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SEPW Parametric Study (U)

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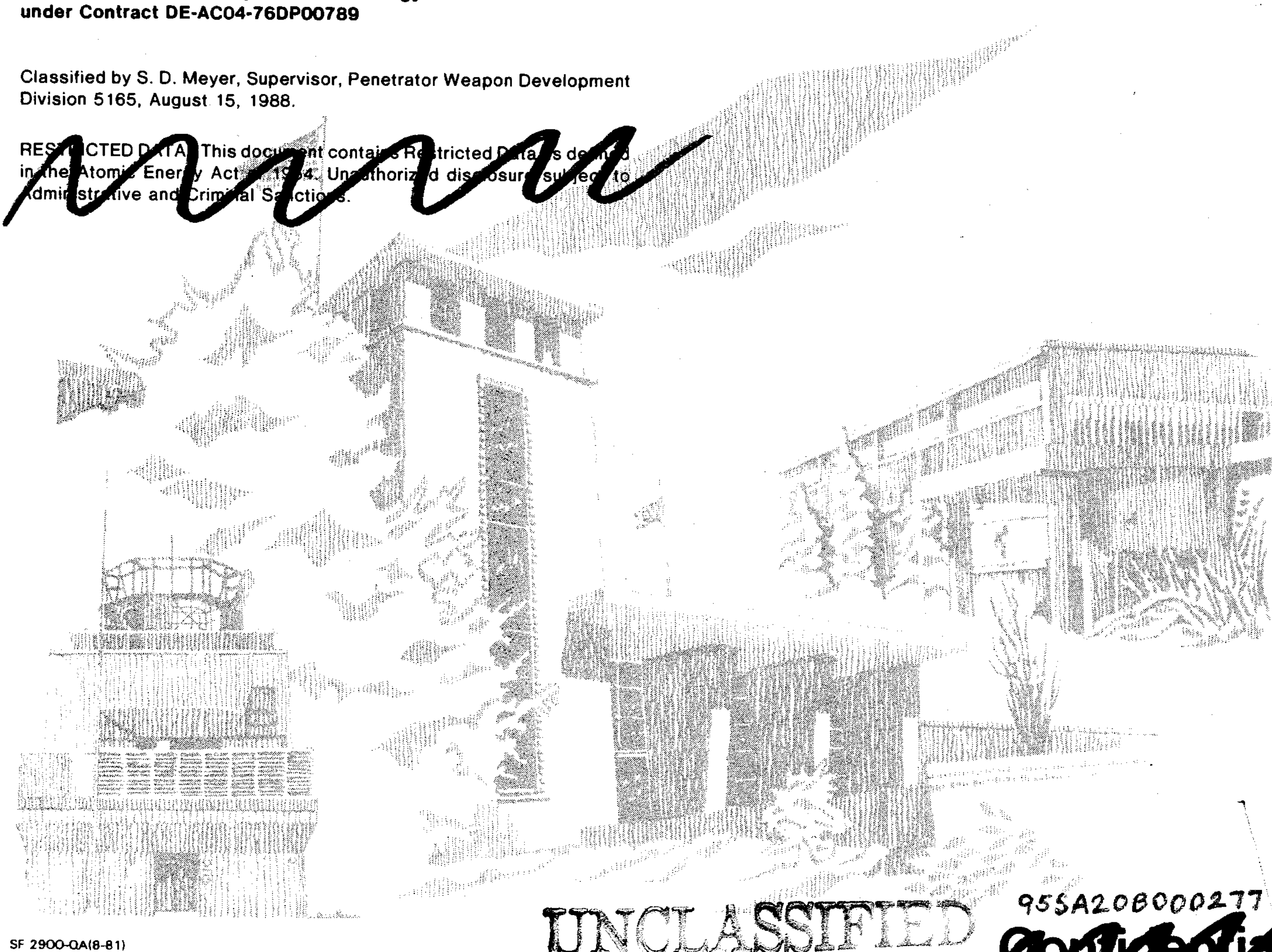

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SEPW PARAMETRIC STUDY (U)

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November 2, 1988

Abstract (U)

A parametric analysis of the Strategic Earth Penetrator Weapon (SEPW) and a variety of design excursions have been completed. The study evaluated the system capabilities as restricted by axial deceleration limits, lateral aceleration limits, case stress limits, and minimum velocity requirements for impact angles of 90, 70, and 50 degrees and angles of attack of -2, 0, and +2 degrees. A discussion of the analysis methods and implications of the results are included.

Executive Summary

A parametric study of the Strategic Earth Penetrator Weapon (SEPW) and a variety of design excursions has been completed to evaluate the operational limits of the systems. The analysis was conducted using a modified version of the empirically based penetration code SAMPLL [1].

[redacted] DOE b(3)

The results of the analysis using these failure criteria for the baseline SEPW design are shown in Figures 3-11 for impact conditions of 90, 70, and 50 degrees angle of impact and -2, 0, and +2 degrees angle of attack. An alternate method for presenting the results is an impact velocity-trajectory angle (V-γ) map. These results, for the SEPW baseline for medium and low strength rocks at angles of attack of -2, 0, and +2 degrees, are shown in Figures 13-15 respectively.

Design excursions have also been evaluated using the same methodology. A table summarizing the design parameters along with the survivability curves for each design are included in the appendix. Among the parameters varied in these design excursions were: nuclear package configurations (yield), case wall thickness, and case material (aluminum, tiatanium, and AF1410 steel). As a result of the analysis of the alternate materials, it was determined that aluminum was not a viable candidate for reducing case weight while maintaining system operational capabilities (also verified by field test).

In addition to evaluating potential weight savings of alternate designs, the analysis has been used to assist in selecting impact conditions for field tests and evaluating the balance of the SEPW baseline design (i.e., is the case overdesigned relative to the survivability of the components?). Using a target set distribution, impact conditions or alternate designs can be compared relative to the number of targets which can be held at risk. These results are also useful for specifying the impact requirements for carrier vehicles.

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Introduction

A parametric study of the Strategic Earth Penetrator Weapon (SEPW) was undertaken to evaluate the gross system performance of the Baseline SEPW and a variety of design excursions. As opposed to evaluating a point design at a specified impact condition into a specific target with a complex analytical technique, this analysis was performed with a simplified analytical model that gives reasonable results quickly, thereby allowing a great number of iterations to be performed for establishing the operational limits of the designs. The operational limits were bounded by the maximum peak axial deceleration, maximum peak lateral acceleration, maximum case stress, and minimum velocity to guarantee adequate penetration depth. The impact angle and angle of attack were parametrically varied over the spectrum of rock targets.

The results from these analyses are useful for the following purposes:

- Balancing the design by assuring that one operational limit does not drive the performance of the system (i.e., is the penetrator case overdesigned compared to electrical component capabilities?).

- Evaluating the capabilities of lighter weight designs which were achieved by either reducing the penetrator case wall thickness or using alternate case materials.

- Using a target set distribution to evaluate the ability of different designs to hold targets at risk.

- Specifying impact condition requirements for the carrier vehicle(s).

- Selecting testing conditions near system threshold levels to maximize the useful data gathered in each test.

Although much of the analytical detail is sacrificed with this type of analysis, the results presented have great utility for quickly comparing different designs and/or impact conditions.

Analysis Method

The analysis was performed using a computer program developed specifically for parametrically evaluating the performance of penetrator designs. This analytical tool evolved from the SAMPLL code developed by C. W. Young, 9122 [1]. SAMPLL is a penetration code based on empirical penetration equations that characterize a geological target hardness by an "S Number".

Predicted depth is directly proportional to the empirically based S Number for fixed penetrator mass, geometry, and impact velocity. Historically, two different empirical penetration equations have been used to predict penetration depth in rock targets. These equations, both developed by C. W. Young, have been labeled the Soil and Concrete Equations. [1] For reference purposes the Soil and Concrete Equations are:

$$SOIL: \quad D = 0.0031\, S\, N \sqrt{\frac{W}{A}}\,(V - 100)$$

$$CONCRETE: \quad D = 0.0008\, S\, N\, \frac{W}{A}\,(V - 100)$$

where

D = Penetration Path Length (ft)
S = "S Number"
N = Nose Coefficient (=.86 for 3 CRH Tangent Ogive)
W = Weight of Penetrator (lb)
A = Penetrator Frontal Area (in^2)
V = Impact Velocity (ft/s)

The reader should be cautioned that for the same rock, S Numbers based on the Soil Equation are slightly lower (10-20 percent) than those based on the Concrete Equation and must recognize the potential differences when comparing to other results.

[1] Recently C. W. Young [2] has revised his recommendation on the best penetration equation for use with rock targets. After a thorough review of the penetration database, he concluded that the Soil Equation matched rock penetration performance, over the complete spectrum of rock targets, slightly better than the previously used Concrete Equation.

The Concrete Equation fits the data much better than the Soil Equation for approximately thirty tests thus far performed on the SEPW. It was therefore decided to use the former equation to model the SEPW penetration phenomenon. All results presented in this report use S Numbers based on the Concrete Equation. Throughout the parametric study, the target is assumed to be semi-infinite and homogeneous. Layering effects have not been included.

In its standard form, SAMPLL is a menu driven interactive FORTRAN code which runs on either a VAX or a PC. SAMPLL was modified to be used as a subroutine in the parametric analysis code but the results from the subroutine version are identical to the results obtained from the interactive version. By predetermined variations of impact angle[2] , angle of attack[3], and S number, the failure velocity was determined using a Fibonacci search algorithm [3] for the specified penetrator design and failure criterion (described below).

Four different failure criteria were used in the parametric study. The failure criteria are as follows:

[redacted]

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[2]Impact angle (γ) is defined as the angle from the target surface to the velocity vector of the penetrator.

[3]Angle of attack (α)is defined as the angle between the velocity vector and penetrator centerline. A positive angle of attack is nose down relative to the velocity vector.

DOE
b(3)

Case Stress: A stress failure occurs when the loads cause significant permanent deformation of the penetrator case. SAMPLL models the penetrator case as a beam with a section modulus based on the inside and outside diameters of the case. The stresses in this simple beam model are calculated by using the SAMPLL loads for calculating the rigid body kinematics. A typical total stress (axial + bending) response history for a penetrator case is shown in Figure 1. The highest stressed region along the penetrator body, as calculated and verified with experimental data, is typically near the mid-station. For this parametric study, the mid-station was used for all designs as the location for the stresses calculated.

Because the stress could exceed yield at the outer fibers for a short time duration without causing permanant deformation, the criterion of failure resulting from any stress above yield is overly conservative. A method was developed by C. W. Young, based on experimental data, for inferring significant permanent deformation of a penetrator case. Using an empirically based stress threshold value, indicated by $\bar{\sigma}$ on Figure 1, when the integral of the absolute value of the total stress-time history above $\bar{\sigma}$ exceeds a stress failure value (Figure 2) then permanant deformation will occur. The stress failure value, shown in Figure 2, varies with the ratio of axial stress to yield stress. As the ratio of axial to yield stress approaches unity, the stress failure value approaches zero. This is because the stress will be above yield through the complete cross section. This method seems to correlate well with the five SEPW case failures experienced thus far. An impact velocity greater than that required to cause the absolute value of the integral of the stress-time above $\overline{\sigma}$ to exceed the stress failure value is considered to result in a system failure.

Minimum Velocity: The minimum velocity limit insures the penetrator will reach an adequate depth. Two phenomena cause insufficient vertical depth. The first is insufficient kinetic energy to penetrate to depth or lock in[4] and the second occurs when the combination of velocity, angle of attack, and impact angle induces a ricochet of the penetrator. The minimum velocity for failure is defined as the maximum of the above two requirements. For the parametric analysis a minimum acceptable vertical depth of 1.5 body lengths was used.

Baseline SEPW Results

The analytical results for the baseline SEPW, designated B1, at 90, 70, and 50 degrees impact angle and -2 ,0, and +2 degrees angle of attack, are presented in Figures 3 through 11. Each figure indicates a survivability envelope at the specified impact condition. The envelope, as indicated by the shaded region on the figures, is bounded on the upper end by the minimum of the axial deceleration limit, lateral acceleration limit, or case stress failure limit and on the lower end by the minimum allowable velocity curve. Any condition outside this envelope is predicted to result in a system failure. [redacted] As can be seen in the figures, survivablity envelope size decreases with deceasing impact angle and negative (nose up) angles of attack. A positive angle of attack tends to enlarge the envelope [5].

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DOD b(3)

[4] The inability to lock in or stick in the target is referred to as "rebound" and results in a potential loss of weapon effects coupling.

[5] Very little data are available for positive angles of attack, therefore the enlarged envelope should only be considered as a possible trend at this time.

For high impact angles (70 to 90 degrees) the axial deceleration limit bounds the system capability and for the lower angles the lateral acceleration and/or case stress limits appear to establish the upper bound on the impact velocity. The current SEPW baseline design appears to be most balanced at 70 degrees impact angle and -2 degrees angle of attack. A balanced design is characterized by having the axial deceleration, lateral acceleration, and case stress failure limits approximately coincident.

The curves represent the results from perfectly homogeneous semi-infinite targets. In the "real world", targets are not homogeneous and the fissures and layering can cause a normal (90 degree) event to respond much like a lower impact angle event [5]. It would therfore be inadvisable to restrict impact conditions to nearly normal and assume that the complete survivability envelope would still be valid.

Another caution when using the calculated results with "real world" targets is the empirically based penetration equations, as with the other calculational tools, can be conservatively biased. In preparation for most field tests, targets are cored to determine their competency, homogeneity and/or material properties. If the field test target does not possess the desired qualities, then it is not used. When attempting to predict the response of a penetrator to a "real world" target, the analyst attempts to find a field test target description that closely matches the "real world" target. He then uses the properties of the field test target to predict the response in the "real world" target. But the "real world" targets are weathered and/or fissured and therefore possess less resistance to penetration than the field test target. Hence this process could cause a conservative bias of the calculational results.

The database used to develop the empirical penetration equations has no information for impact velocities above 3000 fps. This parametric study extrapolated the empirical equations beyond their database and the actual curve shapes could deviate due to this assumption. No tests are presently planned to verify these high velocity limits.

SEPW Design Excursions

An identical analysis of 12 design excursions was also completed. Figures, similiar to those already presented for the baseline SEPW, have been generated for each of the designs and are included in the appendix.

The parameters varied in these excursions were: nuclear package geometry(yield) per LANL direction, outside case diameter of cylindrical section, case length, and case material. Several parameters remained constant in all the designs. These parameters were: 3 CRH tangent ogive nose shape, cylindrical midbody with a flared aft end, and electrical system weight and volume. Figure 12 is a sketch of the geometric parameters which define the designs. Except where noted otherwise, the penetrator case material is HP 9-4-20 steel. Each design was given a two character identification code. A summary of the parameters varied for the various designs along with the assigned codes is shown in the following table.

DESIGN SUMMARY TABLE

DOE b(3)

A brief description of each design in the table and corresponding results, found in the appendix, follows:

B1: Baseline SEPW design. Description and results presented and discussed in the previous section.

B2: Weight reduced version of B1 design, accomplished by removing material from outside diameter. Removing material tends to reduce the mass and case stress capabilities. The reduced mass tends to increase the axial and lateral accelerations for the same impact condition, thereby also reducing its capability. These trends are seen by comparing the reults of the B2 and B1 designs.

B3: Further weight reduction of B1 design. The capabilities are further reduced. For example the most competent target (lowest S number) this design could attack at 50 degrees impact angle and -2 degrees angle of attack is S=1.4. The corresponding capabilities for the B1 and B2 designs are S=0.9 and S=1.0 respectively.

C1 [redacted] Other case dimensions are consistent with the B1 design. Capabilities are approximately equivalent to the B1 design. **DOE b(3)**

C2: Weight reduced version of C1 design, accomplished by removing material from outside diameter. Capabilities are appproximately equivalent to the B2 design.

C3: Further weight reduction of C1 design. Capabilities are appproximately equivalent to the B3 design.

D1: A low yield, small diameter design proposed for a Navy system.

D2: Weight reduced version of D1 design, accomplished by removing material from outside diameter.

D3: Further weight reduction of D1 design.

E1: A 7075-T6 aluminum case design using the B1 physics package. Case weight is equal to B1. Resulting capability is less than B1 design thereby indicating no weight savings potential.

F1: An AF1410 steel case with the B1 physics package. AF1410 steel possesses a higher strength and fracture toughness than HP 9-4-20 and shows a potential weight savings for a capability equivalent to B1. A field test is planned to evaluate this material.

G1: A Titanium 10-2-3 alloy case with the B1 physics package. This design is of equal weight to B1 and shows an increased capability.

G2: A weight reduced version of G1 for approximate capability of B1. Another field test is planned to verify the capability of Ti 10-2-3.

Penetration V-Gamma Map

An alternate way to present the survivability envelope is to fix the target (S Number) and angle of attack and show the failure velocity as a function of impact angle. This presentation scheme is similiar to the v-γ maps used by the ballistic RV community. Penetration v-γ maps for the present SEPW Baseline design are given for -2, 0, and +2 degrees angle of attack in Figures 13 through 15 respectively. The medium (S=1.0) and low (S=1.8) strength rocks shown on the maps correspond to tested targets of Sidewinder Tuff and Antelope Tuff respectively.

The impact conditions for the SEPW field tests are indicated on the maps. It may appear that the analysis does not predict the failures well because some of the test data points indicated to have exceeded the limits are inside the survival region on the v-γ maps. It must be understood that "medium strength rock" implies a band of S Numbers (0.7 - 1.3) and the calculations were done with an average. The data points indicating failures inside the "safe" region were actually tested into harder targets (S=0.8) than the hardness (S=1.0) used in the analysis. Indicated on the figures are the regions where the different failure criteria dominate. The v-γ presentation more clearly illustrates the effects of impact angle and angle of attack. As the angle of attack increases, from the worst case of -2 degrees to the best case of +2 degrees, the survivability envelope increases. The angle of attack only affects the failure criteria relating to lateral loading (i.e. case stress, lateral acceleration, and ricochet), not axial acceleration or rebound.

The v-gamma map also illustrates that testing to demonstrate survivability against low strength rocks will not ensure the survival into a higher strength rock at the same impact condition. Conversely testing into higher strength rocks will ensure survivability into a lower strength rock.

Conclusions

The analysis method presented has been developed to illustrate the relative effects of different failure modes and the effects that impact conditions and excursions in design have on survivability. The approach is useful in specifying tests and investigating new materials and design concepts. The calculational method does not model a system in great detail. Results of this analysis should not be taken as absolute but can be used to make system performance comparisons. As stated earlier, this method has been used on other types of designs and will continue to be used and upgraded as data become available.

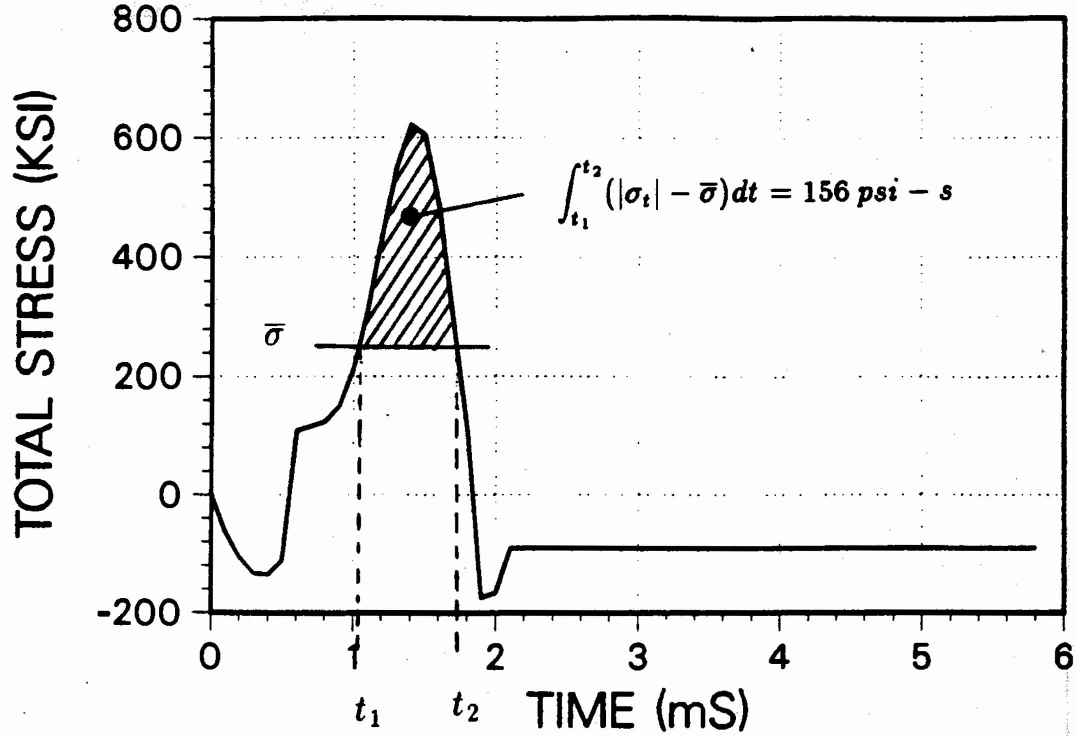

Figure 1: Typical Stress vs Time Curve.

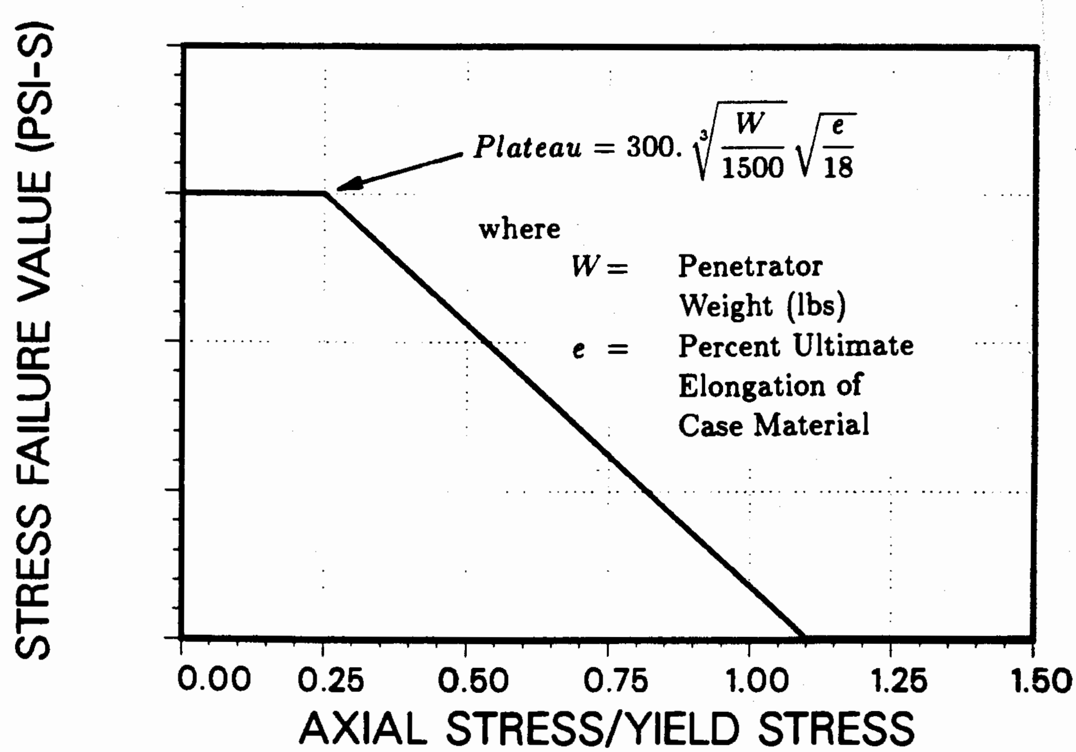

Figure 2: Stress Failure Value.

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SEPW PARAMETRIC STUDY

B1 Case Design

90 degree Impact Angle

-2.0 degrees Angle of Attack

DOE
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DOE
b(3)

Figure 3: Baseline SEPW at $\gamma = 90^o$ and $\alpha = -2^o$

SEPW

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SEPW PARAMETRIC STUDY

B1 Case Design

90 degree Impact Angle
0.0 degrees Angle of Attack

DOE
b(3)

Figure 4: Baseline SEPW at $\gamma = 90^o$ and $\alpha = 0^o$

SEPW

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DOE
b(3)

DoD
b(3)

Figure 5: Baseline SEPW at $\gamma = 90^o$ and $\alpha = +2^o$

SEPW
NRH:5165, 6/88

DOE
b(3)

Figure 6: Baseline SEPW at $\gamma = 70^{\circ}$ and $\alpha = -2^{\circ}$

SEPW
NRH:5165, 6/88

DOE
b(3)

DOE
b(3)

Figure 7: Baseline SEPW at $\gamma = 70^o$ and $\alpha = 0^o$

SEPW
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DOE
b(3)

Figure 8: Baseline SEPW at $\gamma = 70^{o}$ and $\alpha = +2^{o}$

SEPW
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DOE b(3)

Figure 8: Baseline SEPW at $\gamma = 70^o$ and $\alpha = +2^o$

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DOI
b(3)

DOD
b(3)

DOE
b(3)

DOD
b(3)

Figure 11: Baseline SEPW at $\gamma = 50^\circ$ and $\alpha = +2^\circ$

SEPW
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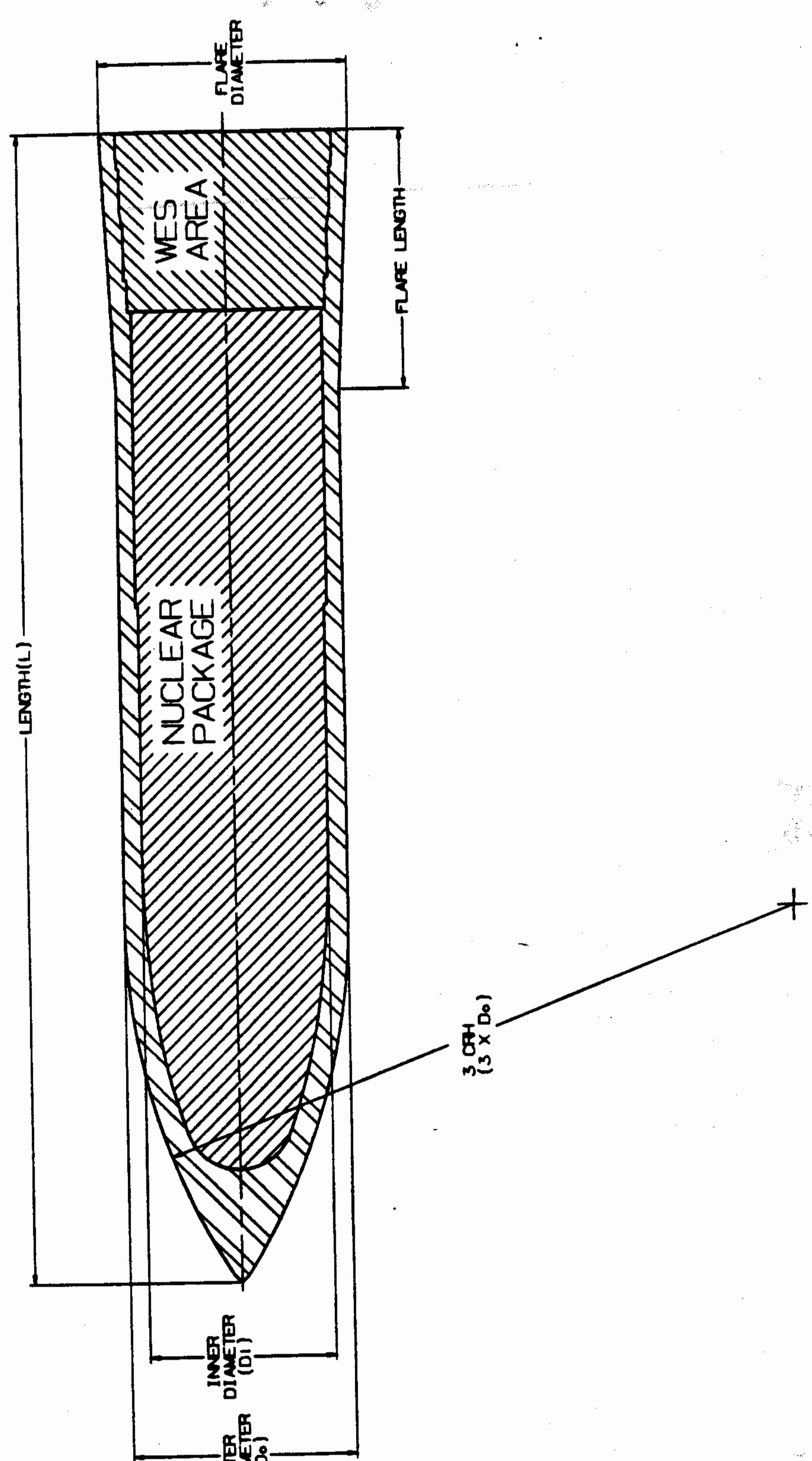

Figure 12: SEPW Geometric Parameters.

SEPW PARAMETRIC STUDY

880 lb Baseline Design

DOE
b(3)

DOD
b(3)

Figure 13: Penetration V-Gamma Map for Baseline at $\alpha = -2^{o}$.

SEPW

SEPW PARAMETRIC STUDY

880 lb Baseline Design

DOE
b(3)

DOD
b(3)

SEPW
NRH:5165, 6/88

Figure 14: Penetration V-Gamma Map for Baseline at $\alpha = 0^o$.

SEPW PARAMETRIC STUDY

880 lb Baseline Design

DOE
b(3)

DOD
b(3)

Figure 15: Penetration V-Gamma Map for Baseline at $\alpha = +2^{\circ}$.

SEPW

NRH:5165, 6/88

APPENDIX
SEPW Design Excursions

DESIGN SUMMARY TABLE

DOE
b(3)

DOE
b(3)

SEPW PARAMETRIC STUDY

B1 Case Design

DOD b(3)

DOE b(3)

SEPW PARAMETRIC STUDY

B1 Case Design

DO
b(3

SEPW PARAMETRIC STUDY

B2 Case Design

DOE
b(3)

DOD
b(3)

SEPW PARAMETRIC STUDY

B2 Case Design

DOE
b(3)

SEPW PARAMETRIC STUDY
B3 Case Design

DOE
b(3)

DOD
b(3)

Figure A-3(a): Survivability Curves for B3 Design. NRH:5165, 6/88

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SEPW PARAMETRIC STUDY

B3 Case Design

DOE
b(3)

DOE
b(3)

SEPW PARAMETRIC STUDY

C1 Case Design

DOE
b(3)

DOE
b(3)

SEPW PARAMETRIC STUDY

C1 Case Design

DOE
b(3)

DOD
b(3)

SEPW PARAMETRIC STUDY

C1 Case Design

DOE
b(3)

DOD
b(3)

SEPW PARAMETRIC STUDY

C2 Case Design

DOE
b(3)

DOD
b(3)

SEPW PARAMETRIC STUDY
C2 Case Design

DOE
b(3)

Figure A-5(b): Survivability Curves for C2 Design. NRH:5165, 6/88

SEPW PARAMETRIC STUDY

C3 Case Design

DOE
b(3)

DOD
b(3)

SEPW PARAMETRIC STUDY
C3 Case Design

DOE
b(3)

Figure A-6(b): Survivability Curves for C3 Design.

SEPW PARAMETRIC STUDY

D1 Case Design

DOE
b(3)

DOD
b(3)

Figure A-7(a): Survivability Curves for D1 Design.

SEPW PARAMETRIC STUDY
D1 Case Design

k

DOE
b(3)

Figure A-7(b): Survivability Curves for D1 Design.

Figure A-8(a): Survivability Curves for D2 Design.

SEPW PARAMETRIC STUDY
D2 Case Design

DOE
b(3)

Figure A-8(b): Survivability Curves for D2 Design.

DOE
b(3)

DOD
b(3)

Figure A-9(a): Survivability Curves for D3 Design.

SEPW PARAMETRIC STUDY
D3 Case Design

DOE
b(3)

DOD
b(3)

Figure A-9(b): Survivability Curves for D3 Design.

SEPW PARAMETRIC STUDY

E1 Case Design

DOE
b(3)

Figure A-10(a): Survivability Curves for E1 Design. NRH:5165, 6/88

SEPW PARAMETRIC STUDY

E1 Case Design

DOE
b(3)

DOD
b(3)

Figure A-10(b): Survivability Curves for E1 Design.

DOE
b(3)

DOD
b(3)

Figure A-11(a): Survivability Curves for F1 Design.

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SEPW PARAMETRIC STUDY
F1 Case Design

DOE b(3)

DOD b(3)

Figure A-11(b): Survivability Curves for F1 Design. *NRH:5165, 6/88*

DOE
b(3)

DOD
b(3)

Figure A-12(a): Survivability Curves for G1 Design.

SEPW PARAMETRIC STUDY
G1 Case Design

DOE
b(3)

Figure A-12(b): Survivability Curves for G1 Design.

SEPW PARAMETRIC STUDY
G2 Case Design

DOE
b(3)

Figure A-13(a): Survivability Curves for G2 Design.

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SEPW PARAMETRIC STUDY
G2 Case Design

DOE
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DOD
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Figure A-13(b): Survivability Curves for G2 Design.

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