

Ammunition stores are inherently vulnerable to combat-induced damage. The propagation of damage by fire and cook-off is always a danger in such circumstances. Stacked ammunition may respond adversely to kinetic energy impacts, blast-inducing weapons and heat-producing agents (e.g., napalm or white phosphorus).

Some practical methods for decreasing the vulnerability of stacked ammunition are:

- Bag the propellant charge in nylon bags or insert heavy wax paper liners between the propellant charge and the cartridge case.
- Select HE filler which is less sensitive to shock - or add desensitizing agents to shock-sensitive fillers.
- Select HE fillers with low flammability indices and high explosion temperatures.
- Separate fuzes from rounds until the rounds are ready to be used.
- Use noncombustible packaging materials.
- Apply fire-retardant paints to wooden storage boxes for ammunition.
- Impregnate wooden boxes under pressure with water solutions of selected chemicals to make the boxes less flammable.
- Use inside fiber containers with built-in fire-retardant features.
- Cover stacked ammunition with ballistic blankets.

5.6 Protection of Ammunition and Other Flammables.

The storage, handling, and transportation of ammunition and other flammables present problems whose solutions have always been elusive. Errors in judgment, carelessness, and lack of proper planning or discipline may result in tragedies of monumental consequences.

Some guiding principles for attacking the aforementioned problems follow:

- Whenever possible, an environment should be provided for flammables which avoids extremes of heat, cold, humidity, and abrasion.

- For storage, these flammables must have an adequate shelter, appropriate drainage, and proper ventilation.

- Priorities should be established for storing flammables and other sensitive materials. Thus, the most sensitive of these materials, such as fuzes, primers, boosters, pyrotechnics, and propelling charges, would be given high priority when storage facilities are heavily taxed.

- The most vulnerable items in storage should be surrounded with items that are relatively insensitive.

5.7 Survivability Value of Suction-Boost Fuel Systems.

The BRL has conducted experiments to compare the vulnerability characteristics of suction-boosted fuel systems with that of fuel systems which operate with positive pressure in the supply lines (the pressure developed from a centrifugal boost pump immersed in the fuel cell). When the fuel plumbing is damaged by bullets, helicopters with positive pressure in the supply lines often sustain disastrous in-flight fires. The alternate design, under test, uses engine-mounted fuel pumps which draw fuel to the engines under a suction head.

The investigation presented strong evidence that the vacuum system does not develop fires when the fuel supply lines are hit. Thus, the vacuum system could be used to reduce the vulnerability of many types of aircraft. BRL has investigated the possibility of using suction-type fuel pumps in new designs of aircraft and in retrofit applications.

The suction-type fuel system also increases the chances for surviving a crash by reducing the chances of a catastrophic fire and explosion should the aircraft crash. Furthermore, such systems have been found to have superior reliability and maintainability characteristics. In many applications, the suction-type fuel system has the additional advantages of lower cost and weight.

Whereas the first applications of suction boost fuel systems have been made in helicopters, some efforts are now under way to adapt this concept to surface vehicles.

5.8 Marine Corps Philosophy for Improving Helicopter Survivability.

The Marine Corps believes that helicopter manufacturers can do much to improve the survivability of present helicopters by increasing lift capability, range, and speed, and by certain other modifications.

The Marines are making the CH-46 more survivable with the following modifications:

- Replace the T58-10 engine with the T58-16 for more horsepower and speed.
- Add infrared engine suppression devices that are hydraulically operated. These devices mix ambient air with the exhaust plume.
- Insert a crashworthy fuel system.
- Insert crash-resistant seats. The armored seats will be mounted on shock absorbers for crash attenuation.
- Use ballistically tolerant rotor blades.

5.9 Reduction of Fire Hazards in Army Aircraft.

In the short period of less than 20 years, tremendous strides have been made to reduce fire hazards in Army aircraft. The fuel tanks have evolved from crude metal cans to light bladders to self-seal bladders which offer some degree of protection against nonexplosive 7.62, 12.7, and even 14.5 mm projectiles.

Crashworthy fuel systems with self-seal tank material and self-closing fittings have proved outstandingly successful in decreasing the likelihood of thermal fatalities during aircraft crashes. Such systems have been retrofitted into existing Army helicopters and are a requirement in all new helicopter development.

Fires in flight may still occur from impacts on self-seal fuel tanks by incendiary bullets. To counter the occurrence of such fires, inert plastic foams have been inserted inside the fuel tanks and into the voids between the outside skin and the fuel cell wall.

Since the engine compartment has been found to be the location of most fire starts, efforts to correct weak design points in that area may have big payoffs. The engine area must be sealed off to prevent the extension and growth of fires to other areas. Within the engine compartment, rubber and fabric flex lines should be replaced with steel-braided flex lines. Long flex lines should be replaced with solid stainless steel lines and short flex lines. Provisions should be made for any leaking flammable fluids to be collected and exhausted overboard. Engine mount struts should be reinforced so that they will be less likely to collapse during a fire.

Fuel systems should be isolated spatially from electrical systems. Batteries have been shown to be a weak point in the electrical systems of aircraft; when these units are overloaded, fires may develop. Aircraft crews require special training and instruction in the use of flares and ammunition since fires can be deadly in aircraft. Hazardous aircraft cargo requires special protection.

In summary, some guidelines for reducing fires aboard aircraft are:

- Place flammable fluid containers or tankage within the airframe to avoid leakage into potential ignition areas.
- Provide scuppers or drains to dump leakage overboard into areas where such leakage is not likely to be ignited downstream.
- Where structural compartments or voids adjacent to such containers cannot be avoided, provide fire/explosion suppressant materials or extinguishing systems to prevent the ignition or propagation of fires or explosions.
- Isolate oxygen systems from flammables. Where such isolation is not practical, provide structural containment or fire barriers.
- Provide fire suppression methods in those areas, such as an engine accessory bay, where a sustained fire would cause loss of the aircraft.

5.10 Ballistic Blankets -- Flexible Armor.

Commercially available materials such as nylon and Kevlar can be used to fabricate ballistic blankets. The number of plies and the dimensions can be adjusted to meet many given applications.

These blankets are examples of parasitic armor - materials that may be emplaced as needed - and then easily removed when the need no longer exists. Some examples of applications of ballistic blankets follow:

Artillery propellant in the open. In a typical combat-ready field artillery position, propellant canisters may be stacked in the open, readily available for use. These canisters are vulnerable to projectile impacts which may cause violent reactions resulting in the spewing of debris and burning propellant over the nearby area. The products of such reaction may injure personnel, initiate fires and cause similar reactions in other canisters. One method considered to reduce the vulnerability of such canisters employs ballistic blankets.

Field tests were performed to investigate the usefulness of ballistic blankets in protecting propellant canisters. Without protection, one burning canister in a stack was found to result generally in the loss of one to nine canisters. Furthermore, a burning canister normally causes forceful scattering of canisters, canister lids, burning propellant, and unburned propellant over a wide area.

The use of nylon blankets (10' x 12', weighing about 150 pounds) provided total containment of those objects which are otherwise forcefully scattered about. A burning canister may possibly ignite the nylon blanket, but the resulting fire is easily extinguished with water.

It is concluded that the use of ballistic blankets over stacks of artillery rounds can add significant survivability value to a field artillery battery in two ways:

- through containment of fires caused by ballistic impact on projectile stacks.

- through direct ballistic protection.

Blanket design may be optimized with respect to size, shape, weight, and material. The blanket may not prevent all damage but its presence may decrease the extent of damage to tolerable levels.

Shroud for artillery weapons. Parasitic armor in the form of Kevlar or nylon blankets is under consideration for protection of certain artillery weapons and crews. For example, the XM-204 105mm Howitzer may be outfitted with a ballistic shroud. The shroud would cover the entire assembly except for the front and breech sections of the tube and the panoramic telescope. Fittings welded to the front of the carriage would keep the shroud clear of recoil effects. The shroud would provide additional benefits in the areas of camouflage and weather insulation.

Reduction of spall damage. Ballistic blankets are under consideration for reducing the spall threat to personnel and/or cargo within an M113. Such spall occurs when armor-piercing projectiles impact the external shell of the vehicle.

To indicate the potential of parasitic armor in reducing spall damage, an experiment was designed to determine how many of the spall fragments formed from the impact of 14.5mm armor piercing incendiary tracer (APIT) projectiles on 1.75" aluminum armor (M113 side armor) could be stopped by the protective blanket. The striking speed was 3400 fps, and the impact was set for normal obliquity. The collecting material was nylon, set at various distances up to one foot from the impacts. After each firing, the spall particles which penetrated the nylon blanket were counted.

Table 7 displays the results of the experiment. As many as 73 particles are generated from a typical impact. The number of plies and the spacing determine the efficiency of the blanket. Apparently the best case, from the point of view of protection, is a 24-ply nylon blanket placed one foot from the impact. (No attempt was made to determine the optimum number of plies or the optimum spacing). This arrangement permitted the blanket to catch and retain all the spall particles formed from the impact. The main slug of the projectile passed through the blanket in each case.

Figure 4 shows a sectional view of the M113. According to the experimental evidence, emplacement of two vertical 24-ply nylon blankets parallel to the lateral sections at the dashed lines located in the schematic would provide complete protection from 14.5mm APIT spall particles.

Kevlar shows promise as a spall catcher when used as an inside liner for aluminum armor. The number of plies that are used would depend on the anticipated threat and the application. Tests have demonstrated the advantage of aluminum alloy/Kevlar over bare aluminum alloy under impacts by shaped charge projectiles. (See report of preliminary tests of Armoflex-Kevlar Armors, FMC, Oct 23, 1974).

Developers and users should find many situations where spall-catching materials such as Kevlar, properly used, will save lives and equipment in combat situations.

Protection for TOW on M113. The TOW system (hardware, gunner and assistant gunner) on the M113 and on the ground is vulnerable to fragments from high explosive munitions. A versatile kit was developed to decrease such vulnerability. Figures 5 and 6 show the APC without and with the kit, respectively.

Table 7 Spall Data

1.75 inch Al. Armor vs 14.5mm APIT

Suppression Material (Nylon)	Spacing (Inches)	Number of Frags Penetrating Blanket
24 Ply	0	73
24 Ply	1	63
24 Ply	3	7
24 Ply	12	0
12 Ply	12	3

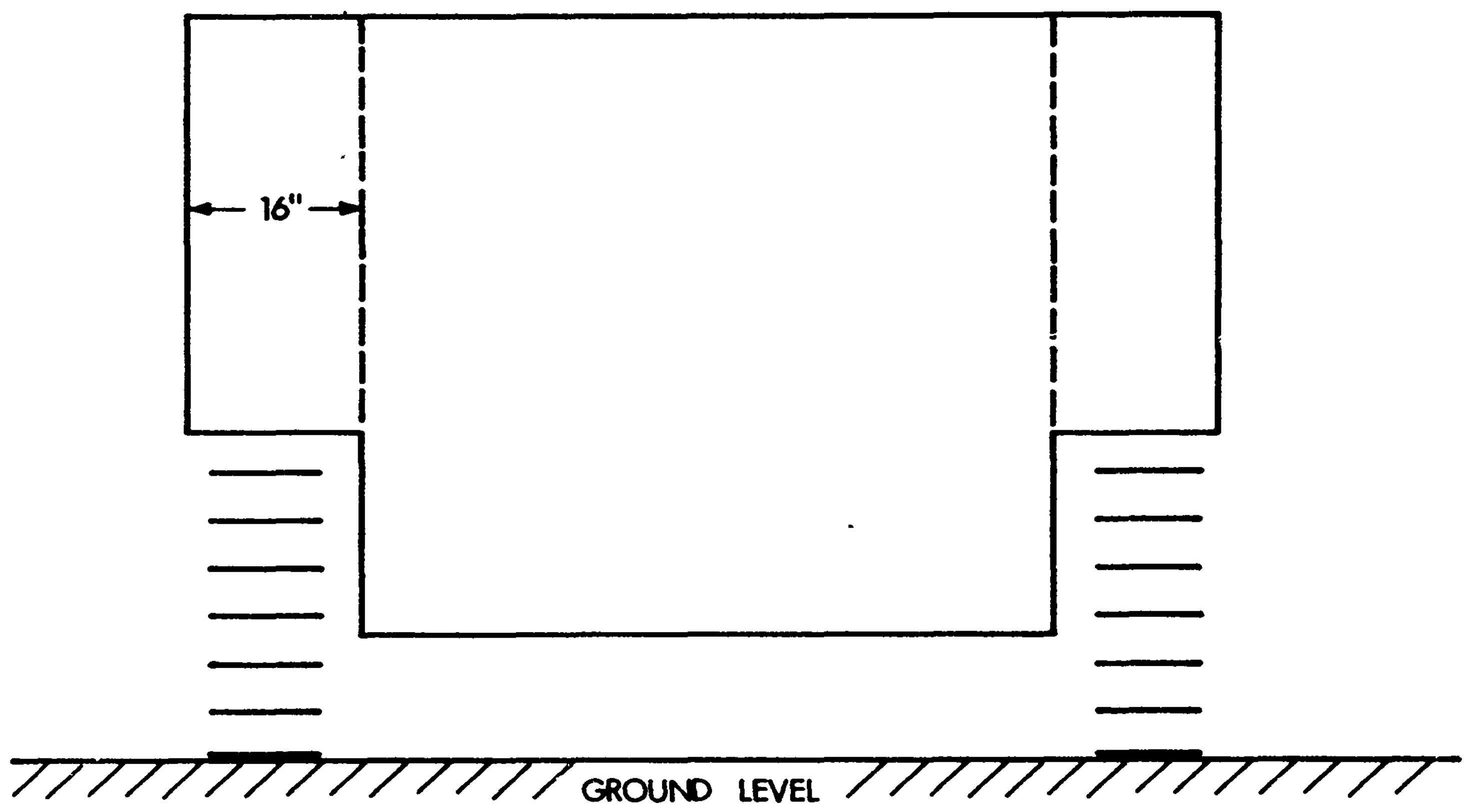

Figure 4. Sectional View of M113.

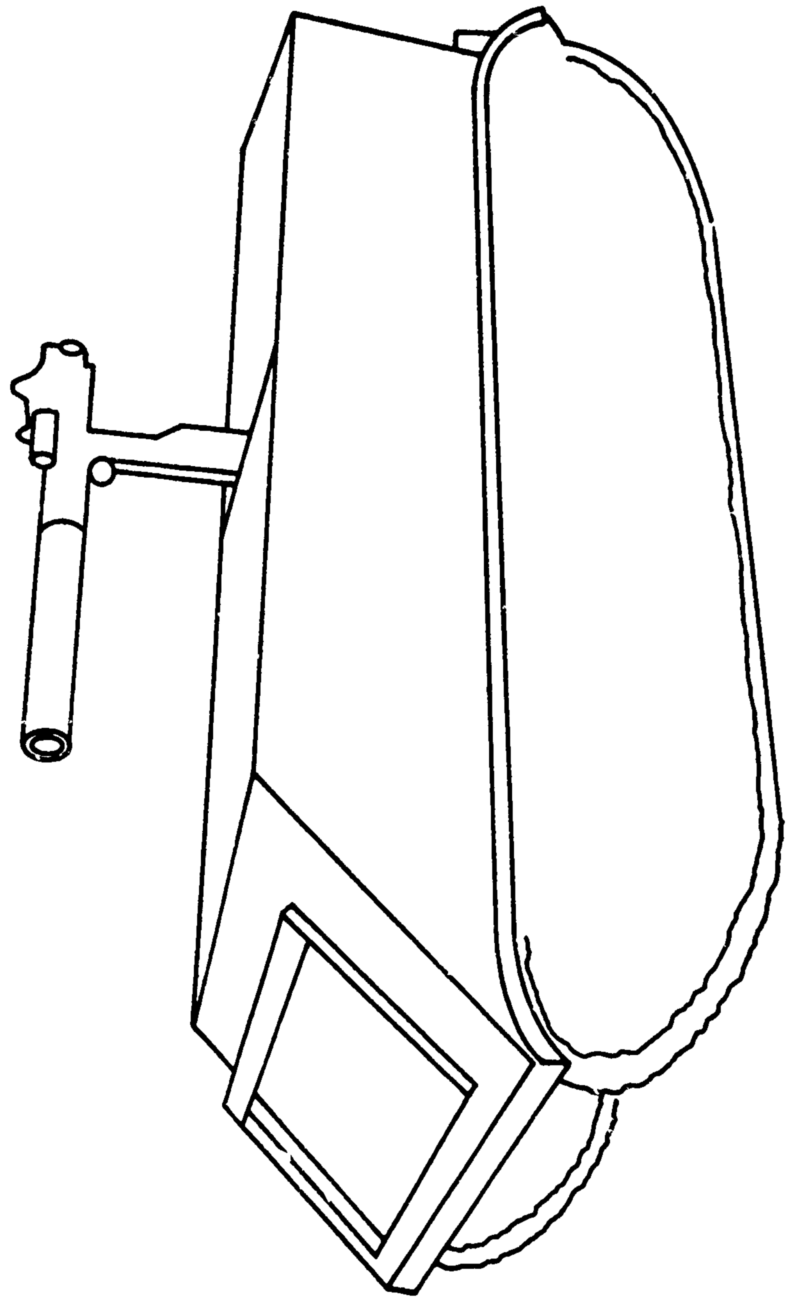

Figure 5. Sketch of APC/TOW

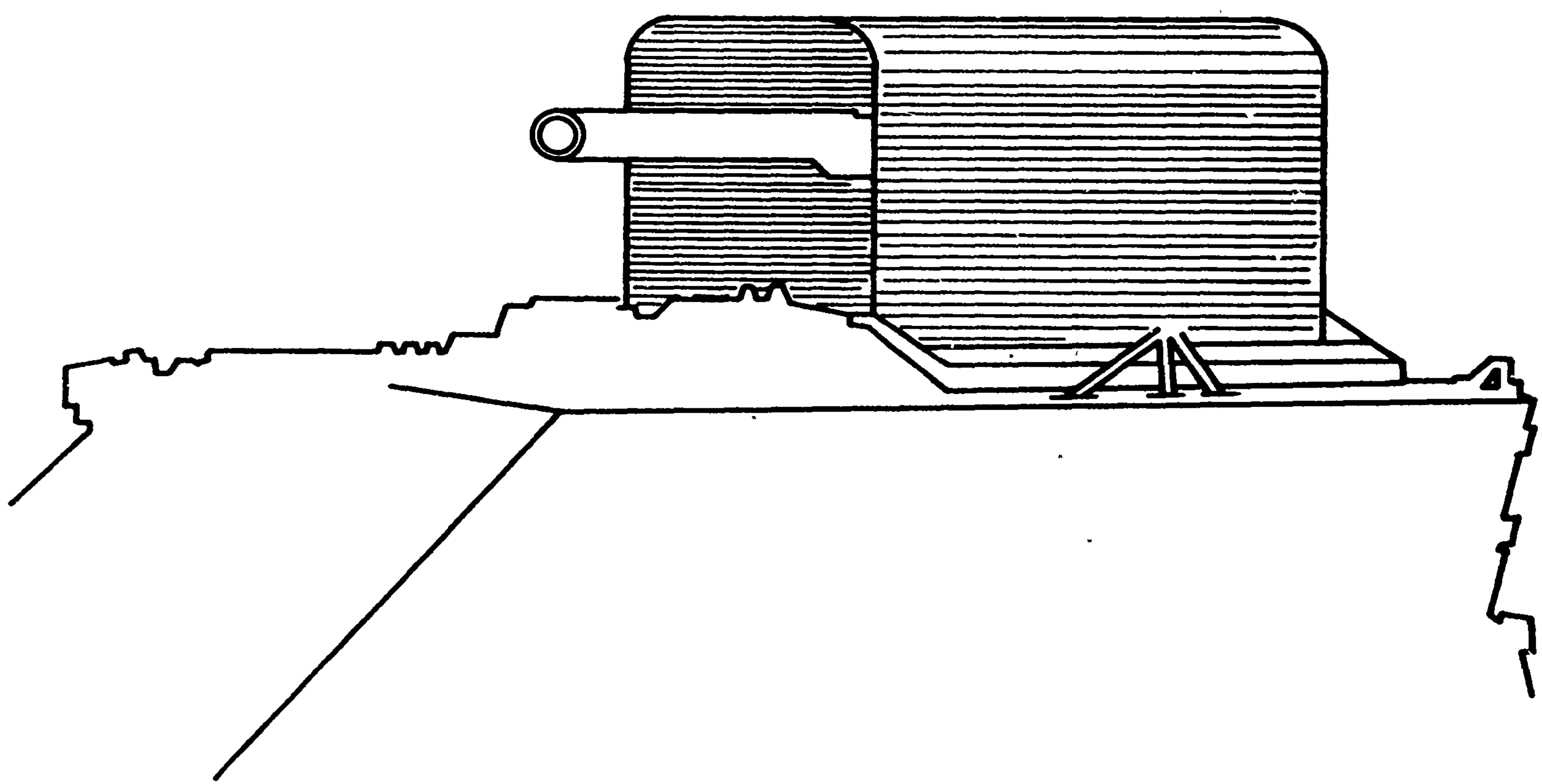

Figure 6. UAT Ballistic Blanket Concept – Canopy Up.

The kit consists of easily and rapidly erectable and removable frame and nylon blankets. The kit is relatively lightweight and can be transferred by the crew from the vehicle to a ground-emplaced TOW within several minutes.

The degree of protection varies with the number of plies of nylon in the blanket. Table 8 offers estimates of the percent reduction in vulnerable area of the TOW system on the M113 from the use of various thicknesses of blankets. For example, 48 plies of 714 Standard Ballistic Nylon offer almost as much reduction in TOW vulnerable area to fragment impacts as 1.5 inches of aluminum alloy. In fact, for fragments weighing less than 60 grains, the 48-ply nylon offers as much protection as aluminum alloy weighing four times as much[Other synthetic materials, such as Kevlar, may offer greater protection than nylon. Similar protection may be provided to other systems where blanket type materials are applicable.

Protection of Communications and Electronics Equipment. The vulnerability of several communication and electronic items to various artillery threats has been analyzed, and means to reduce this vulnerability have been explored. The items and their functions are:

- PRC-25/77 Backpack Radio is carried by a radio-telephone operator and provides communications capability within the squad and platoon.

- S-250 Shelter (Carrying the TRC-145 Communications Van) is transported by a truck and can accommodate any of several electronics packages.

- Weapon Control Unit (WCU)-PATRIOT Control Van provides radar control, performs the data processing function for the fire control group, and controls and initiates launch commands.

Although it may not be practical to protect these items of materiel against small caliber projectile impacts, several types of protective material might offer ballistic protection to steel fragments from mortars and larger projectiles. A practical range of areal densities was determined for the protective material under test.

The material selected for this study was a glass-reinforced plastic known as Woven Roving Fiberglass (WRF). Three thicknesses of this material were selected for the experiment - corresponding to areal densities of 40, 80, and 120 oz/ft^2, respectively.

Table 8 Percent Reduction in Vulnerable Area

0° Elevation*
3000 fps } Impact Conditions

Fragment Mass (Grains)	16 Ply Nylon	32 Ply Nylon	(4.8 lb/ft²) 48 Ply Nylon	(21 lb/ft²) 1.5 inch Al	Maximum Percent Reduction**
1	34	56	59	59	59
5	28	51	58	58	58
15	24	46	55	57	57
30	18	42	56	57	57
60	11	32	51	57	57
120	7	24	47	57	57
240	5	16	42	56	57
500	3	10	31	54	54
1000	2	5	18	6	49

*Horizontal impacts of various obliquities.

**Assumes no fragment penetration through TOW cap material.

The protective material WRF offered considerable protection against fragments of assumed threats with the extent of protection increasing with the areal density of material used. For example, the survivability of the TRC 145 can be increased substantially by the addition of WRF panels.

Armor Vests for Personnel. The military forces are constantly seeking flexible armoring materials which may display greater resistance to penetration than the standard armor vests now in use. The Army currently uses a 9-lb, 12-ply nylon vest while the Marine Corps prefers the 11-lb M-1955 armor vest.

In 1973, HQ DA approved a Materiel Need (MN) for a Personnel Armor System for Ground Troops. Casualty reduction was ranked in the MN as the characteristic which warranted highest priority.

From this program, a fiber developed by DuPont (known commercially as Kevlar 29) shows considerable promise for use in body armor. A comparison of constructional features of Kevlar 29 and nylon fabrics is shown in Table 9. The nylon properties reported in the table reflect the values shown in military specification MIL-C-12369E dated 25 July 1968. The Kevlar 29 data are as measured in the laboratory and/or certified by the manufacturer. No military specifications exist for Kevlar fabrics.

For the purposes of ballistic evaluation, the above fabrics were formed into layered panels. With Kevlar, 32 plies were needed to achieve the desired areal density while only 12 layers of the heavier nylon fabric were required.

The casualty reduction potential of Kevlar 29 was compared with that of the Standard Army nylon vest. The basis for the comparison was ballistic test data for right circular cylinders fired against these materials. The cylinders used in the firings had length-to-diameter ratios of unity, varied in weight from 2 grains to 64 grains, and hit the target materials with velocities approximating those from actual munitions. After each firing, the target (1.17 lb/ft^2 in areal density) was examined to determine whether the penetration had been complete or partial. In the cases of complete penetration, a residual velocity was also recorded.

Although the results of the firings are classified, the results clearly show a decided advantage of the Kevlar 29 fabric over the standard nylon fabric under ballistic impact.

Such tests, procedures, and results provide a basis for improving the current armor vests. The end result will be fewer fatalities and fewer serious wounds for our personnel in combat.

Table 9 Some Constructional Features of Kevlar 29 and Nylon

Fabric Properties

Fabric Property	Kevlar 29	Nylon
Weave	8 harness satin	2 x 2 basket
Areal Density (oz/sq yd)	5.0 - 5.1	13.5 - 15.0
Yarns/Inch, W x F	50 x 50	46 x 42 (min)

Yarn Properties
(for both warp and filling yarns)

Yarn Property	Kevlar 29	Nylon
Polymer Type	Aromatic Polyamide	Aliphatic Polyamide (Nylon 66)
Nominal Denier	400	1050
Number of Filaments	267	175
Number of Plies	1	1
Twist (turns per inch)	2-4 "Z"	2-4 "Z"

5.11 Vulnerability Reduction of Helicopter Rotor Blades.

Rotor systems of helicopters provide a significant portion of the presented area of the entire helicopter. Rotor blades often receive more fragment and projectile hits than other systems when helicopters operate in a combat area. Current Army helicopter rotor blades are made of conventional metals such as aluminum and steel; damage to such blades resulting from ballistic impacts tends to propagate and become more severe. Aircraft can not withstand the high structural loads resulting from the loss of a major portion of a single blade. Vibrations and forces from rotor imbalance can destroy an aircraft in a matter of seconds.

The main rotor blades constitute an essential system for any helicopter; the loss of a small portion (less than 3 percent) of the span segment of any blade is sufficient to prevent continued flight. Any damage to the main rotor blades may induce severe vibrations in the aircraft.

Figure 7 relates loss of spar materials in composite and metal blades to safe remaining flight time. Note the greater tolerance to ballistic damage of composite blades over the traditional metal blades.

Current efforts to reduce the vulnerability of helicopter rotor systems focus on the following:

- Increase rotor blade tolerance to ballistic damage.
- Modify (increase or decrease) size of blade to decrease effectiveness of main threat.
- Select optimum number of blades in view of anticipated threat and kill mechanisms.
- Utilize high strength metals and composites with characteristics that strengthen rotor blade structures altogether.
- Consider fan-in-fin concept for tail rotor or pursue designs which eliminate the tail rotor system.
- Utilize blade geometry which forms multiple or alternate load-bearing paths while inhibiting damage propagation.

Incidentally, proper design of rotor systems will also address the noise problem. The characteristic noise generated by helicopter rotors provides a loud alert to enemy forces in the combat area. Although much of this noise is a necessary evil, the noise may be minimized with proper attention to the number of blades, blade chord size, blade span, and airfoil.

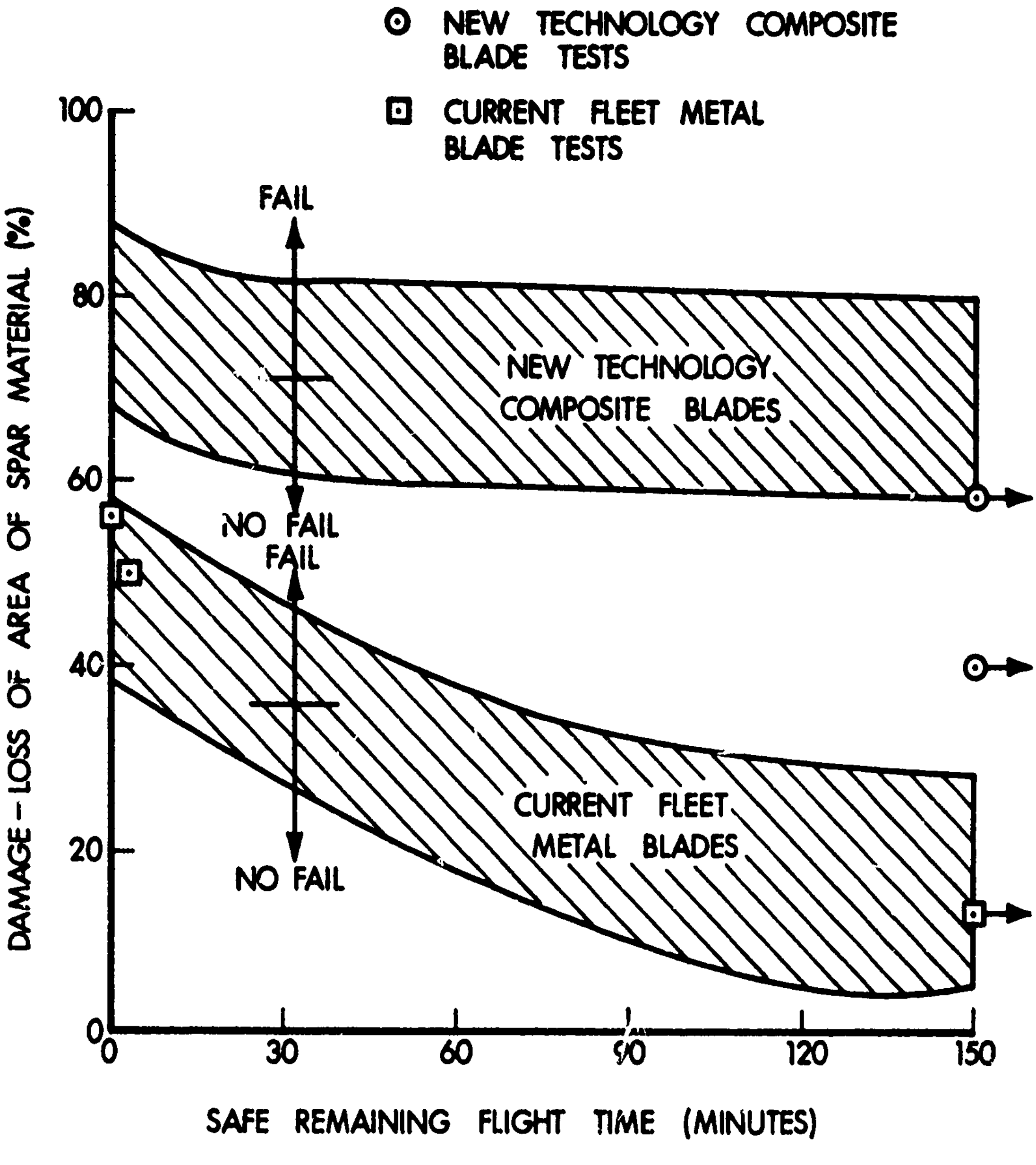

Figure 7. Influence of Blade Material on Damage Tolerance.

The developer should consider the selection of a blade material with low radar reflectivity.

5.12 Redesign of Tank Hatches on Armored Vehicles.

Tank commanders have sustained a high number of casualties in recent wars. In one fierce war where tanks played a major role, over 25 percent of the actively participating tank commanders were wounded; in 40 percent of these cases, the wounds were fatal. Most of the wounds were inflicted while the tank hatches were open. The main threat to tank commanders is air-bursting munitions.

In most tanks, the hatch is hinged at the rear. The tank commander opens the hatch to obtain better and direct vision. In the process he exposes himself to the threat.

A simple redesign of the hatch cover (see Figure 8) allows the hatch cover to be lifted vertically. The opening permits direct vision by the tank commander but provides protection from airburst fragmenting munitions by virtue of the position of the hatch cover.

This principle has already been adopted on some M48 tanks, but could be applied with equal benefit on the M60, the M113, M551, and the MICV to protect all armor crew members who have occasion to expose themselves through open hatches. The cost of this redesign feature is relatively small and there is no significant weight penalty.

5.13 Eye Protection for Armored Vehicle Crewmen.

Among wounds which have been reported and categorized in recent wars, the frequency of eye wounds is increasing steadily. In World War II, only 2 percent of the wounds were described as eye wounds. In Korea, this percentage was reported as 2.7 percent. In a more recent war, this percentage increased to almost 7 percent of all wounds. A breakdown of recent data reveals that about three-quarters of the eye wounds occurred among members of armored units, about one-half more specifically among tank crew members. Even more specifically, about one quarter of the eye wounds were sustained by tank commanders. Most of these eye wounds have been traced to secondary fragmentation (spall or debris). These wounds may or may not have been fatal, but they probably were incapacitating because eyes are extremely sensitive.

Lenses made from 2mm thick polycarbonate (material and thickness currently used for aviator eye shields) can provide significant protection against primary (emanating from the munition) and secondary fragments. For example, at 100 feet from detonation such lenses will provide eye protection from the majority of fragments from several Soviet high explosive munitions.

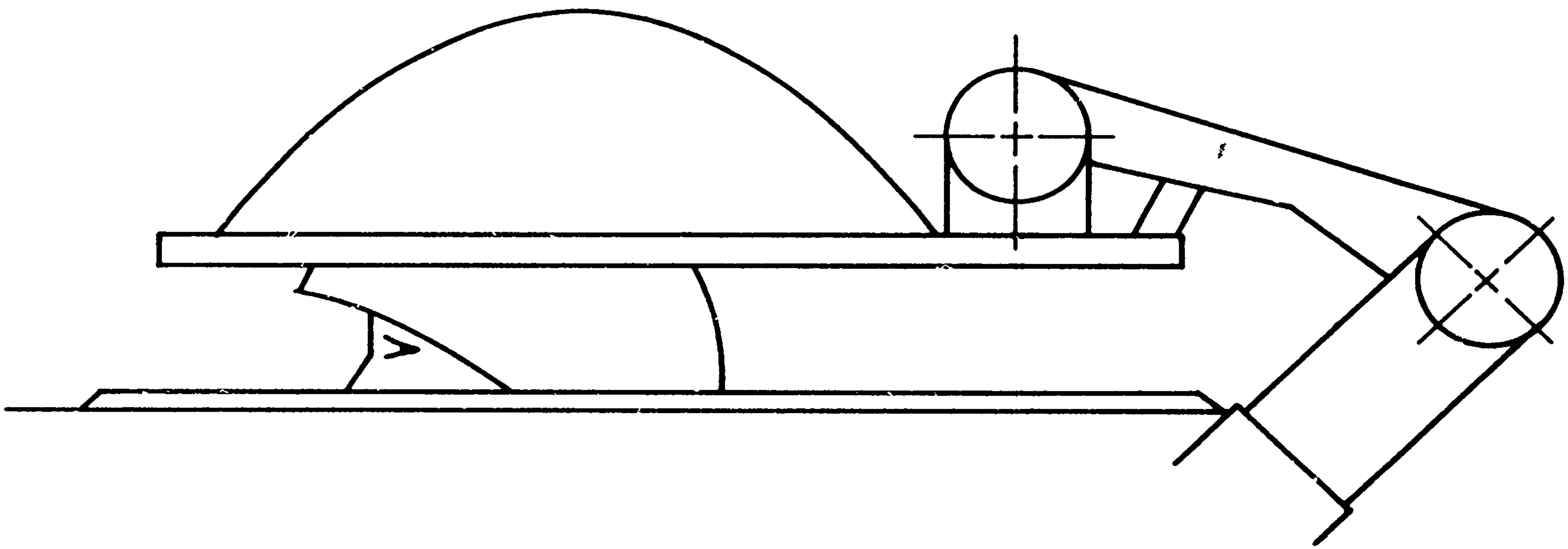

Figure 8. Proposed Tank Hatch Redesign.

5.14 Fuel System Design for Survivability.

Survivability of combat vehicles is affected by the type of fuel, location of fuel tanks, size of fuel tanks, fuel cell material, fuel-feed principle, and many other features. Weight always is a factor for consideration.

Fuel system components include all components necessary to store the fuel and move the fuel to the engine. Typical components are fuel tank, filters, fuel lines, fuel/engine oil heat exchanger, cross-over lines, and booster or suction pumps.

Each of these components may be damaged by blast, projectile/fragment impact, crash or violent impact of the parent system. Often, the booster pump may be buried within a fuel tank and thereby derive some protection from the surrounding fuel. Components may be shielded, armored, or routed so as to achieve added protection from specified threats.

Self-sealing may be utilized - but only with the penalties in performance resulting from the added weight. Table 10 provides estimates of the weight per unit area of various types of fuel cell materiels.

Various means are available to cope with the air spaces adjacent to the fuel tanks and above the fuel level within the tank. Such actions are important to prevent the formation of pockets of fuel/air mixtures that may contribute to disastrous fires or explosions caused by impacts of incendiary projectiles. Some of the methods utilized to counter the danger of these air pockets are:

- Nitrogen gas
- Foams
- Fuel cell designed as part of external structure
- Fuel cell mounted externally
- Fuel cell bladders designed to collapse as fuel is consumed

5.15 Rendering Fuels Fire-Safe via Additives.

Some preliminary tests by BRL concerning the addition of halogen compounds to diesel fuel have been promising and suggest further work in this area.

Table 10 Specific Weights of Fuel Cell Materials

Fuel-Cell Material	Specific Weight (lb/ft^2)
Light Bladder	0.1 - 0.2
Ram-Proof	0.3 - 0.4
Crash-Resistant	0.1 - 0.7
Self-Seal (Caliber .30)	0.4 - 0.7
Self-Seal (Caliber .50)	1.2 +

The goal of such studies is to alter the flammability characteristics of fuel so that the resulting product acts as a fire extinguishing agent under open combustion conditions and still functions as a fuel by burning in an engine.

If this goal is ever achieved, combat vehicles can be more efficiently designed. Since the fuel itself would offer some protection, the fuel could replace some of the armor and might be used to protect the ammunition. Furthermore, the vulnerability of bulk storage systems for fuel would be significantly reduced.

AMSAA has contacted many of the industrial experts in the field of fuels and fuel additives for a solution to this problem. Some preliminary findings of this effort are summarized below:

- Some degree of fire retardation has been observed by the addition of bromine compounds and by the pressurization of the fuel.
- Some additional additives combined with the bromine may increase the degree of fire retardation even further.
- Further investigation should establish the best additives, the concentration level, and effects of these additives on fuel combustion in the engine, and the toxic and corrosive properties of the new fuel product along with related problems.

5.16 Resistance of Materials to Ballistic Impact.

One of the important factors in the choice of materials for the design of military equipment is resistance to ballistic impact. Understandably, there are other material characteristics which, on occasion, may be so critical in a particular component that it may be necessary to choose a material that does not have high resistance to ballistic impact.

Many materials are available today that did not exist a decade ago. These materials may be fibrous, monolithic, or composite. Some, such as Kevlar, show remarkable potential for use as ballistic blankets and panels.

During the 1960's, a large-scale effort was initiated by the Ballistic Research Laboratories to furnish ballistic experimental data for steel fragments and for small caliber projectiles impacting on a variety of basic materials of interest. The experimental data were analyzed in a series of Project Thor reports*.

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*See Bibliography found on page 81.

In these reports, perforation data related to the impact of steel fragments on each of ten metallic and seven nonmetallic materials were collected and analyzed. The experimental data are characterized by fragment sizes from 5 to 825 grains, striking velocities as high as 12,000 feet per second, and obliquities (angle measured from normal to surface of impact) of strike as high as 80 degrees. Empirical formulas of a given type were fitted to the data for each target material, thereby relating residual velocity and residual weight, in separate equations, to important impact parameters.

The two sets of estimating equations, used together, served as a basis for several extensions or applications: (1) the determination of impact conditions for which the fragment disintegrates during perforation, (2) a comparison, for equal weight per unit area of target materials, of the resistance of target materials to perforation, (3) a calibration of the resistance of a target material to perforation in terms of the maximum thickness of a standard medium that the residual fragment can perforate, and (4) a more realistic consideration of the effect of a barrier on the potential of the fragment to damage a primary target behind the barrier.

From the empirical equations that were developed, a series of useful graphs was produced which a designer could readily interpret for his own purposes. For example, Figures 9 and 10 relate thickness in inches of material to the areal density of the material in pounds per square foot. These figures permit a comparison of the various metallic and nonmetallic material on an equal weight per unit area basis.

Figure 11 shows a typical V_0 graph, where V_0 represents the analytical estimate of the minimum impact velocity at which perforation is anticipated. Such graphs were produced for various target materials and angles of obliquity of impact.

Figure 12 shows a typical graph which provides estimates of fragment residual weight and velocity after perforating a given target. Such graphs were produced for various target materials, angles of obliquity of impact, and selected fragment weights.

With the tools provided by the organized presentation of estimates of material resistance to fragment impact, the developer is assisted in rendering decisions concerning the optimum choice of materials in various applications.

An experimental/analytic effort, similar to that which produced the Thor reports, is now needed with respect to many of the new candidate materials (fiber, monolithic, and composite) so that the developer may continue to have a logical basis for selecting a "best" material for a given application.

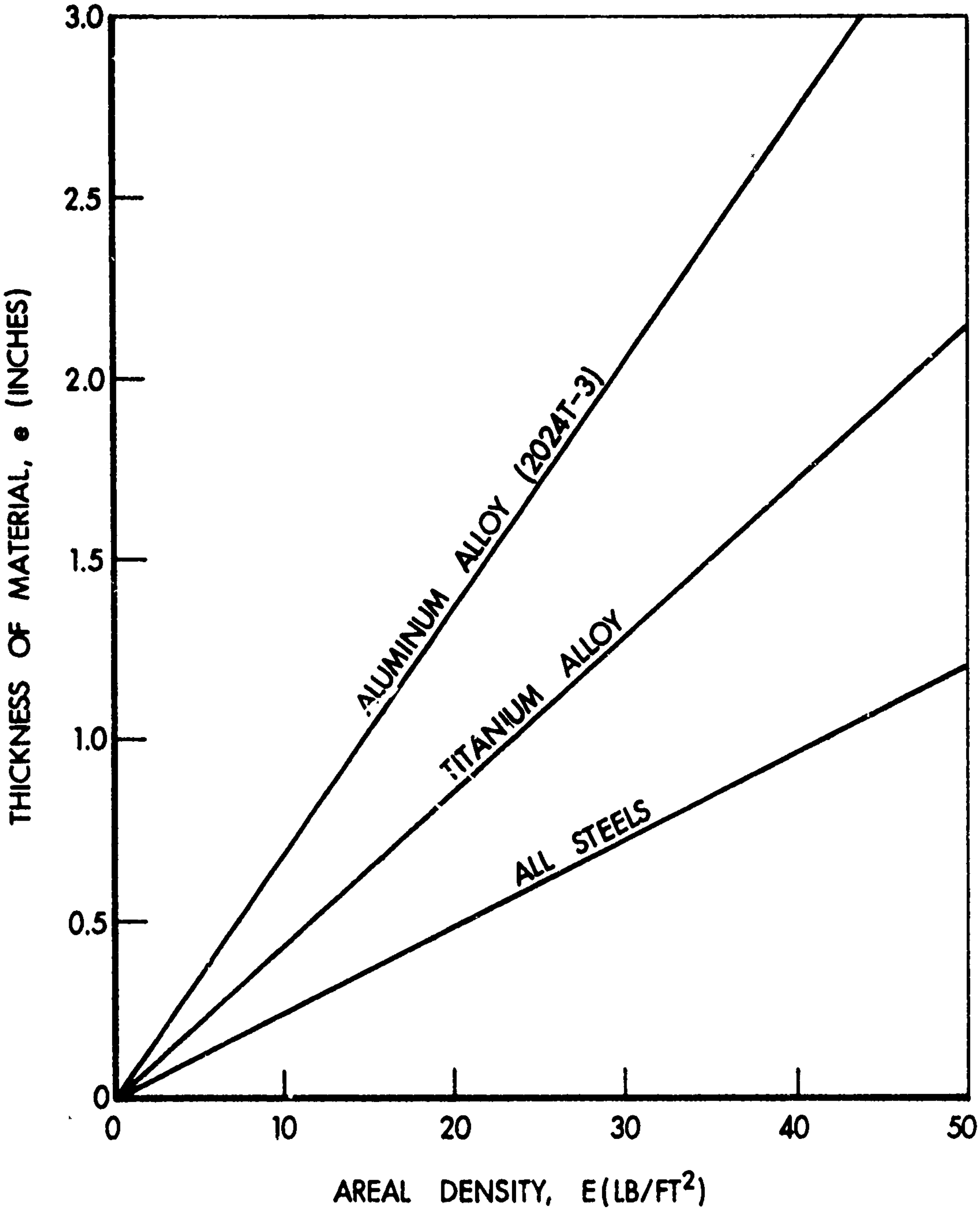

Figure 9. Thickness of Metallic Target Materials vs Areal Density.

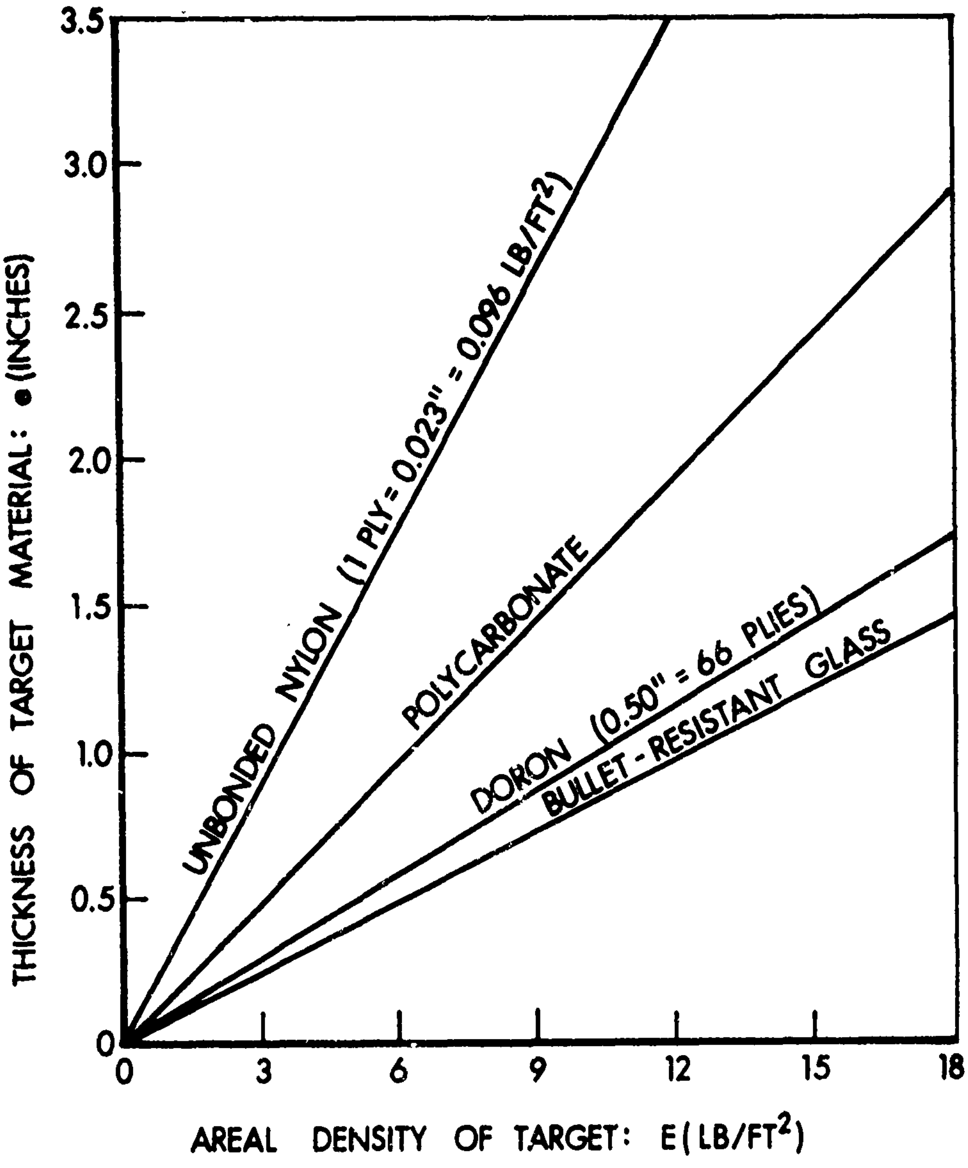

Figure 10. Thickness of Non-Metallic Target Materials vs Areal Density.

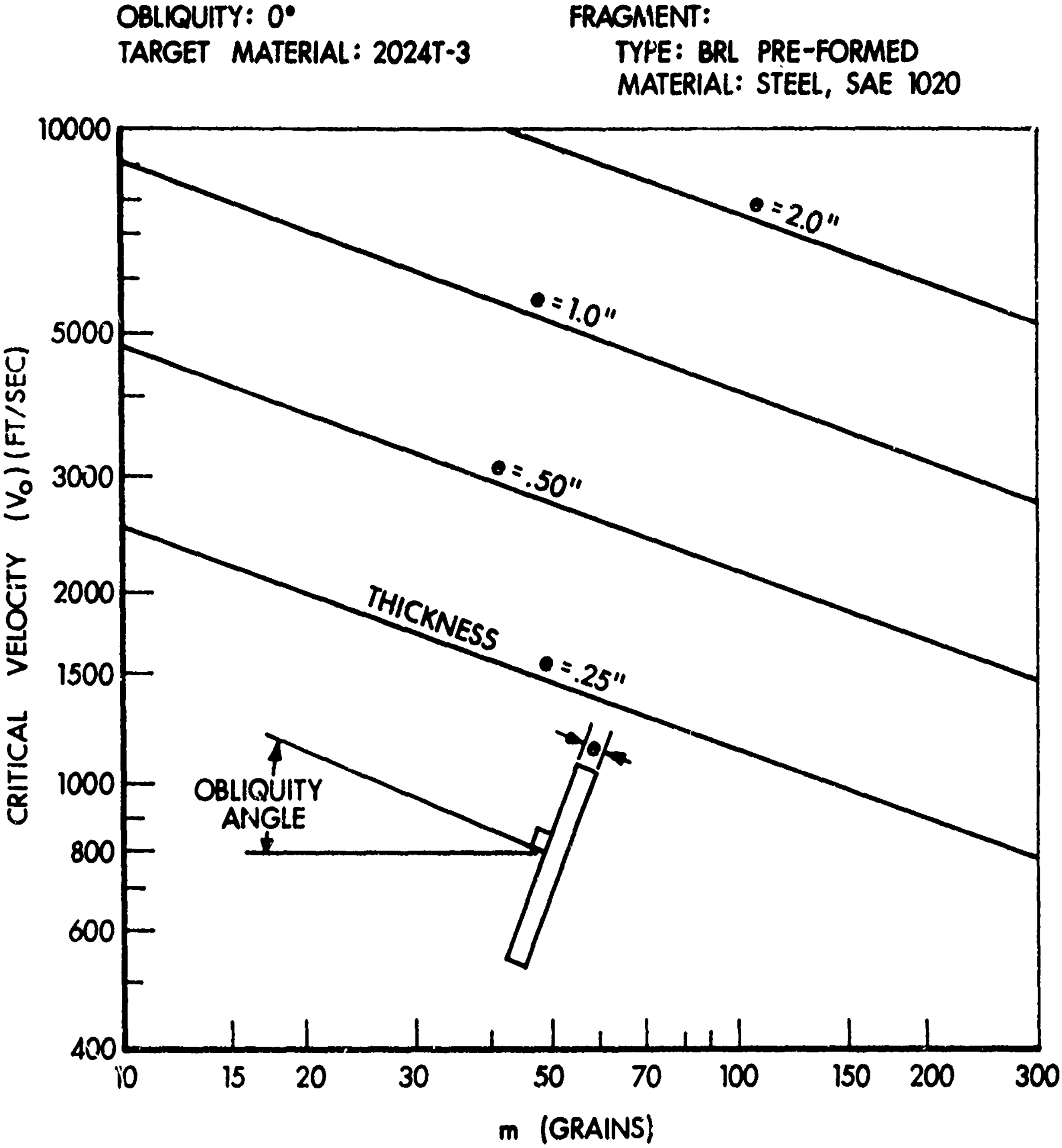

Figure 11. V_O vs Fragment Weight for Selected Target Thickness.

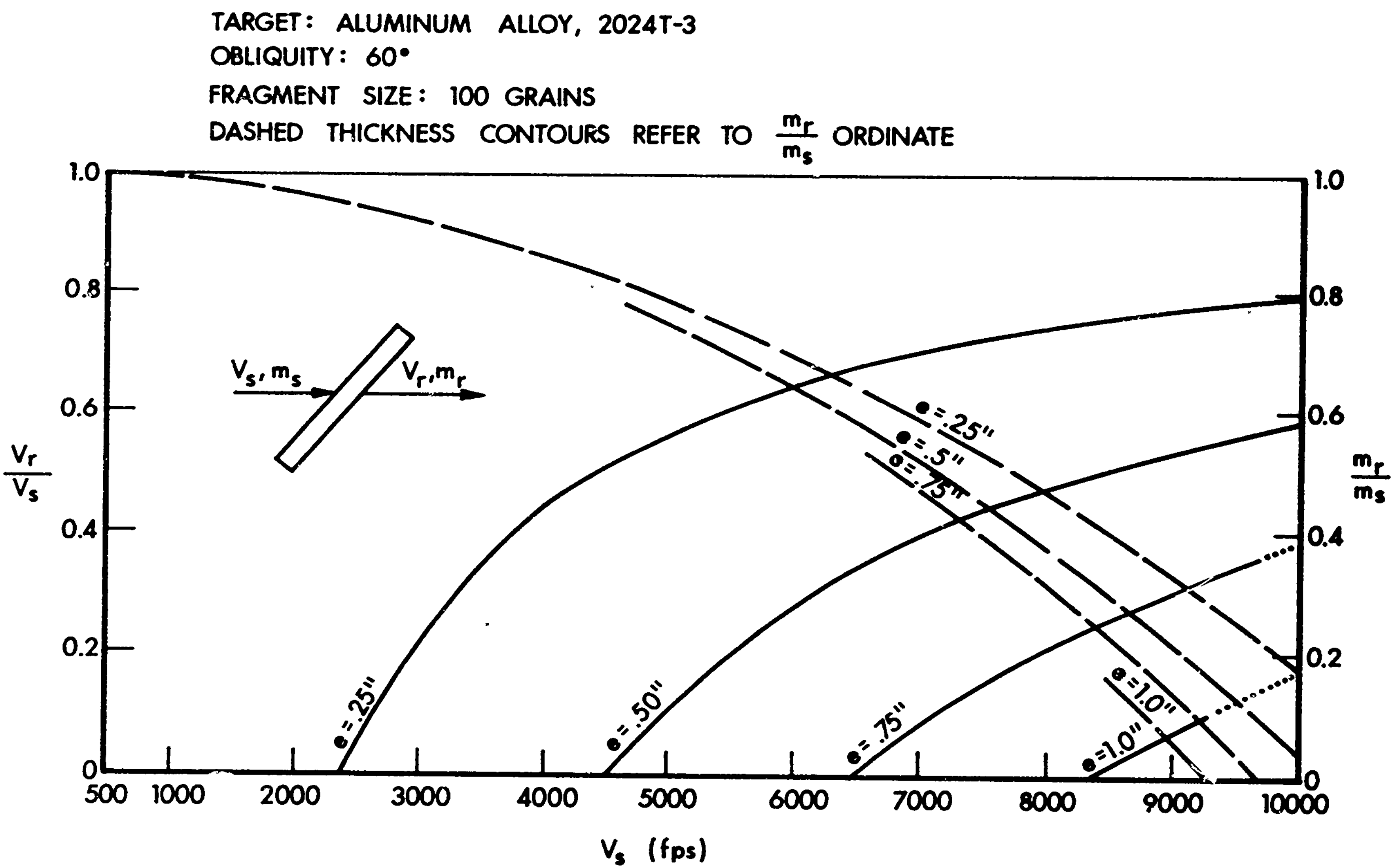

Figure 12. $\frac{V_r}{V_s}$ and $\frac{m_r}{m_s}$ vs V_s for Selected Target Thickness.

5.17 Chemical Defense.

Protection for our equipment and personnel against chemical/biological attack has received little attention. Equipment design, doctrine, and training are areas with great potential for improving the survivability of our materiel and personnel in this environment. Observed weaknesses where survivability principles should be applied include:

- Military personnel have difficulty using optical equipment while wearing protective masks,
- There is a lack of chemical defense equipment on military vehicles.

The threat of chemical/biological weapons is a subject of such great importance that it deserves separate examination from the viewpoint of survivability and survivability enhancement.

5.18 Status of Research in Vulnerability Reduction.

The status of research efforts related to vulnerability reduction is reflected in Tables 11 and 12. These efforts should result in an enhancement of survivability of military hardware.

6. REPAIRABILITY

Repairability is defined as:

THE CHARACTERISTIC OF MILITARY EQUIPMENT
WHICH DETERMINES HOW READILY AND EASILY
THAT EQUIPMENT IS REPAIRED OR REPLACED
WHEN IT SUSTAINS COMBAT DAMAGE.

6.1 General.

The characteristic of repairability for an item is formed during the design stage. With respect to survivability, repairability relates explicitly to the functions involved in the repair of end items and their components damaged in combat. When the routine functions of

Table 11 Survivability Enhancement Measures That Have Been Implemented — Vulnerability Reduction

Item	Measure Taken	Stage of Life Cycle at Which Measure was Implemented	Benefit Observed (O) Expected (E)
M48	Redesigned tank hatch	Fielded item	Reduction of vulnerability to VT-fuzed artillery and better vision for tank commanders (E)
M113	Armor kit	Fielded item	Reduced vehicle damage and personnel casualties to mines (O)
M551	Armor kit	Fielded item	Reduction in crew casualties and in vehicle damage from mines (O)
M551	Redesign of 152mm cartridge case	Fielded item	Reduction in breakage under shock of mines and therefore reduction in fire potential from spilled propellant (E)
M48A3	Diesel engine installed	Fielded item	Reduction in fuel flammability (O)
TOW	Fragment shield	Fielded item	Will reduce fragment damage to TOW and crew of TOW (E)
Jet Fuel	Fuel additives	Fielded fuels (JP-4)	Reduced flammability (O)

Table 11 Survivability Enhancement Measures That Have Been Implemented — Vulnerability Reduction (Cont)

Item	Measure Taken	Stage of Life Cycle at Which Measure was Implemented	Benefit Observed (O) Expected (E)
CH-47, OV-1	In-flight Integral Fire Suppression System	Design/development	Many in-flight engine fires extinguished — some aircraft and crew saved (O)
OH-58	Inerting air pocket around fuel cells	Design, field	Fewer fires will be caused by incendiary projectile impact on fuel cells (E)
OH-6	Crashworthy airframe	Design/development	Fewer fatalities resulting from crashes (O)
UH-1H	Crashworthy fuel system	Fielded item	Drastic decrease in frequency of post-crash fires and thermal fatalities to crew (O)
UH-1H	Strengthened structure	Fielded item	Structure withstands greater stress and resists damage (E)
AH-1G	Lightweight armor	Design/development	Reduction of vulnerability of pilots and critical components (O)
AH-1G	Caliber .30-qualified fuel system	Fielded item	Less vulnerable to combat damage (E)
AH-1G	Caliber .50-qualified fuel system	Fielded item	Less vulnerable to combat damage (E)

Table 12 Survivability Enhancement Measures for Consideration — Vulnerability Reduction

Item	Measures under Consideration	Expected Benefit
Aircraft	Advanced structure design concepts and composite materials, fiberglass rotor blade, composite material rotor hub, composite fuselage, composite tubular rotor, composite transmission housing, boron rotor blade	Reductions in maintenance, in vulnerability, in fatigue of components
Aircraft	Fire-safe fuels	Fewer fires in flight
Aircraft	Ballistically tolerant flight controls such as the bellcrank on the AH-1G	Reduced vulnerability of controls
Aircraft	Improved crash survivability - crashworthy fuel system	Fewer injuries to personnel, reduced damage to aircraft
Aircraft	Improved cargo restraints	Fewer crew injuries under crash conditions
Aircraft	Crashworthy armored seat for helicopter crews	Fewer crew injuries
Aircraft	Ducted replacement for tail rotor	Reduced vulnerability to foreign objects and fewer injuries to personnel
Aircraft	Oil-mist lubrication as emergency back-up in turbines	Provides additional running time for engines with damaged lubrication systems
Helicopters	Sensors of serious blade damage would initiate shaped charges to sever damaged blade and opposite blade	Restores rotor balance after severe ballistic damage to rotor system
Aircraft	Armor blanket	Protect parked aircraft from low velocity fragments

Table 12 Survivability Enhancement Measures for Consideration — Vulnerability Reduction (Continued)

Item	Measures under Consideration	Expected Benefit
Aircraft (UTTAS)	Suction boost fuel system	Fewer fires in event fuel lines are broken or engine stops running
Aircraft	Integrated actuator package	Reduced vulnerability of hydraulic systems through reduction of vulnerable areas
Aircraft	Lateral axis redundancy for actuators	Reduced vulnerability by providing redundant paths and redundant controls
Aircraft	Oil-starvation-tolerant transmission systems	More aircraft returning to base after sustaining ballistic damage to transmission system
Aircraft	Improved structural adhesives (polyimide adhesive)	Greater load bearing under conditions of metal fatigue
Aircraft (UTTAS)	Minimize hydraulic ram effect	Reduced damage to fuel tanks from penetrators
Aircraft (UTTAS)	Fail-safe lubrication	Reduced damage to moving parts from failure of lubrication system
Aircraft	Transparent plastics for high speed flight vehicles with exceptional mechanical properties at high temperatures	Reduced vulnerability for plastic windshields
Track Vehicles	Split track	Reduced damage from mines
Vehicles	Armor kit for fuel tanks	Protect fuel tanks; fewer fires and leaks

Table 12 Survivability Enhancement Measures for Consideration — Vulnerability Reduction (Continued)

Item	Measures under Consideration	Expected Benefit
Personnel	Vest to accept survival components and also serve as body armor	Improved survivability of personnel
Personnel	Lightweight clothing using new fiber types of graded protection from chemical agents, camouflage for the individual, body armor, eye protective devices	Reduction in injuries from the effects of various weapons
Personnel	Transparent armor	Reduced vulnerability of personnel
Personnel	Prophylaxis against lethal chemicals	Fewer personnel casualties from poisoning
Personnel	Fire-resistant clothing for naval personnel	Fewer injuries from fire
Personnel	Buoyant cold weather clothing	Reduce probability of drowning or injury from exposure for personnel forced into water
Personnel	Lightweight armor for trucks	Protect personnel from small arms fire
Personnel	Armor by the yard	Protect personnel in boats, trucks and emplacements
Personnel	Sealed and actively pressurized flight suit	Personnel protection in event cabin pressure collapses at high altitude
Personnel	Miniature oxygen regulator	Increased reliability for oxygen flow

Table 12 Survivability Enhancement Measures for Consideration — Vulnerability Reduction (Continued)

Item	Measures under Consideration	Expected Benefit
Artillery	Confining effects of burning ammunition	Reduced casualties and damage to fires
Ammunition	Decrease sensitivity of propellants to impact by projectiles	Fewer fires and explosions
Cables	Fireproof cable sheath	Fewer fires in cables
Fuel systems	Harden fuel systems to withstand effects of high energy lasers	Reduced vulnerability of fuel system
Materials	Coatings to harden materials against laser damage and increase radar absorption	Reduced damage and fewer fires
Communications	Fault-tolerant digital communication by integrating and time sharing use of circuits	More reliable communications through less vulnerable area and resistance to EMI and lighting
Fuel systems	Fuel solidification upon projectile impact	Fuel gelling will result in less leakage following penetration and fewer fires
Transmissions	Integral cooling/lubrication system for transmission	Less vulnerable transmission by virtue of less vulnerable area
Controls	Integrally-armored servo-actuators	Reduced vulnerability to penetrators
Hydraulic system	Silicon-based hydraulic fluids	Reduced flammability

Figure 12 Survivability Enhancement Measures for Consideration — Vulnerability Reduction (Continued)

Items	Measures under Consideration	Expected Benefit
Communications	Propagation of low frequency radio waves	Provides backup communications means in event other systems are useless because of severe ionospheric disturbances
Airbase	Non-destructive pavement	Reduced damage to air strips

preventive maintenance and servicing are properly performed, the extent of combat damage and its effects may be reduced. (For example, the cleaning of bilges in tanks may reduce the incidence of sustaining fires.) With the focus on damage which may result when equipment is hit by enemy weapons, repairability will refer to efforts made to minimize both the time and effort required to repair the damage. Repairability may be measured in manhours or elapsed hours.

The developer of military hardware is well aware of the trends of such hardware toward increased complexity. Figure 13 quantifies this trend by showing how the average number of components in sophisticated electronics equipment has grown over the years. The repair of combat damage is highly complicated by this proliferation of components.

The maintenance and logistic support plans should be revised as necessary during the development cycle as a result of variations in hardware and support requirements (see AR 750-6 and AMCR 706-134). Changes in maintenance and logistics support concepts should occur well into the operational life cycle of the equipment as it is modified and as employment concepts are revised. Economic evaluation of life cycle maintenance support alternatives is required prior to any decision to finalize for production.

Among the myriad design objectives for good maintainability there are some which are equally valid for ease in repairability. They include:

- Provisions for greater accessibility to equipment and components that may require repair or replacement.

- Reduction of mean time to repair/replace a given component to assure combat and operational readiness of the equipment.

- Provisions for interchangeability of components wherever feasible.

- Provisions for modular construction as appropriate and design-for-repair wherever feasible.

Guidance for achieving these design objectives is contained in paragraph 5.9 of MIL-STD-1472B and in section 16 of MIL-HDBK-759.

Lack of satisfactory repairability can jeopardize other military systems and the lives of personnel. For example, an out-of-action air-defense radar may open a path for enemy aircraft to freely attack other facilities. An inoperative radio may result in delay of fire mission information which would have provided support fire for the salvation of a patrol in contact. A delay in proper repair of a tank may decrease the shock and firepower effects needed by a unit conducting reconnaissance in force.

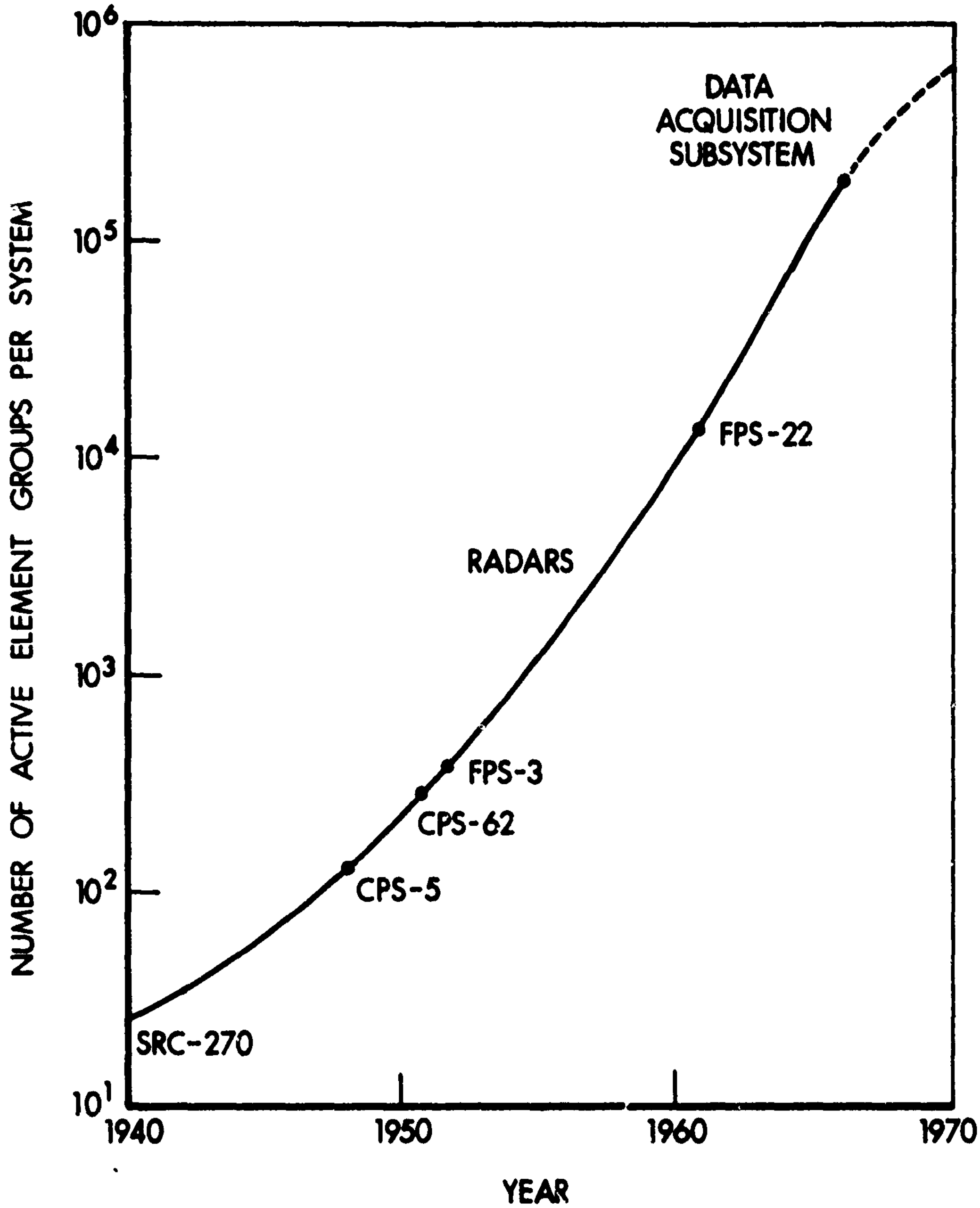

Figure 13 Trends in System Complexity (Ground Electronics).

The location of maintenance activities with capability for modular replacement at the most forward area practicable in the combat zone will reduce turn-around time. Equipment should be designed to be more rugged, more reliable, simple to adjust, and to contain components which may be replaced modularly.

Ease of replacement, of course, implies the ready availability of replacement parts. To reduce costs, it is customary in a peacetime environment to stock at convenient locations those parts that wear out or need replacement as a result of wear and tear. Unfortunately, parts which rarely need attention in peacetime may be damaged often when exposed to combat. Therefore, repair parts needed in a given combat environment may be different in type and in quantity from those needed in a noncombat environment. For example, fuel tanks seldom require repair in a noncombat role. Because of their relatively large size and location on the vehicle, they are often damaged in combat. Historically, the removal of fuel tanks for repair or replacement has been arduous and time-consuming.

Obviously, the fewer parts needed, the greater the mobility of the units that carry them. Since all parts and components have to be reasonably available, the developer must strike a compromise with design for ease of replacement/repair and considerations of ready availability. The inventory of repair parts may be reduced by proper design. For example, if a fuel tank is designed so that it is readily repaired without need for draining or removal, considerable time will be saved. Also, in this circumstance, less storage space would be needed since fewer spare fuel tanks would be necessary.

The types of parts and the numbers of these parts to be maintained in inventory locations near the combat areas are matters which can now be resolved with the aid of computers. Data on parts requirements in recent combat situations may be used as basic input.

The concept of maintaining or repairing equipment must include those actions, facilities, and equipment required to maintain and repair correctly, since a faulty repair which results in failure of equipment to perform as intended is worse than no repair.

Within the concepts of support as defined for individual items of materiel, the plan for repairability should include a consideration that maintenance and repair or replacement be conducted as much as possible by the using unit. This requires awareness that, initially, skills may be wanting, sophisticated tools and calibration equipment may be lacking, facilities may be austere, and the environment may include enemy fire, dust, snow, wind, rain, darkness, and heat. Ideally, equipment should be designed so that user personnel can readily diagnose a problem and identify the parts to be adjusted or replaced. By the same token, parts to be removed or adjusted should be designed so that illumination is not required for these functions; undamaged parts should not have to be removed to obtain access to the damaged part. Replacement, if required, should be accomplished with a minimum number of actions and a minimum of elapsed time.

Developers should employ proven and promising new state-of-the-art materials/components for production-line items. Although this concept may add more cost to the item initially, the costs may be less over the life cycle of the item. Studies should be conducted on feasible alternatives for frequently replaced, low purchase-priced, high labor/replacement time components. Such components might include:

- Wheel bearing seals,
- Hoses for cooling system, vacuum and fuel lines,
- Wiring protected by sheathing,
- Roof tops for vehicles; vinyl tarpaulins,
- Seat cover materials of vinyl in lieu of canvas,
- Paint for exterior protection,
- Aluminum fuel tanks (steel fuel tanks require interior protective coating for storage),
- Constant velocity universal joints which are interchangeable and more durable,
- Sealed wet-cell batteries whose electrolyte levels do not require continuous checking.

6.2 Cannibalization.

Cannibalization is defined as:

THE USE OF PARTS FROM ONE OR MORE DAMAGED PIECES OF EQUIPMENT IN ANOTHER DAMAGED PIECE OF EQUIPMENT IN ORDER TO MAKE THAT ONE FUNCTIONAL.

It appears that there has been little emphasis on concepts relating to the repair of equipment under less than ideal conditions, or under combat conditions when replacement supplies are inaccessible or unavailable. More attention is now being paid to concepts of carefully planned and supervised cannibalization to be implemented by crews especially trained for such purposes. Some nations routinely practice cannibalization to repair damaged equipment.

Some basic tests were conducted on battle-damaged tanks to examine the feasibility of cannibalization at the individual and team levels before examining the implications at higher levels. These tests were designed to examine feasibility of cannibalizing equipment by U.S. teams on the battlefield to expedite availability of end items when repair parts are not readily available. The conclusions reached from these tests are:

- Training is needed in use of diagnostic equipment and technical publications, selection and use of tools, and performance of technical inspections.

- Doctrine should permit cannibalization on the battlefield when repair parts are not immediately available for combat equipment essential to the situation.

- Tank crews already demonstrate abilities exceeding those required by maintenance tasks normally assigned to the tank crew.

- The Table of Organization & Equipment for the support company should be augmented with mobility and communications equipment to support contact teams.

One disadvantage of cannibalization is that the items which are subjected to cannibalization often end up as scrap. It may follow that cannibalization should be considered only at the DS and GS levels, under command supervision, and with specific guidelines.

6.3 Manhours Required for Repair/Replacement.

Flat Rate Manuals* have been prepared by the Saint Louis University under contract to the U.S. Army Aviation Systems Command. These manuals provide estimated manhours to perform various tasks associated with the repair of certain Army aircraft at various maintenance levels.

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*AH-1G Flat Rate Manual, U.S. Army Aviation Systems Command, Product Assurance Directorate, Volumes 1 and 2, July 1973.

The manuals report the mean downtime recorded for many specified jobs related to maintenance, repair, or replacement. The mean downtime includes non-productive hours and does not represent the most efficient time possible for performing the work in question. Such information as is furnished in these manuals should provide a basis for:

- Evaluating and predicting maintenance/repair requirements.
- Establishing a standard for comparing the timely performance of maintenance/repair activities.

The importance of the information provided in these manuals is that clues are furnished concerning potential trouble areas in maintenance. If it takes, on the average, several manhours to perform a given maintenance/repair/ replacement task, and if combat damage records reveal that such tasks are frequently necessary, the ingredients for a maintenance logjam exist. The analyst should grasp the potential danger of such combinations of circumstances and offer solutions to prevent these logjams. These solutions, successfully implemented, will enhance the survivability of the equipment in question through more efficient repairability.

6.4 Parts Standardization.

Parts standardization refers to the establishment of engineering practices to achieve the greatest practical uniformity in equipment design. It applies to efforts to select, design, or manufacture parts, components and equipment (as well as associated tools and service materials or procedures) so they are identical to, or physically and functionally interchangeable with, other parts. When standardization is carried to the maximum degree, there will be substantial savings in cost, ease in repairability, and greater reliability. For example, in World War II, non-standard fixed paper capacitors, constituting only 2 percent of all the capacitors in use during that period, caused almost half of all capacitor failures reported in 29,000 failure reports.

Some factors that contribute to a high failure rate for non-standard items include:

- Deterioration while on the shelf due to low demand,
- Maintenance- induced errors because of lack of knowledge by mechanics concerning "unusual" materiel,
- Lack of uniformity in manufacture in small quantity production.

Standardization trends are evident in the family of industrial and automotive type engines, the current individual small arms, and in tactical wheeled vehicles. There is a strong tendency to forget about standardization, especially in times of mobilization, under the guise of expediency. Standardization becomes of vital concern in times of emergency when maintenance shops in a combat area are cut off from rapid supply, and the only alternative is cannibalization.

Standardization, however, is a continuous process and should not be permitted to interfere with technical advances when such approaches result in more effective and more economical use. Proper application of standardization techniques will:

- Avoid requirements for special or close-tolerance parts,
- Save design and manufacturing time and costs,
- Save maintenance time and costs,
- Minimize misapplication of parts,
- Facilitate cannibalization when appropriate,
- Limit the number of supply line items,
- Increase the stock level of supply line items.

Areas where parts standardization should proceed most naturally are:

- Arrangement and packaging,
- Wiring identification,
- Parts identification,
- Selection and application of fasteners,
- Servicing materials (oils, fuels),
- Starting motors, generators, air cleaners, batteries, instruments, lights, radiators, controls.

6.5 Examples of Some New Developments Which Offer Enhancement in Survivability Through Novel Repairability Concepts.

New Suspension System. Tracked vehicles may achieve greater effectiveness in combat through improvement in mobility and cross-country speed. These improvements could be brought about by high wheel travel, low spring rate, and optimized damping. Developers have apparently gone as far as possible in these areas with standard torsion bars.

TACOM is working on a novel suspension development known as the in-arm suspension. Two different systems are under consideration. Both systems utilize velocity to control hydraulic damping. The systems may provide the suspension characteristics to meet the high-mobility requirement of future military vehicles. With either system, accessibility from outside the vehicle will result in reduced maintenance time during repair or replacement of components.

New Tire Design for Armored Vehicles. Brazil has recently become a major manufacturer of armored vehicles. A vehicle referred to as the CTRA, for example, is a chassis-less vehicle with a fully enclosed steel hull capable of accommodating up to 15 troops.

A novel feature incorporated into the CTRA design is a set of 11.00 x 20 bullet-proof tires. These tires resemble other military run-flat tires with reinforced casings and stiffened side walls. This design permits the tire to function for a time after it has been punctured and the inflation pressure is reduced to zero.

The advantages of these tires relate to the use of a solid rubber spacer and are listed as follows:

- The spacer prevents the beads from coming off the rim when the tire has been punctured,

- The spacer seals the punctured casing so that the tire can act as a tubeless tire (other run-flat tires require an inner tube).

- Without the inner tube, these tires do not experience a sudden loss of pressure when the tire is punctured; furthermore, there is less friction when the tire is operating while uninflated.

- Bullet holes and other damage can be repaired from the outside, without dismounting the tire.

- The spacer prevents excessive deflection of the tire side walls when running at zero inflation pressure.

- In the event of major casing damage, the spacer enables the wheel to run on it as if it were a solid rubber tire.

6.6 Status of Research in Repairability.

Tables 13 and 14 offer brief designations of measures taken or under consideration to improve repairability of military equipment.

Table 13 Survivability Enhancement Measures That Have Been Implemented — Repairability

Item	Measure Taken	Stage of Life Cycle at Which Measure was Implemented	Benefit Observed (O) Expected (E)
UH-1H	Hub design with elastomeric and Teflon-faced bearings	Fielded item	No requirement for lubrication; greater reliability (E)
M48	New track design	Fielded item	Facilitated installation and reduced probability of a thrown track (O)

Table 14 Survivability Enhancement Measures for Consideration — Repairability

Item	Measures under Consideration	Expected Benefit
Aircraft	Advanced structure design concepts and composite materials; fiberglass rotor blade, composite material rotor hub, composite fuselage, composite tubular rotor, composite transmission housing, boron rotor blade	Reduction in maintenance and reduction in vulnerability, reduction in fatigue of components
Aircraft	Composite materials in helicopter shafting	Reduced fatigue
AH-1G	Quick-replacement scheme for fuel cells	Efficient repair potential of combat damage
Aircraft	Roller gear transmission	Reduced weight, size and number of parts should reduce hits and improve maintenance
Aircraft	Ducted replacement for tail rotor	Reduced maintenance requirements
Vehicles and aircraft	Engine advanced technology - regeneration aircraft engine; reduced noise, reduced IR signature, increased power	Reduced maintenance
Vehicles	Winterization kits	Reliable starts and operation in severe cold conditions
Personnel	Replace, redesign and standardize modular medical treatment/supply equipment, water and waste management for MUST facilities	Maximize personnel survival and improve medical treatment capability
Drive Train	Titanium alloys	Reduced fatigue for drive shafts and rotor hubs
Engines	Processing of silicon nitride and silicon carbide ceramics into engine components	Increased strength and improved high temperature operation

Table 14 Survivability Enhancement Measures for Consideration — Repairability (Continued)

Item	Measures under Consideration	Expected Benefit
General	Maintain spare parts in inventory in numbers to reflect expected combat damage	Efficient repair potential of combat damage
General	Maintain assemblies (e.g., wheels <u>with</u> tires rather than wheels <u>and</u> tires) in inventory	Efficient repair potential of combat damage
Electric motors	Solventless varnish for magnet wire	In-place application without expensive removal of motors/generators
Cables	Free-stripping, water-stop, cable filler	Reduce cable cost and stripping labor costs
Cables	New submarine outboard sonar cable	Greater reliability than present type SS

7. SUMMARY

Survivability has been defined, and its current importance to our Armed Forces has been clearly established. To achieve survivability enhancement of our materiel, we are led to the consideration of actions which make our materiel:

- more difficult for the enemy to detect and acquire,
- more difficult for the enemy to hit, once acquired,
- more difficult to damage, once hit,
- easier to repair, once damaged.

The ultimate measure of success of our military systems is effectiveness. Survivability, one of the ingredients of system effectiveness, must be achieved at some maximum level without compromising the effectiveness of the system.

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