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**LFT&E PROCESS
ASSESSMENT AND
RECOMMENDATIONS**

FINAL REPORT

To

Office, Under Secretary of Defense for Acquisition

Assistant Deputy Under Secretary of Defense (LFT)

Washington, D.C. 20301-3110

JUNE 1991

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Final Report

LFT&E PROCESS ASSESSMENT AND RECOMMENDATIONS.

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DLA900-86-C-2045, Task No
214

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This report reviews the implementation of the Live Fire test and evaluation law within the Department of Defense, by describing LFT&E program management, products, procedures and opportunities for improving the conduct of the program.

Live Fire Testing and Evaluation (LFT&E)
LFT&E Management
Vulnerability/Lethality Assessment

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LFT&E PROCESS ASSESSMENT AND RECOMMENDATIONS

FINAL REPORT

JUNE 1991

Contract No. DLA-A-900-86-C-2045
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Prepared for:

Office, Under Secretary of Defense for Acquisition
Assistant Deputy Under Secretary of Defense (LFT)
Washington, D.C. 20301-3110

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TOPICS

Part 1 - INTRODUCTION

Part 2 - LFT&E MANAGEMENT

Part 3 - VULNERABILITY ASSESSMENT

Part 4 - LETHALITY ASSESSMENT

Part 5 - FINDINGS and RECOMMENDATIONS

Appendix - LFT&E Elements of RDA Cycle

- Brief Descriptions of Models
- Sources for Historical Damage
and Casualty Data

An objective of the Live-Fire Testing and Evaluation (LFT&E) program is to assure that battle damage tolerance and control for crew-carrying combat systems is known and acceptable. Another objective of the LFT&E program is to assure that the lethality of conventional munition warheads against intended targets is known and acceptable. These objectives are pursued using combinations of analysis, testing and other data collecting events to identify vulnerability or lethality design weaknesses early enough in the acquisition process that corrective action may be taken prior to committing to full-scale production and deployment.¹ The Congress expressed its interest in these objectives by creating a statutory requirement for live-fire test and evaluation of weaponry prior to full-scale production. *This report reviews how the law is being implemented within the Department of Defense by describing LFT&E program management, products, procedures, and opportunities for improving the conduct of the program.*

¹ J.F. O'Bryon, "The Role of Live Fire Testing in the Acquisition Process", *ITEA Journal of Test and Evaluation*, Vol X (1989) No. 2, p. 16.

WHAT IS WEAPON SYSTEM LFT&E ?

- REALISTIC ASSESSMENTS OF
 - *WEAPON PLATFORM/CREW VULNERABILITIES to damage/injury that could be inflicted by the conventional munitions most likely to threaten the system in combat*
 - *CONVENTIONAL WARHEAD LETHALITY against the type of targets likely to be fired at in combat*
- AN ESSENTIAL CONSIDERATION WHEN DECIDING IF A WEAPON PLATFORM OR MUNITION SHOULD PROCEED INTO FULL-RATE PRODUCTION/RE-FIT
- A 10 USC 139 STATUTORY REQUIREMENT SINCE FY87

LFT & E MANAGEMENT

The Secretary of Defense is the departmental executive obligated by law to comply with LFT&E provisions of 10 USC.² The Congress intends LFT&E to be one of the duties of the Under Secretary of Defense for Acquisition. The Deputy Director, Defense Research and Engineering (Test and Evaluation) [DDRE(T&E)] has been designated by the Under Secretary to be the Defense Department's focal point³ for issuing the policy necessary to have an LFT&E program capable of fulfilling the Secretary's obligation. The position of Director, Live Fire Testing (LFT), was created to develop that policy, with the cooperation of DoD Components, and, after issuance, to abet its implementation.^{4,5} These responsibilities are more fully described on the facing page.

² National Defense Authorization Act beginning Fiscal Year 1987 (amends Chapter 139 of U.S. Code Title 10)

³ OSD Test and Evaluation Committee Memorandum, "Live Fire Test and Evaluation Guidelines," 1 Jun 1988, sec. 7.

⁴ *Ibid.*

⁵ O'Bryon, statement before the Acquisition Policy Panel of the House Armed Services Committee, House of Representatives, 10 Sep 1987.

LFT DIRECTOR'S MISSION RESPONSIBILITIES

- IMPLEMENT LIVE-FIRE TEST & EVALUATION PROGRAM REQUIRED BY LAW
 - *Develop LFT&E policy for the DoD*
 - *Ensure system/munition LFT&E plans prepared by the Services are thorough and combat-representative*
- PERFORM INDEPENDENT VULNERABILITY/LETHALITY ASSESSMENTS OF LIVE-FIRE TESTED SYSTEMS/MUNITIONS
- HELP MILDEPS/PMS ACHIEVE STRONG LFT&E CAPABILITIES
 - *Sponsor/advocate improvements of LFT&E procedures, facilities, and evaluation criteria*
 - *Prioritize the acquisition of selected foreign targets/ munitions for LFT&E purposes*

OSD directions to the DoD components for conducting an LFT&E program were first published in May 1987 as *Draft Live Fire Test and Evaluation Guidelines*. The Draft Guidelines contained instructions for developing an LFT&E strategy and for writing LFT&E plans; the OSD oversight role was also described. A final version of the *Guidelines* was issued in June 1988. The DoD Components have relied on these *Guidelines* to define LFT&E policy and prescribe general procedures to be followed by performing organizations. LFT&E policy and procedural instructions are being included in the latest versions of the Defense Department policy and procedure regulations governing system acquisition. These regulations had not been issued at the time this report on the LFT&E process was prepared, although they were approved for publication near the end of 1990. *Acquisition regulations of the DoD Components must also be re-issued to explain and implement DoD policy on LFT&E and to conform to other contemporary acquisition requirements. Some key Component regulations do describe the policy for LFT&E, and some currently make no reference to it all, but should. See adjacent chart.* Publication of Component regulation revisions will likely occur after the revised 5000-series DoD regulations are published. *These revisions would be appropriate occasions for the Components to issue specific LFT&E instructions that supplement the general instructions formulated by OSD and to designate the special LFT&E roles of routine participants in the chain of program management that extends beyond the OSD-to-Component headquarters staff relationships published in the Guidelines.*

LFT&E POLICY/PROCEDURES REFERENCES

LFT&E CONTENT
YES NO

OSD

- | LFT&E CONTENT | YES | NO | REFERENCE |
|------------------|-----|----|--|
| ✓ | | | OSD T&E Committee Memo, "Live-Fire Test & Evaluation Guidelines," 1 Jun 88 |
| ✓ | | | OSD Live Fire Test Office, "LFT&E Planning Guide," Jun 89 |
| ✓ | | | DoDI 5000.2 "Defense Acquisition Management Policies and Procedures," Sep 90 (final draft) |
| ✓ | | | DOD 5000.2M "Defense Acquisition Documentation and Management Reports," Sep 90 (final draft) |
| <u>ARMY</u> | | | |
| ✓ | | | DA Pam 70-21 "Test and Evaluation Guide," Nov 88 |
| ✓ | | ✓ | AR 70-1 "Systems Acquisition Policy and Procedures," Oct 88 |
| ✓ | | | AR 73-XX "Test and Evaluation Policy," Nov 90 (final draft - will replace AR 70-10) |
| ✓ | | | DACS-TE (TEMA) Handbook "An Army Guide to Live Fire Test and Evaluation," Aug 90 |
| <u>NAVY</u> | | | |
| | ✓ | ✓ | SECNAVINST 5000.1B "System Acquisition" |
| | | ✓ | OPNAVINST 3960.10C "Test and Evaluation" |
| ✓ | | | USMC Order 5000.11B "Testing and Evaluation of Systems and Equipment for Marine Corps" (final draft) |
| <u>AIR FORCE</u> | | | |
| | ✓ | | AFR 80-1 "Air Force Research and Development," Jun 79 |
| | ✓ | | AFR 80-14 "Test and Evaluation," Nov 86 |
| ✓ | | | AFR 80-38 "Air Force Systems Survivability Program," Sep 89 |
| | | ✓ | AFR 800-1 "Air Force Acquisition System," Feb 90 |

OSD procedural instructions specify that "Heads of DoD Components may issue supplementary (LFT&E) instructions to provide for the unique requirements within their respective components."⁶ This leeway provides Components freedom of choice to organize the management of LFT&E activities in different ways. It is also an allowance for variability among the techniques that may be suitable to conduct LFT&E. *Currently, the Components are using management chains styled to superimpose LFT&E responsibilities on traditional Component domains of development testing and evaluation activity.* These chains are illustrated on the facing page. Only the Army Component, however, has explained to its performing organizations how to tailor Army-unique requirements to fit within the OSD guidelines for LFT&E.⁷ A preferred method of selecting test shots, test target prescriptions, and the role of modeling are among the topics covered in the guidance by Army Headquarters to organizations involved in the conduct of LFT&E. *The Army's specific guidance is not transferable to other Components, since it is largely about the distinctive subject of land warfare armor/anti-armor LFT&E. However, these topics are worthy of guidance from the headquarters staffs of the other Components to subordinate organizations with responsibilities for participating in the LFT&E process and refining its application to Component product developments.*

⁶ OSD LFT&E Guidelines, sec. 3.

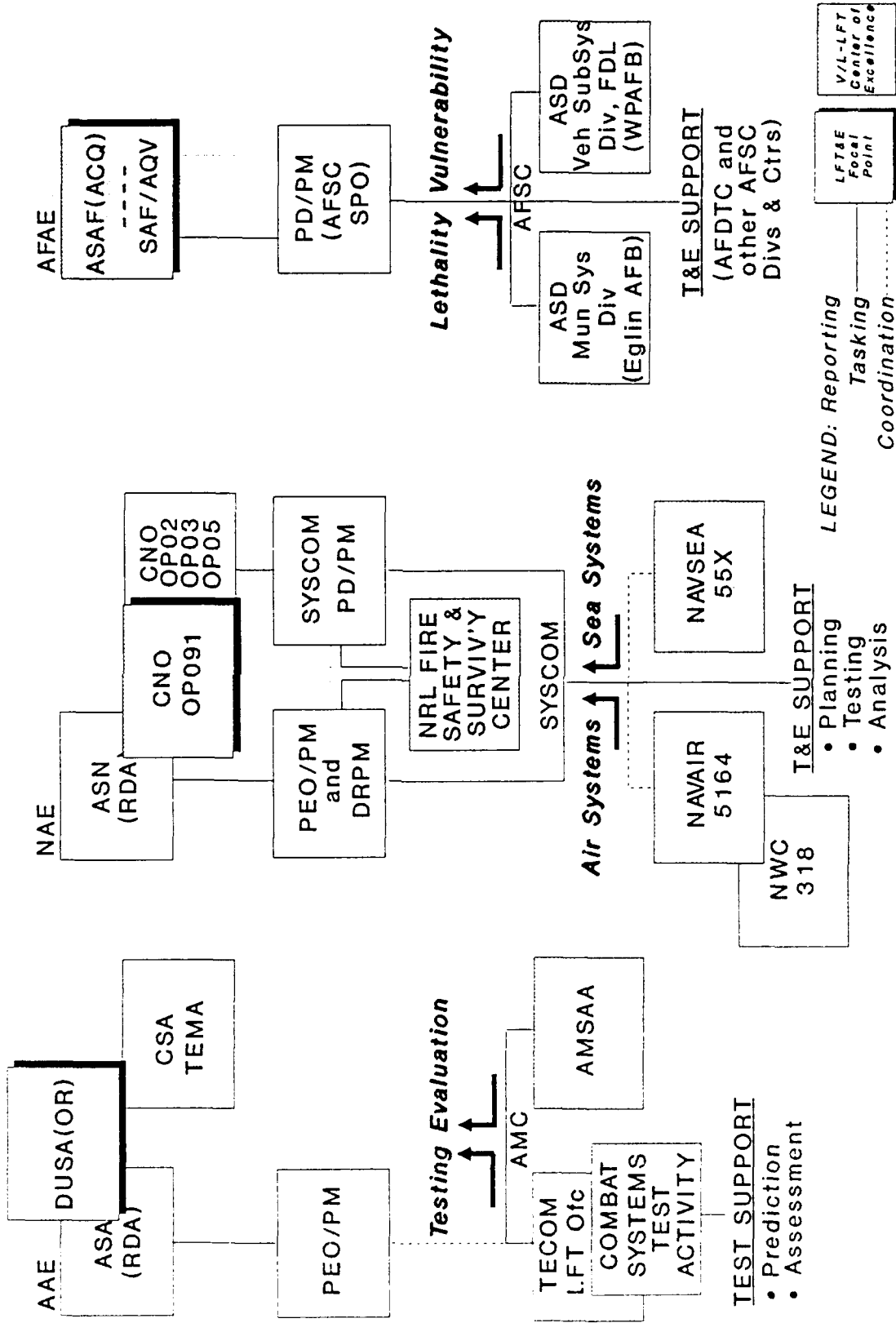
⁷ *An Army Guide to Live Fire Test and Evaluation*, Department of Army Test and Evaluation Management Agency (TEMA), August 1990

LFT&E MANAGEMENT CHAINS

ARMY

NAVY

AIR FORCE



A general process for the conduct of LFT&E has been evolved by the Components to implement OSD policy. The LFT&E process is a sequence of activities that provide opportunities to appraise weapon platform vulnerability performance or munition warhead lethality performance. Elements of the process are depicted on the chart below. The process begins with a definition of technical performance objectives that represents the fulfillment of vulnerability or lethality performance needs prescribed in Component platform or munition descriptions of required operational capability (ROC/TLR/SORD). Requisite operational capabilities can be derived from a System Threat Assessment Report (STAR) containing technical intelligence about the weaponry that could threaten a platform and intelligence about the construction of a munition's intended targets (potential foe order-of-battle estimates and generic target descriptions do not reveal enough information to determine the degree of capability needed). Performance assessments of the as-developed weapon platform or munition can be compared with performance objectives to determine development progress. When objectives are unmet, these appraisals may stimulate further developed work until acceptable robustness can be attained. This is the value-added role intended for the LFT&E process. When levels of vulnerability or lethality performance are known and acceptable, the platform or munition can exit the process. The realm of acceptable performance is bounded by the values of desired and required performance considered to be important for mission success of an LFT-eligible platform or munition.

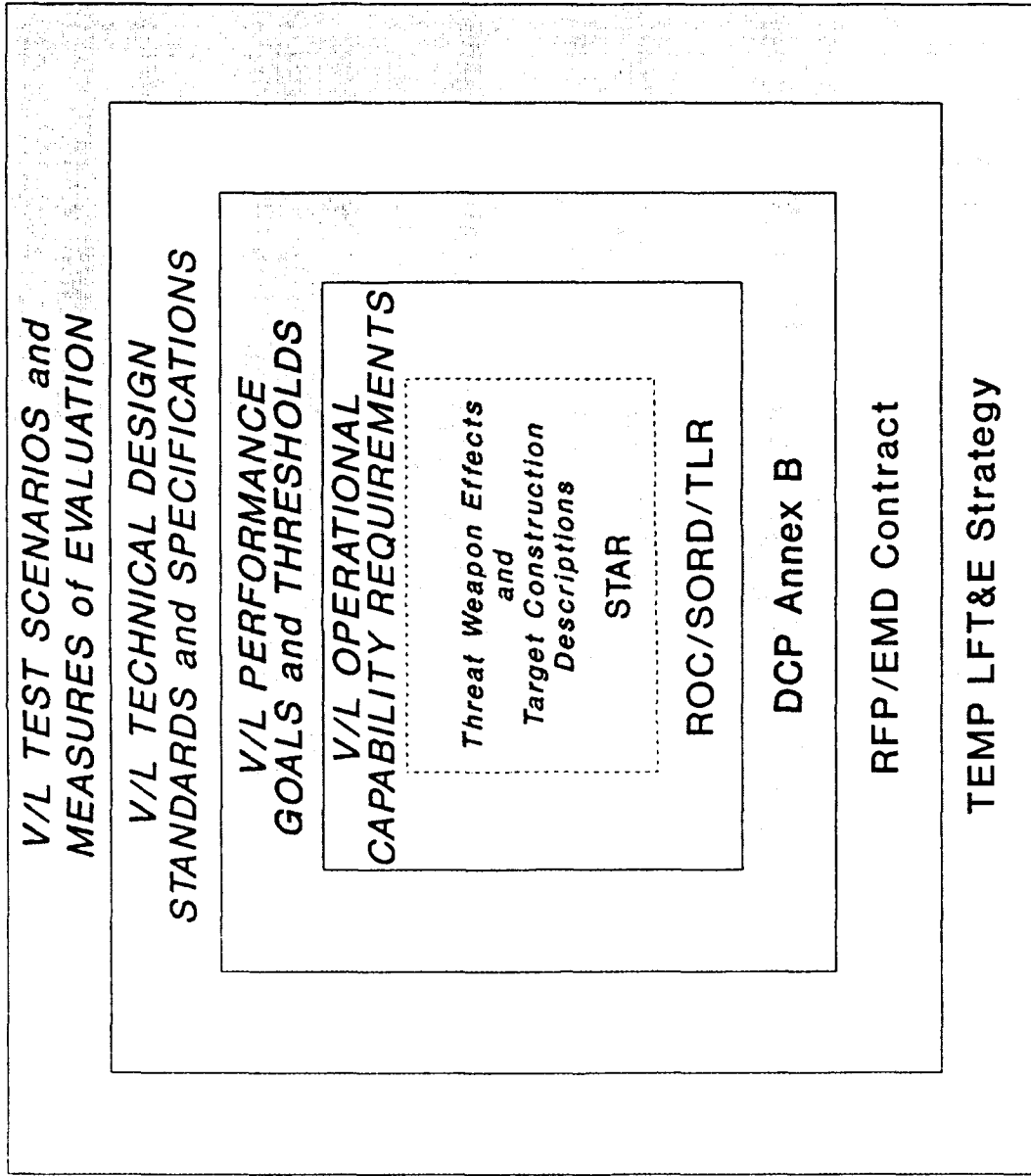
ELEMENTS OF LFT&E PROCESS

- VULNERABILITY/LETHALITY PERFORMANCE OBJECTIVES
- LFT STRATEGY FORMULATION (part of OSD-approved TEMP)
- PREPARATORY ANALYSIS AND DATA COLLECTION
- DETAILED LIVE-FIRE TEST PLAN (reviewed by OSD Dir,LFT)
- LIVE-FIRE TESTING (with on-site OSD oversight)
- OSD SYSTEM-LEVEL LFT ASSESSMENT FOR USD(A), SECDEF AND CONGRESS

Technical vulnerability or lethality performance goals, as well as thresholds of minimum acceptable performance, are prescribed in Annex B of the weapon platform or munition Decision Coordinating Paper (DCP). These desired and required technical objectives are the basis for specifying and, later, gauging platform or munition design performance. Performance better than the minimum essential performance prescribed by the DCP results in a performance margin for coping with threats to platform or munition effectiveness. If DCP prescriptions are an analog of the capabilities required to cope with likely threats to a platform or munition's performance when deployed, then a program of technical testing and evaluation ought to be capable of gauging operationally meaningful performance. *Program events meant to produce information about system or munition performance progress for officials who must decide the next acquisition course-of-action are described in the Test and Evaluation Master Plan (TEMP).* LFT&E events described in the TEMP are intended to produce appraisals of platform vulnerability performance or munition lethality performance attainment that can be compared with development goals and objectives. *Omitted or non-quantitative operational requirements and quantitative operational requirement metrics that are difficult to convert into technical language are barriers impeding creation of a bridge between operationally significant vulnerability or lethality capabilities and the LFT&E portion of the TEMP. Without that linkage the correspondance between LFT&E results and design expectations can be verified, but the relationship of LFT&E results to requisite battlefield performance can only be inferred.*

VULNERABILITY/LETHALITY (V/L) OBJECTIVES

Requirement Analogs



LFT&E is paced by the availability of hardware and typically occurs during the transition phase between development and production. Since development baseline objectives defined in a platform or munition DCP must be attained before the baseline can be re-defined for production, any platform or munition exhibiting performance as good or better than the performance thresholds prescribed in Annex B of the development DCP has demonstrated a performance readiness to be produced and put into service. Accordingly, *vulnerability or lethality performance thresholds appearing in DCP Annex B become yardsticks of vulnerability/lethality eligibility to transition from EMD - e.g. LFT&E exit criteria.* A decision to boost the size of a performance margin would require consideration of the additional costs and time that would need to be invested to achieve the desired performance level or DCP goal. These factors, together with a convincing assessment that system-level exit criteria have been verified at the conclusion of the LFT&E process, constitute a basis for decision-making about the sufficiency of expected vulnerability or lethality performance.

Current methods used by the Components to analyze and portray vulnerability and lethality performance information will be examined in the next portions of this report. Modifications offering some potential of enhancing the communication value of assessment presentations will also be described. Once a suitable scheme is devised, these assessments could be melded with other relevant information to convey to decision-makers the impact of vulnerability or lethality performance on gains in combat power expected from the system.

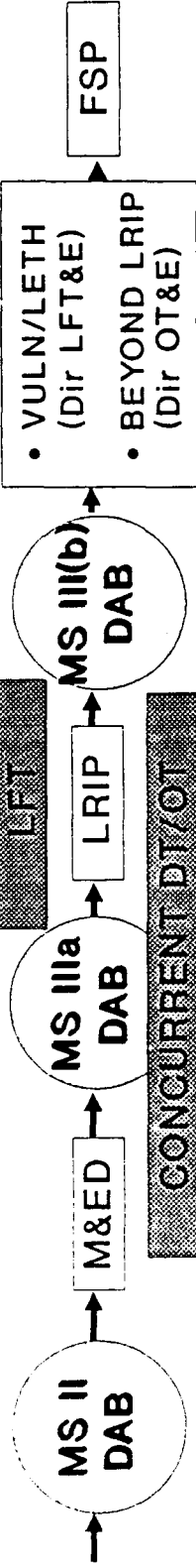
T&E INFLUENCES ON ACQUISITION DECISIONS

CSC/DAB INTEREST

Is acquisition of new/modified platform or munition justified by prospective worth of combat capability?

CSC/DAB INTEREST

Have performance goals and thresholds been verified by DT&E and LFT&E (technical)? by OT&E (operational)?



CONSIDERATIONS

- PROGRAM RISK vs ADDED CAPABILITY (DEMO Report)
- PROGRAM COST vs MILITARY VALUE (COEA Report)
- PERFORMANCE GOALS/THRESHOLDS (DCP Annex B)
- PERFORMANCE TESTING/EVAL (Detailed TEMP)

CONSIDERATIONS

- LIVE-FIRE T&E STRATEGY (Updated TEMP)
- LFT&E ENTRY PREPARATIONS (L-F T&E Plan)
- THREATS TO V/L PERFORMANCE (DIA validation)
- LIVE-FIRE TESTING OUTCOME (LFTE Report)
- DEVELOPMENTAL TESTING OUTCOME (DTE Report)
- OPERATIONAL TESTING OUTCOME (OTE Report)

**VULNERABILITY
ASSESSMENT**

The Components use distinctive formats for describing platform-level vulnerability performance, and platform-unique analysis is relied on in differing degrees to form conclusions about this vulnerability performance. ***The methods expected to be favored to analyze and portray the live-fire vulnerability performance of each platform class (ground, sea, air) will be described and assessed in this section, beginning with ground platforms.***

A degree of damage sufficient to cause total loss of function is called a kill criterion. Kill criteria for firepower and mobility, the primary combat functions of a weapon-carrying ground vehicle, are defined on the opposite page; they are useful to assess whether or not a kill has occurred. The significance of these functions can vary from mission to mission. Intermediate damage conditions that aren't as severe as those defined to exist when a kill occurs can also have tactical significance. By convention, a range of zero (functional capability unaffected - even if damage has occurred) to one (no remaining functional capability - a kill has occurred) is used to portray fractional (decremented) combat utility. This decremented combat utility (DCU) "meter" is sometimes relied on to portray the consequences of an attack on a ground weapon platform. The information value of this device could be improved if impressions of a continuum of meaningful outcomes were dispelled by labeling the dysfunction thresholds of tactical significance and indicating their relationship to the damage causes of failure. This relationship can be learned from an analysis of damage modes and their likely effects on the functioning of a ground platform.

GROUND VEHICLE KILL CATEGORIES

CATASTROPHIC (K) - total loss of vehicle by explosion or burning after being hit

MOBILITY (M) - crew unable to repair hit damage and execute the controlled movement necessary for completion of mission

FIREPOWER (F) - crew unable to repair hit damage and deliver the controlled firings necessary for completion of mission

This Damage Mode and Effects Analysis (DMEA) is a criticality analysis of the components used in the systems/sub-systems required to perform a combat function and the association of those critical components with the kinds and amounts of damage that can result in tactically significant functional disabilities. The DMEA establishes damage cause-effect relationships similar to those depicted in abbreviated form on the adjacent graphic. A picto-graphical representation of critical components and the functional impact of critically damaging these components is termed a disablement diagram.⁸ Disablement diagrams are a clear means of attributing specific kinds of damage to tactically significant conditions of fractional combat utility. These diagrams may be used in lieu of or in amplification of a vulnerability report of DCU when they portray a partial or total loss of function that would be typical of vehicle engagements by threats capable of causing those losses. A characteristic vulnerability can be assessed from an examination of occurrences of vehicle kills and each circumstance of tactically significant impairments (decrements) to the vehicle's capability for performing important combat functions. The frequency of these occurrences can be estimated from analyses of the damage created when the vehicle is repetitively attacked at various locations and angles of arrival from typical firing distances. Vulnerability models calibrated by test and historical data are the sources of frequency-of-occurrence estimates.

⁸ See Robert E. Ball, *The Fundamentals of Aircraft Combat Survivability Analysis and Design* (New York: AIAA, 1985), p.144 for an example of a disablement diagram.

GROUND VEHICLE FAILURE MODES

DAMAGE PROCESS

ARMOR-BREACHING PENETRATION
and BEHIND-ARMOR DEBRIS
GENERATION

TERMINAL EFFECTS

Propulsion Element Hoing
Interior Equipment Perforation
Crew Injury/Incapacitation
(punctures, burns, blinding,
blunt trauma, shock)
POL Transfer Line/Reservoir
Rupture
Ammo Propellant Perforation

BALLISTIC IMPACT

Exterior Element Destruction
(stowage, antennae, wheels,
suspension)
Equipment Shock Damage
(AFSS discharge, optics/
E-O mis-alignment)



LOSS CRITERIA

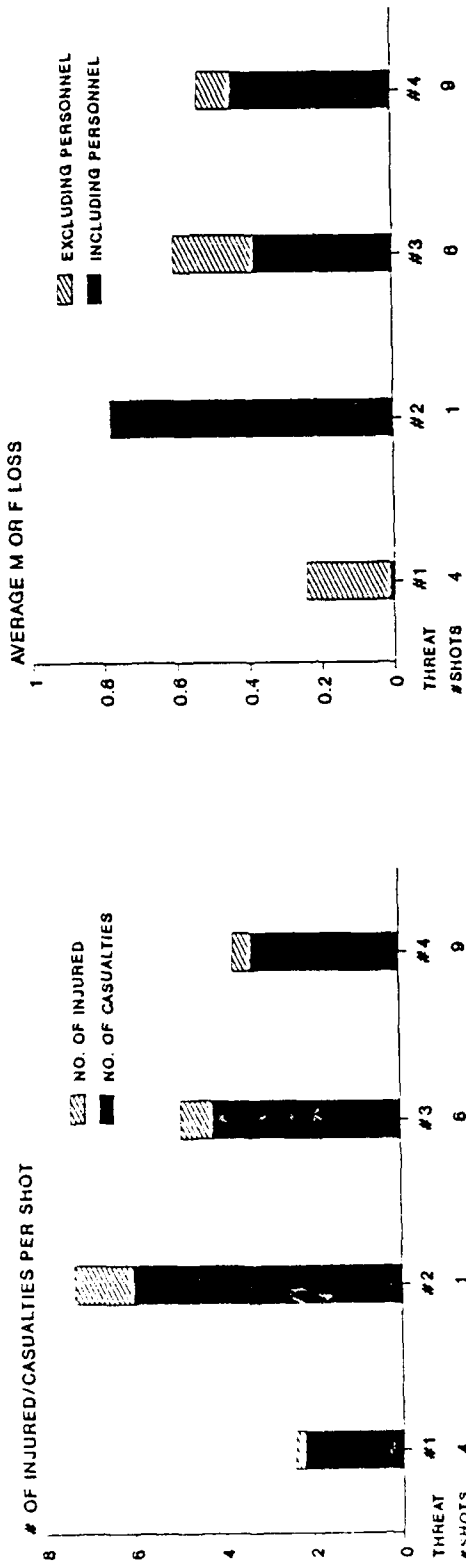
- *Crew casualties*
- *Firepower or mobility inactivation*
- *Unextinguished crew/engine area fire*
- *Ammunition fratricide*

A vulnerability frequency-of-occurrence for a weapon-carrying ground vehicle function is usually denoted as P_k , a probability of kill stemming from a hit on the vehicle. P_k signifies the vulnerability performance revealed by a COEA to be the characteristic result of many attacks on many platforms. Accordingly, the vulnerability performance capability desired from a weapon platform when fielded is usually specified with P_k requirements.⁹ P_k requirements, without any accompanying analysis for establishing a correspondance between design features and P_k outcomes, are often used in government RFPs to describe vulnerability performance needed from the as-built platform. Computer models capable of describing weapon platform material properties and critical component placement must then be relied on by engineers to rate the P_k performance of design approaches. Design decisions are reinforced by data collected from the testing of candidate construction materials, components and major vehicle sections. *Typically, when the Army Component evaluates system-level live-fire testing, P_k results are aspect-averaged to assess a single shot function kill probability, P_{SSk} , expected from each threat munition. Crew casualty estimates are based on this average loss of function. These net assessments of vulnerability performance are then supplemented by a shot-by-shot results narration when live-fire testing is reported.* See adjacent chart.

⁹ Examples of other metrics that have been used are ballistic limit velocity to prescribe percentile defeat of a specific fragmentation threat at a specified standoff detonation point and prescription of an optical density for eye-safe attenuation of a specific laser fluence at a named wavelength.

LFT VULNERABILITY ASSESSMENT REPORT

Format of Ground Vehicle Test Results



Shot plan sequence number	Threat munition	Static or dynamic	Impact location	Critical item/ damage mechanism (preliminary data)	Component LOF (%)	Vehicle LOF (fractional value) M F K	Results/Remarks (narrative)
SHOT-BY-SHOT DESCRIPTION OF TEST OUTCOME							

A sea vehicle assessment is quite different from the land vehicle assessment described in the last section, although categories of kill applicable to sea warfare surface vehicles are like those applicable to land warfare surface vehicles. The definitions of criteria for ship float and function kills shown on the adjacent chart were assembled from several sources. Float kill criteria are those used at NAVSEA 55X to assess the shock and whipping responses of ship structures. Each float kill criterion is associated with a ship-specific limit to the amount of list that can be tolerated before the defined threshold of catastrophic flooding is exceeded. The propulsion (mobility) kill criterion originates from an OPNAV 643C determination that a mission loss occurs when wartime mission performance capability falls below 50%.¹⁰ A kill criterion for the wartime performance of a ship in mission areas other than mobility, collectively called ship combat systems, stems from applying the 50% threshold to the general published definitions for combat readiness.¹¹ *Navy Component ship vulnerability and survivability analysts have to use comparable kill criteria to examine the consequences of attacks against surface warships. However, ship float and function kill criteria have not been specified in top-level publications, and Navy-wide definitions to provide a uniform basis for surface ship vulnerability analysis may not exist.*

¹⁰ Reported in OPNAVINST C3501.66B, *Definition of Combat Readiness Levels*, 26 June 1979.

¹¹ *Ibid*

SURFACE WARSHIP KILL CATEGORIES

CATASTROPHIC (FLOAT)

- (Ship Length < 100 ft) flooding of 1 watertight compartment
- (100 ft < L < 300 ft) flooding of 2 watertight compartments
- (L > 300 ft) failure to stem flooding from holing extending more than 15% of length between perpendiculars or flooding of three watertight compartments

PROPULSION - hit damage leaving a wartime mobility capability of less than 50%

COMBAT SYSTEM - hit damage resulting in less than 50% residual C3 capability or less than 50% of wartime performance capability in 2 or more mission areas (AAW, ASW, SUW, ...)

The dominant influences on naval construction seem to be the top-level ship requirements for seakeeping ability, mission performance, weaponry integration, and habitability.¹² Although surface ships can be threatened with a number of potentially significant weapon effects, vulnerability performance is not uniquely specified in ship capability requirement descriptions. Instead, there is a general qualitative requirement for survivability during combat operations. Good survivability has three principal attributes: a low vulnerability to damage, the ability to detect damage and perceive the damage situation, and the means to repair and recover from the effects of damage.¹³ No routine procedures appear to exist for invoking analytic assistance to create damage-limiting criteria meant to cope with prospects for threat-caused damage of the kind shown on the adjoining chart. A design philosophy to prevent complete loss of mission capability from light damage (the "cheap" kill) weakly substitutes for these absent criteria. By default, then, an assessment of vulnerability performance will be an assessment of the ship architect's design philosophy, rather than an assessment of how well the ship's design conforms with battle requirements for the vulnerability performance deemed essential for the ship to be able to keep fighting.

¹² RADM Julian S. Lake, "Warship Survivability," *International Defense Review*, 6/81, pp. 721-724.

¹³ Dr. P.J. Gates, *Surface Warships: An Introduction to Design Principles*, (London: Brassey's Defence Publishers, 1987), p. 170.

SURFACE WARSHIP FAILURE MODES

DAMAGE PROCESS

UNDERWATER SHOCKWAVE IMPACT

HYDRODYNAMIC WHIPPING

AIRBLAST FRAGMENT SPRAY

AERODYNAMIC OVERPRESSURE

MAIN PENETRATOR ENTRY or
BEHIND-HULL FRAGMENTATION

TERMINAL EFFECTS

Hull Breaching
Structural Support Cracking
Sensitive Equipment Breakage

Hull Wrinkling
Bulkhead-Stiffener Separation

Exposed Equipment Perforation
Crew Wounding

Structure Plating Distortion
Drag-Sensitive Parts Break-off
Structure Bending (confined
blast)

Utilities Severance
Inner Compartment Destruction
Damage Volume Crew Casualties
Combustibles Ignition



LOSS CRITERIA

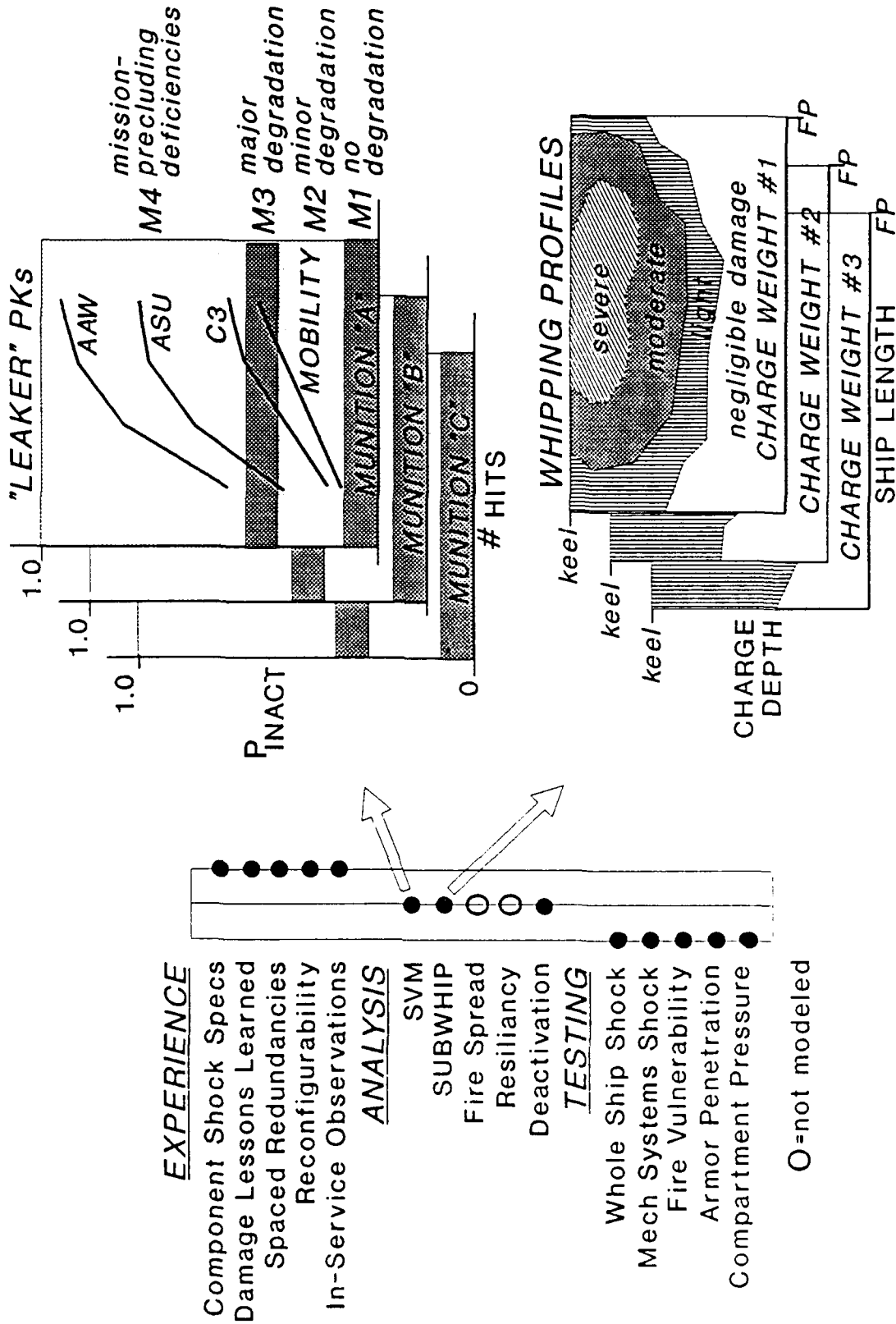
- *Mission-essential system inactivation*
- *Munition magazine mass detonation*
- *Uncontrollable fire propagation*
- *Excessive flooding from holing*
- *Hull break-up*

Although a detailed plan exists for conducting LFT&E of a guided missile destroyer, the Navy Component has not yet had to report the outcome of LFT&E for this warship. When the Navy does make a report, its conclusions will very likely be in the form of a net assessment of ship vulnerability to threats likely to be encountered while performing the battle missions assigned the ship in the top-level requirement document and OPNAVINST 3501.2F (14 October 1982). Since whole-ship vulnerability analysis is not relied on to create ship vulnerability capability requirements, there is no rational basis for ship vulnerability models to be subsequently used as rally points for portraying vulnerability performance. A matrix format similar to the one depicted on the adjoining chart can be expected to be used to display evidence of ship damage tolerance. Conveying the importance of this evidence and its integration into a net assessment of ship vulnerability performance will likely be the difficulties that burden this form of reporting. Nonetheless, the matrix format will provide a comprehensive report of : (1) vulnerability reductions incorporated after a review and analysis of vulnerability lessons learned from experiences with previously deployed classes of surface ships¹⁴ (a form of then-now side-by-side comparison); (2) ship-specific and carry-over testing related to weapons effects damage mechanisms; and (3) analytic estimates of as-built ship and mission capability losses attributable to a few hits by "leakers."

¹⁴ Exemplified by classified "Survivability Review Group Report of Surface Ship Design Principles", NAVSEA TR 072-55X-TR-005, Feb 1987, Volumes I-IV.

LFT VULNERABILITY ASSESSMENT REPORT

A Matrix Format for Surface Ships



The matrix assessment of ship vulnerability depends heavily on modeling; so too does the assessment of aircraft. Although based on practical experience, MIL-STD-2089¹⁵ kill definitions classifying the effects of aircraft damage were coined to be convenient for analyses and combat simulations of aircraft survivability. They are less often used in the phrasing of aircraft operational capability requirements, since only the requirement descriptions for fire support aircraft (e.g. AC-130) and anti-armor aircraft (e.g. attack helicopter or A-10) have historically contained vulnerability capability requirements. The four MIL-STD-2089 attrition levels described on the chart below are time-dependant because the elapsed time between the onset of damage and the eventual loss of the aircraft is a determining factor of the chances for recovering the aircrew. The mission abort kill implies a dependence on mission profile. Therefore, it is necessary to define the mission the aircraft is engaged in to be able to assess mission abort damage. Helicopters are treated as a separate case when classifying aircraft damage consequences, since many of their features have no counterpart in fixed wing aircraft. The forced landing category includes a forced landing at any time after damage occurs, but before the fuel load is expended (this condition implies the aircraft may still be vulnerable to post-landing damage related to the fuel system or the aircraft may be self-recoverable if damage is repairable by the aircrew).

¹⁵ MIL-STD-2089, "Aircraft Nonnuclear Survivability Terms"

TACTICAL AIRCRAFT KILL CATEGORIES

ATTRITION (KK) - catastrophic aircraft loss immediately after being hit
(K/A/B) - loss of control and aircraft within (30 sec/5 min/30 min) after being hit

MISSION ABORT - aircraft hit damage prevents mission completion, but aircraft is still flyable (scenario-dependent kill)

HELICOPTER - hit damage to aircraft prompts
FORCED LANDING powered or unpowered setdown

Although specific vulnerability capability requirements aren't usually included in descriptions of aircraft operational requirements, it is standard practice by each Component to invoke a requirement for the conduct of an aircraft survivability program.¹⁶ Vulnerability assessments of the aircraft, DMEA examinations that reveal kill modes of aircraft systems, and impact analyses of vulnerability reduction techniques are included in this program. The priorities for coping with possible damage effects are to save the man, machine, and mission - in that order. Conduct of the program is aided by the existence of numerous handbooks and guides for design, layout, and location of the critical system elements in fixed and rotary wing aircraft. A major contributing factor to the vulnerabilities of a modern tactical aircraft (sized smaller than in the past to lower susceptibility) is the high density of component packing within the airframe. Evidence of this packing can be seen in computerized representations of fully equipped aircraft with transparent skin rendering. Effectively protecting these many components with operationally significant armoring would be problematic. Consequently, most solutions for lessening the prospects of performance losses tend to be about tolerating the kinds of damage pictured on the adjacent chart, instead of resisting them. Although contractual documents may lack explicit vulnerability capability criteria, aircraft design is still disciplined to account for vulnerability performance.

¹⁶ By citing MIL-STD-2069, "Requirements for Aircraft Nonnuclear Survivability Program"

TACTICAL AIRCRAFT FAILURE MODES

DAMAGE PROCESS

MAIN PROJECTILE and
DETONATION FRAGMENTS
PENETRATION

TERMINAL EFFECTS

Control Surface Removal
Structural Member Cracking
Propulsion Element Holing
Oil/Lubricant Leakout
Combustibles Ignition
(incendiary penetrators
and particles)
Fuel Cell Rupture/Depletion
(hydraulic ram action)
Engine Fuel/Debris Ingestion
Control Link Jamming/Severing
Mission Equipment Perforation
Crew Injury

AIRBLAST

Control Surface/Hinge Damage
Structural Member Overload



LOSS CRITERIA

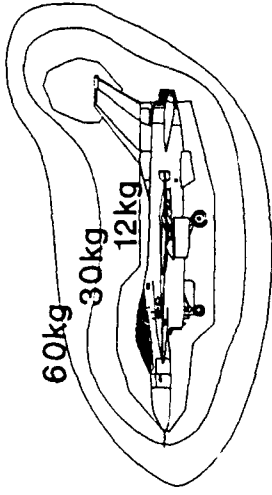
- *Flight lift, thrust or control failure*
- *Mission-essential system inactivation*
- *Unquenchable fire*
- *Pilot/crew casualties*

One approach by the Components to the problem of assessing an aircraft's vulnerability is to determine the most vulnerable regions of such critical elements as the pilot, engines, and fuel system. The sum of these vulnerable areas, A_v , is a theoretical representation of a fraction of the aircraft silhouette accessible to a threat that would subject the aircraft to some level of kill if impacted by a penetrator or a fragment. The so-called "survivor rule" when redundant components are involved is sometimes used to portray the change in A_v of an aircraft receiving multiple hits. Another measure of vulnerability, $P_{K/H}$, can be empirically determined from knowledge about the $P_{K/H}$ s of critical components that are vulnerable to being killed by a single fragment. $P_{K/H}$ s for untested critical components are assigned using engineering judgement. Aircraft vulnerability to HE detonation damage at a specified altitude is approximated by $P_{K/DETONATION}$ contours around the aircraft to represent specific blast kill levels. ***A net sense of aircraft vulnerability can also be difficult to portray when different formats must be used to gauge vulnerabilities from a variety of threats.*** See the chart on the opposite page for examples. The A_v format is most commonly used to communicate aircraft vulnerability, but its meaning as a "stand-in" for a map of observable vulnerabilities may be difficult to comprehend. Also, it is unlike any assessment format used for other platforms. All aircraft assessment methods require a strong foundation of component vulnerability data to convey confidence in their use and, perhaps, some whole-aircraft test evidence to vouch for the correctness of combinatorial techniques, as well.

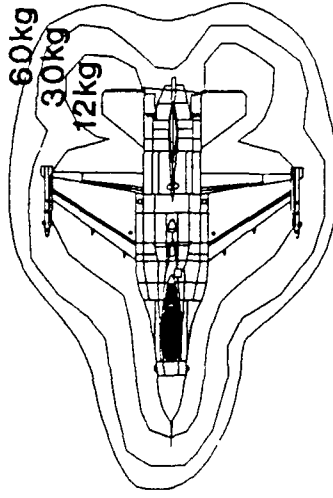
LFT VULNERABILITY ASSESSMENT REPORT

A Multi-Level Format for Tactical Aircraft

1. VULNERABILITY REDUCTION FEATURES
2. MAJOR COMPONENT TEST DATA BASE
3. AIRCRAFT VULNERABILITY ANALYSIS
4. KEY COMPONENT/SUB-SECTION LFT
5. ANALYSIS CONFIDENCE ESTIMATE

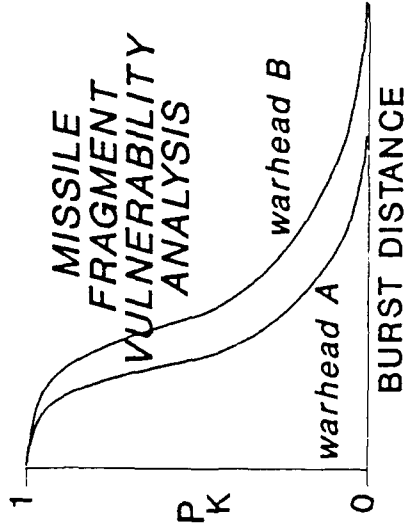


**EXTERNAL BLAST
VULNERABILITY ANALYSIS**
 $K \text{ kill } R_{\text{eff}} = k \cdot (\text{CHARGE kg})^{1/2}$

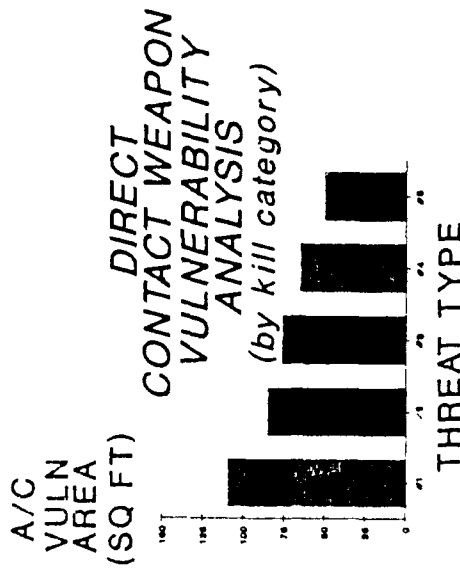


(c) Blast Format

TYPES OF ANALYSES



(b) P_k Format



(a) A_v Format

A common framework of inquiry and investigation is being used by the DoD Components to probe the vulnerabilities of all LFT&E-eligible platforms. This generic methodology for assessing the vulnerabilities of ground, sea, or air platforms is outlined on the opposite page. The methodology can be used, in conjunction with explicit vulnerability performance criteria, to highlight critical performance questions by evaluating platform performances during operationally significant circumstances. Those circumstances include "hits" from each type of munition that would likely be used to attack the platform while engaged in combat with potential foes. Some of these munitions may be known or suspected to be overmatching, but not catastrophic in their effects on platform design candidates or manufacturing prototypes. Vulnerability appraisals that do not account for post-penetration platform failures producible from such threats can obscure the contribution to a platform's vulnerability capability that could be achieved or is being achieved with component redundancies, component placement, and other non-armor techniques of damage control. Exposure of a platform's damage control attributes by means of testing and other data collection activities, as well as its damage blocking attributes, is required to create an informed and informative assessment of the platform's inherent vulnerability performance capability. This, in turn, proscribes the limits of technical techniques for reducing a platform's vulnerability to moderately overmatching threats and focuses the thinking of tacticians who are developing procedures about "how-to-fight" the platform.

VULNERABILITY ASSESSMENT METHODOLOGY

A. Assessment Preparation

SYSTEM CHARACTERIZATION

MISSION-ESSENTIAL FUNCTIONS Establish which warfighting capabilities are most important during each phase of a typical mission profile.

FUNCTION EXPECTATIONS Assemble a system performance and technical description.

CRITICAL COMPONENTS Create "wiring diagrams" that identify system elements vital to accomplishing each function.

SYSTEM CONFIGURATION Ascribe spatial positions to critical components/structural features; ascribe physical properties to system coverings.

SHOTLINE INTERROGATION

ATTACK ON SYSTEM Select a munition type and path of attack against the system; characterize the attacking munition's warhead effects

B. Platform Assessment

INACTIVATION CRITERIA

COMPONENT DAMAGE CRITERIA Create look-up tables of critical component/structure damage (kill) criteria for each weapon effect damage mechanism.

VULNERABILITY ANALYSIS

DAMAGE ASSESSMENT Determine extent of damage to critical components located in the weapon effects regions.

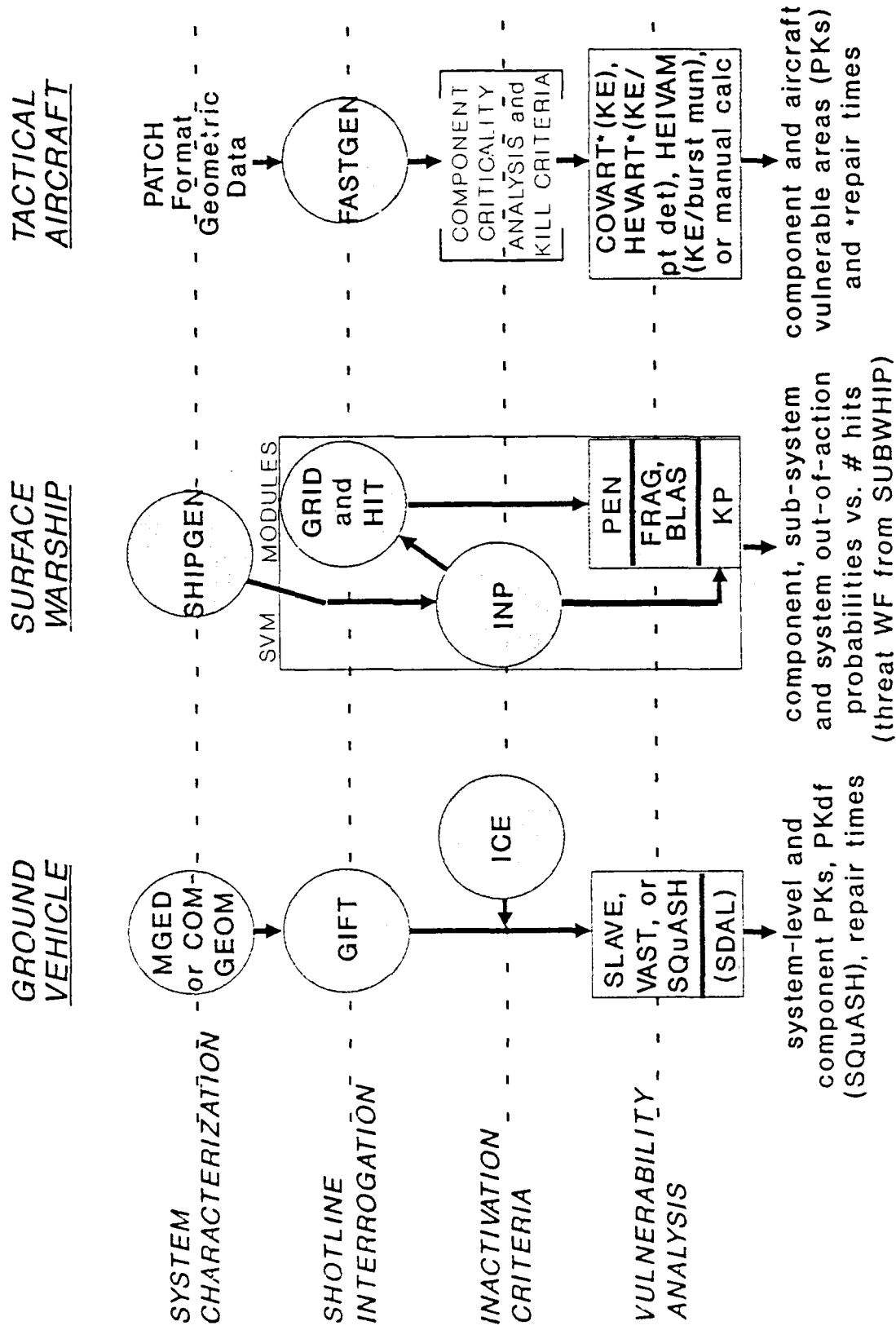
DISABILITY ESTIMATE Estimate degree of dysfunction stemming from damage to the components needed for normal performance of each function.

KILL PROBABILITIES Relate levels of hit-induced performance disabilities to the incapacitation levels defining total loss of each function.

MISSION-CONTINUATION CAPABILITIES Evaluate impacts of residual functionality on the mission demands against the system.

A thorough assessment of a weapon platform's vulnerability is a significant task, since damage due to attacks from different directions at various standoff distances must be accounted for, and this must be done for the warhead effects of each attacking munition. Vulnerability performance can hardly be comprehended when so many factors are involved, unless mathematical models that run on high speed computers are used to analyze platform vulnerability characteristics. That is the case whether the analysis is employed to confirm that a design approach is yielding the requisite P_k , or whether the analysis is used to communicate an assessment of vulnerability performance to decision-makers. *The principal computer-aided models relied on by DoD Components to assess platform vulnerability differ in the degree of detail used to portray a platform.* These models are identified on the facing page. The models for ground vehicles and aircraft portray these platforms as collections of elemental piece-parts and individual cables, while ships are modeled on the larger scale of compartments, cabinets, and conduits. The code for these models is configuration-controlled. Although it is true that tests of materials, components, assemblies, and whole systems are necessary to keep the data bases for these models current, other kinds of collection activities can also contribute to model credibility. Thus, the *data files for a model such as the Ship Vulnerability Model (SVM) can serve as a convenient archive for relevant information from sources such as peacetime incidents, wartime operational reports of damage, foreign munitions exploitation, and the combat experiences of allies.*

VULNERABILITY ASSESSMENT MODELS



Analytic assessments of all types of platforms reflect the imperfect match between complex reality and simplified assumptions. Assumptions inevitably lag the state of real world technology. Changes in threat warhead technology are regularly reported. New recipes for materials that resist perforation and platform skins being created from advanced aerospace materials are typical features of contemporary weapon platform construction. Model algorithms of warhead-material interaction need to be updated to keep pace with these changes. A new Serious/Lethal Wound Model is being developed by the BRL to predict ground/air crew ballistic wound effects in terms that will allow a better assessment of crew vulnerabilities. Casualty criteria for other forms of trauma require better correlation of physiological damage with loss-of-function. Team/group vulnerability is an appropriate level of assessment for the crew of a large ship. However, analytic modeling is not being used to assess potential ship crew casualties, in any aggregation. Shipboard casualties could presumably occur as the consequence of a spreading fire. Fire spread is a major damage control concern. But fire spread is not modeled during analysis of hit-induced damage effects; therefore, only ship vulnerabilities stemming from prompt hit damage are currently assessed. These and other problems needing to be remedied (see chart below) are the reasons why vulnerability modeling produces imperfect assessments of vulnerability. While computer modeling is highly useful, designs must always be verified, to some extent, with testing and other forms of data collection.

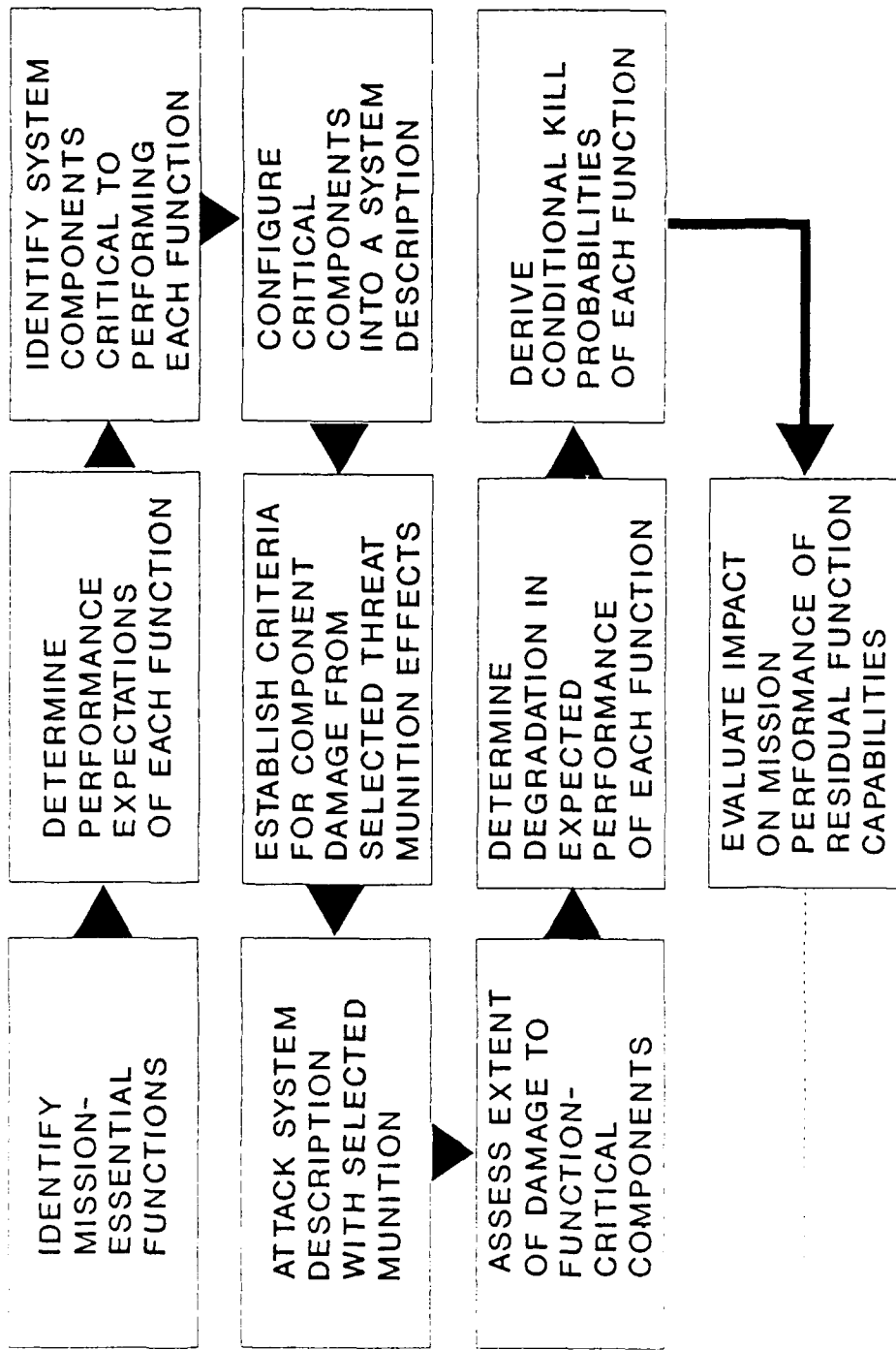
SOME PROBLEMS OF ANALYSIS

LFT Vulnerability Modeling

GROUND VEHICLE	SURFACE SHIP	TACTICAL AIRCRAFT	
		X	Few threat munition blast fields characterized
		X	Sparse structural response data to determine lethal charge radii
X			BAD info lacking for many warhead-armor combinations
X	X	X	Sparse or inadequate contemporary component Pk/h data and damage data for new aerospace materials
X	X	X	A means to combine effects on components subject to more than one type of damage causation
X	X	X	Alternative to "survivor rule" approximation for aggregating component damage from multi-fragment hit
X	X	X	Normative crew vulnerability/prompt casualty criteria
X			A means of estimating secondary damage mechanisms to narrow the correlation gap with full-up test data
X	X	X	A means of estimating delayed hit damage (spreading fire/worsening crew incapacitation, for example)

All vulnerability assessments are being created from comparable building blocks of activities, regardless of the type of weapon platform being assessed. These activities are identified on the chart that accompanies this text; they may be performed during the course of preparing, conducting, and evaluating a vulnerability performance test of a platform or during the process of analytically assessing platform performance. The logic of the process is sound enough. *At issue is a question about the proportions of prior experience, testing, modeling, and judgement that would result in an economic, but credible, assessment of vulnerability for LFT&E purposes.* Vulnerability assessments of aircraft, and ships to some extent, depend on computations and modeling. Model accuracy is limited by uncertainties inherent in the prediction of damage to complex systems, and the assessed damage levels will likely be too high or too low. However, the influence of these limitations is minimized when a model is used to compare differences in vulnerability performance between replacing and replaced systems. *This application of a model to assess the incremental vulnerability performance of a weapon platform, rather than its absolute performance level, yields a useful measure of effectiveness for acquisition decision-making.*

FLOW OF TYPICAL VULNERABILITY ASSESSMENT

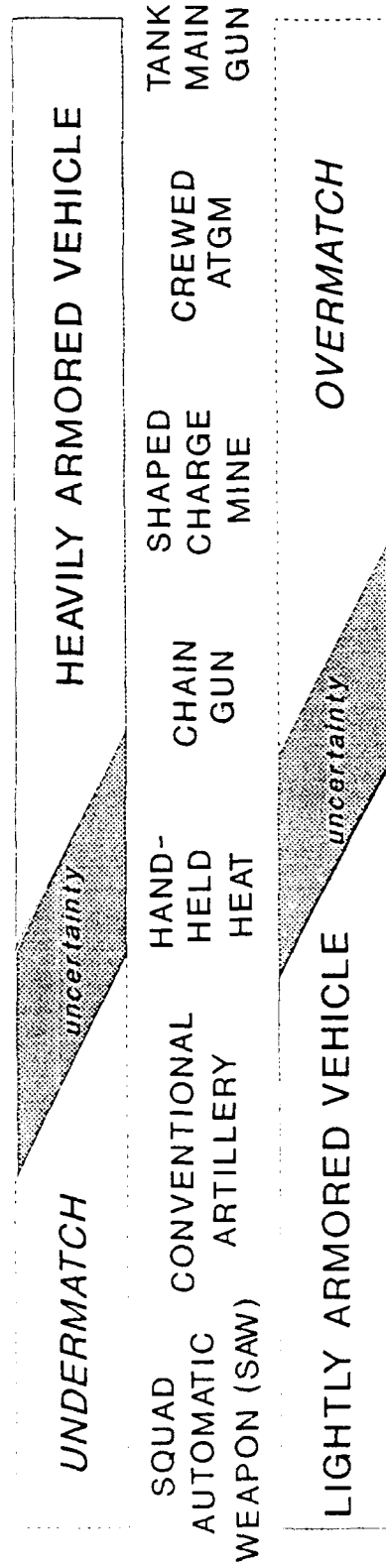
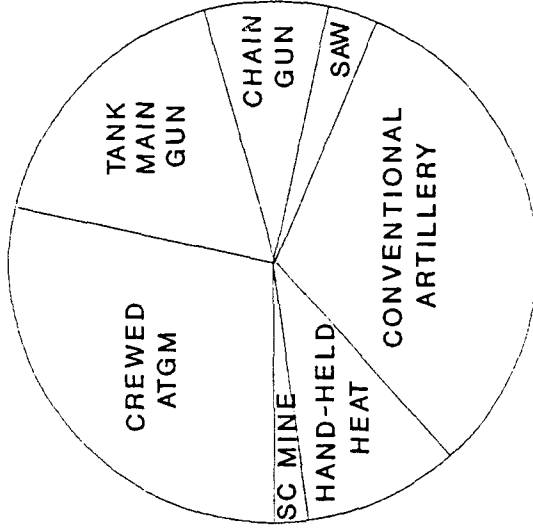


Acquisition decision-makers could also benefit from having vulnerability information presented to them with ingredients of context and perspective. LFT&E planners are encouraged to determine vital vulnerability concerns by conceptualizing the spectrum of damage and casualty sources that weapon platforms must contend with.¹⁷ The prospective frequency-of-encounter and the vulnerability significance of each threat are supposed to be determinants of which threats deserve to be examined during the course of LFT&E. The chart on the opposite page is a notional depiction of significant threat interactions with ground platforms. There is license to weight threats when preparing an LFT&E strategy, since requirements documents that mention all likely threats to a platform often don't make a distinction among their importance as attrition sources. The reasoning employed to rank threat-platform interactions for the purpose of developing vital LFT&E issues ought to be similarly applied to the outcome of LFT&E. Alternatively, the outcome of LFT&E could be post-processed with a threat distribution function that represents frequencies-of-hit experienced during OT II. **This would weight the vulnerability attributable to each threat in proportion to its vulnerability significance and, as a result, transfer additional, useful information about a platform's assessed vulnerability to acquisition decision-makers. Threat significance weighting could be applied to ground, sea, and air platforms.**

¹⁷ *Live Fire Test and Evaluation (LFT&E) Planning Guide*, OSD Live Fire Testing Office, June 1989, sec. 3.

LFT&E VULNERABILITY WEIGHTING

Threat Significance Distribution



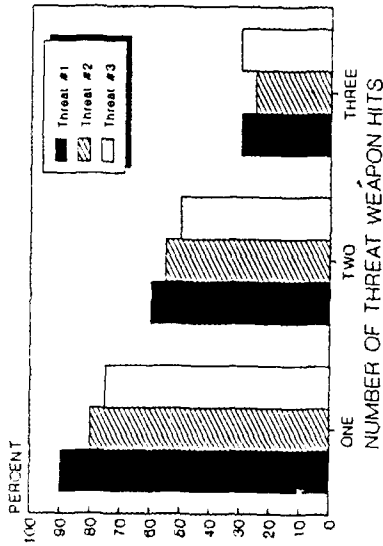
Another means of putting vulnerability performance into perspective is to consider the relative dependency on each function during each operational role that a weapon platform would be required to fulfill while performing a typical combat mission. Most single-mission platforms are equipped to perform multiple functions and a multi-role platform relies on some functions more than others in each of its roles. Function weighting has been used to assess the relative impact of a ground fighting vehicle's mobility and firepower vulnerabilities on the capability needed to perform all modes of a typical mission profile.¹⁸ The amount of time spent performing each mode of the mission profile provided a basis for proportionally combining weighted function vulnerabilities into a net assessment of ground platform survivability (the mathematical complement of vulnerability, P_{KH}). Function weighting of a sea surface platform vulnerability assessment has been informally demonstrated using the ship information shown on the facing chart; it likely can be demonstrated to apply to air platforms, as well. The mission profile of a platform (also known as an operational mode summary or cycle of combat activities) on which to base functional weighting is usually defined in the description of platform required operational capabilities (ROC/TLR/SORD). Function weighting is an alternative to threat weighting. The two forms of weighting could conceivably complement one another when applied to the same vulnerability assessment.

¹⁸ *Live Fire Testing Damage Assessment Methodology (U)*, SECRET technical report prepared for the DoD Live Fire Test Office by Wackenhut Applied Technologies Center, April 1990.

LFT&E VULNERABILITY WEIGHTING

Function Dependency Distribution

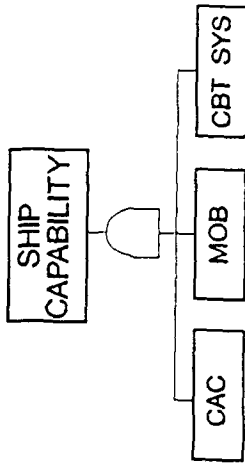
REMAINING SHIP CAPABILITY



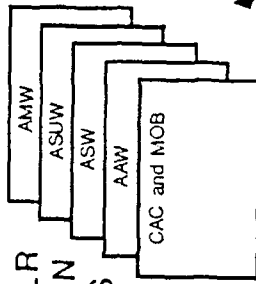
THREAT
"LEAKER"
ESTIMATE



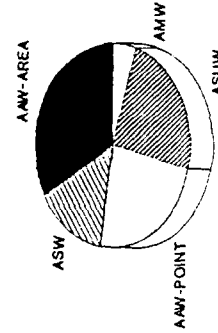
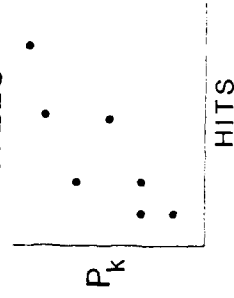
MISSION MODE
FRACTIONAL CAPABILITY
SUCCESS TREE



SHIP TLR
MISSION
AREAS



SVM MISSION AREA
OUT-OF-ACTION
LEVELS



SHIP TLR
WARTIME CYCLE
COMBAT SYSTEM
ACTIVITY



Combat subjects a weapon platform to the most extreme conditions under which it will perform its basic functions. Combat damage data, like those shown on the chart opposite, are available from several archives. Vulnerability assessments can account for these experiences of predecessor platforms in a number of ways. One way is to select simulation or test shotlines that reflect the prevailing directions of recorded attacks on the type of platform being assessed. Vulnerability assessments can also be reported for platform views subjected to the most attacks in past conflicts. Alternatively, when cardinal views are averaged to assess platform vulnerability, the weight of each view can be made proportional to the amount of combat hit data that applies to each view.¹⁹ There may also be some utility to weighting the relative frequency-of-occurrence of platform kill categories. Aircraft K:A:B kills reportedly occur 3:8:15 times more frequently than KK kills.²⁰ These data would tend to focus vulnerability assessments on extending the delay time performance of air platform elements capable of improving the historical prospects for recovering pilots and aircraft. Combat data, then, can be used to illuminate land, sea and air platform vulnerability reporting in many ways, including a sizing of the payoff from contemporary vulnerability performance.

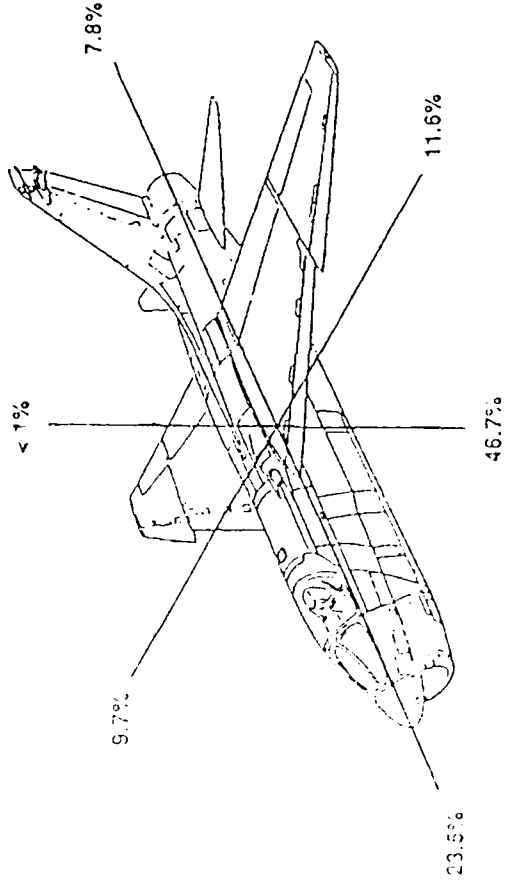
¹⁹ This was the technique used to portray historical hit distributions for the cardinal views of CAS aircraft in *(U) Comparative Close Air Support Aircraft Vulnerability Analysis*, SECRET SURVIAC TR-89-012, 20 December 1988, p. 35.

²⁰ P. Borgart, "The Vulnerability of the Manned Airborne Weapon System - Part 2: Probability of a Kill," *International Defense Review*, vol. 10/77.

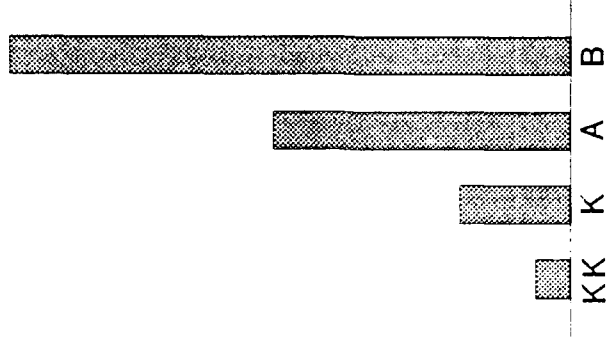
LFT&E VULNERABILITY WEIGHTING

Historical Combat Data Distribution

CAS MISSION HIT DISTRIBUTIONS



AIR COMBAT ATTRITION RATIOS



SPECTRUM OF THREATS:

- small arms
- armor piercing incendiaries
- high explosive incendiaries
- hand-held SAM

EXAMPLES OF KILL CAUSES:

- KK (2 sec) - ammunition explosion
- K (30 sec) - major fire
- A (5 min) - control surface damage
- B (30 min) - cumulative hydraulic fluid losses

**LETHALITY
ASSESSMENT**

Penetrating warheads are intended to perforate armor and enter the internal volume of the target to cause damage to critical elements of the system, including personnel. The usual criterion governing the lethality of kinetic energy penetrators is first round probability of kill, which takes into account penetration capability, target size, projectile accuracy, and the time of flight. Shaped charge rounds introduce an added complexity because a stand-off is required for charge initiation before excessive crush-up of the projectile nose has taken place. Those warheads which do not perforate the target's armor can deposit sufficient energy in the form of impact shock to cause damage to key components of the target and thereby degrade its effectiveness as a threat. When perforation of the armor does occur, a number of environmental changes are produced in the internal volume of the target. See the chart below. These changes are referred to as behind-armor effects; they include impact shock effects and additional effects from: the remnant of the penetrator traveling at some residual velocity; armor fragments, the majority of which are produced from cavitation of the internal surface of the armor during the penetration process; a pulse of overpressure; a thermal pulse; flash illumination; and possibly some harmful gases. Although all of these environments must be classified as hazardous, extensive investigations indicate the majority of damage to target personnel and components will be caused by the remnant(s) of the penetrator and a behind armor debris (BAD) cloud consisting of penetrator and armor fragments.

LETHALITY ASSESSMENT

Penetrators

INTERCEPTION

- Target Velocity
- Target Aspect
- Round Velocity
- Standoff Distance
- Point of Detonation

TARGET

material penetrability

component spatial position and criticality

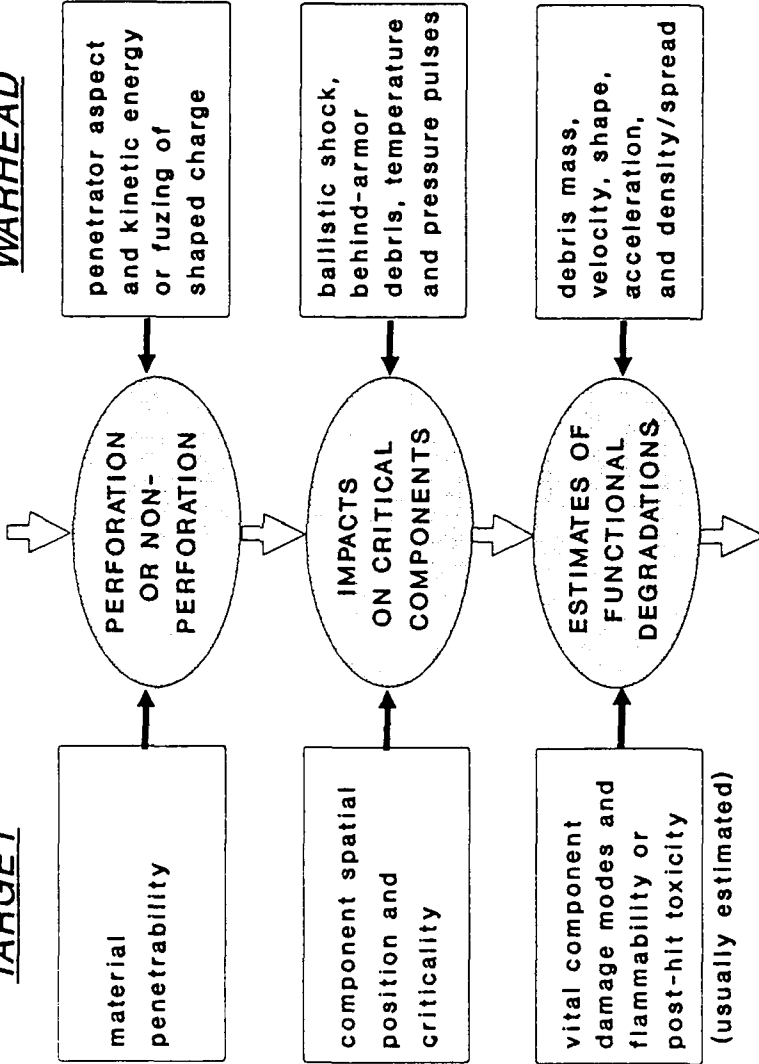
vital component damage modes and flammability or post-hit toxicity
(usually estimated)

WARHEAD

penetrator aspect and kinetic energy or fuzing of shaped charge

ballistic shock, behind-armor debris, temperature and pressure pulses

debris mass, velocity, shape, acceleration, and density/spread



PENETRATION KILL PROBABILITY

Munitions designed to detonate in proximity to a target propagate energy stored in the warhead by means of blast and ballistic fragments. Warhead energy is transferred more efficiently for greater distances by fragments than by blast, but the energy can only be transferred along the travel paths of the fragments. The assessment procedure for fragmentation-capable warheads is outlined on adjacent chart. An assessment usually begins with detonation of a munition at various points along and about the target heading line. Detonation spatial coordinates can be calculated from models that describe the appropriate fuzing process. The fragment group angle of spread determines allowable variations of the point at which the warhead must be detonated with respect to the target. For a specific warhead design, the velocity and the masses of fragments hitting various portions of the target can be predicted fairly accurately. Given the type of target and the nature of its material to be penetrated, the number of hits and their penetration into vital components can be derived. Conclusions about whether a particular component will fail when hit depend on component robustness and a variety of fragment factors such as fragment residual velocity when a component is struck, fragment size and shape, hit densities of these fragments, and the tendency of the fragments to burn. Impact energy density is often used to simplify the damage estimation, since damage mechanisms and kill criteria for foreign target components aren't usually known. Target losses-of-function are, in turn, estimated by attributing a collective impact to the damage estimates for all components involved in each function.

LETHALITY ASSESSMENT

Fragments

INTERCEPTION

- Target Velocity
- Round Velocity
- Point of Detonation

TARGET

geometry

fragment velocities and spread angle

WARHEAD

material data and critical components

residual fragment speed

component damage mechanisms and kill criteria
(engineering judgements)

fragment weight, shape, density, flammability

FRAGMENT FLIGHT PATHS

HITS ON CRITICAL COMPONENTS

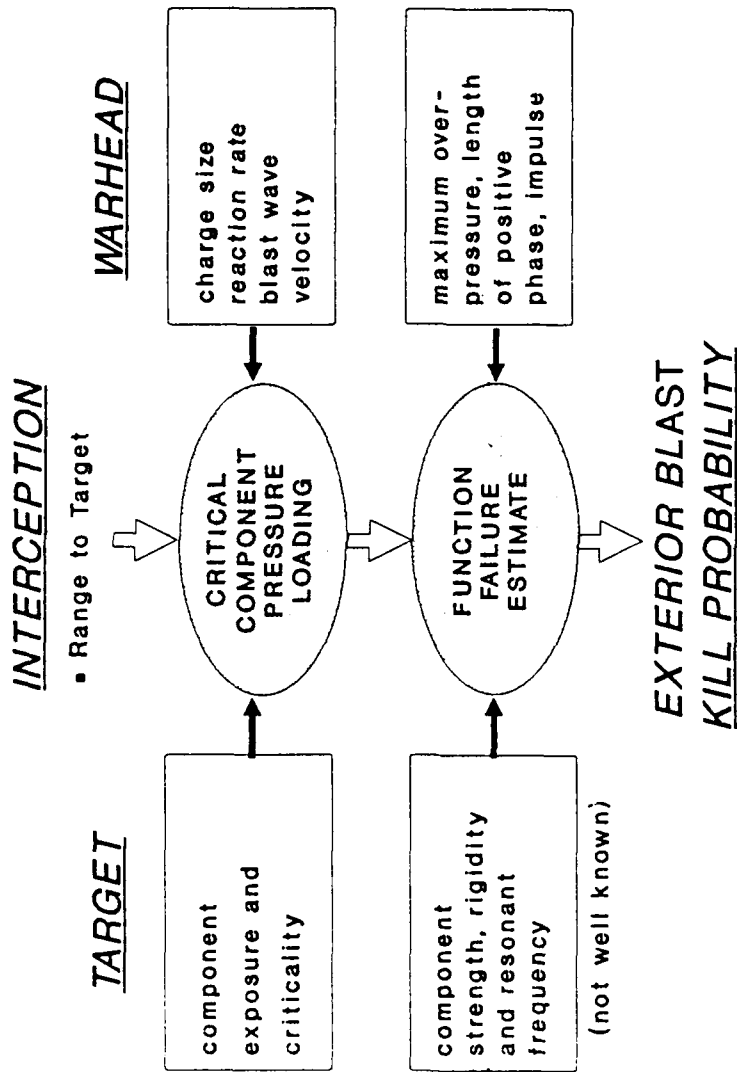
ESTIMATES OF FUNCTIONAL DEGRADATIONS

FRAGMENTATION KILL PROBABILITY

Detonation of an explosive charge releases gaseous products heated to a high temperature. The gas expands rapidly and drives the surrounding medium, air or water, before it, compressing the medium in the process. This produces the so-called blast wave, with the peak overpressure occurring at the leading edge of the wave. An underwater blast has a relatively greater effect than an airblast due to the greater density of the water medium. The blast wave from a warhead charge acts in all directions, but covers a shorter range in air than detonation fragments. Blast wave pressure loading on a target is a combined effect of dynamic loading which induces sudden displacement pressure on target components due to the velocity of the wavefront and a subsequent period of crushing overpressure. Blast wave characteristics at a target location can be accurately calculated for a particular size of charge detonated at various distances from the target. A mechanical response of the target can be determined from fundamental calculations of such factors as the drag resistance of attached components and the deformation tolerance of extended structures (such as ship hulls) that can be subject to uneven pressures over their lengths. Blast wave interaction with an actual target structure will be quite complex, however, since individual target components will each have unique physical properties and respond differently to the blast wave. These responses are normally not well known for foreign target components. A target blast damage assessment, therefore, includes a degree of uncertainty largely arising from uncertainties about the extent of target component damage attributable to blast effects. See chart below.

LETHALITY ASSESSMENT

Exterior Blast



A lethality assessment reporting format presently used by all the Components is depicted on the opposite page. Their is very little variation to this format for reporting different categories of munitions and missiles: air-surface, air-air, surface-air, surface-surface or subsurface. A "flash and bang" style of reporting target damage is used that avoids having to explain warhead kill probabilities to an audience of decision-makers. Munition and missile lethality are assessed using a qualitative net estimate of warhead effectiveness supplemented by a shot-by-shot narration of results. No change to this format is deemed to be warranted, as lethality conclusions may easily be determined by decision-makers from the type and amount of information presented. The qualitative net estimate clearly communicates whether or not the warhead is lethal if the target set closely resembles the intended victims and unambiguous declarative sentences are used to assess warhead effectiveness. The supplemental narration can include a description of exploitable target vulnerabilities, especially those vulnerabilities that were evident from destructive testing or were revealed by a lethality analyses having a high degree of plausability (possibly as a consequence of demonstrating reasonably accurate predictions during LFT&E preparatory tests or during other tests of similar munitions).

LFT LETHALITY ASSESSMENT REPORT

Warhead Effectiveness Format

TYPICAL MUNITION REPORT FORMAT

Date	Test shot number	Target description (type, presentation aspect, condition,...) Munition hit information (location, velocity, obliquity,...)	Narrative damage assessment
------	------------------	---	-----------------------------

EXAMPLE: AIR-SURFACE MUNITION

Date	Test shot number	Launch Parameters				Weapon TOF, sec	Target Description	Narrative damage assessment
		Altitude, ft AGL (000)	Slant range nmi	Speed, KTAS	Dive angle, deg			

Models used to perform a lethality analysis are categorized on the facing page. Lethality models are sometimes the same models previously identified as vulnerability analysis models, but with foe system vulnerabilities being assessed as friendly warhead lethalties. These models require a great deal of input data describing target construction details and the hardness of individual system components to compute an assessment. That kind of information is seldom known about the latest foe systems and can only be guessed about for follow-on foe systems. Consequently, models that portray targets with less detail than higher resolution vulnerability models are most often preferred for conducting lethality performance analyses of new and improved warheads. The description of a target as a configuration of generic major components, the parametric correlation of warhead size with damage volume, and cross-sectional representations of component vulnerabilities are examples of simplifications that may be used in lethality modeling to make analysis of foe future systems possible. Lethality modeling, like vulnerability modeling, is relied on to predict damage from planned test firings; the firing order will be based on these predictions. Like vulnerability assessments, the impact of simplifications and assumptions on the accuracy of lethality modeling answers can be lessened when only the incremental improvement of replacing-replaced warhead lethality is assessed, instead of attempting to assess the absolute value of the new warhead's characteristic lethality.

LETHALITY ANALYSIS MODELS

"TWO-COLOR" MODELS - reversible red/blue models normally used for own system vulnerability analysis, but equally applicable to own munition lethality analysis (such as VAST, SquASH, etc)

PREFERRED MODELS - models frequently used for foreign target damage assessment; may utilize damage prediction algorithm tailored to foreign target (examples: PDAM, SovietSVM)

SPECIALIZED MODELS - models designed to estimate the damage that could be inflicted by special purpose munitions on target victims (munition examples: FAE, DE)

Lethality assessments are largely going to be a report of destructive, limit, and other forms of testing, rather than analysis, if the pattern of past assessments continues. Since lethality analysis, unlike vulnerability analysis, is being used as a secondary means of conveying conclusions about a warhead's lethality to acquisition decision-makers, the state-of-the-art of lethality modeling is mostly of importance for planning test shotlines. Major lethality analysis problems are listed on the opposite page. These problems can be attributed to uncertainties about modeling munition-target interactions of victim systems that haven't had a "hands on" exploitation. There is no reason to believe this circumstance will change in time, since technical information about foe future systems will, undoubtedly, always be clouded with uncertainty. This is likely to be especially true for information about foe system modifications meant to reactively countermeasure a new warhead's lethality performance after it has been fielded (a warhead is normally prescribed to be lethal against foe targets for a minimum in-service period of IOC plus five years).

SOME PROBLEMS OF ANALYSIS

LFT Lethality Modeling

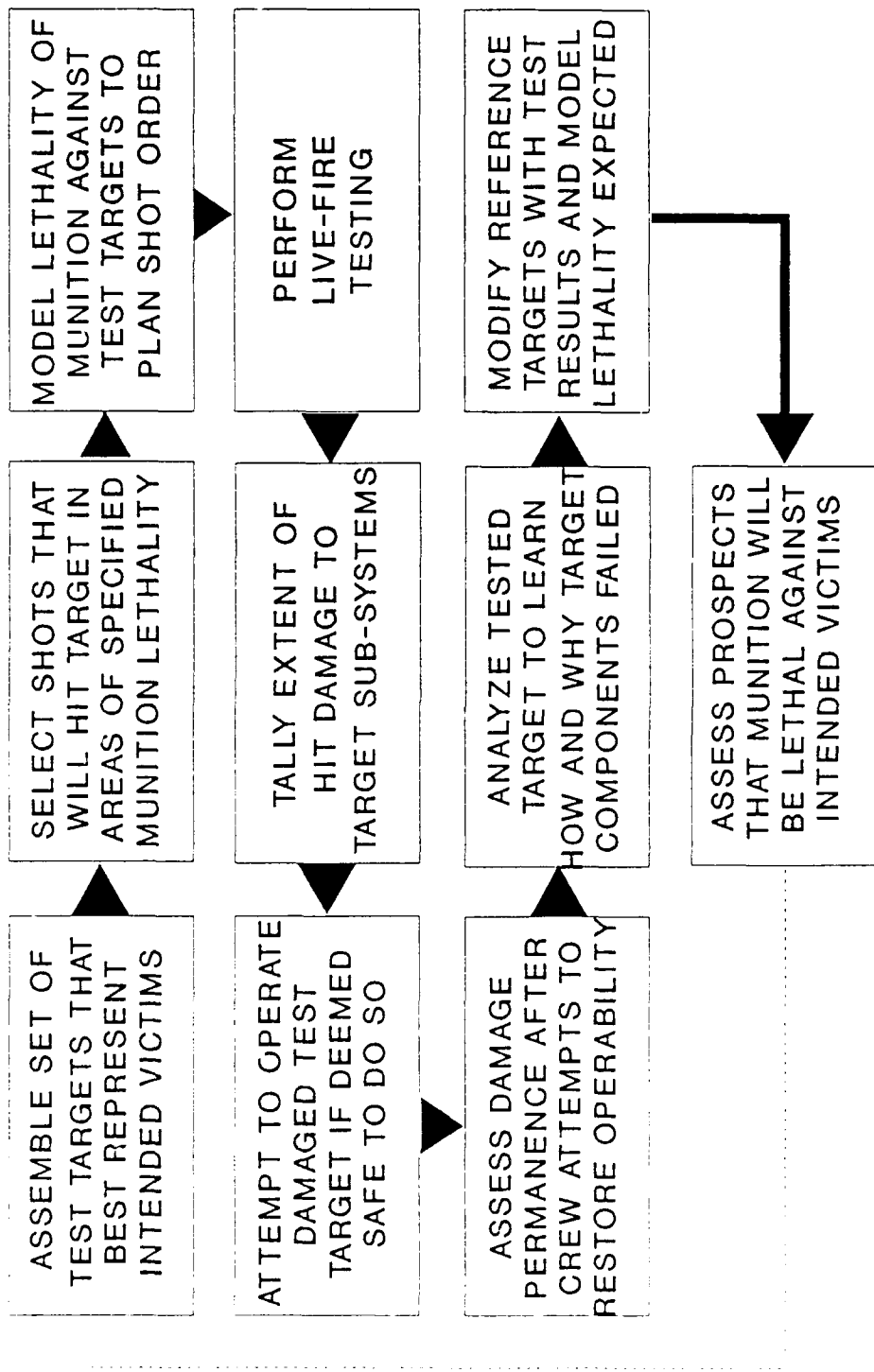
Data to develop penetration and perforation algorithms
descriptive of foreign armors and other materials
used in the construction of the newest target systems

Validated configuration information in sufficient detail
to include important redundancies and chokepoints in
system fault trees / deactivation diagrams

Conditional kill probabilities of critical componentry
to be assessed by point-burst methods of analysis

The steps of a typical lethality assessment are charted on the opposite page. The assessment requires knowledge of the damage inflicted on the intended target(s) by all of the possible damage mechanisms that can act against each part of a target (including stores and cargo) and its crew (also passengers, if appropriate). This knowledge is mostly derived from testing the best available approximation of the real target's ballistic protection, component robustness, and component locations. Target modification is often necessary because the foreign targets that become available for testing usually only represent the older fraction of the target set that would be encountered during the future service lifetime of a new munition. Foreign targets are usually not available, at all, to test anti-aircraft and anti-ship warheads. In such cases, U.S. drones and other surrogates of foe systems are used as test targets. Surrogate damage and destruction has been the accepted basis of past lethality assessments. *If test results are going to continue to dominate lethality reporting, then test preparations and procedures will be much more of an influence on lethality assessments than will analytic prowess. However, an analytical assessment of a warhead's incremental gain in lethality performance (replacing-replaced warhead comparison) could conceivably add value to the lethality information that is normally available to acquisition decision-makers from the present reporting format.*

FLOW OF TYPICAL LETHALITY ASSESSMENT



FINDINGS and RECOMMENDATIONS

LFT&E PROCESS IMPROVEMENT

FINDINGS

- A. Adequate OSD LFT&E guidance to DoD Components will exist when acquisition policy is updated by publication of newly revised versions of DoDI 5000.2 and DoD 5000.2M; LFT&E guidance to R&D organizations and PEOs/PMs is presently missing from some DoD Component policy and procedures documents that regulate platform and munition RDA activities

RECOMMENDATIONS

Consultations with Component LFT POCs about augmentation of Component-common LFT&E guidance issued by DoD with LFT&E instructions specific to the products and practices of each Component when Component regulations, especially those concerning T&E, are being modified to conform with newly issued DoD acquisition policies

LFT&E PROCESS IMPROVEMENT

FINDINGS

B. Descriptions of required operational capabilities for weapon platforms (ROC, TLR, or SORD) do not always specify the vulnerability performance that will be needed, and, as a consequence, do not anchor the design of the platform to account, in some degree, for each of the munitions that would likely be used to attack the platform during combat with prospective foes (some of these munitions may be overmatching, but not catastrophic in their effects on any reasonable platform design - these munitions do not become less threatening by foregoing the need to cope with them tactically or assess their effects technically)

RECOMMENDATIONS

LFT&E Focal Points of the DoD Components should be requested by OSD LFTO to review the formulas of system requirement documents for adequacy of conventional vulnerability content and usage of criteria that can be translated into hardware/test designs; and to collaborate with the Component staff element(s) responsible for requirement document policy when formula changes are warranted (NOTE: requiring a platform to be "N" times more robust against a named threat than its predecessor fosters a role for comparative analysis)

LFT&E PROCESS IMPROVEMENT

FINDINGS

- C. Baseline thresholds of minimum acceptable platform performance prescribed for inclusion in DCP Annex B are intended to be measurable, demonstrable indicators of performance that would be critical for achieving success of the platform mission

RECOMMENDATIONS

When platform operational capability descriptions include specific vulnerability and lethality requirements, there is justification for equivalent parameters to be among those deemed to be the critical performance factors of a mission-capable platform

OSD LFTO seek joint agreement that requirements-based thresholds of essential vulnerability or lethality performance defined in Annex B of the DCP also are definitions of LFT&E exit criteria and will be the basis for LFT&E conduct, assessment, and reporting

LFT&E PROCESS IMPROVEMENT

FINDINGS

- D. OSD LFT&E Guidelines are permissive about allowing LFT&E to be conducted in ways that would accommodate the unique requirements of DoD Components; the resultant variability among techniques used by Components to assess vulnerability has led to dissimilar reporting formats based on non-transferable analytic approaches and platform-unique units of vulnerability measurement

RECOMMENDATIONS

OSD LFTO conduct occasional "cross-breeding" sessions for Component assessors to promote data sharing, portability of platform geometric description formats, uniformity of simplex damage effects algorithms, comparability among the codes used to compute complex damage, and, possibly, compatibility among other vulnerability assessment elements with multi-platform application prospects; Component reporting can become common, to some extent, if each would supplement its reporting with a display of replacement system vulnerabilities normalized to vulnerabilities of the system being replaced

LFT&E PROCESS IMPROVEMENT

FINDINGS

E. Each Component holds to a different viewpoint about the relative proportions of prior experience, testing, modeling, and judgement that would result in a credible, cost-effective LFT&E vulnerability assessment of platforms such as ships and aircraft that must synthesize full-up, full-scale destructive testing

F. In the meantime, there are no precedents to be followed as guidance for field activities having the responsibility to prepare strategies and plans for performing LFT&E

RECOMMENDATIONS

This is an issue that could benefit from scrutiny by an independent third party to produce advice about practical roles for each factor likely to play a role in the creation of a vulnerability assessment; issue debate needs to be focused before opinions can be reconciled into a blueprint for conducting synthesized LFT&E

DoD Components publish interim instructions that implement OSD LFT&E Guidelines by tailoring guideline application to fit each major category of platform (and munition)

LFT&E PROCESS IMPROVEMENT

FINDINGS

- G. Model accuracy is limited by uncertainties inherent in the prediction of damage to complex systems, and vulnerability analysis results will normally be biased to be too high or too low for each type of platform
- H. Aircraft vulnerabilities are sometimes analyzed using more than one kill metric (area, probability, blast stand-off); differences in the formats that portray each kind of analysis result make it difficult to convey a net assessment of platform vulnerability performance to acquisition decision-makers

RECOMMENDATIONS

- Consultation with Component LFT POCs about modeling comparative vulnerability performance of replacement-replaced platforms to supplement stand-alone LFT&E analysis of a platform with an analysis that has bias removed
- Consultation with Component LFT POCs about using *dimensionless* analytic comparisons of replacement-replaced aircraft vulnerabilities to serve as a net assessment of replacement aircraft performance in lieu of a spectrum of munitions needing different metrics to display all aircraft vulnerabilities to all threatening weapon effects

LFT&E PROCESS IMPROVEMENTS

FINDINGS

- I. Hit-induced fires can be a time-delayed cause of warship function losses, but only the prompt effects of hit damage are accounted for when SVM computes out-of-action probabilities

- J. Standard fault tree and follow-on vulnerability analyses will reveal the criticality of ship systems/sub-systems/components, but not the criticality of the support elements required to repair damage to these systems and restore them to service

RECOMMENDATIONS

OSD LFTO and/or DoD Navy Component invest in development of Fire Spread Simulation Model (FSSM) that will post-process SVM inactivation probabilities to show additional loss of function from delayed (fire-caused) hit damage

DoD Navy Component develop a methodology for assessing the resiliency of ship support and services personnel and the special equipment (toolkits, MHE, etc) that would be relied on to reconstruct continuity of ship system fault trees

LFT&E PROCESS IMPROVEMENT

FINDINGS

K. The Survivability Review Group, a special study group convened to extract survivability design lessons learned from shipboard fire cases, Bellknep incident, and ship combat damage during WWII and Falklands campaign, created the main sourcebook of ship vulnerability reduction design ideas before disbanding

RECOMMENDATIONS

The Navy Component ought to be persuaded to institutionalize the SRG, perhaps as a standing organizational duty of OP-03 Surface Ship Survivability, to continuously gather damage data and analyze the design consequences for new ships (classes, flights, major overhauls, and re-activations)

LFT&E PROCESS IMPROVEMENT

FINDINGS

L. Army Component has established a tentative ground vehicle vulnerability reporting format patterned after the BFVS and ABRAMS LFTE presentations, but ship-level and aircraft-level LFT&E presentation formats can only be forecast, since none are known to have been reported prior to completing this study

M. Anticipated vulnerability LFT&E result displays can be modified to include a dose of context or perspective and, thereby, help decision-makers who aren't vulnerability language experts to gain a better understanding of platform LFT&E performance

RECOMMENDATIONS

OSD LFT Office initiate talks with Army, Navy and Air Force Component LFT POCs to develop concepts of presenting LFT&E findings that report on the vulnerability performance of air and sea/undersea platforms and to re-examine alternatives to dependance on the arcane Pk metric to explain quantity-limited damage experiences

OSD LFT Office inform CSC/DAB about *expected* forms of LFT&E reporting, *supplemental* reports (of comparative analysis) that could be used, and *extended* reports of (weighted) findings to learn member opinions about each format's decision value

LFT&E PROCESS IMPROVEMENTS

FINDINGS

N. Lethality modeling for LFT&E is handicapped by uncertainties arising from attempts to model munition-target interactions of equipment that hasn't had any "hands-on" analysis; however, portrayal of lethality LFT&E conclusions relies much less on detailed modeling than does vulnerability LFT&E

O. The present lethality reporting format differs little among the various categories of munitions and missiles; effectiveness of warhead clearly portrayed from results observed at live-fire field trials attacking older in-service Soviet equipment and surrogates of other equipment not available for testing

RECOMMENDATIONS

No recommendation - there is no reason to believe circumstances will change over time to greatly improve component-level modeling of major compartments, since information about future foe system structures, interior layouts, and parts will likely always be clouded with uncertainty

OSD LFTO consult with Component LFT POCs about the possible use of comparative analyses to portray gain in replacement munition/missile effectiveness when live-fire demonstration opportunities are limited by poor/no inventories of actual foreign equipment that could be destructively tested

LFT&E PROCESS IMPROVEMENTS

FINDINGS

- P. Intent of LFT&E is to assess terminal robustness of weapon carriers (platform vulnerability) and munitions (warhead effectiveness), yet statutory language is muddled by phrases that stray from the common use and meaning of "end-effect" (hit>destruct) terms

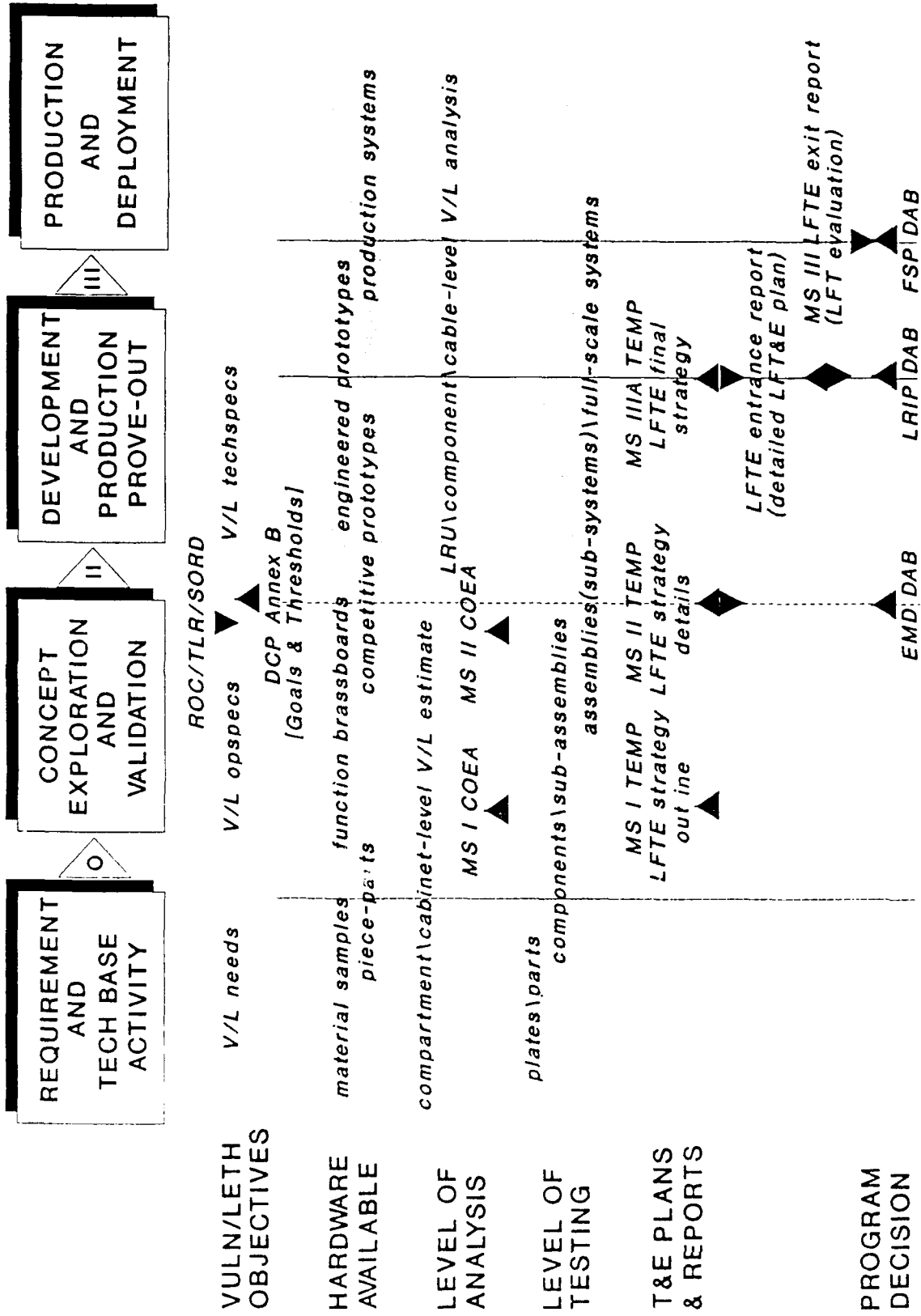
RECOMMENDATIONS

OSD LFTO recommend Congress clarify wording of such phrases as "survivability and lethality testing of major systems," and "testing for vulnerability and survivability," as well as terms with blurred meaning found in such phrases as "lethality of a weapon system"

APPENDIX:

- LFT&E ELEMENTS OF RDA CYCLE
- BRIEF DESCRIPTIONS OF MODELS
- DAMAGE/CASUALTY DATA SOURCES

LFT & E-RELATED ELEMENTS OF RDA CYCLE



MODEL DESCRIPTIONS

GROUND VEHICLES

MGED (Multi-Device Graphics Editor) - Solid geometry editor tool of Ballistic Research Laboratories-CAD. Combines geometric primitives into solid representatives of vehicle components. Replacing older COM-GEOM editor. Requires VDECK utility to convert format of MGED output into COM-GEOM format readable by GIFT.

GIFT (Geometric Information for Target) - Generates data about shot lines and spall lines in victim.

ICE (Interactive Criticality Estimator) - Automation aid for transforming Criticality Analysis information about the relationship between component or sub-system failure modes and combat-caused damage (from the Damage Mode and Effects Analysis or DMEA) into format useable by SLAVE, VAST, or SquASH.

SLAVE (Simple Lethality And Vulnerability Estimator) - Uses spall cone/shotline data and conditional kill probabilities to compute $P_{k/h}$ and vulnerable area for components and system. Lower resolution / faster speed compared to VAST. Expected value, point-burst (component) class of model. This class of model is capable of modeling behind-armor debris (BAD).

VAST (Vulnerability Analysis for Surface Targets) - Uses spall ray / shotline data and conditional kill probabilities to compute $P_{k/h}$ for components (singly) and for the system. Expected value, point-burst (component) class of model.

PDAM (Point Burst Damage Assessment Model) - USAF target kill predictor for tactical vehicle targets. Given a shotline, PDAM tallies component damage from shaped charge or kinetic energy penetrators. Fault tree methodology is used to combine component damage values into an overall prediction of damage to the target.

SQuASH (Stochastic Quantitative Analysis of System Hierarchies) - Derives a distribution density function for outcomes typical of SLAVE and VAST by jittering impact yaw or hit location over a small area while stochastically varying warhead performance, residual penetrator deflection, the statistics of spall generation, and the component $P_{k/h}$ s. Termed a stochastic, point-burst class of model, since it attempts to account for the physical

randomness that is associated with the complex destructive processes. Has the capability to calculate the probability of encountering killed components in combination.

SDAL (Standard Damage Assessment List) - Model data. The Criticality Analysis (see ICE description) and the Damage Assessment List are two of the most critical documents needed for a SLAVE, VAST, or SQUASH vulnerability analysis. For each component or sub-system determined to be vital by the Criticality Analysis, the DAL defines the loss-of-function (LOF - also known as DCU, or degraded combat utility, and usually synonymous with P_k) that results for each of several states of damage to the sub-system or component.

VAMP (Vulnerability Analysis Methodology Program) - Uses "lumped parameter" functions (look-up curves) built from the results of system-level field tests to correlate warhead/armor interactions with damage to vulnerable areas of major system elements (crew, engine, ammo, fuel, main gun, structure, and mobility elements) modeled in simple geometry. Does not model BAD. Compartment class of model with low resolution (does not use component deactivation data) that can only be used to predict outcomes of warhead/target combinations already fired to create the look-up data points characterizing expected values of damage. Primary use of this model is and will continue to be in force-on-force simulations used for COEA, not vulnerability analyses.

SURFACE SHIPS

SHIPGEN (Ship Generator) - Ship description editor which creates a geometric configuration of the hull, decks, bulkheads and compartment. Plating materials and thicknesses are defined. Vital components, such as turbines, generators, etc. are described in terms of bounding coordinates and shape. Major systems are defined as lumped series or parallel combinations of sub-systems or their vital components and are described in the same manner. Pre-processing program for SVM.

SVM (Ship Vulnerability Model) - Models the effects of conventional weapon attacks on surface ships. Two variants: cruiser version for general ships of the line and platform version. Warheads may be contact, delay, or proximity fused. SVM can analyze results of (up to) a 10 hit attack to determine impairment of capabilities for seaworthiness (i.e. sinking, capsizing or magazine explosion), mobility, major system/sub-system operation, and overall combat readiness. Hit damage to vital components, compartment flooding and other damage data from randomly selected air trajectory and underwater hit/burst points are tallied to determine kill probabilities. Procedure is repeated until a statistically significant number of trials have been done. Out-of-action probabilities are then determined as the ratio of the number

of trials in which inactivation occurred to the total number of trials conducted.

INPMOD - Reads ship description formatted tape prepared by SHIPGEN and processes data for linkage to inputs of all succeeding modules of SVM. Also contains system deactivation records and produces table of inactivation criteria that is read by KPMOD to perform inactivation analysis.

GRIDEXC - Controls routines that generate a hit grid on ship.

HITEXC - Controls routines that select grid cell(s) for hit.

PENMOD - Based on hitpoint(s), module performs burst point calculations and determines the damage volume and components affected by warhead penetration and detonation.

BLASM0D/FRAGMOD - Modules assess blast and perforation damage to vital components and structures passed from *PENMOD*.

KPMOD - Combines inactivation criteria from *INPMOD* with damage summaries from *BLASM0D* and/or *FRAGMOD* to produce probability tables of vital component, sub-system, and system inactivations caused by various damage mechanisms.

SUBWHIP - Computer program used to predict skeletal whipping response of submarines and surface ships. Compares calculated deformations with yield moment data accumulated from testing ships in a similar weight class.

TACTICAL AIRCRAFT

FASTGEN (Fast shotline Generator) - Obtains shotline descriptions by superimposing a planer grid over geometric model of target, passing a shot ray through the individual grid cells, and generating a list of components, fluids, and voids encountered along the shot path. Component surfaces represented as a set of facets created from triangular patches that form a wireframe representation of the object. These PATCH files can be imported into and used by BRL MGED. Geometric editing element of SHOTGEN, an earlier shotline generator, uses a combinatorial geometry approach of basic shapes such as spheres, boxes, cylinders to describe objects.

IFT (Interactive Fault Tree) - a developmental computer aid to generate fault trees for aerial systems and attendant criticality analysis.

COVART (Computation of Vulnerable Area and Repair Time) - Imports component kill probabilities and computes component vulnerable areas for each grid cell having a shotline passing into the component. Sums component vulnerable areas to determine FW or RW aircraft vulnerable areas. Can account for critical component overlap. Suitable for non-explosive

penetrator (KE) class of hits (single fragments, AP, and API projectiles). Outputs single-shot $P_{k/h}$ vulnerability. Multiple hits better analyzed with stochastic flyout (endgame) or engagement simulation model. Output can be directly used by some end-game routines such as IREM and TARMS.

HEVART (High Explosive Vulnerable Areas and Repair Times) - Expected value, point-burst class of model. Same features as COVERT model, but intended for assessment of aircraft vulnerability to small HE or HEI rounds and point-detonating missiles. HEVART and COVERT outputs usually are presented using a 6-view average of the vulnerable area for the aircraft. This is a commonly accepted standard and is arrived at by summing the vulnerable areas across each of the six cardinal views and dividing by the number of views, six. Occasionally, a 26-view average is used.

HEIVAM (HEI Vulnerability Assessment Model) - View of aircraft divided into impact zones of critical components. Determination of average $P_{k/h}$ over each zone permits calculation of vulnerable areas for impact detonation (surface burst), delayed detonation (internal burst), impact-fuzed missile and close-in warhead burst (radiating fragment paths).

HISTORICAL DAMAGE/CASUALTY DATA SOURCES

TRACKED/WHEELED VEHICLE

CAMPAIGN/REGION	DATABASE	CUSTODIAN
A Survey of Casualties Amongst Armoured Units in NW Europe UK - WW2, Korea, Malaysia US - Southeast Asia US - Southeast Asia IS - 1973 Yom Kippur War IS - Lebanon	Wright, Harkness-1946 Equipment/Personnel Casualty Records GROUNDVEHICLE WDMET (mostly dismounted casualties) YOMKIPPUR Unpublished Report of Casualties	COR&DA, London SURVIAC USAESG SURVIAC HQDA DCSPER

SURFACE SHIP

CAMPAIGN/REGION	DATABASE	CUSTODIAN
WW2, Falklands, USS Belknap, fires Southwest Asia - USS Stark Southwest Asia - USS S. B. Roberts Southeast Asia (1972) - USS Worden	Report 072-55X-TR-0005 Report of Board Investigation Report of Board Investigation Report of Board Investigation	NAVSEA Code 55X

TACTICAL AIRCRAFT

CAMPAIGN/REGION	DATABASE	CUSTODIAN
Southeast Asia 1965 - 1973 Southeast Asia - Fixed Wing Southeast Asia - Rotary Wing Panama - FW/RW 1989	Carrier Aircraft Loss/Cause ACFTDAB HELODAB JUST CAUSE	CNA SURVIAC SURVIAC SURVIAC