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13. ABSTRACT

Landing craft are vulnerable to three independent factors, enemy action, mechanical failure, and personnel error. This document analyzes vulnerability to enemy action, and provides methods for the combination of all three factors into usable attrition rates.

Vulnerability of landing craft to enemy action has been estimated using two complementary methods, one of wide applicability, the other of narrow applicability.

The former method estimates craft vulnerability, defined as the extent to which a craft is exposed to attack or damage, as a function of exposed area and time, and considers all types of weapons at all ranges but does not consider accuracy in detail. It provides values that are proportional to the number of fragments that might be taken during one round trip to the beach. Provision is made for extension of the method to more elaborate models and for the conversion of the vulnerability values to attrition rates.

The latter method is a probability analysis of the craft in a very specific artillery environment. It provides values for the probability of a hit, the probability of a "kill," and attrition rates, and also provides a method for estimating the downtime resulting from attrition.

Results are presented for seven out of over 40 craft that were examined in detail. Data are included on craft unloading times and artillery shell fragmentation.

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Attrition Rates						
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Kill Probability						
Repair Times						
Shell Fragmentation						
Landing Craft Unloading Times						
Air Cushion Vehicles						
Planing Hulls						
Displacement Craft						

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Research Report

NWRC/LSR-RM-52

SYSTEMS ANALYSIS OF AMPHIBIOUS ASSAULT CRAFT:
VULNERABILITY OF LANDING CRAFT

Prepared for:

NAVAL SHIP SYSTEMS COMMAND AND
THE OFFICE OF NAVAL RESEARCH
WASHINGTON, D.C.

STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

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April 1969

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PREFACE

This report describes an analysis of landing craft vulnerability conducted as part of the Systems Analysis of Amphibious Assault Craft, a project which is, in turn, part of the Navy's Amphibious Assault Landing Craft Program (Project S-41-17X). The vulnerability analysis has been concerned with developing a technique for measuring landing craft vulnerability and with applying the technique to present and proposed landing craft.

Stanford Research Institute's systems analysis of advanced amphibious assault craft is under the technical guidance of Mr. James L. Schuler, NavShips Code 03412, who manages the Amphibious Assault Landing Craft Program. Administrative direction is provided by Mr. J. R. Marvin, Director, Naval Analysis Programs, Office of Naval Research, through the Institute's Naval Warfare Research Center, Lawrence J. Low, Director.

Andrew R. Grant was task leader and principal investigator and worked under the direction of Paul S. Jones, project leader. Support was provided by Michael J. Nielsen, Jerome I. Steinman, Stanley J. Davenport, and Robert K. Meister of Stanford Research Institute. Mr. Thomas E. Mansfield and Mr. Robert L. Ragot of the Annapolis Division of the Naval Ship Research and Development Center and Mr. Robert A. Sniffin of the Personnel Research Laboratory provided valuable technical advice.

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I INTRODUCTION

There are no widely accepted measures of vulnerability, although the concept and the problems it presents are just about universal. Neither is there a single accepted definition that is usable to devise a measure. In fact, vulnerability would normally have different definitions according to the specific interests of those concerned with the problem. We feel free, therefore, in this study to suit our own interests by defining the vulnerability of a particular landing craft as the "degree to which it is exposed to attack or damage."

Vulnerability can arise from three separate and largely independent sources--enemy action, mechanical failure, and human error. Enemy action is probably the most influential of these factors, but in the evaluation of new or proposed craft the other two factors are important and may be critical. The analysis of vulnerability due to enemy action has been conducted at Stanford Research Institute, and the results form the bulk of this document.

Vulnerability due to mechanical failure and personnel error is being studied at the Navy Ships Research and Development Center at Annapolis and at the Navy Personnel Research Laboratory, respectively.

Objective

The objective of this task was to develop an analytical technique for measuring amphibious landing craft vulnerability to enemy action and use the technique to measure the vulnerability of existing and proposed amphibious landing craft.

Scope

This report describes a technique for measuring landing craft vulnerability due to enemy action. It also describes a combination of the three vulnerability factors (enemy action, mechanical failure, and human error) into a single attrition rate for use in analyzing landing craft performance in simulated amphibious assaults. The method of analysis has been tailored to suit the types of data that are available today or that can reasonably be expected in the future. For this reason, the result is less intellectually satisfying than might be wished. However, we believe that the necessary compromises have not sacrificed the validity of the technique for comparing the relative vulnerability of alternative craft in similar environments.

The analysis has been restricted to the vulnerability of landing craft. We have not considered the vulnerability of the ships of the amphibious fleet, nor have we, with one exception, made value judgments concerning the relative attractiveness of different targets. The exception is that landing craft while engaged in loading at a ship are considered less attractive targets than the ships from which they receive their loads.

Only conventional weapons have been considered. We have not studied the use of tactical or other nuclear weapons against landing craft. To the extent possible we have taken into account expected near-term advances in the characteristics and use of conventional weapons. However, evaluation of these advances has been severely limited by the need for detailed accuracy and fragmentation data.

The analysis has stressed quantitative results suitable for simulation analysis. To achieve these results, assumptions have been made to cover data deficiencies. As more information becomes available on the design, performance, and operation of advanced craft, vulnerability calculations will be repeated and the revised figures will be used in subsequent simulation analyses.

Method of Approach

There is a wide range of approaches that can be used in a landing craft vulnerability analysis. The choice of approach depends on the type of result desired. At one extreme is a very definitive result that is applicable in only one mode of operation in a very particular environment. At the other is a less definitive result that has a wider degree of applicability in a more complex environment.

Using the first approach produces a result that is more indicative of environment than of craft characteristics. By altering the assumed environment, attrition rates can be made to have any permissible value whatever. There is no "normal" amphibious assault environment but only an immense range of environments. As examples of that range, consider Iwo Jima, Kiska, Inchon, and Normandy, a highly diverse selection. Even within a given level of enemy effort, the type and number of weapons and the variations in physical environment make for very large differences in the results.

The second approach provides results that are applicable to a variety of environments, although with less accuracy in any particular one. By simplifying the environmental considerations, however, the results are more representative of craft characteristics. Intermediate approaches that share some of the qualities of each are also possible.

This paper has followed both approaches, within the limits of available information and desired coverage. One method is developed for estimating the vulnerability in an environment that includes all types of enemy weapons, while the other examines the very particular problem of vulnerability to artillery. Both are considered to have merit in the evaluation of advanced landing craft. The impetus in both methods is toward results that facilitate comparisons of existing and proposed landing craft. An attempt has also been made to provide procedures that can be expanded to greater levels of detail.

The text of this report describes the development of methods for measuring landing craft vulnerability and outlines the major decisions that were made to reach quantitative results. Appendix A presents the results of the application of the procedures to a number of proposed and existing craft. Appendixes B and C provide data on unloading cycle times, an important component in vulnerability calculations. Appendix D provides selected data on shell fragmentation. Appendix E presents a partial bibliography.

II VULNERABILITY DUE TO ENEMY ACTION

Phases of the Analysis

Analysis of vulnerability due to enemy action has been divided into two phases. The first phase is an analysis aimed at the essential part of the definition given in the Introduction. It attempts to determine the "degree to which a craft is exposed to attack or damage." It considers all types of weapons at all ranges but without detailed consideration of weapon accuracy, the number of weapons available, or the relative weight of forces. It can be considered as "pure" vulnerability or as "overall" vulnerability. That is, it represents a measure of the degree to which a craft is exposed to attack or damage if the enemy applies all of his different types of weapons against it. This aspect of vulnerability will be referred to as "overall" vulnerability or as simply "vulnerability." It has two parts, hit vulnerability and kill vulnerability; the latter, an offshoot of the former, considers the effect of serious or fatal damage. More detailed definitions and discussion are given below.

Vulnerability will normally be stated as a relative measure, and indeed will have significance only as a relative measure. The LCM-6 will serve as the basis of comparison, and will be referred to as the base craft.

The second phase of vulnerability analysis is a highly specific one, composed of a probability analysis of the disablement or destruction of a craft in a particular environment. Its results will be stated in specific terms such as hit probability, kill probability, and attrition rates, and will normally be stated as absolute values to facilitate use in the simulation of amphibious operations using different mixes of landing craft.

Vulnerability to Detection

Detection of landing craft can be accomplished by visual means, by radar, or by sonic, infrared, or magnetic detectors. At the current state of the art the principal reliance will continue to be on radar and visual means. In both cases the probability of detection can be taken as roughly proportional to target size.

For air cushion vehicles the apparent visual size of the vehicle is increased by the spray thrown up when the vehicle is in the lifted mode. Depending on the sea and sky conditions, this may or may not increase the probability of detection. The sound levels associated with air cushion vehicles are many times those of current landing craft, a factor that will aid in the detection of their activity but not necessarily in their destruction once detected.

Environment

The environment in which vulnerability is measured has many parameters. They include (1) the type and numbers of weapons mounted against the landing craft, (2) the manner in which these weapons are employed, (3) the area of each craft that is exposed to the different weapons, (4) the characteristics of projectiles and fragments from the different weapons, (5) the manner in which the craft are employed, (6) the skill of the individual crews, and a host of other factors. In this analysis the project team has specifically studied the first four factors and normalized the others--that is, we have assumed similarity among all craft in terms of the relative crew skills and other operating considerations.

Type and Numbers of Weapons

In the analysis, we have examined all of the conventional weapon types likely to be used against landing craft in an amphibious assault. These weapon types are listed below together with those craft characteristics likely to affect their successful use.

Weapon	Major Factors Affecting the Hit Vulnerability of a Craft
Artillery	Craft dimensions, weapon accuracy, range, craft speed
Mortars	Craft dimensions, weapon accuracy, range, craft speed
Salvo rockets	Craft horizontal area, craft frontal area,* craft speed
Bombs	Craft horizontal area, craft frontal area, craft speed
Guided missiles	Craft horizontal area, missile guidance type, craft speed
Recoilless rifles	Craft frontal area, craft speed
Fragments from artillery, bombs, mortars, rockets	Craft horizontal area, craft frontal area
Machine guns	Craft frontal area, craft speed
Small arms	Craft frontal area, craft speed
Strafing	Craft frontal area
Land mines	Craft ground pressure, track width, beam width
Water mines	Craft beam width, draft, operating height

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* Frontal area is defined as the average vertical presented area as viewed by an observer located in the same horizontal plane as the craft, considering all possible angles of view.

It is neither necessary nor desirable to evaluate each of the landing craft against all possible weapons. Using one weapon of each type probably provides sufficient data for comparison of vulnerability between two different landing craft under identical circumstances. It is necessary, however, to pick a particular weapon of each type. The weapon chosen should be well suited for its purpose but need not be a special purpose weapon. It should be a weapon such as might reasonably be used in defense against an amphibious landing. We have used U.S. weapons throughout, because detailed and unclassified data are available that describe their performance. Comparable weapons exist in the armed forces of potential enemies. Consideration of specific foreign weapons is not required unless those weapons have markedly better characteristics than the corresponding U.S. weapons and are a probable part of the craft environment. No foreign weapon has been so chosen for this analysis, although the methods would apply equally well.

The artillery weapon chosen for direct fire is a rapid-fire, high-velocity weapon with a reasonably long range, such as a 90-mm gun with the ballistic qualities of tank guns or of the old AA guns. It has a maximum range of about 10 miles, a muzzle velocity of about 2700 ft/sec, and (on an AA or similar mount) can fire as much as 10 rounds per minute for a few minutes. Larger weapons would be slower firing and probably would have mobility problems; smaller weapons would be less effective. Conventional artillery of about 105-mm caliber is appropriate against craft on the beach or in its rear.

The mortar weapon selected is in the 4.2-in. class. Larger caliber mortars conceivably could be used against an amphibious landing, but mortars of the 4.2-in. class would probably be more readily available. Smaller ones would also be available but less effective.

Parallel comments apply to the machine gun. Larger automatic weapons might be available, but weapons on the order of .50 caliber probably would be. Smaller caliber weapons would be available as would small arms. Either has trajectory characteristics similar to the .50 caliber machine gun although with lesser effectiveness.

The aerial bombs considered are the 100- and 500-pound categories.

Salvo rocket and recoilless rifle warheads are of a size on the order of 4.2-in. mortar rounds. Guided missiles for use against landing craft would probably not be larger than NIKE Hercules although larger missiles might be directed against the ships.

Concept of Employment

The number of each weapon type employed against an amphibious landing craft and the method of their employment are highly variable. They depend on the size, composition and deployment of the enemy's armed forces, the extent and success of prelanding bombardment, the enemy's choice of targets for his weapons, and a host of other factors. A study of all of the relevant factors in defensive arms employment is a major research effort in itself and clearly beyond the scope of this work. Rather, we have sought environments that might be termed plausible to use as a basis for measuring relative craft vulnerability.

It is considered that bombs and guided missiles might be applied against landing craft anywhere in the area of operation. Direct fire artillery (located to the rear of the beach and perhaps to one side) would be effective in firing at the craft as they moved in toward the beach, but might be of lesser effectiveness at the shorter ranges or in the rear of the beach because of masking problems. Once the craft is at the beach or in the rear of it the appropriate weapons would be the mortars, conventional field artillery, recoilless rifles, and the heavy machine guns, with emphasis on artillery. Uses of land mines and water mines are obvious, but the development and use of advanced fuses should be anticipated. ACV craft would not set off conventional land and water mine fuses, but the state of the art allows development of mines that will be triggered by proximity devices.

Two different time frames are involved in attacking the landing craft used in an amphibious assault: the first comprises the period when the craft is approaching or leaving the beach; the second covers the time spent on the beach or in an unloading area to the rear. During the first period the craft is a highly visible, moving target surrounded by water. For accurate weapons it is best attacked with contact fuses. Less accurate weapons should rely on air bursts as bursts in the water are ineffective unless very close.

During the second period limited movement is involved, and during much of the period the craft will be motionless. Direct fire methods will be less effective against the craft because of the reduced visibility and the increased concealment and protection offered by the terrain. Precision adjustment fire might be attempted by artillery. Except for very short ranges, the primary reliance for area weapons should be placed on contact fuses, as surface bursts are more effective against such targets than air bursts. Accurately adjusted artillery fire can be expected to produce direct hits.

Characteristics of Projectiles and Fragments

Each weapon produces its own kind of projectile or explosive effect, each of which has a distinctive potential effect on landing craft. Bombs, artillery, mortars, rockets, recoilless rifles, and guided missiles all have explosive warheads. These warheads may hit vulnerable portions of the craft directly but are more likely to explode elsewhere and scatter fragments about the craft.

The explosive projectiles usually approach the craft on a slanting trajectory. Bombs, mortar shells, rockets, and some guided missiles have high angle trajectories in the vicinity of the target. Artillery, recoilless rifles, and some guided missiles normally have low angle trajectories. These projectiles burst either on contact with the craft or the surrounding terrain, or above the surface.

Fragments from explosive projectiles that burst in the craft or nearby and damage vulnerable portions of the craft usually travel in a flat trajectory. Fragments striking vulnerable portions of the craft from air bursts travel in trajectories that are more vertical than horizontal.

Frontal Area and Horizontal Area

The size of the target exposed to an enemy weapon is called the presented area as "seen" by the approaching projectile. Presented area depends on craft frontal area, craft horizontal area, and projectile angle. Frontal area has been computed to account for different craft aspects.

Horizontal area denoted H(X) is defined as:

$$H(X) = (\text{overall length}) \times (\text{average beam, viewed from above}).$$

The relative horizontal area of craft-X compared to the base craft is denoted as RH(X) and is defined as:

$$RH(X) = \frac{H(X)}{H(LCM6)}$$

Frontal area,* F(X) is computed as:

F(X) = 0.64 x (average length + average beam) x average height.

The factor 0.64 takes into account the different aspects of the craft with respect to different weapons and at different times.

Average length and average beam are taken from side and front views. Average height is taken from a side view. Relative frontal area RF(X), computed in a manner similar to RH(X), will vary with the mode of operation for some craft. The ACVs and hydrofoils normally unload in a non-lifted mode and thereby temporarily lose a few feet of height compared to their height when moving. On the other hand, LVTs and LARCs normally unload with the entire vehicle exposed, thus presenting a much larger area than when moving through the water. Relative frontal area during unloading will be denoted to as RFU(X).

Vulnerability to Specific Weapons

Vulnerability to Direct Fire Artillery

A landing craft is vulnerable to direct fire artillery principally during the movements to and from the beach and very little during the

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* The frontal area formula was determined by finding the average vertical presented area as a craft is rotated horizontally through a 90° arc. Specifically:

$$F(X) = \frac{H}{\pi/2}\int_0^{\frac{\pi}{2}}(W \sin \theta + L \cos \theta)\, d\theta = \frac{2H(W + L)}{\pi} \approx .64H(W + L)$$

where:

H = Height
W = Width or beam
L = Length.

As the average presented area is the same in each quadrant, only one quadrant need be examined.

more or less static period at or behind the beach. During the latter period the craft is vulnerable to other types of attack, but direct fire artillery will be restricted in effectiveness due to visibility, masking, and cover. For the current purpose, vulnerability to direct fire artillery will be considered to apply only during movements to and from the beach.

During these movements the craft represents a moving target over the operational range of the defending weapon. For each specific range there is a different relationship between the target configuration, and the shape of the trajectory.

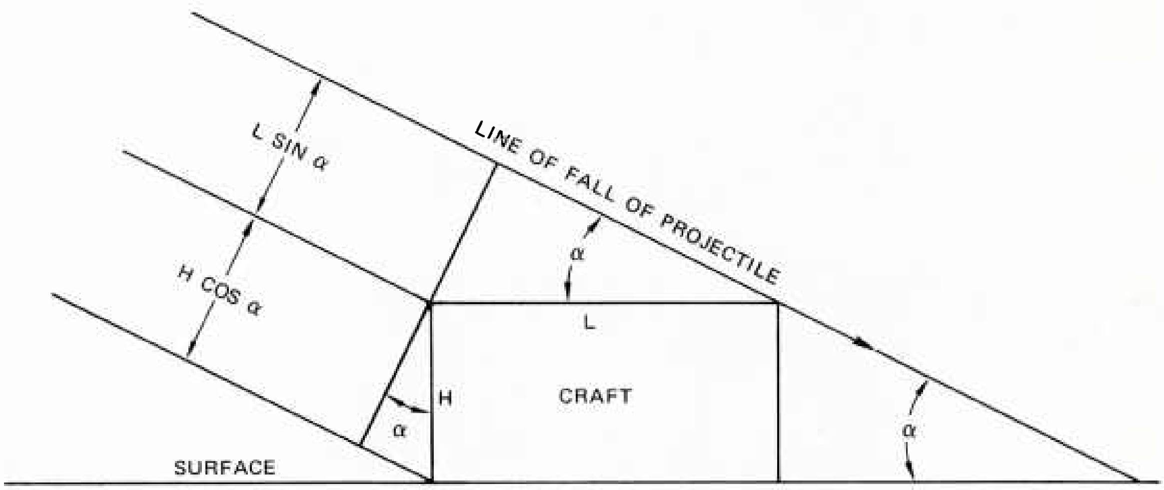

FIGURE 1 APPARENT TARGET SIZE WHEN "END-ON"

Vulnerability will be roughly proportional to the presented area of the target as "seen" by the approaching projectile. That area can be computed by the relation:

$$A = W(L \sin \alpha + H \cos \alpha)$$

where:

W = width* of craft, L = length* of craft

H = height* of craft above the surface

α = angle of fall of the projectile.

Because the craft will not usually be end-on to the gun, an average value of A will be appropriate, considering various approach angles. For this purpose, the broadside and end-on areas are averaged for each range, and the resulting average area for range r, is denoted by A(X)r.

$$\begin{aligned} A(X)_r &= 1/2\ [L(W \sin\alpha + H \cos\alpha) + W(L \sin\alpha + H \cos\alpha)] \\ &= 1/2\ [LW \sin\alpha + LH \cos\alpha + LW \sin\alpha + WH \cos\alpha] \\ &= 1/2\ [2\ LW \sin\alpha + (L + W)H \cos\alpha] \quad . \end{aligned}$$

The relative area compared to that of the base craft is given by:

$$RA(X)_r = \frac{A(X)_r}{A(LCM6)_r}$$

and the average value of $RA(X)_r$ over the entire effective range of the gun is given by:

$$RA(X) = \frac{\sum_{r=1}^{n} RA(X)_r}{n}$$

where: n = the number of values of range considered.

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* Average dimensions are used in these computations in order to eliminate the unduly complex calculations associated with irregular craft shapes. Each craft is reduced to a "box" shape.

The Effects of Craft Speed on Vulnerability. Increases in craft speed reduce the length of time during each trip to the beach that a craft is exposed to enemy attack and increase the probability of aiming errors by enemy gunners. Aiming errors are defined as the errors in selection of the proper aiming points. A properly aimed round is one in which the aiming error is zero. Total absence of aiming error would require continuously accurate information as to target location, accurate and continuous prediction means, and accurate and continuous ballistic and adjustment corrections. For moving targets such accuracy can be approached under very favorable circumstances (e.g., linear target movement) by modern fire control directors such as are used by air defense artillery and missiles. Because artillery lacks such means, fire control methods for attack on landing craft will be subject to aiming errors of a wide range of magnitudes.

Components of Aiming Errors. The basic components of aiming errors are errors in measurement of the location of the target, errors in the measurement of the speed vector of the target, and incomplete ballistic data. The latter can be compensated for by fire adjustment if time is available. The two former items of data, however, affect the aiming error in direct proportion to the speed of the target. The predicted position of the target (where the shell and target meet) is determined by the present position (position at time of firing), direction of movement, speed, and the time of flight to the predicted position. The distance traveled by the target from the present position to the predicted position is equal to the speed times the time of flight. Errors in measurement of speed or in estimation of time of flight therefore affect accuracy directly. An error in speed determination can be expected to be proportional to the speed itself. That is, speed can only be measured to a certain percent of accuracy. Errors in range will be reflected in approximately proportional errors in time of flight, which will in turn result in a position error approximately proportional to the speed. Lateral errors in the location of the predicted position due to errors in the determination of the direction of travel will be proportional to target speed and to the accuracy in determining target direction. The latter factor is independent of craft characteristics and need not be considered further here. In summary, errors in the location of the predicted position will be approximately proportional to the speed.

The effect of these errors is that the percent of time that the aim is proper will be less than 100 percent. The extent of degradation will depend on the precise characteristics of the fire control system. For both the vulnerability and probability analysis we have assumed a fire control system that will maintain the center of impact on an 8-knot target 10 to 15 percent of the time. This would correspond to the performance that might be expected from a field artillery unit thrust into a coastal defense role and subjected to suppressive fire.

The actual degradation in accuracy will vary with speed in a rather complex relation that is critically dependent on factors that have little to do with craft characteristics and vulnerability. A simple relation that gives approximate results will be sufficient for the purpose of comparing craft. In view of the fact that aiming errors are directly proportional to craft speed, we have chosen a relation in which the percent of time the center of impact is on target is inversely proportional to target speed, subject to the (artificial but necessary) constraint that the speed never be considered to be less than one knot.

This above discussion has been primarily concerned with artillery, but the relation applies equally well to other weapons systems with a few exceptions that are identified below.

We denote by VW(X) the speed over water of craft-X. In keeping with the practice of comparisons with the LCM-6, we denote the relative speed of craft-X as RVW(X) and define it as:

$$RVW(X) = \frac{VW(X)}{VW(LCM6)} .$$

A proper evaluation of relative vulnerability should take into account the differing speeds of two separate craft. This can be done by dividing the relative vulnerability by the relative speed, as in:

$$\frac{RA(X)}{RVW(X)} \quad \text{(for artillery)} .$$

Exposure Time for Artillery. The time required for a landing craft to pass from the outer limits of artillery coverage to the beach will, for the 90-mm gun, be equal to or less than the time required to traverse 18,000 yards at operational speed. This time period is inversely proportional to the speed. The times required have been summarized in Table 1 for various speeds. It should be noted that, at the speeds of present day landing craft, about an hour would be required to traverse the artillery zone, a period which is clearly sufficient for a competent gunner to do considerable damage. Contrasted with this is the 10 minutes that is available for firing at an advanced craft approaching on the same course.

Vulnerability to Mortars

The most effective use of mortars against landing craft is with air bursts over water and with surface burst on land. In both cases the primary effect is due to fragments as direct hits are unlikely. The vulnerability of a craft to mortar fire is therefore roughly proportional to the horizontal area over water and to the average frontal area

Table 1

TIME REQUIRED TO PASS FROM 18,000 YARDS
RANGE TO ZERO RANGE AT VARIOUS SPEEDS

Time (min) = 532.8/speed (knots)   18,000 yards = 8.88 nmi

Speed (Knots)	Time in Minutes
5	106.6
8	66.6
10	53.2
15	35.5
20	26.6
25	21.3
30	17.8
35	15.2
40	13.3
45	11.8
50	10.7
55	9.7
60	8.9
65	8.2
70	7.6
75	7.1
80	6.7
85	6.3
90	5.9

over land. The accuracy will be degraded by target speed. Infantry mortars are almost completely unsuited to fire at moving targets due to their long time of flight and cumbersome aiming mechanisms, nor are they suited to precision fire on small targets because of their large dispersion pattern. They are, however, highly suited for area fire because of their high rate of fire and excellent fragmentation characteristics.

Vulnerability to Rockets

Rockets usually have trajectories whose final portions are more vertical than horizontal. The vulnerability associated with them will be approximately proportional to the horizontal area of the craft and will be degraded by the craft's speed.

Vulnerability to Bombs

The vulnerability to bombs over water is roughly proportional to the horizontal area of the craft, and if the craft is moving, inversely proportional to the speed.

Because of the inaccuracy of bombs and their relatively large bursting radius, hits by bomb fragments on landing craft that are operating over land are a greater hazard than direct hits by the bombs themselves. Therefore, over land, hit vulnerability to bombs is roughly proportional to the relative average frontal area and inversely proportional to craft speed.

Vulnerability to Guided Missiles

Ballistic missiles, even those of short range, would be unsuited to attack of landing craft, but air defense and antitank missiles might be effective. The HAWK missile, or something like it, should have a good potentiality, although its effectiveness would be degraded in firing at a surface target, fusing would probably present a problem, and the air defense mission would have priority. If used, however, the missile would probably approach the target from above, so that the hit vulnerability would be roughly proportional to the relative horizontal area and inversely proportional to the relative speed.

Antitank missiles are short range weapons with a flat trajectory. For this purpose they have been included with recoilless rifles.

Vulnerability to Strafing, Machine Guns and Small Arms

The threat to landing craft from strafing attacks is qualitatively similar to that from small arms and from machine guns in that the attack is delivered with moderate accuracy parallel to the horizontal plane. Therefore, the vulnerability is roughly proportional to the average frontal area of the target.

For machine guns and small arms the vulnerability is degraded by the craft's speed.

The probability of a hit by strafing is affected very little by target speed as the speed of the airplane is much greater than the landing craft speed. Therefore, no reduction is made for craft speed.

Exposure Times

During the trip to (or from) the beach a landing craft is exposed to attack by various weapons for various periods. It is exposed to bombs, guided missiles, and strafing for the entire period. It is exposed to fire by other weapons out to the limit of their range.

During the period at the beach the craft is exposed to all types of weapons for the entire period, which must be long enough to allow for unloading and for movements from the beach to the unloading area and return.

Vulnerability While Moving to and from the Beach

Table 2 summarizes systematically the vulnerable time (column 3) and the relative vulnerability of a craft per unit time with respect to each of the weapons considered. The weighted vulnerability (column 5) is the product of the relative vulnerability and the time of exposure, computed as shown. The nomenclature and the rationale are as explained on previous pages. Column 6 gives specific references.

Vulnerability While at or Behind the Beach.

All these same weapons can be brought to bear on a craft during the entire time it is at or behind the beach, except that direct fire is usually not possible for the same direct fire weapons used during the incoming trip. Take:

U = distance in nautical miles from the beach to the unloading area

TU(X) = unloading cycle time in minutes for craft-X.

Because the principal vulnerability while on the beach is to shell fragments and flat trajectory weapons, the relative hit index when the craft is motionless is RFU(X) and RF(X)/RVL(X) when in motion. RVL(X) is the relative speed over land.* Therefore, the relative vulnerability given below applies to each of the nine weapon types:

$$\frac{(120U)}{VL(X)} \cdot \frac{RF(X)}{RVL(X)} + TU(X) \cdot RFU(X) \quad .$$

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* The LCM-6, used in this analysis as the basis for comparison, has no land speed, of course. Therefore, a fictitious land speed must be developed for use in computing RVL(X). We note that an ACV would have the same absolute vulnerability traveling over land as over water, and would be traveling at the same speed. The modification to vulnerability to account for speed would therefore be the same over land as over water. We conclude that the fictitious LCM-6 land speed should be equal to its water speed.

Table 2

RELATIVE VULNERABILITY DURING TRIP TO AND FROM THE BEACH

1	2	3	4	5 (3 x 4)	6
Weapon	Vulnerable Distance (nmi)	Vulnerable Time (min)	Relative Vulnerability	Weighted Vulnerability	Reference (pages)
Artillery	9.0	$\frac{540}{VW(X)}$	$\frac{RA(X)}{RVW(X)}$	$\frac{540RA(X)}{VW(X)RVW(X)}$	12
Mortars	3.0	$\frac{180}{VW(X)}$	$\frac{RH(X)}{RVW(X)}$	$\frac{180RH(X)}{VW(X)RVW(X)}$	17
Rockets	5.4	$\frac{324}{VW(X)}$	$\frac{RH(X)}{RVW(X)}$	$\frac{324RH(X)}{VW(X)RVW(X)}$	19
Bombs	D	$\frac{60D}{VW(X)}$	$\frac{RH(X)}{RVW(X)}$	$\frac{(60D)RH(X)}{RVW(X)VW(X)}$	19
Guided Missiles	D	$\frac{60D}{VW(X)}$	$\frac{RH(X)}{RVW(X)}$	$\frac{(60D)RH(X)}{VW(X)RVW(X)}$	19
Machine Guns	1	$\frac{60}{VW(X)}$	$\frac{RF(X)}{RVW(X)}$	$\frac{60RF(X)}{VW(X)RVW(X)}$	20
Strafing	D	$\frac{60D}{VW(X)}$	$\underline{RF(X)}$	$\frac{(60D)RF(X)}{VW(X)}$	20
Recoilless Rifles	1	$\frac{60}{VW(X)}$	$\frac{RF(X)}{RVW(X)}$	$\frac{60RF(X)}{RVW(X)VW(X)}$	20
Small Arms	0.25	$\frac{15}{VW(X)}$	$\frac{RF(X)}{RVW(X)}$	$\frac{15RF(X)}{RVW(X)VW(X)}$	20

D = the standoff distance in nmi.

Note: For standoff distances less than 9 nmi, the vulnerable distance column must be modified so that no number therein is greater than D. Columns 3 and 5 will then also change.
VW(X) = speed over (or in) water (page 17). RVW = relative VW(X).
The remaining terms are defined on the pages indicated.

Time per Trip

The elapsed time per trip during which a craft is vulnerable to damage or destruction begins when the craft departs from the loading area and continues until the craft returns to the loading area (or the boat pool). This elapsed time is approximately equal to:

$$TPT(X) \text{ (minutes)} = \frac{120D}{VW(C)} + \frac{120U}{VL(X)} + TU(X) + LT(X)$$

where: LT(X) denotes the amount of lost time during the cycle, over and above the maneuver time in the unloading area. For this purpose, it will normally consist of time spent waiting for an unloading position. In most of this analysis LT(X) has been taken equal to zero.

TU(X), the unloading cycle time, as defined previously, is treated in some detail in Appendixes B and C.

This value of time per trip includes all time spent in the unloading area, but does not include any time in the loading area. The reasoning for this is that in the loading areas the craft will be isolated from most enemy weapons and protected by friendly fires and further by the fact that enemy weapons which can be directed to the loading area would most likely be directed against the large ships rather than against the landing craft.

Vulnerability due to personnel error and mechanical failure must be applied over the entire operating cycle, including the loading cycle and lost time in the loading area such as waiting to load and boat pool time. Therefore, when considering total vulnerability, the time per trip must also include those factors. At this writing the only data available on lost time come from the STS-2 simulation program,* but a valid pattern has not yet been established for it.

The Combined Vulnerability Function

Following the procedures outlined above, and using the weighted vulnerabilities listed in Table 2, we can now state a value for a combined vulnerability function, denoted by CV(X). For $D \geq 9$ nmi:

$$CV(X) = \frac{1080RA(X)}{VW(X)RVW(X)} + \frac{(120D)RF(X)}{VW(X)} + \frac{(1008 + 240D)RH(X)}{VW(X)RVW(X)}$$

$$+ \frac{270RF(X)}{VW(X)RVW(X)} + \frac{(1080U)RF(X)}{VL(X)RVL(X)} + 9RFU(X)TU(X)$$

CV(X) can be considered to be proportional to the square-foot minutes of exposure.

Inserting in this equation the various values associated with the LCM-6, we find a value for CV(LCM-6), after suitable reductions:

$$CV(LCM\text{-}6) = 295 + 45D + 9TU(LCM\text{-}6) \quad .$$

For $D < 9$ nmi similar equations were separately derived.

The relative combined vulnerability per trip is defined as:

$$RCV(X) = \frac{CV(X)}{CV(LCM\text{-}6)} \quad .$$

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* For a description of the Ship-to-Shore Model (STS-2) see "Analysis of Present Craft in Future Environments," by P. S. Jones et al., SRI and NWL, Dahlgren, Virginia, February 1969.

This value, divided by the time required per trip TPT(X), gives the relative combined vulnerability per specified unit time. That is,

$$RCVT(X) = \frac{RCV(X)}{TPT(X)} \quad .$$

Unloading Cycle Times

Unloading times used in this analysis have been based on loading and unloading tests conducted by M. Nielsen* of SRI at Camp Pendleton, California, in May 1968 on data collected by A. Grant and M. Nielsen of SRI during Operation Bell Banger at Coronado and Camp Pendleton, California, in July 1968 and on a previous SRI study, "An Amphibious Logistic Model," of June 1962. (See Appendixes B and C.)

Based on these sources, the unloading cycle time for a vehicle load from craft-X, denoted as TU(X), is as follows:†

For displacement craft, planing hulls, and hydrofoils, all of which unload in the surf zone:

$$TU(X) = 3.0 + 0.012A \text{ (minutes)}$$

where A = cargo area in square feet.

For air cushion vehicles, LVTs, LARCs, and similar craft which can unload at a hardstand in rear of the beach:

$$TU(X) = 1.7 + 0.0036A \text{ (minutes)} \quad .$$

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* M. Nielsen, "Systems Analysis of Amphibious Assault Craft: Vehicle Loading Test," SRI, April 1969.

† Over 95 percent of the craft loads during the assault phase of a landing are made up wholly of vehicles and personnel. Of these, few are made up solely of personnel.

In both cases these times include not only the unloading itself but also a certain amount of maneuver time and operational delays. They do not include time spent waiting to move to an unloading position.

Vulnerable Portions of a Craft

We define the vulnerable portion of a craft as that part of the craft in which a hit by one or more fragments or bullets will probably affect the operation of the craft. These portions vary from craft to craft and are discussed on page 36 .

Explosive projectiles will normally approach the craft on a more or less slanting trajectory depending on the weapon type and projectile, but fragments and solid projectiles that would affect the vulnerable parts of the craft would in most cases follow flat trajectories. A detailed consideration of the vulnerable parts with differing angles of approach is exceedingly complex in view of the differing shapes of the vulnerable parts and the wide variety of possible angles. However, a complete analysis of fragment damage would require more data on the nature and extent of vulnerable parts and on the materials and shape of protective coverings than have been supplied with the preliminary craft designs. Therefore, we have adopted a simplified approach that is both consistent with the available data and provides acceptable accuracy when comparing different landing craft.

Most projectiles and fragments which will be affecting vulnerable parts of a craft will approach the vulnerable parts in a flat trajectory. Therefore, we have selected a vertical presented area of the vulnerable part as a measure of its size. In order to be conservative as possible and to follow an identical rule for each part of each craft, a vertical presented area was found by drawing a box around the part; then we measured the area of a vertical plane passing through the diagonal of the box. Although somewhat crude, this rule is considered adequate for the purpose.

Kill Vulnerability

Damage to a craft that sinks it, destroys it, or puts it out of action for a period longer than the duration of its usefulness is termed a kill. The degree to which a craft is open to such damage is termed kill vulnerability and represents that portion of CV(X) that is associated with a "kill." It is computed by multiplying the vulnerability, CV(X), by the ratio between the total area of the vulnerable portions of a craft and the area of the craft itself. The craft area used for this purpose is the artillery presented area (for an angle of fall of 30°), which in most cases has a value between that of the horizontal and frontal areas.

The vulnerable portions considered in this analysis are the fuel tanks, the engines, and exposed propellers. The pilot house was not included because a craft can be operated using emergency controls even if the pilot house is destroyed. Lift mechanisms were not included because a craft can be operated, at reduced effectiveness, without lift. Flotation was not considered because damage sufficient to sink the craft would have already put it out of action by damage to the fuel tank, engines, or propellers. Other components critical to operation of the craft can also be considered if sufficient information is available as to the component characteristics.

The Vulnerability Function

The vulnerability function, CV(X), is a measure of the degree to which craft-X is exposed to attack by all of the weapons examined, during one trip to the beach and return. It measures vulnerability per trip and can be considered to be roughly proportional to the number of fragments and bullets that might be taken during the trip (or to their weight). Kill vulnerability can be considered as a function that is roughly proportional to the number of fragments and bullets that might be taken by the vulnerable portions of the craft.

The vulnerability function can be used to estimate attrition rates due to all enemy weapons. For this purpose, the function must be translated into absolute, rather than relative, terms. As its value is proportional to the number of fragments, a convenient and plausible way to do this is to apply some multiplier and then consider the result as representing the absolute number of fragments of average size that would be taken. It then becomes a matter of military and engineering judgment as to the effect on craft operation of that particular number of average fragments striking the craft and its vulnerable components.

Appendix D provides a discussion of fragment sizes and speeds.

The Defensive Mix

So far we have not discussed the specific mix of weapons that might be used by the defensive forces nor the level of their use. Clearly, a defense that is heavy with artillery and light on small caliber weapons will have a different effectiveness from one that is the reverse. We can reflect this difference in our model by weighting each weapon type in proportion to its ability to put high velocity fragments into the vulnerable areas of the craft. That ability can be taken as being proportional to the weight of ammunition in a single "day of fire" for each type weapon times the number of such weapons that are capable of influencing the action. As an example, assuming that a "day of fire" for a mortar weighs 1,000 lbs and that there are 10 such mortars available. Then the weighting factor for mortars would be:

$$W(M) = K(10)(1000) = 10{,}000K$$

where K is an arbitrary constant.

The weighting factor for other weapons can be computed in a similar manner. Each is then applied to the relative vulnerability value (computed as on page 21 and page 22 before proceeding to the combined vulnerability function.

The above procedure allows the consideration of variation in defense mix and in the level of defense when sufficient information about enemy defenses is available. No use will be made of the procedure in this document as its use requires entry into the field of two-sided war gaming, which is beyond the scope of the current treatment. However, as more detailed data become available on advanced landing craft, it will be possible to make finer comparisons. At that time, consideration of war gaming may be appropriate.

III HIT PROBABILITY ANALYSIS

Introduction

In the previous section vulnerability to a wide range of weapons was examined. The results are indicative of the outcome of a highly diversified hostile effort but are probably most applicable to situations where cumulative fragment damage is the governing effect. While landing craft are certainly vulnerable to fragments from noncontact bursts, the effect on the craft of direct hits by artillery projectiles is even more serious. This section examines the probability of direct hits, and their effects on the craft when they occur. Mortar rounds are of a size comparable to artillery rounds. They are, however, unsuited to precision fire and were found to be less effective against craft than artillery when direct hit damage is the criterion.

Procedure

The following procedure was followed to determine craft vulnerability to direct hits:

- Select an environment in which to examine each craft.
- Find the single shot hit probability (SSHP) for each range to be used, given perfect fire control.
- Find the SSHP for nominal (less effective) fire control. This consists primarily of incorporating the effects of target speed into the calculations.
- Find the number of expected hits during a trip to the beach and return.

- Find the probability of at least one hit during the same period.

- Find the probability that a hit will put the craft out of action for longer than its immediately useful life.

- Find the extent of fragment damage resulting from direct hits.

- Translate the above into attrition rates to be used in the STS-2 simulation model.

Specified Environment

After an examination of various possibilities, the environment chosen for the computation of vulnerability to direct hits by artillery (and of attrition rates for use in the STS-2 simulation) was one in which each craft is fired on by a 90-mm gun during the incoming trip and by a 105-mm howitzer during the unloading cycle. This will hereafter be referred to as the "specified" environment. In this model the craft is not taken under any other fire. More complicated models are possible but were not considered necessary for the purpose of craft comparison as these artillery weapons were found to be the most effective of those considered.

Originally the maximum rates of fire (ten rounds per minute for the 90-mm gun and three rounds per minute for the 105-mm) were used, but these resulted in such high hit probabilities and attrition rates that comparisons between craft were hindered. Consequently, a milder environment was specified in which a total of ten 90-mm rounds was fired at the craft as it was approaching the beach, and 0.3 105-mm rounds per minute were fired at it during the unloading cycle. This is a much milder environment, but is not unrealistic if a major friendly suppressive effort is present, and it provides a much better spread of attrition rates.*

Probability of a Direct Hit

Using as inputs the target configuration, trajectory shape, and weapon accuracy, it is possible by ordinary gunnery methods to find the probability of a direct hit by a perfectly aimed round, i.e., one with zero aiming error. We denote the single shot hit probability on craft-X at range r as $PH(X)_r$, and define it as the average of the hit probabilities obtained considering the target broadside and end-on.

Values of the range and deflection probable errors as given in the firing tables are generally considered optimistic and cannot be achieved in normal practice. When empirical data is not available, usage in U.S. artillery is to take a value for probable error which is double that given in the firing tables.† Values of $PH(X)_r$, computed using the doubled probable errors, have been plotted in Fig. 2 for three of the craft under evaluation. Note that at close ranges the probability of a hit is quite large, but that beyond 10,000 yards the hit probability is quite small, even for a large craft.

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* Even the reduced defensive effort above may be too high as it assumes that sufficient artillery is on hand that each craft can be fired on each time it approaches the beach. The environment is a grim one, although by no means impossible. Lower levels of defense, in which each craft does not receive fire each time, can be represented by stipulating that each craft be fired on only some fraction of its trips and by using a random selection process to determine which craft would even be considered for attrition. The current purpose of craft comparison would not necessarily be better served by the additional complication. For detailed war gaming some such procedure should be applied.

† FM 6-40, Field Artillery Cannon Gunnery, 1967.

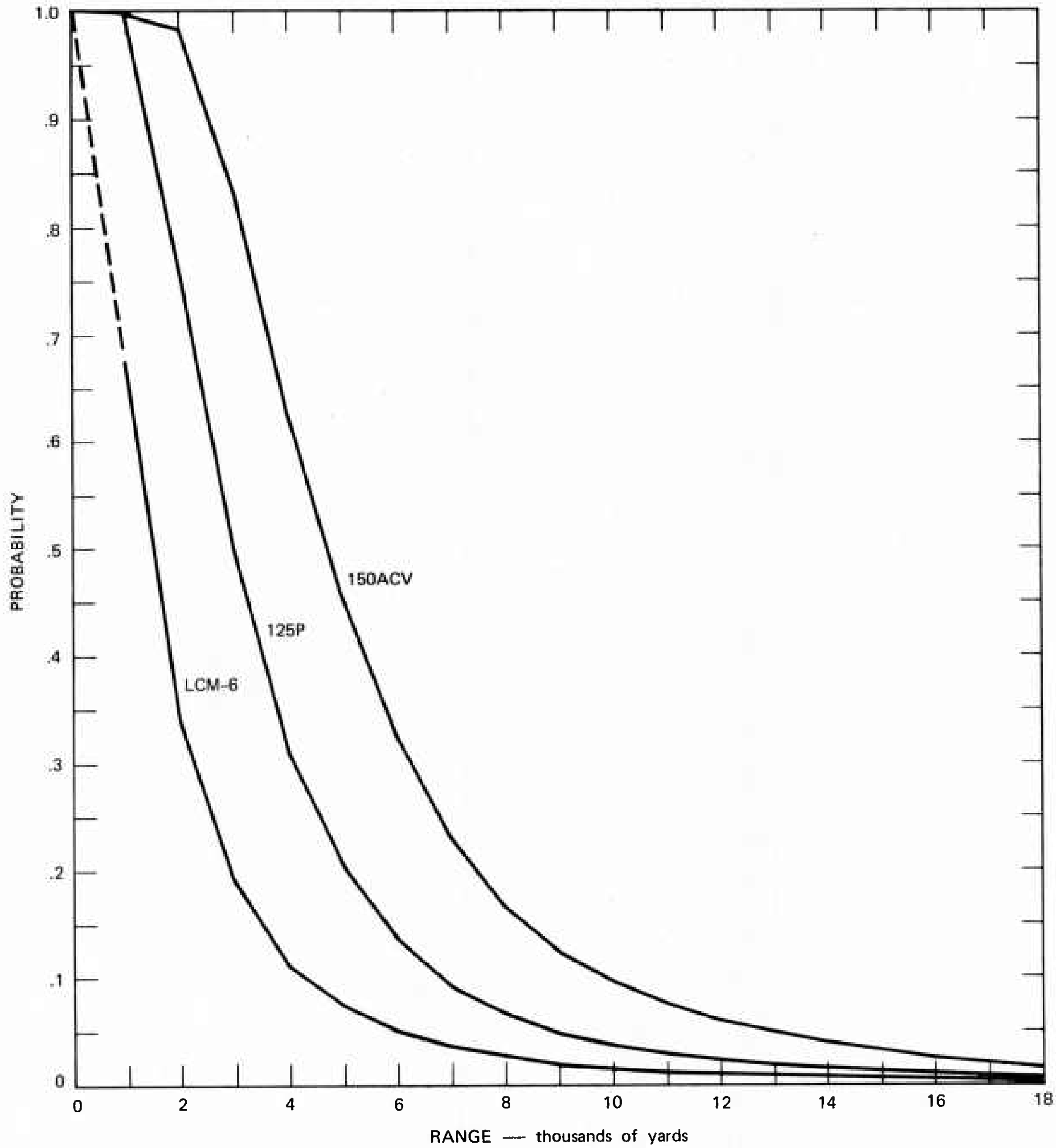

FIGURE 2 PROBABILITY OF A SINGLE SHOT HIT ON THE INDICATED CRAFT BY A 90 mm GUN FOR VARIOUS RANGES. Assuming perfect fire control.

For this combination of weapon and target the value of $PH(X)_r$ represents the maximum attainable accuracy. It corresponds roughly to the value of RA(X) in the vulnerability analysis and is subject to degradation by target speed in much the same way.

The Effects of Speed

We have assumed a fire control system such that the percent of time the center of impact is kept on the target is roughly inversely proportional to the target speed. (See discussions on page 15.) For the probability analysis, however, we need to assign absolute values to the degraded hit probabilities. A method of doing this is developed below.

Assuming a perfect fire control system, we find (Table A-5, Appendix A) that during the incoming phase an LCM-6 has an average PH(X) value of 0.52 and thus would expect to take 5.2 hits out of the 10 rounds fired in our model. This high percentage occurs because firing at slow targets takes place close to the beach where the single-shot hit probabilities are high. Higher speed craft take fewer perfectly aimed hits because the firing starts earlier at points where the hit probabilities are lower, but even the smallest ACV in the table takes 3.0 hits.

Such a firing record is clearly better than would normally be expected. Following the reasoning given below we reduce the expected hits and the single shot hit probability, $PH(X)_r$, in inverse proportion to target speed. The LCM-6 speed is 8 knots. Dividing its hit probability of 0.52 by 8 we get a reduced hit probability of 0.065 after considering the effects of speed. This should be multiplied by a numerical constant of yet undetermined size. We note, however, that dividing the maximum hit probability by 8 implies a fire control system that maintains the center of impact on the target about 12.5 percent of the time. This is within the 10 to 15 percent specified in our model. We infer that a plausible multiplier for this fire control system might well be approximately unity. Thus, dividing the hit probability associated with a perfect fire control system by the craft speed in knots gives the hit probability for the fire control system in the model, subject to the constraint that for this purpose the speed is never considered to be less than one knot. We shall hereafter refer to a fire control of this effectiveness as a "nominal" fire control system.

Computation of Expected Hits and Probability of a Hit

Given a single shot hit probability (SSHP) of p, the number of expected hits in n shots is np, and the probability of at least one hit in n shots is $1 - (1 - p)^n$. During the incoming trip, the single shot hit probability is different for each range. Therefore, the "expected number of hits" must be computed for each shot and totaled over the entire firing time. An average SSHP can then be computed to be used in obtaining the probability of at least one hit. More complicated and rigorous ways also exist, but this method is accurate enough for the current purpose. During the unloading phase only one range is involved, so the method is straightforward.

Table A-6, Appendix A, gives the expected hits and probability of a hit for several craft when nominal fire control is used. Note that for the LCM-6 the number of expected hits is less than one per trip, while the probability of at least one hit per trip is about 0.5. When the number of expected hits is less than unity, the probability of at least one hit is more significant than the number of expected hits.

The Effect of Hits on Vulnerable Portions of a Craft by Artillery Projectiles and Fragments

1. Fuel tanks, if hit by an artillery projectile will probably explode and destroy the craft. Fragments will have a much less

drastic effect on fuel tanks which will be, or can be, constructed so as to be self-sealing.

2. Pilot houses are protected with armor that will stop most fragments but are vulnerable to direct hits by artillery or larger projectiles. Alternate means are available for controlling the craft, although control is more difficult with the alternate means.

3. Engines will be put out of action by direct hits but probably not by a few fragments. The gas turbine is a relatively rugged piece of machinery as evidenced by the helicopter record in Viet Nam. In most craft there are multiple engines.

4. Water propellers are vulnerable to shore fire only during the withdrawal from the beach. At other times they are shielded by the craft itself.

5. Air propellers will be destroyed by direct hits by artillery. They are easily hit by fragments and would normally expect to take a number of fragment hits for each round striking the craft. They are, however, of rugged construction and can continue operation after several hits, though perhaps at reduced effectiveness. Most craft equipped with air propellers have more than one.

6. Lift systems for air cushion vehicles are rugged and can take a lot of damage, and are normally installed in parallel. Even if the lift is knocked out, the craft can proceed in the displacement mode in the water at diminished effectiveness.

7. The foils on hydrofoil craft would be severely damaged by direct hits but would be little affected by fragments. Foils on a catamaran hydrofoil would not be vulnerable to either.

8. Flotation is provided for in the proposed craft by separate compartments. Sinking a craft would require several artillery hits or comparable damage by other weapons. It is unlikely that this would occur except if the craft were previously immobilized.

9. Damage to some minor components of the craft could also put it out of action. The hydraulic and electrical systems are examples. However, such components are in large measure protectable and can easily be made redundant. They are not considered in this analysis.

The Kill Probability

Artillery rounds striking a craft may cause damage to vulnerable portions of the craft directly or by fragments from the explosion. It is considered that direct hits into the fuel tank or into all engines or all propellers would put the craft out of action either permanently or sufficiently to require major repair. (See discussion page 36.) The conditional probability that a round will hit a vulnerable part, given that it hits the craft, can be taken as the ratio between the presented area of the part and the presented area of the craft.

PE = the probability that an engine will be hit, given a hit on the craft

PP = the probability that a propeller will be hit, given a hit on the craft

PF = the probability that a fuel tank will be hit, given a hit on the craft.

If there are multiple hits, and if there are m engines, n propellers, and one fuel tank, then:

$PAE = [PE]^m$ = the probability that all engines will be hit

$PAP = [PP]^n$ = the probability that all propellers will be hit.

The conditional kill probability, CPK, resulting from a hit on all engines, or all propellers or the fuel tank is:

$$CPK = 1 - (1 - PAE)(1 - PAP)(1 - PF) \quad .$$

Even without multiple hits this procedure still has some validity because near misses have much of the effect of a direct hit. It can be inferred from Appendix D that the fragment density at 10 feet from the point of burst of a 105-mm shell is more than 12 times than at 30 feet, while at 5 feet the fragment density is more than 70 times that at 30 feet. That is, direct hits should not be treated as single point events but should cover a sizable area. Therefore, vulnerable parts that are somewhat separated can suffer the same "direct hit."

The probability of a kill, PK, during a mission is the product of the conditional kill probability and the hit probability per trip, PH_t. That is:

$$PK = (CPK)(PH_t).$$

<u>The Probability of Fragment Damage</u>

Fragments from shells bursting on contact with the craft can be expected to hit vulnerable portions of the craft. The number of effective fragments varies with distance from the point of burst and with the orientation of the shell at the time of burst. As the distribution of bursts about the craft can be expected to be approximately random, the orientation of the shell with respect to a vulnerable part cannot be predicted. Therefore, an average fragment density should be used. A partial table of fragment densities is given in Table D-1, Appendix D. At any given distance the number of fragments that will be taken by a vulnerable part will be the product of the area of the part and the number of fragments per square foot.

The important output from this portion of the analysis is the number of fragments that will be taken by a vulnerable part per hit on the craft. This number provides a basis for military and engineering judgment as to the effect on the craft of the fragment hits. Table A-9, Appendix A, summarizes the number of effective fragment hits on engines and air propellers, the two principal craft components considered vulnerable to fragment damage. The number of fragment hits was arrived at after consideration of the shielding qualities of the structural plate of which the craft are built as well as the fragmentation characteristics of the shells. For this particular table a distance of 30 feet was assumed between the burst and the vulnerable component.

Damage to the Payload

A detailed analysis was made of the number of fragments that would be taken in the cargo well from artillery air bursts over the craft. The primary results of the analysis were that for precision fire the lower the height of burst the greater the number of fragments that would be received in the well, and that the expected contact bursts put more fragments into the cargo well per round fired than the air bursts that occurred within bursting radius. Payload damage should therefore be based on bursts that hit the craft rather than on the less effective air burst procedure.

Referring to Table D-1, Appendix D, we note that for a distance of 30 feet from the point of burst the following fragment densities per pound apply:

	Fragments Per Square Foot Causing: Personnel Casualties	Fragments Per Square Foot Causing: Vehicle Casualties
90mm	0.0538	0.0170
105mm	0.0889	0.0375

As an example of application, taking an average exposed area of 3 square feet for personnel and 10 square feet of vulnerable area for 2-1/2-ton trucks, we note the following average number of fragments per burst:

	Fragments Per Trooper	Fragments Per Truck
90mm	0.11	0.17
105mm	0.27	0.38

Personnel at 30 feet can expect to take 15 to 30 percent casualties per direct hit. Vehicle casualties will be slightly greater. Personnel and vehicles at closer ranges would take much higher casualties while those at a greater distance much less.

IV ATTRITION RATES

Rules for Attrition

The rules by which attrition is assessed against landing craft are subject to considerable latitude, depending on the purpose of the assessment, the strictness of the standards, the accuracy of the available input data, the completeness of information as to the hazards of operation, and the amount of detail included in the simulation. For the primary purpose of craft comparison, the attrition criteria used for the STS-2 simulation program are as follows:

- A craft that suffers a direct hit is "attrited"
- A craft that suffers damage such that it will be out of action for a period in excess of six hours is considered "killed"
- An "attrited" craft that is not "killed" will be out of action for an amount of time varying from a few minutes to six hours
- Selection of craft for "attrition" and for "killed if attrited" and for "time out of action" is by random selection.

Combining Attrition Rates

Given attrition rates per trip due to various causes the rates can be combined as below:

Take (for any given craft):

AE = attrition rate per trip due to enemy action

AM = attrition rate per trip due to mechanical failure

AP = attrition rate per trip due to personnel error.

The overall attrition rate per trip is then:

$$AO = 1 - (1 - AE)(1 - AM)(1 - AP)$$

Attrition rates per trip due to enemy action were calculated in the manner described in the preceding section. Attrition rates due to mechanical failure were developed by the Annapolis Division of the Naval Ship Research and Development Center. Because no appropriate data exist, rates for both present and advanced craft were estimated using an analytical procedure that takes into account the reliability of different components and the manner in which they are coupled together. Attrition rates due to personnel error were estimated by the Naval Personnel Research Laboratory. These were based on estimates of the complexity and maneuverability of the different craft and considerations of ride comfort. Typical attrition rates for present and advanced craft are listed in Table A-8, Appendix A.

In event an overall attrition rate is desired for specified portions of the trip, it is only necessary to divide the given rates (AE, AM, or AP) into whatever parts are indicated and then combine as above.

Attrition due to enemy action can easily be divided between incoming and unloading periods. Further division is somewhat arbitrary and depends on the specified environment.

Attrition due to mechanical failure and attrition due to a personnel error tend to be proportional to time, but the tendency toward failure probably increases with approach to the shoreline and with the close proximity to other craft as in the loading area. In the STS-2 model such failures are considered twice as likely (per unit time) as during transit.

The initial attrition rates used in the STS-2 simulation model were based on the specified environment and the characteristics of the craft being simulated. Early runs revealed that attrition was the single most important factor affecting craft performance. Continued exposure to heavy enemy action severely crippled the amphibious assault. A review of the assault assumptions suggested that as the amphibious force pushes inland the vulnerability of landing craft to enemy action will decline. Accordingly, attrition rates due to enemy action were twice reduced during the assault phase of the operation, and they were eliminated during general unloading. Subsequent simulation results were more representative of successful amphibious assaults.

Early simulation results also revealed that, even with the reduced attrition rates, for most craft mixes the fraction of time that craft spent attrited often approached half of the total craft time. Further investigation suggests that the time that damaged craft are out of action after being attrited appears excessively long. An alternative method for determining lost time due to attrition is given in the following section.

Time Lost Due to Attrition

When a landing craft has suffered attrition, it may be destroyed (e.g., by sinking or burning) or may be put out of action for the period of time required to accomplish the repairs. Repair time sufficiently long that a landing craft is substantially unable to perform its mission during an amphibious assault would have the same effect during that assault as destruction or "kill." For the STS-2 simulation it has been taken that repair times in excess of six hours would constitute a kill. The value of six hours was arrived at based on consideration of both engineering and operational factors.

Therefore, damage that would require longer times was used as a basis for computing the probability that the craft would be "killed" if attrited. This disposes of that part of the problem associated with long repair times, but the problem remains of assigning repair times for lesser degrees of damage. Experience factors that directly apply to proposed craft are not available, and data on currently existing craft are scanty and of limited applicability in any case.

We note, however, that mechanical repair times are reasonably well described by the negative exponential function.* Lacking specific empirical data, this function has been taken as an approximation to the distribution of repair times. Therefore, we define the probability (P) that the time (T) lost following attrition will be greater than H hours as:

$$P = \exp(-AH) \quad , \tag{1}$$

where A is an arbitrary constant. We denote the probability that time lost is equal to or less than H hours by Q. Then, Q = 1 - P. Therefore,

$$Q = 1 - \exp(-AH) \; . \tag{2}$$

In order to use these formulas it is necessary to assign a value to A for each craft. This can be accomplished using Equation (1) and substituting therein the "kill" criterion and the probability associated therewith. We denote the "kill" criterion (e.g., more than six hours of lost time) by H_1, (measured in hours), and the probability of a "kill," if attrited, by K. Then:

$$K = \exp(-AH_1) \quad , \tag{3}$$

and

$$A = \frac{1}{H_1} \log(1/K) \quad . \tag{4}$$

Substituting this value in equations (1) and (2), we obtain:

$$P = K^{H_1/H} \tag{5}$$

and

$$Q = 1 - K^{H_1/H} \tag{6}$$

* Feller, "An Introduction to Probability Theory and its Applications," Vol. I, Wiley, 1957.

Table 3 shows the values of H associated with each value of Q for several craft. Tables such as this may be used to generate delay times for the STS-2 simulation program. The procedure is to select a random number between 0 and 1, then enter the table with that number in the probability column. The delay time is then read out of the appropriate craft column. The random selection of table entries will, over a large number of tries, provide approximately even coverage over the range of probabilities, and that even coverage provides a set of values that conform to the cumulative distribution given in Eq. (2), above.

The values from Table 3 have been plotted in Fig. 3. Note that this function combines into a single curve the probability of a "kill," if attrited, and the delay time if there is no "kill." The straight lines connecting the origin with various points on the H = 6 ordinate represent the delay time distribution, assuming a linear relation between delay time and probability. Note that delay times for the negative exponential distribution are considerably lower than for the linear distribution, sometimes by a factor of two or more.

Table 3

DELAY TIMES VERSUS PROBABILITY

Probability of T ≤ H	Delay Times (hrs)					
	LCM-6	30P	30ACV	125P	150ACV	320P
K =	0.100	0.172	0.102	0.233	0.181	0.168
.05	0.134	0.175	0.135	0.211	0.180	0.173
.10	0.275	0.359	0.277	0.434	0.370	0.354
.15	0.424	0.554	0.427	0.669	0.571	0.547
.20	0.582	0.761	0.587	0.919	0.783	0.751
.25	0.750	0.981	0.756	1.185	1.010	0.986
.30	0.929	1.216	0.938	1.469	1.252	1.200
.35	1.123	1.468	1.132	1.774	1.512	1.449
.40	1.331	1.741	1.343	2.104	1.793	1.718
.45	1.558	2.038	1.571	2.462	2.099	2.011
.50	1.806	2.363	1.822	2.855	2.433	2.332
.55	2.081	2.722	2.099	3.289	2.803	2.686
.60	2.388	3.123	2.408	3.774	3.217	3.082
.65	2.736	3.578	2.759	4.324	3.685	3.531
.70	3.137	4.104	3.165	4.959	4.226	4.050
.75	3.612	4.725	3.644	<u>5.710</u>	4.866	4.663
.80	4.194	<u>5.486</u>	4.230	6.629	<u>5.650</u>	<u>5.414</u>
.85	4.944	6.467	<u>4.986</u>	7.814	6.660	6.381
.90	<u>6.000</u>	7.849	6.052	9.484	8.083	7.745
.95	7.806	10.211	8.460	13.258	11.299	10.827

Note: Underlinings indicate the six-hour cutoff or nonlethal damage.

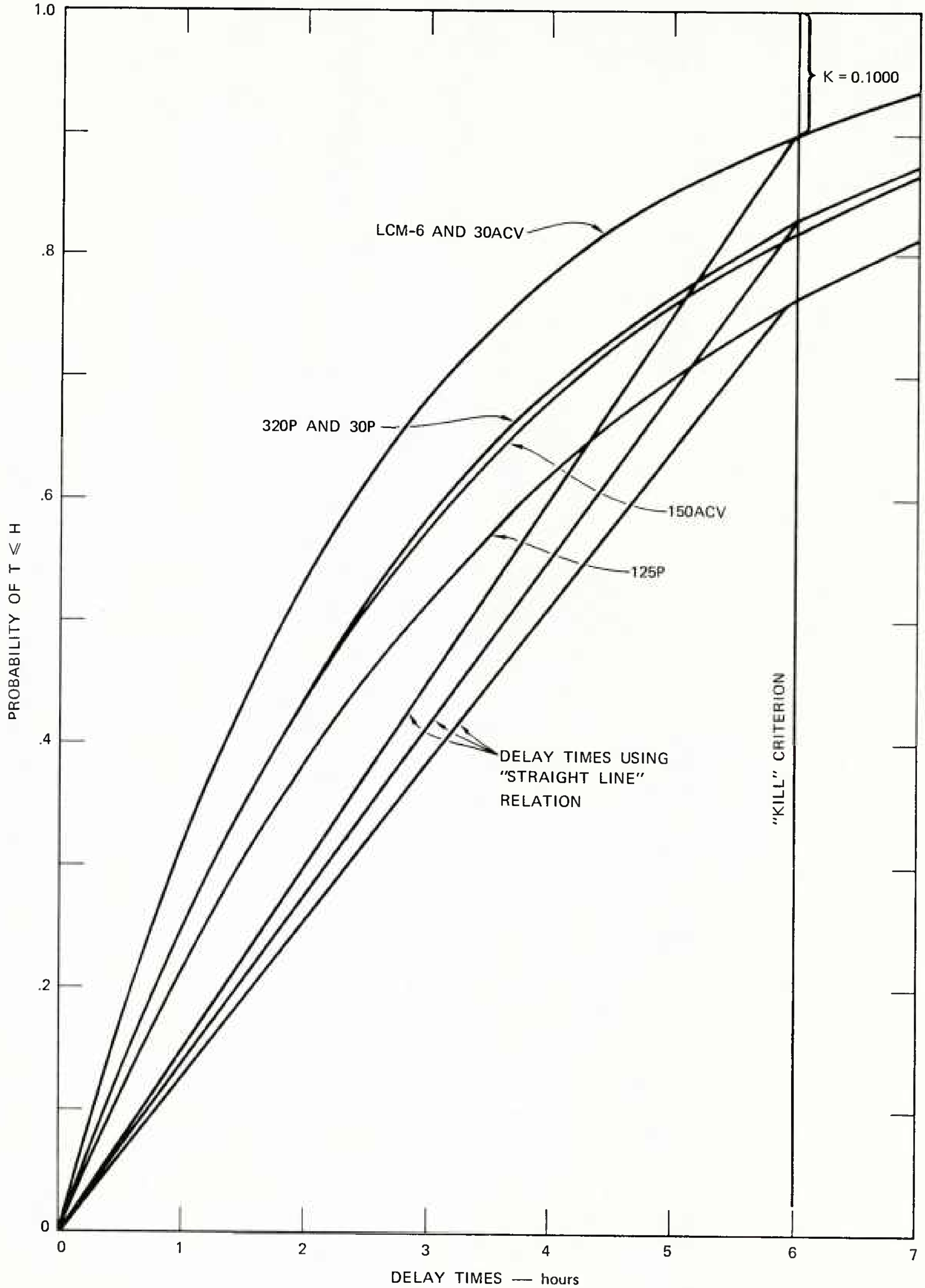

FIGURE 3 PROBABILITY OF DELAY TIMES EQUAL TO OR LESS THAN A SPECIFIED NUMBER OF HOURS. A 6-hour delay ⇒ a "kill".

V SYMBOLS AND FORMULAS

H(X) = Horizontal craft area, ft^2

= (overall length) × (average beam, viewed from above)

RH(X) = Relative horizontal craft area

= H(X)/H(LCM-6)

F(X) = Frontal area, ft^2

= 0.64 × (average length + average beam) × (average height)

RF(X) = Relative frontal area

= F(X)/F(LCM-6)

RFU(X) = Relative frontal area during unloading

= FU(X)/FU(LCM-6) using beached dimensions of both craft

$A(X)_r$ = Presented area, ft^2

$= 1/2[2LW \sin \alpha + (L+W)H \cos \alpha]$

$RA(X)_r$ = Relative presented area

$= A(X)_r / A(LCM\text{-}6)_r$

RA(X) = Average relative presented area

$= 1/n \sum_{r=1}^{n} RA(X)_r$

r = weapon range, thousands of yards

VW(X) = speed over water, knots

RVW(X) = Relative speed over water

= VW(X)/VW(LCM-6)

L = craft length, ft

W = craft beam, ft

H = craft height

α = weapon angle of fall, degrees

D = standoff distance, nautical miles

U = distance from beach to unloading area, nautical miles

TU(X) = unloading cycle time, minutes

VL(X) = speed over land, knots

RVL(X) = Relative speed over land

= VL(X)/VL(CCM-6) = VL(X)/VW(LCM-6)

TPT(X) = craft trip cycle time, minutes

$$= \frac{120D}{VW(X)} + \frac{120V}{VL(X)} + TU(X) + LT(X)$$

LT(X) = time lost in the unloading area during a round trip, minutes

TU(X) = time spent unloading craft, minutes

CV(X) = combined vulnerability function, square foot minutes

RCV(X) = relative combined vulnerability per trip

$$= \frac{CV(X)}{CV(LCM\text{-}6)}$$

RCVT(X) = relative combined vulnerability per unit time

= RCV(X)/TPT(X)

A = landing craft cargo well area, ft^2

SSHP = single shot hit probability

$PH(X)_r$ = craft X single shot hit probability from range r

PK = probability of a kill, given that attrition has occurred

PH_t = probability of one hit per trip

AE = attrition rate per trip due to enemy action

AM = attrition rate per trip due to mechanical failure

AP = attrition rate per trip due to personnel error

AO = overall attrition rate

Appendix A

RESULTS OF VULNERABILITY ANALYSIS OF SELECTED LANDING CRAFT

Appendix A

RESULTS OF VULNERABILITY ANALYSIS OF SELECTED LANDING CRAFT

Introduction

The procedures described in the text of this report were applied to 33 proposed advanced craft and to 13 presently existing craft. In this appendix we present some of the vulnerability data pertaining to the craft that were selected for detailed examination with the simulation models. Data on the LCM-6 are also included for comparison purposes. In addition to providing vulnerability data on certain craft, the material presented here will also serve to illustrate the application of the methods discussed in the text.

The advanced craft are identified herein by giving the payload weight (in 1000 lbs) followed by the hull type, P for planing hull, and ACV for air cushion vehicle.

Table A-1 is a summary of selected dimensional and operating data used in the analysis.

Table A-2 gives the value of the vulnerability function for each craft for various standoff distances. This table also provides the basis for Figs. A-1 and A-2 which present some of the data graphically. It should be noted here that:

- Vulnerability increases with standoff distance. This is intuitively acceptable as the close-in vulnerability is the same for both while the vulnerability during the approach is greater for the greater standoff distances.

- The LCM-6 (as do other existing craft) shows up poorly against the advanced craft when vulnerability is plotted against cargo area (an approximate measure of productivity per trip).

Table A-1

COMPARATIVE DATA FOR SELECTED CRAFT

Craft	Horizontal Area (ft^2)	Frontal Area (ft^2)	Presented Area Artillery (ft^2)	Vuln. Area (ft^2)	Vuln. Area Fraction	Cargo Area (ft^2)	Speed Over Water (knots)	Unloading Cycle (min)
LCM-6	785	141	481	66	.137	412	8.0	7.9
10P	590	186	392	40	.102	232	20.0	5.8
30P	700	286	544	119	.219	432	30.0	8.2
30ACV	1,200	853	1,177	190	.161	444	50.0	3.3
125P	1,771	542	1,152	375	.325	782	35.0	12.3
150ACV	4,576	1,806	3,488	520	.149	1,716	50.0	7.9
320P	4,480	1,092	3,063	374	.122	2,990	35.0	38.4

Table A-2

VULNERABILITY TO ALL TYPES OF ENEMY ACTION
PER TRIP FOR VARIOUS STANDOFF DISTANCES

	STANDOFF DISTANCE IN NAUTICAL MILES							
Craft	1	5	10	15	20	25	30	35
LCM-6	195	525	816	1,041	1,266	1,491	1,716	1,941
10P	92	154	219	274	330	385	441	496
30P	169	219	275	325	375	425	475	525
30ACV	172	243	326	404	482	561	639	717
125P	454	537	628	710	792	874	956	1,039
150ACV	761	934	1,129	1,310	1,492	1,673	1,855	2,036
320P	2,738	2,935	3,141	3,325	3,508	3,691	3,875	4,058

Note: The values given are those of the combined vulnerability function, CV(X) and are proportional to the number of square-foot-minutes of exposure, or to the number of fragments that might be taken during one trip to the beach and back.

Table A-3 provides data as to the sizes of the principal vulnerable areas of each craft and compares the total with the craft apparent area. The value used for apparent area is that which applies to artillery (see page 27). The fraction of craft area represented by vulnerable parts is then computed.

Table A-4 gives the number of fragments that might be taken by a craft and its vulnerable parts during one trip to the beach, assuming that the same high level of defense applied equally to all craft. Since the average fragment (or bullet) will be on the order of 100 to 200 grains, those numbers of fragments would likely present a serious hazard to continuous operation.

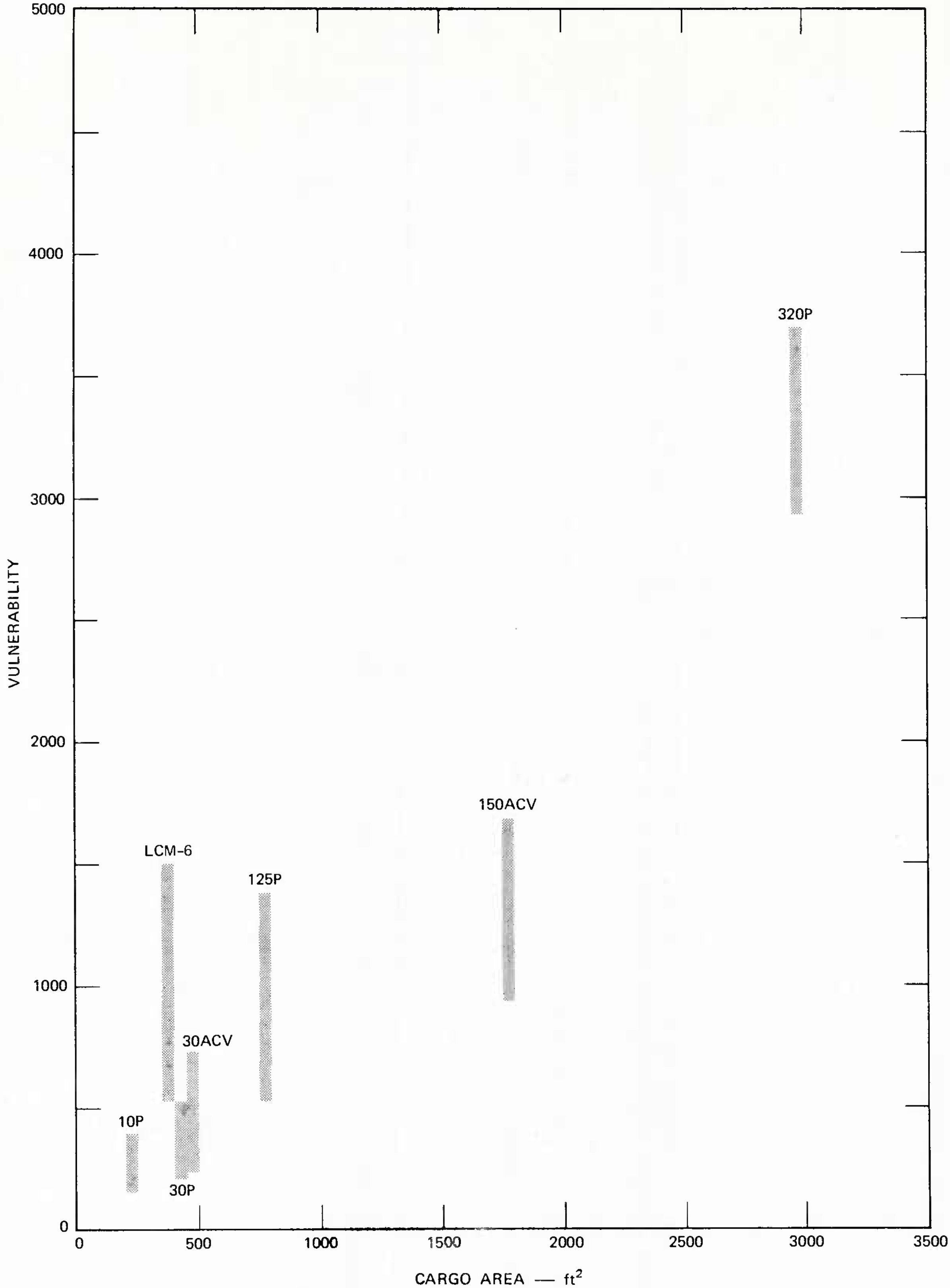

FIGURE A-1 VULNERABILITY TO ALL TYPES OF ENEMY WEAPONS VERSUS SQUARE FEET OF CARGO AREA. Top of bar ⇒ 25 nmi standoff. Bottom of bar ⇒ 5 nmi standoff.

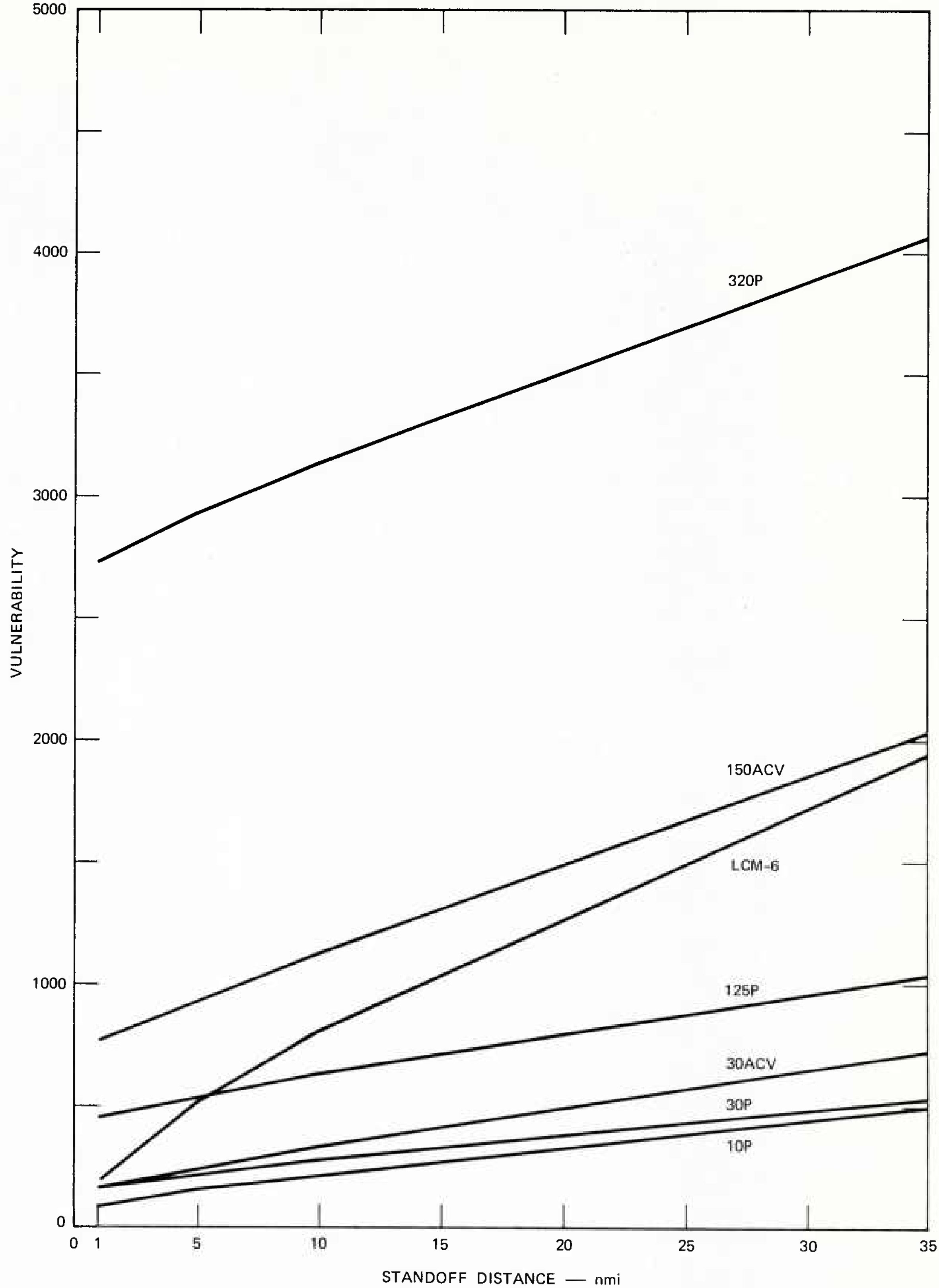

FIGURE A-2 VULNERABILITY TO ALL TYPES OF ENEMY WEAPONS FOR VARIOUS STANDOFF DISTANCES

Table A-3

VULNERABLE AREAS FOR EACH CRAFT
(In Square Feet)

Craft	Fuel	Air Propellers	Engines	Total	Craft Apparent Area	Ratio of Vuln. Area to Craft Area
LCM-6	40	--	26	66	481	0.137
10P	23	--	17	40	392	0.102
30P	69	--	50	119	544	0.219
30ACV	46	120	24	190	1,177	0.161
125P	300	--	75	375	1,152	0.325
150ACV	90	330	100	520	3,488	0.149
320P	248	--	126	374	3,063	0.122

Table A-4

NUMBER OF FRAGMENTS TAKEN BY THE CRAFT
AND ITS VULNERABLE PARTS PER TRIP
(For a Standoff Distance of 10 Nautical Miles)

Craft	Number of Fragments Taken by Craft	Vulnerable Area Fraction	Number of Fragments Taken by Vulnerable Parts
LCM-6	816	0.137	112
10P	219	0.102	22
30P	275	0.219	60
30ACV	326	0.161	53
125P	628	0.325	204
150ACV	1,129	0.149	170
320P	3,141	0.122	371

The above figures were computed by multiplying the vulnerability index by 1.0 to obtain the number of fragments. (See page 28). The results indicate a high level of defense.

Table A-5 gives the expected direct hits by artillery during an incoming trip. Note the high number of hits expected for the LCM-6 (for both perfect and nominal fire control) when compared with larger advanced craft.

Table A-5

EXPECTED ARTILLERY DIRECT HITS DURING INCOMING TRIP
(10 Rounds Fired)

	Perfect Fire Control		Nominal Fire Control	
Craft	Expected Hits	Average Single Shot Hit Probability	Expected Hits	Average Single Shot Hit Probability
LCM-6	5.21	0.521	0.651	0.065
10P	3.51	0.351	0.173	0.017
30P	2.70	0.270	0.090	0.009
30ACV	3.03	0.303	0.061	0.006
125P	3.17	0.317	0.091	0.009
150ACV	3.84	0.384	0.078	0.008
320P	3.97	0.397	0.115	0.012

Table A-6 summarizes the expected hits and probability of at least one hit per round trip with nominal fire control. Note again the high hit probability of the LCM-6. The high hit probability of the 320P results mostly from its long stay in the unloading area. The probability of multiple hits during one trip can be seen to be small. Figure A-3 plots the probability of a hit per trip against cargo area (productivity).

Table A-7 gives the conditional probability that a craft that suffers a direct hit will be "killed". The values shown are derived from a consideration of the size, hardness, protection, and number of the vulnerable areas of a craft. These values are roughly comparable to the vulnerable area fraction (Table A-4) but the latter consider only the sizes involved.

Table A-6

EXPECTED HITS AND PROBABILITY OF AT LEAST ONE ARTILLERY HIT PER ROUND TRIP UNDER SPECIFIED ENVIRONMENT WITH NOMINAL FIRE CONTROL

	Expected Hits			Probability of a Hit		
Craft	Incoming	Unloading	Total	Incoming	Unloading	Overall
LCM-6	0.651	0.023	0.674	0.490	0.023	0.502
10P	0.173	0.018	0.191	0.160	0.018	0.175
30P	0.090	0.025	0.115	0.087	0.025	0.110
30ACV	0.061	0.025	0.086	0.059	0.025	0.082
125P	0.091	0.114	0.205	0.087	0.100	0.178
150ACV	0.078	0.140	0.218	0.076	0.135	0.201
320P	0.115	0.769	0.884	0.109	0.548	0.597

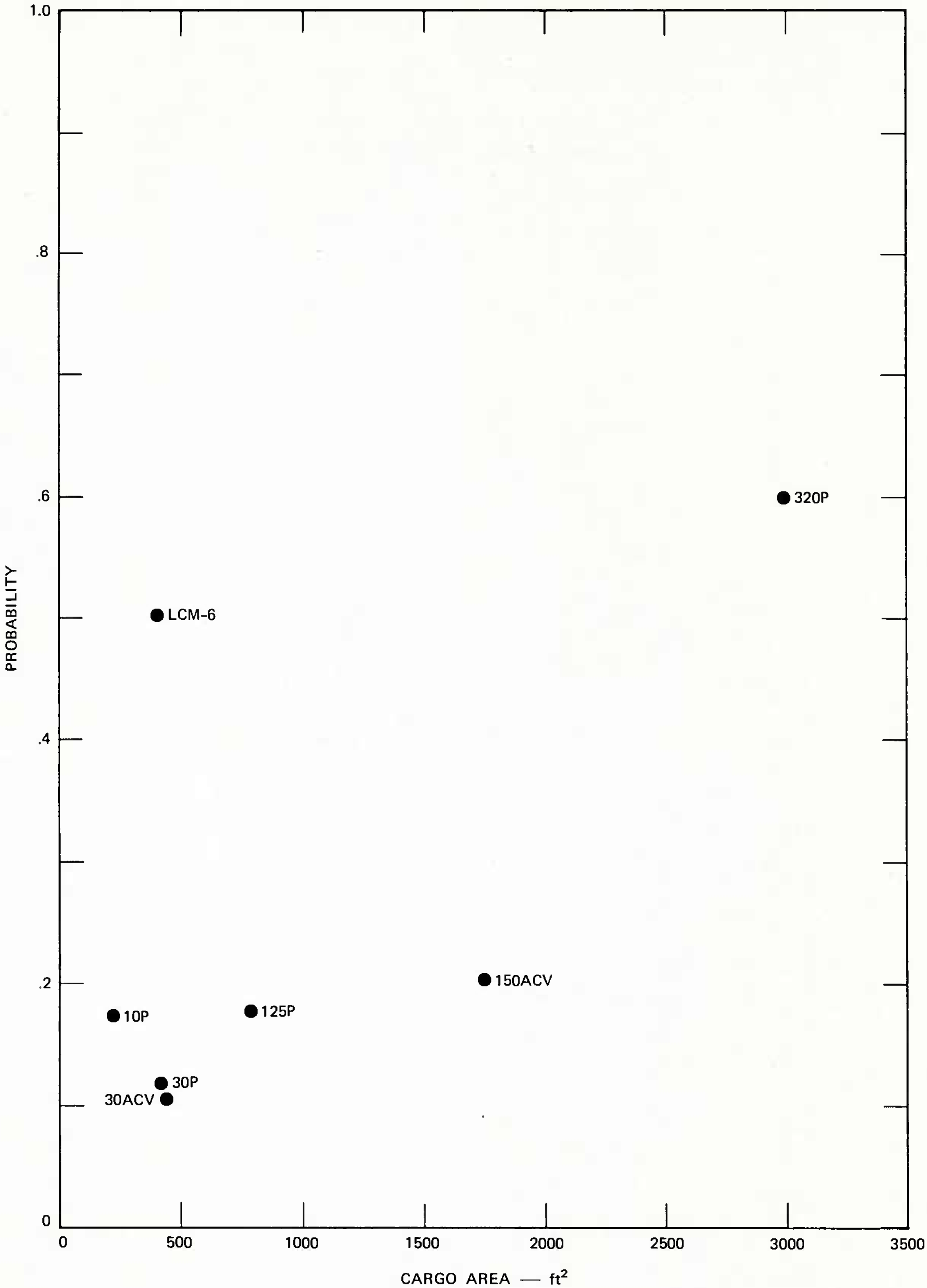

FIGURE A-3 PROBABILITY OF A DIRECT HIT BY ARTILLERY DURING ONE TRIP TO THE BEACH VERSUS SQUARE FEET OF CARGO AREA, NOMINAL FIRE CONTROL

Table A-7

PROBABILITY THAT A CRAFT SUFFERING A DIRECT HIT WILL BE "KILLED"

Craft	Conditional Kill Probability
LCM-6	0.132
10P	0.058
30P	0.127
30ACV	0.037
125P	0.264
150ACV	0.028
320P	0.118

Table A-8 shows the initial attrition rates used in the STS-2 simulation program. The values shown for attrition per trip are those calculated by the methods described in this document or derived by the Naval Ship Research and Development Center or the Naval Personnel Research Laboratory. These are the basic inputs that must be combined and transformed into the attrition rates shown on the right-hand side of the page. The following rules were used in the transformation.

The attrition due to enemy action while incoming was arbitrarily divided so that two-thirds of the value applied beyond the line of departure (LOD) and one-third within it.

In the computation of noncombat attrition double weight was given to time spent in the area near the ships and in the unloading area compared to moving time. Noncombat attrition in the unloading area was divided into two parts, with two-thirds applying during unloading itself and one-third during the approach and withdrawal. The times used in dividing up noncombat attrition to its various parts were obtained from an analysis of STS-2 simulation results.

Table A-8

INITIAL ATTRITION RATES FOR USE WITH STS-2 SIMULATION PROGRAM BASED ON 25-NMI STANDOFF

	Attrition Per Trip			Combined Initial Attrition Rates Per Trip for STS-2		
Craft	Enemy Action	Mechanical Failure	Personnel Error	Seaward of LOD	LOD to Beach	During Unloading
LCM-6	0.502	0.020	0.050	0.371	0.163	0.023
10P	0.075	0.091	0.060	0.225	0.056	0.022
30P	0.110	0.070	0.030	0.141	0.031	0.028
30ACV	0.082	0.090	0.020	0.123	0.023	0.032
125P	0.178	0.075	0.060	0.163	0.032	0.106
150ACV	0.201	0.074	0.050	0.141	0.030	0.142
320P	0.597	0.042	0.080	0.159	0.042	0.552

It will be noted that attrition seaward of the LOD is much greater than between the LOD and the unloading area. This is primarily due to greater exposure time. With one exception, attrition during unloading is much less than during the other periods. This is because of the relatively short unloading times compared with other portions of the cycle, except for the 320P, which has a much longer unloading time than any other craft in the table.

Table A-9 gives the average number of potentially effective fragment hits on engines and air propellers for each round. The table provides a basis for assessing attrition resulting from multiple or cumulative fragment hits.

Table A-9

AVERAGE NUMBER OF POTENTIALLY EFFECTIVE FRAGMENT HITS ON EACH ENGINE AND EACH AIR PROPELLER PER ARTILLERY ROUND EXPLODING AT ABOUT 30 FEET FROM THE AFFECTED PART

	Number of Fragment Hits			
	Each Engine		Each Propeller	
Craft	Incoming	Unloading	Incoming	Unloading
LCM-6	0.4	1.0	--	--
10P	0.1	0.3	--	--
30P	0.5	1.3	--	--
30ACV	0.4	1.0	2.1	4.8
125P	0.2	0.5	--	--
150ACV	0.9	2.0	5.8	13.2
320	1.3	3.2	--	--

Notes: a. Direct hits on vulnerable part are not considered.

b. An effective fragment is defined as one that will penetrate whatever protection exists for the vulnerable part and still have sufficient energy to cause damage.

Appendix B

UNLOADING CYCLE TIMES FOR
DISPLACEMENT LANDING CRAFT

Appendix B

UNLOADING CYCLE TIMES FOR DISPLACEMENT LANDING CRAFT

Introduction

For the purpose of operations and vulnerability analysis it is necessary to have a reasonably accurate measure of the time that will be spent by landing craft in and near the unloading area (the beach in this case) during an operational trip from ship to shore. The period concerned is referred to as the unloading cycle and includes:

- The approach to the unloading area
- The unloading itself
- The withdrawal

The presently operational landing craft are mostly of the displacement type, essentially the same as those in use for many years--LVTs, LCVPs, LCMs, and LCUs. The behavior of these craft in the surf, is of interest not only because they will remain in the inventory for some time but also because some advanced craft, such as planning hulls and hydrofoils, essentially operate as displacement craft during the unloading cycle, although they operate differently at other times.

Data on unloading cycle times were obtained on 14 and 15 July 1968 during an amphibious exercise by U. S. Navy and Marine forces at Silver Strand Beach, Coronado, California, and at White Beach, Camp Pendleton, California. The operation was called "Bell Banger" and included both regular and reserve Marine Forces. Naval forces were primarily regular.

A total of 38 craft loads were timed, though complete data were not always obtained.

Craft	Number of Loads
LVT	7
LCVP	9
LCM-6	18
LCU-1610	4

The Unloading Cycle

In the approach to the beach the craft hits the bottom and pauses or stops, then moves forward riding the breakers until the craft commander is satisfied with (or reconciled to) his position, after which he drops the ramp, ending the approach.

Unloading can start as soon as the ramp is down. There were numerous delays observed in this period, some explainable and some not. A major reason for delays was the uncertainty as to the depth of the water at the ramp end. There were also some delays at the end of unloading before preparations for departure were apparent.

The withdrawal is considered to start at the time the ramp starts up. Once the ramp is up, the craft then disengages from the beach and backs out through the surf. Timing stopped when there was no longer any contact with the bottom. The beach cycle for LVTs was a single period, taken to start at the time the craft stopped for unloading on the beach and ended when the craft started to move away after unloading. For all types of craft intermediate events were also timed.

The Environment

The beach at Silver Strand is fairly steep, over 10 percent above the waterline and estimated at 5 to 6 percent underwater near the shore.

At the time of the operation (on 14 July) there was a plunging surf of about two feet, breaking about 50 feet from shore. The beach was of fine material.

The beach at Camp Pendleton is flat, with slope estimated at less than 5 percent and is composed of fine material. In the morning (15 July) there was a two-foot plunging surf breaking about 100 feet from shore. During the day the surf gradually rose to about four feet.

The landings generally proceeded smoothly. No instances were noted of vehicles foundering in the surf, although in one instance a jeep was pulled from an LCU by a LARC-5 because it was believed that the water was too deep for it. No dry landings were noted; water depths at the ramp ends were estimated at half a foot to about four feet.

The Fixed Component of Unloading Cycle Time

The first and last periods in the beach cycle (beaching and withdrawal) are largely independent of the type load. The average times for these periods are tabulated below in minutes and seconds:

	LCVP	LCM-6	LCU
Average time from first contact with bottom until ramp down	1:04	1:23	5:15
Average time from start of ramp up until craft clears beach	2:03	2:38	2:54
TOTAL	3:07	4:01	8:09

These values can be considered as a "fixed" component of the beach cycle time. The other component, the unloading period of the beach cycle, will be variable depending on the precise load. Loads may be vehicles, troops, or general supplies, and each will have different unloading rates. Vehicles were not carried on the LCVPs in the observed exercises.

Average Unloading Times for Vehicles (minutes and seconds)

	LCM-6	LCU-1610
Per vehicle	1:02	3:07
Per craft	2:15 (not all fully loaded)	19:47 (all fully loaded)

The vehicles unloaded from the LCM-6 were mostly small vehicles with or without trailers, but there were a few 3/4-ton trucks. The vehicles unloaded from the LCU-1610 were mostly large trucks, bulldozers, and tanks, plus a few jeeps, some with trailers. The trailers made little difference in unloading times. With fully loaded LCM-6 carrying only vehicles, it would probably take about four minutes for the vehicle to clear the craft.

The average time per vehicle from an LCU would have been about two minutes per vehicle except that there were in every case operational delays that increased the time to the higher figure given above. These delays resulted from faulty loading practices or equipment trouble. Similar delays were noted in previously observed landings.

Average Unloading Times for Troops (minutes and seconds)

	LVT	LCVP	LCM-6
Per craft	0:15	1:02	1:06
Computed rate per 100 troops	0:50	3:20	1:06

Accurate troop counts were not obtained, but approximately 30 troops were carried in the LVTs and the LCVPs and about 100 in the LCM-6s. The comparatively long times associated with the LCVP can be attributed at least in part to the craft's unstable platform and its sloping decks, which slant to the rear and to the side when the craft is at the beach. A value of 100 troops per minute is considered realistic for displacement craft not so handicapped.

There was little unloading of general supplies. A few net loads were taken from an LCM-6 by a truck crane, requiring about six minutes per load. Forklift operations were not observed. On a previous exercise at the same beach in April 1968 ammunition pallets were observed being removed from an LCM-6 by two forklift trucks at about one load per minute with one or two pallets per load. The entire LCM-6 was unloaded in about 25 minutes.

Total Beach Cycle Times for Vehicular Loads

Based on this limited sample, it would appear that a full load of vehicles could be unloaded from an LCM-6 with a total beach cycle time of about 8 minutes. An LCU load would require about 28 minutes.

In an effort to extend these results to other craft, a number of relations were computed and plotted. It was noticed at once that vehicle unloading time for a fully loaded craft was approximately proportional to the cargo area. There was about 0.57 seconds of unloading time for each square foot of cargo area. These results are consistent with previous SRI analyses although giving slightly higher unloading time.

Fixed beach cycle time plotted against cargo area gives a relation that appears to be linear.

Fitting a linear equation to the data we find fixed beach cycle time is:

$$T_f = 180 + 0.1462A \text{ (seconds), or}$$
$$= 180 + 0.15A$$

where: A = square feet of cargo area.

Vehicle unloading time, as noted above, is:

$$T_{uv} = 0.57A \text{ (seconds)}$$

Therefore, total beach cycle time for unloading of vehicles is:

$$T_v = 180 + 0.15A + 0.57A$$
$$= 180 + 0.72A \text{ (seconds)}$$

or

$$T_v = 3.0 + 0.012A \text{ (minutes)}$$

Total Unloading Cycle Time for Troop Loads

The fixed unloading cycle time for landing troops is the same as for landing any other type load:

$$T_f = 180 + 0.15A \text{ (seconds)}$$

where:

$$A = \text{square feet of cargo space.}$$

The time required for unloading is developed above, amounting to one minute for each 100 men. The troop capacity of various landing craft is roughly proportional to the amount of cargo space. For planning purposes, about three square feet of space is required for each man and his equipment (FM 101-10, January 1966). On this basis, unloading time for troops can be stated as:

$$T_{ut} = \frac{A}{3} \times \frac{1}{100} \times 60 = 0.20A \text{ (seconds).}$$

Total unloading cycle time for troops is then:

$$T_t = 180 + 0.15A + 0.20A = 180 + 0.35A \text{ (seconds) or}$$
$$= 3.0 + 0.0058A \text{ (minutes).}$$

Appendix C

UNLOADING CYCLE TIMES FOR AIR CUSHION CRAFT

Appendix C

UNLOADING CYCLE TIMES FOR AIR CUSHION CRAFT

Introduction

The unloading cycle for an air cushion craft is qualitatively different from that of a displacement craft because it does not need to stop at the beach or unload in the water or on soft sand. It can, in fact, pick its unloading site with a considerable degree of freedom. There are, unfortunately, little quantitative data on unloading cycle times for air cushion vehicles. Nevertheless, reasonable estimates can be made of times that will be required.

The Unloading Cycle

As with displacement craft, the unloading cycle has three main parts: the approach, the unloading, and the withdrawal.

The approach starts at the time the craft enters the general unloading area and continues through the movement to a specific unloading site, followed by deflation and the lowering of the ramp, at which time the unloading can begin.

The unloading part is defined as starting as soon as the ramp is down and ending as soon as the ramp starts up.

Withdrawal starts as soon as the ramp starts up, followed by inflation, and then movement out of the unloading area. It is believed that deflation will not be conducted simultaneously with lowering the ramp, and that inflation will not be concurrent with raising it. Although such procedures are possible, it is believed that conservative operating practice will not allow it.

The Approach

Although air cushion craft are capable of high speeds, they would probably move at slow speeds in the unloading areas because of the presence of other craft, vehicles, troops, and supplies in the area, and because of the difficulty of stopping or maneuvering quickly. The unloading area itself would probably be rather large, but movement to the unloading position will not necessarily be easy. There will be numerous constraints on routes and tight maneuvering of the craft may be required. Other difficulties, such as wind and gradient, may cause problems.

Having arrived at the unloading point, cushions must be deflated and the ramp lowered for unloading.

The Unloading

As the unloading point can be picked, within reasonable limits, an acceptable hardstand should be available at least for the early loads. Ideal unloading conditions should not be assumed, however. Normal expectation would be for some hindrances in the form of uneven quality of ground, vegetation, difficulties in clearing the area, and interference by other vehicles, troops, etc. Simultaneous unloading will not always be possible even if the ramp would allow it.

The Withdrawal

Raising the ramp can be followed by inflation, after which the craft can depart the area. Departure will be subject to many of the same restrictions that applied on the way in. Movement must be at slow speed, with numerous constraints and some tight maneuvering.

Rationale for Time Values

Movement of a large craft (of, say, 2000 square feet of cargo space) will be subject to greater difficulty than that of a small craft (500 square feet of cargo space). Assuming an approach trip of 100 yards at slow speeds plus some maneuvering and jockeying for position, 60 seconds for a small craft and 120 seconds for a large craft seem reasonable for the approach. Departure should require a comparable period, but slightly shorter by perhaps 10 seconds.

No firm data are available as to times required for inflating and deflating the flexible skirts, but the following are considered plausible:

	Deflate	Inflate
Large craft ($A = 2000\ ft^2$)	10 sec	20 sec
Small craft ($A = 500\ ft^2$)	5 sec	10 sec

Data taken by an SRI representative during amphibious operations with LCM-6 and LCU-1610 on 14 and 15 July 1968 indicated average ramp-down and ramp-up times of:

	Ramp-Down	Ramp-Up
LCU-1610	35 sec	35 sec
LCM-6	9 sec	24 sec

Unloading tests for vehicular loads were conducted by SRI representatives at Camp Pendleton during June 1968.* Some of the results obtained there are considered suitable for air cushion craft, which can choose their unloading positions and are not limited by unloading into the surf or onto soft sand. The tests most applicable to ACV situations were those in which a small obstruction was placed at the foot of the ramp, thus restricting the speed of exit somewhat. It was observed that unloading under those circumstances required 1.2 to 2.1 times as long as for unobstructed loads. The above were extrapolated to the averages obtained from other craft loads and it would appear that a factor of 0.1 seconds per square feet of cargo space is a reasonable one though subject to wide variation.

It is possible to convert the above to linear functions of cargo area as a means of determining the unloading times for other sizes of craft.

For approach:	$t_a = 40 + 0.040A$	(seconds)
For deflate:	$t_{df} = 3 + 0.003A$	(seconds)
For ramp down:	$t_{rd} = 2 + 0.016A$	(seconds)
For unload:	$t_{ul} = 0.100A$	(seconds)
For ramp up:	$t_{ru} = 21 + 0.007A$	(seconds)
For inflation:	$t_{if} = 7 + 0.007A$	(seconds)
For departure:	$t_d = 30 + 0.040A$	(seconds)

A = square feet of cargo space.

Total Unloading Cycle Times for Vehicular Loads

Summing the times for the various parts of the cycle as computed above, the total unloading cycle time is:

$$T = 103 + 0.213A \quad \text{(seconds), or}$$

$$T = 1.7 + 0.0036A \quad \text{(minutes)}$$

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* M. Nielsen, *op. cit.*

Applied to assorted sizes of craft, unloading cycle times would be:

Cargo Space (sq. ft)	Air Cushion Vehicle Cycle	Displacement Craft Cycle
	Unloading (minutes)	Unloading (minutes)
500	3.5	9.0
1000	5.3	15.0
1500	7.1	21.0
2000	8.9	27.0
2500	10.7	33.0
3000	12.5	39.0

Evaluation

The above results are considered reasonable. The ramp times and unloading times are based on observation. The inflation-deflation times are based on having watched a few ACVs in operation but without obtaining measured times. It is not believed that inflation-deflation times will be much greater than the above. For special type loads, such as tanks or large engineer equipment, longer unloading times may apply. The major uncertainty, however, is in the approach and departure periods, a factor for which observational data are needed.

Appendix D

FRAGMENT DISTRIBUTIONS AND EFFECTS

Appendix D

FRAGMENT DISTRIBUTIONS AND EFFECTS

As part of the probability analysis in the main portion of the text it was necessary to develop information on the fragmentation of 90-mm and 105-mm shells. The material obtained was used in the landing craft analysis and selected portions are presented in this appendix.

Table D-1 gives the number of effective fragments per square foot capable of causing a specified level of damage at various distances from the point of burst. Figures D-1, D-2, and D-3 present the same material in formats that allow for effective interpolation for other thicknesses of steel and other distances from the point of burst. Certain classified data not presented here enable the application of this data to shielding material other than mild steel.

Table D-2 provides information as to the number and sizes of fragments in the two types of shells considered. It can be noted here that the 105-mm shell has about 50 percent more fragments than the 90-mm, and its fragments on the average are somewhat smaller. In both cases the average fragment size is about the size of a typical rifle or pistol projectile.

Table D-3 summarizes the data on fragment velocities measured at 20 feet from the point of burst. The range of velocities is surprisingly large with the highest velocities being about twice as large as the smallest. A separate analysis was made of the relation between velocities at 20 feet and the fragment weights. The results are shown in Fig. D-4, which indicates that there is little relation between the two factors.

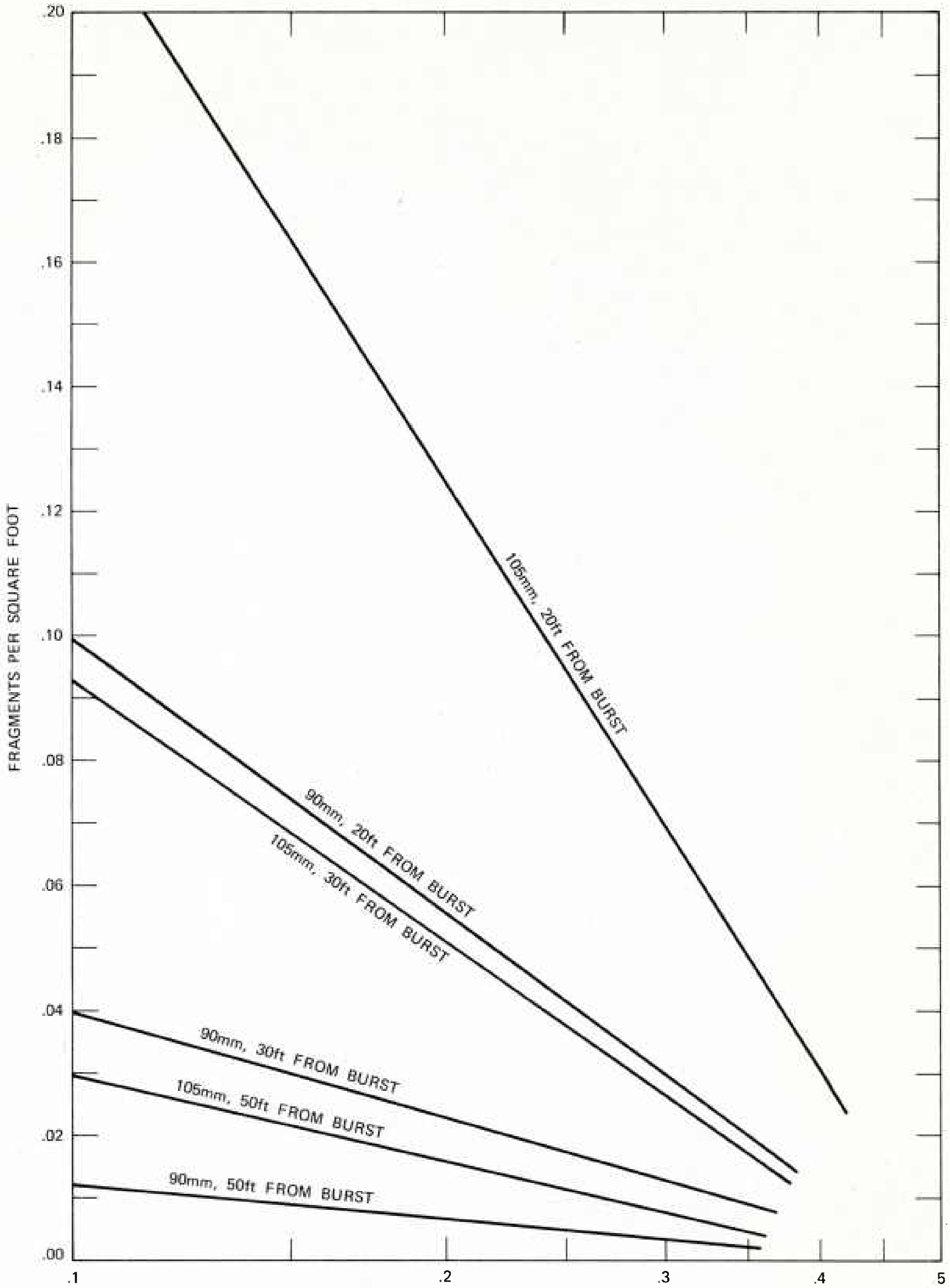
Table D-1

AVERAGE NUMBER OF EFFECTIVE FRAGMENTS
PER SQUARE FOOT CAUSING SPECIFIED DAMAGE

Distance from Burst (ft)	Damage Level		
		Perforation of Mild Steel	
	Casualties	1/8" Plate	1/4" Plate
	90-mm Shell, M71		
20	.134	.0855	.0414
30	.0538	.0343	.0170
50	.0163	.0102	.00503
60	.0106	.00641	.00309
80	.00537	.00311	.00137
100	.00318	.00172	.00064
150	.00124	.00056	.00014
200	.00064	.00021	.00004
300	.00024	.00005	--
500	.00006	.00001	--
	105-mm Shell, M1		
20	.201	.189	.0951
30	.0889	.0796	.0375
50	.0312	.0251	.0111
60	.0211	.0162	.00696
80	.0112	.00721	.00311
100	.00681	.00382	.00158
150	.00272	.00112	.00033
200	.00134	.00042	.00009
300	.00046	.00008	--
400	.00021	.00002	--
500	.00011	.00001	--

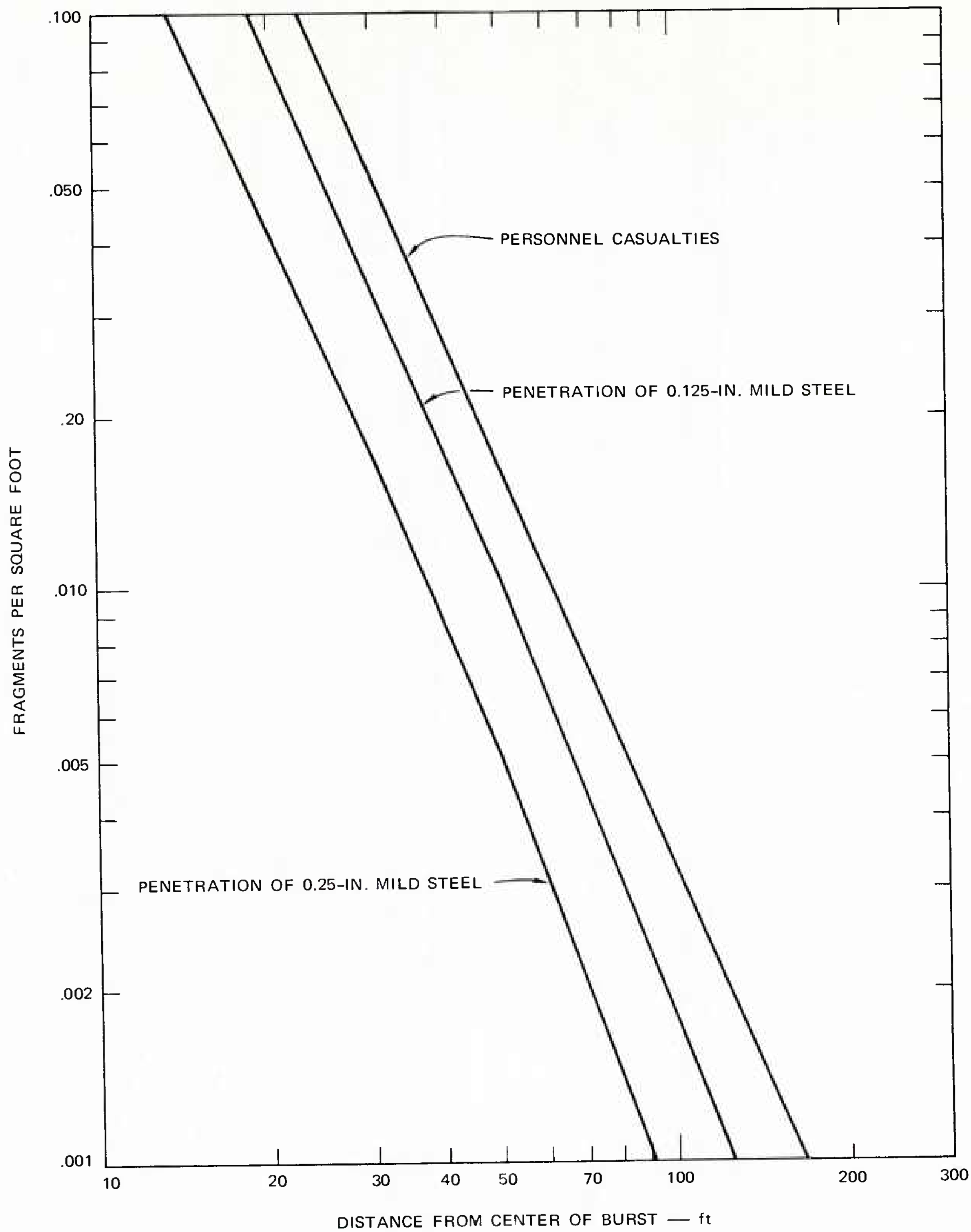
Note: Perforation of 1/8" mild steel is effective against aircraft. Perforation of 1/4" mild steel is effective against trucks and light armored vehicles.

Source: DA TM-9-1907, July 48, "Ballistic Data, Performance of Ammunition."



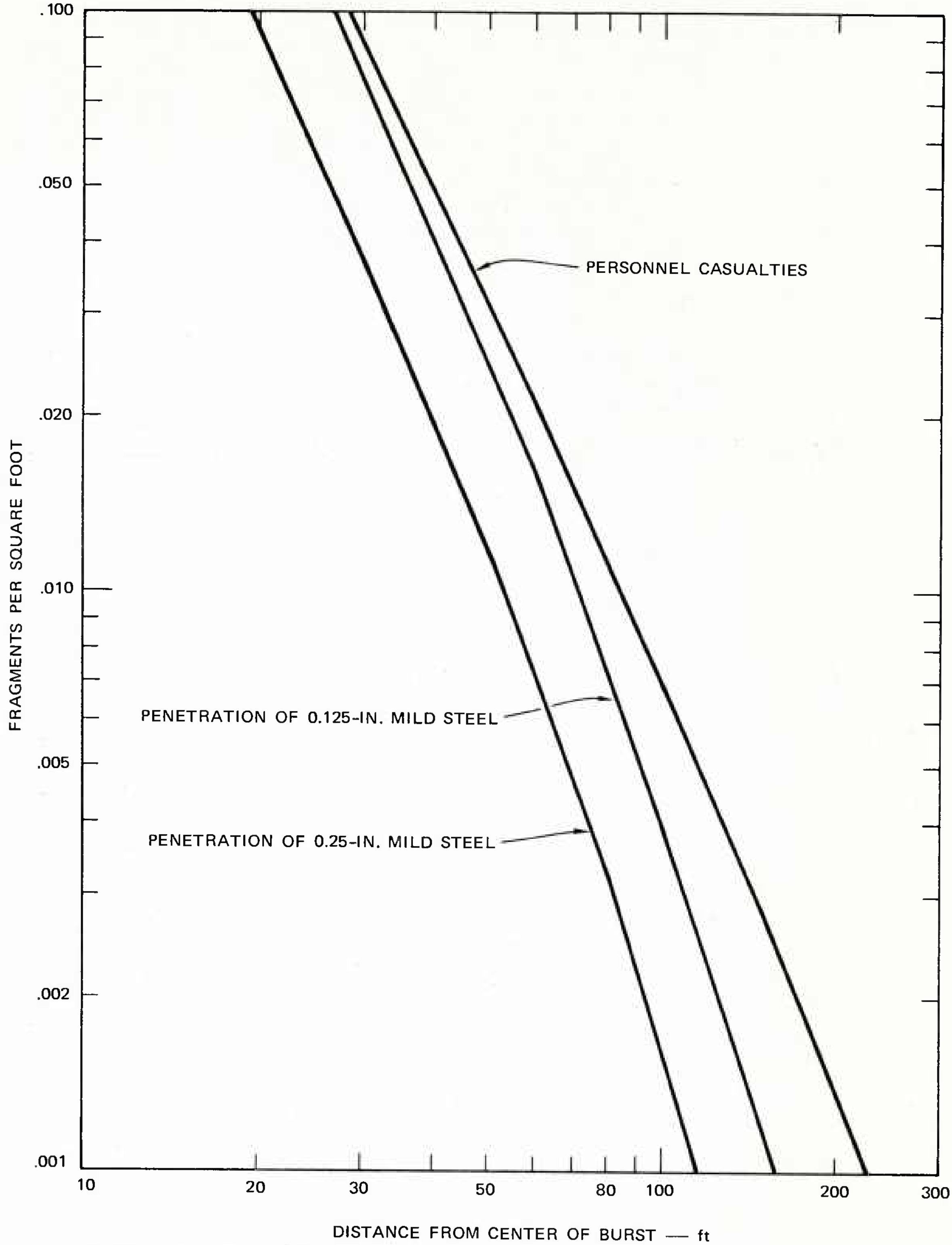
SOURCE: TM 9-1907, 1948

FIGURE D-1 EFFECTIVE FRAGMENTS PER SQUARE FOOT FOR PENETRATION OF VARIOUS THICKNESS OF MILD STEEL FOR SHELL, 90 mm, M71, AND SHELL, 105 mm, M1



SOURCE: TM 9-1907, 1948

FIGURE D-2 AVERAGE NUMBER OF EFFECTIVE FRAGMENTS PER SQUARE FOOT FOR INDICATED EFFECT FOR VARIOUS DISTANCES FROM POINT OF BURST FOR SHELL, 90mm, M71



SOURCE: TM 9-1907, 1948

FIGURE D-3 AVERAGE NUMBER OF EFFECTIVE FRAGMENTS PER SQUARE FOOT FOR INDICATED EFFECT FOR VARIOUS DISTANCES FROM POINT OF BURST, FOR SHELL, 105 mm, M1

Table D-2

SHELL FRAGMENTATION CHARACTERISTICS
FOR 90-MM SHELL, M71 AND 105-MM SHELL, M1
(20 Feet from Point of Burst)

Fragments Weight Range (grains)	Number of Fragments per Shell		Percent of Total		Cumulative Percent		Average Fragment Weight (grains)	
	90-mm	105-mm	90-mm	105-mm	90-mm	105-mm	90-mm	105-mm
0-15	220	351	30.5	29.7	30.5	29.7	6	6
16-30	71	145	9.8	12.3	40.3	42.0	33	33
31-60	75	141	10.4	12.0	50.7	54.0	44	45
61-120	86	177	11.9	15.0	62.6	69.0	87	88
121-240	98	145	13.6	12.3	76.2	81.3	177	173
241-480	77	118	10.7	10.0	86.9	91.3	352	345
481-960	64	74	8.9	6.3	95.8	97.6	681	650
961-1,920	25	26	3.5	2.2	99.3	99.8	1291	1320
Over 1,920	5	2	0.7	0.2	100.0	100.0	2481	1970
TOTAL	721	1179	100.0	100.0		AVG	202	152

Source: Aberdeen Proving Ground Firing Records B-9615, B-11475, and B11539.

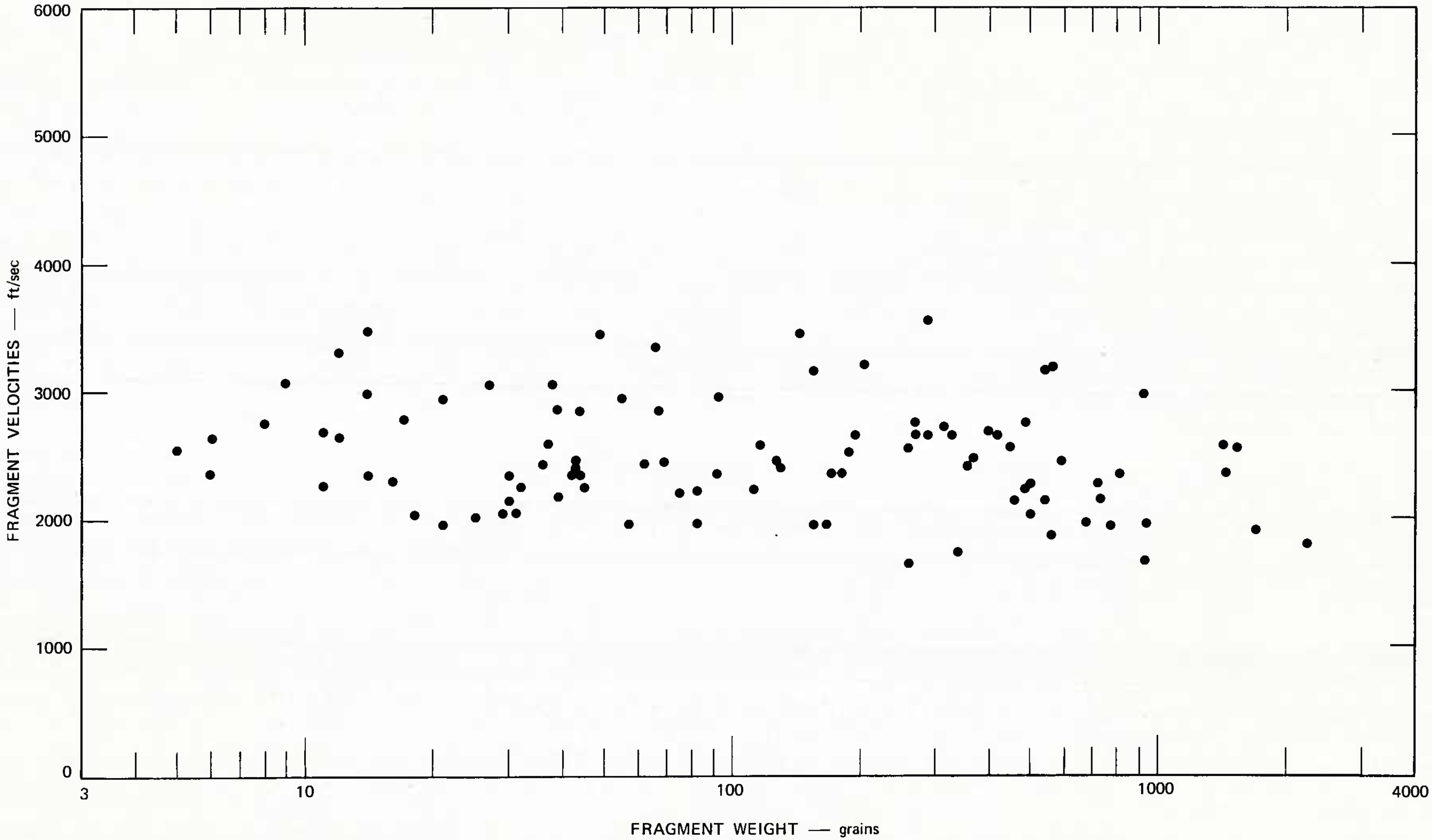
Table D-3

FRAGMENT VELOCITIES FOR 90-MM SHELL, M71 AND 105-MM SHELL, M1
(20 Feet from Point of Burst)

Fragment Velocity Range (ft/sec)	Percent of Fragments in Range		Cumulative Percent	
	90-mm	105-mm	90-mm	105-mm
1600-1699	1.5		1.5	
1700-1799	1.5		3.0	
1800-1899	1.5		4.5	
1900-1999	9.1	0.4	13.6	0.4
2000-2099	6.1		19.7	0.4
2100-2199	8.3	1.4	28.0	1.8
2200-2299	8.3	0.7	36.4	2.5
2300-2399	12.9	2.5	49.2	5.0
2400-2499	6.8	5.4	56.1	10.4
2500-2599	6.8	7.2	62.9	17.6
2600-2699	6.8	8.6	69.7	26.2
2700-2799	4.5	8.2	74.2	34.4
2800-2899	2.3	5.0	76.5	39.4
2900-2999	6.8	5.0	83.3	44.4
3000-3099	2.3	6.5	85.6	50.9
3100-3199	4.5	5.4	90.2	56.3
3200-3299	2.3	4.7	92.4	60.9
3300-3399	2.3	9.0	94.7	69.9
3400-3499	3.8	5.4	98.5	75.3
3500-3599	1.5	5.7	100.0	81.0
3600-3699		6.1		87.1
3700-3799		3.6		90.7
3800-3899		5.7		96.4
3900-3999		2.5		98.9
4000-4099		0.7		99.6
4100-4199		0.4		100.0

Note: Number of fragment-velocity pairs examined: 90-mm: 131
105-mm: 270

Source: Aberdeen Proving Ground Firing Records B-9615, B-11475, and B-11539



SOURCE: APG firing records B-9615 and B-11475.

FIGURE D-4 VELOCITIES IN FT/SEC VERSUS FRAGMENT WEIGHT IN GRAINS
SHELL 90 mm, M71 (7 shells)

Appendix E

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Appendix E

BIBLIOGRAPHY

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