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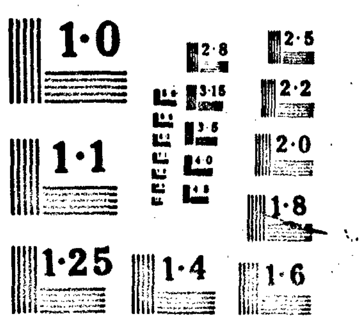

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"HORNET" Anti-Tank Missile Warhead Study (U)

Virgil E. Mulanax

THE WESTERN COMPANY

JUNE 1967

Technical Report AFATL-TR-67-66

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"HORNET" ANTI-TANK MISSILE WARHEAD STUDY (U)

Virgil E. Mulanax

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FOREWORD

(U) This feasibility study performed under Contract AF08(635)-5785 entitled

"HORNET" ANTI-TANK MISSILE WARHEAD
STUDY AND PROTOTYPE FABRICATION

was performed for the Weapons Division, Air Force Armament Laboratory, Eglin Air Force Base, Florida, by the Research Division of The Western Company, Dallas, Texas. This study was made under the direction of Mr. A. L. Anderson, Manager of Explosive Science Department and the technical supervision of Mr. David V. Levey; Sr. This study was accomplished during the period 31 March 1966 to 30 November 1966, and this final report submitted on 19 December 1966.

(U) Acknowledgment is made to the Air Force Project Officer, Lt. Edward L. Shallenberger, and to Mr. O. R. Foley who assumed the project officer duties during the latter part of the contract, for the valuable technical guidance and assistance furnished. Acknowledgment is also made to the personnel of the Hornet Missile Group of North American Aviation, Inc., Columbus, Ohio Div., for the helpful consultation to establish the missile/warhead design parameters

(U) This technical report has been reviewed and is approved.

GEORGE P. BRENNER, Col, USAF
Chief, Weapons Division

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SECRET ABSTRACT

(C) The feasibility of incorporating a follow-through shaped charge warhead in the "HORNET" Anti-tank Missile has been shown. The guidance system concept used with the "HORNET" Missile requires a target seeker to be located in the forward, leading section of the missile. This requirement not only prohibits the placing of the warhead in the most orthodox location, but places an added burden on the warhead in that the seeker section must be penetrated prior to the target. The warhead design obtained from this study is capable of defeating the seeker and heavy arnor. An additional advantage of the design is that a large number of 0.250-inch diameter steel balls are projected beyond the armor as follow-through particles.

(C) In this study the basis for evaluation was the effectiveness of the warhead after first defeating the seeker section. To increase this effectiveness, pre-shaped follow-through fragments were incorporated in the warhead. These particles were attached to the liner between the liner and the explosive, based on the concept that the particles will follow the shaped charge jet through the target perforation. The fragments projected through the perforation not only increase the beyond armor lethality, but assure the presence of lethal particles beyond the armor even when spallation is controlled.

(S) During this study it has been demonstrated that the warhead design provided from this study has a penetration capacity greater than required to penetrate the thickness of armor which has a 0.99 probability of being encountered given a random hit on the JS/3 tank. Of the follow-through particles (0.250-inch diameter carbon steel balls) incorporated in the warhead, thirty percent can be projected beyond the target in a dispersion pattern having an included angle of greater than 70 degrees. The follow-through particles in this pattern had an average P_k of 0.48 (five-minute assault criteria). As an added effect, the lethal area of the case fragments was determined to be 250 square feet against an APC and 750 square feet against a one and one-half ton truck.

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LIST OF ILLUSTRATIONS

LIST OF TABLES

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SECTION I

(U) INTRODUCTION

(C) In many instances where an improvement is made to a device or system, it is accomplished at the expense or detriment of some other characteristic. This holds true for the major advantage offered by the Anti-Tank/Air to Surface Missile.* The guidance system used in the "HORNET" missile provides a distinct advantage of guiding the missile to the target, but this same guidance system offers an interference factor to the shaped charge warhead used with the missile.

(C) To allow the guidance to perform as designed, a part of the system must be located in the forward most section of the missile—that section normally occupied by the warhead. This part of the guidance system not only displaces the warhead, but also places between the warhead and the target certain characteristics normally considered shaped charge defense elements - spaced metal plates and glass.

(C) The objective of this study is to show the feasibility of delivering a highly effective follow-through shaped charge anti-tank warhead with the "HORNET" missile. It was shown that a follow-through shaped charge can defeat the seeker and heavy armor.

(U) To accomplish this objective, the warhead must meet two requirements:

1. The shaped charge jet must be capable of penetrating the depth of armor encountered.

2. A large number of highly lethal particles must be introduced beyond the penetrated armor.

The first requirement is a prerequisite of the second; however, performing the first requirement does not assure the second requirement is properly accomplished.

(C) Usually with a shaped charge warhead, the spall from around the jet penetration hole is relied on to inflict damage inside the tank. Because of the already noted handicap placed on the Hornet warhead and because it was realized that spall can be suppressed, the design evaluated in this study incorporates pre-shaped follow-through fragments which are projected through the jet perforation. The projecting of these pre-shaped fragments beyond the penetrated armor assures a high degree of lethality without reliance on spall particles.

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*In this report, the AT/ASM will be referred to by the more familiar unofficial popular name, "HORNET." No popular name has ever been officially assigned to this missile, however, and use of that name here is for convenience only; use of the name does not imply official approval.

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[redacted] SECTION II

(U) STUDY PROGRAM

(U) 1. CONFIGURATION OF TEST UNITS

(C) The initial definition of this program established five parameters of shaped charge design to be evaluated. They were:

(1) Length of charge
(2) Configuration of charge
(3) Thickness of liner
(4) Placement configuration of follow-through particles
(5) Distance of standoff

During the program the diameter of the charge and the explosive also received evaluation.

(C) Prior to establishing the levels for these parameters it was necessary to define the weight, dimensional, and operational requirements of the warhead as dictated by the missile. Based on consultation with North American Aviation it was determined the warhead could occupy a cylindrical space 7.0 inches in diameter and 17.8 $\pm$ 2 inches in length. This section is immediately aft of a 12.0 inch long nose section in which the seeker portion of the missile guidance system is located. Also taking into consideration a weight limitation of forty pounds, the basic test unit design was then established (Figure 1). This information also allowed the levels for the five variable factors to be established as shown in the following table.

Design Parameters	Level of Evaluation		
	1	2	3
Charge length	10 inches	12 inches	---
Charge configuration	With charge shaper	Without charge shaper	---
Follow-through configuration	3Δ-zone 2	3Δ-zone 3	Solid band zone 2 and 3
Liner thickness (inch)	0.062	0.093	0.125
Standoff distance (inches)	12.0	17.0	22.0

(U) The following is a definition and exploration of parameters and terms used throughout this report:

a. Test Unit Case

(U) The case was mechanical steel tubing having a seven-inch outer diameter. In order to minimize the variation introduced by confinement, a wall thickness of 0.250 inch was used. The cases were machined to insure axial alignment of the cone and were made as identical as possible to keep the number of variables at a minimum.

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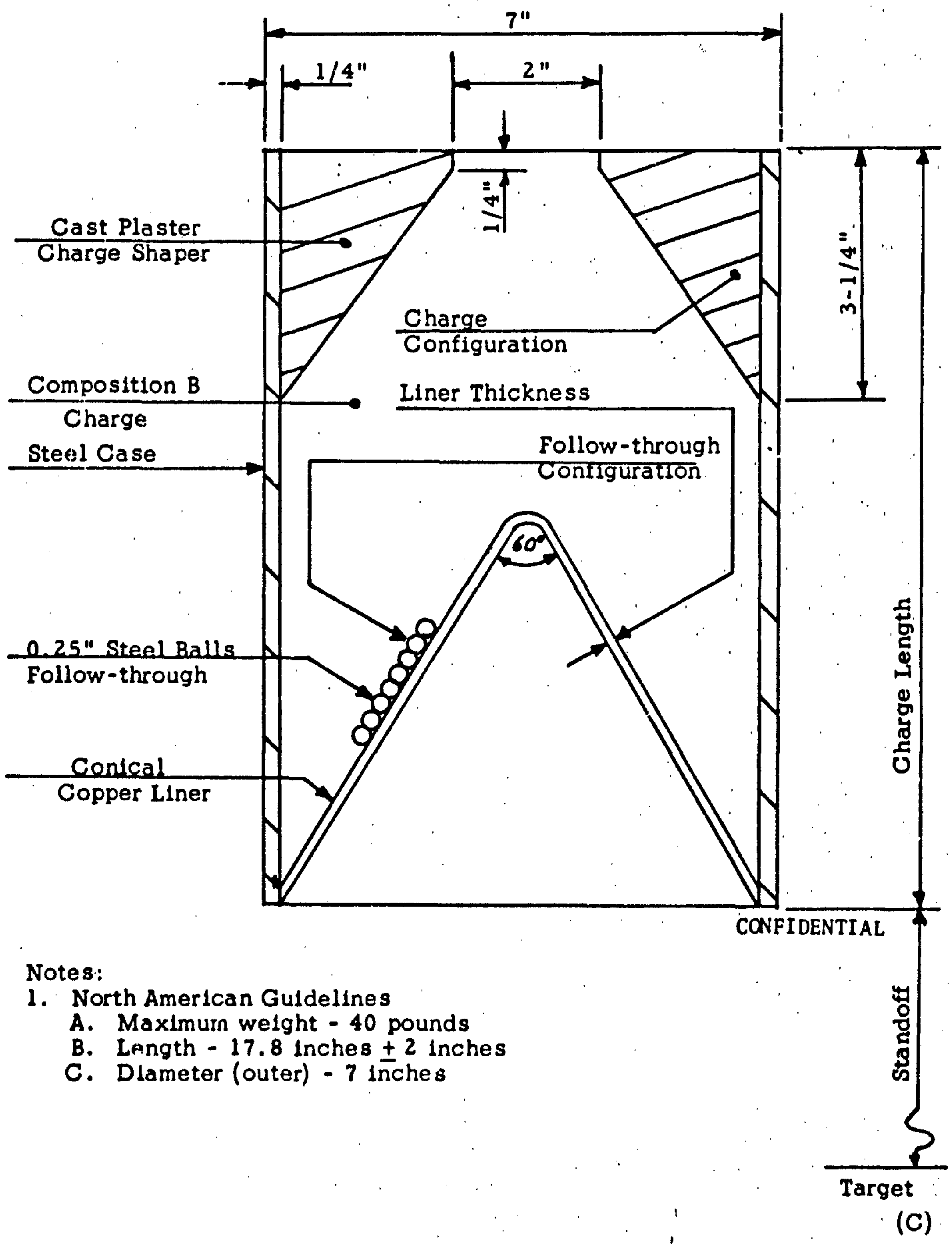


Notes:
1. North American Guidelines
   A. Maximum weight - 40 pounds
   B. Length - 17.8 inches ± 2 inches
   C. Diameter (outer) - 7 inches

FIGURE 1 (C)

Basic Test Unit (U)

the seeker section. The distance separating the warhead and seeker section was by necessity a part of the 17.8 ± 2.0 inches allowed for the warhead.

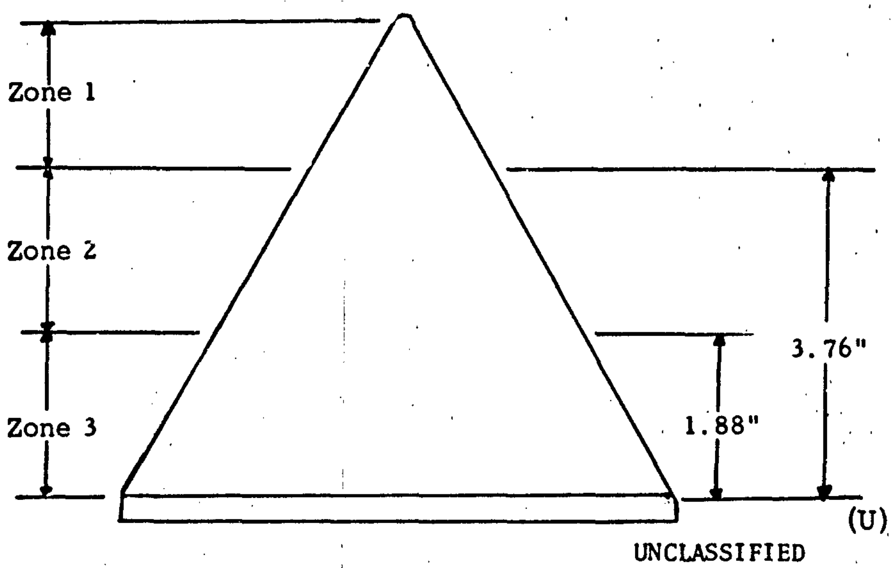


FIGURE 3 (U)

Follow-through Zones (U)

f. Simulated Seeker Section

(C) Basically the seeker consists of a vidicon tube, wire bundles, and the mountings for the tube which were surrounded by a relatively massive two axis gimball set also mounting two gyros and a telescope. To conclusively evaluate the warhead designs it was desirable to make the test with a seeker in place. Not being economically feasible to use an actual seeker, a unit simulating the seeker was designed to provide approximately the same type of interference which the shaped charge jet would normally encounter (i.e., steel, glass, air space, etc.). The simulated seeker design was checked by the "HORNET" Project group at North American Aviation to assure its likeness to the actual seeker (Figures 4, 5 and 6).

g. Hardware Assembly

(U) The liner was retained in the case by using a press fit tolerance. After pressing the liner into the proper location each unit was given a checkout for concentricity and symmetry prior to acceptance for explosive loading.

b. Charge Configuration

(U) A charge design using a tapered aft-body was evaluated as a means of reducing the overall weight. Although weight was not a problem, even with the longest charge, it was desired to keep the weight at a minimum without decreasing the penetration capacity. For this study, the charge shaper was cast from a high strength non-shrinking casting plaster. This cast section was inserted in the aft end of the case prior to loading the explosive. The charge shaper provided a reduction of approximately 3.25 pounds of Composition B.

c. Liners

(C) The liner used in this program was a 60-degree copper cone. The cones were made of electrolytic tough pitch copper plate which was press formed into the conical shape and then machined to the required diameter. The cone thicknesses evaluated (0.062, 0.093, 0.125 and 0.188 inch) are notably less than the usual optimum for penetration, but previous experience with follow-through particles attached to the liner indicated this range of cone thickness would provide the best results.

d. Follow-Through Configuration

(C) In referring to follow-through configurations, the position of the configuration is noted as being in a specific zone. Three basic configurations of the follow-through particles evaluated are Three Delta-Zone 2(3Δ-Zone 2), Three Delta-Zone 3(3Δ-Zone 3) and the Solid Band-Zone 2 and 3 (Figure 2). The zones referred to are three arbitrarily assigned sections on the liner (Figure 3). Configurations in Zone 1 were not investigated in this study as it had been demonstrated in previous studies that the shaped charge collapse mechanics work best if the shaped charge liner apex is void of follow-through particles. The three follow-through configurations were further evaluated with consideration given to:

(1) Particle size. The follow-through particles used were high carbon steel balls. Two sizes used in the experiments were 0.250-inch diameter (1.1 grams) and 0.188-inch diameter (0.44 gram).

(2) Particle attachment to the liner. In all cases investigated, the follow-through particles were attached directly to the liner. The bonding agent was an epoxy resin. As a variation of this attachment method, the particles were placed within an epoxy matrix which contained either 80 percent bronze or 80 percent aluminum.

e. Standoff Distance

(U) The standoff distance evaluated was set at levels which would be compatible with the dimensional requirements of the "HORNET" missile (the 22.0-inch standoff distance is slightly in excess of the available space; however, this distance provided the best indicator of effects to expect from standoff). The 12.0-inch standoff distance was the minimum which could be obtained by placing the liner base directly next to the aft of the seeker section. The standoff distances of 17.0 and 22.0 inches were accomplished by allowing respective separations of 5.0 and 10.0 inches between the liner base and the aft end of

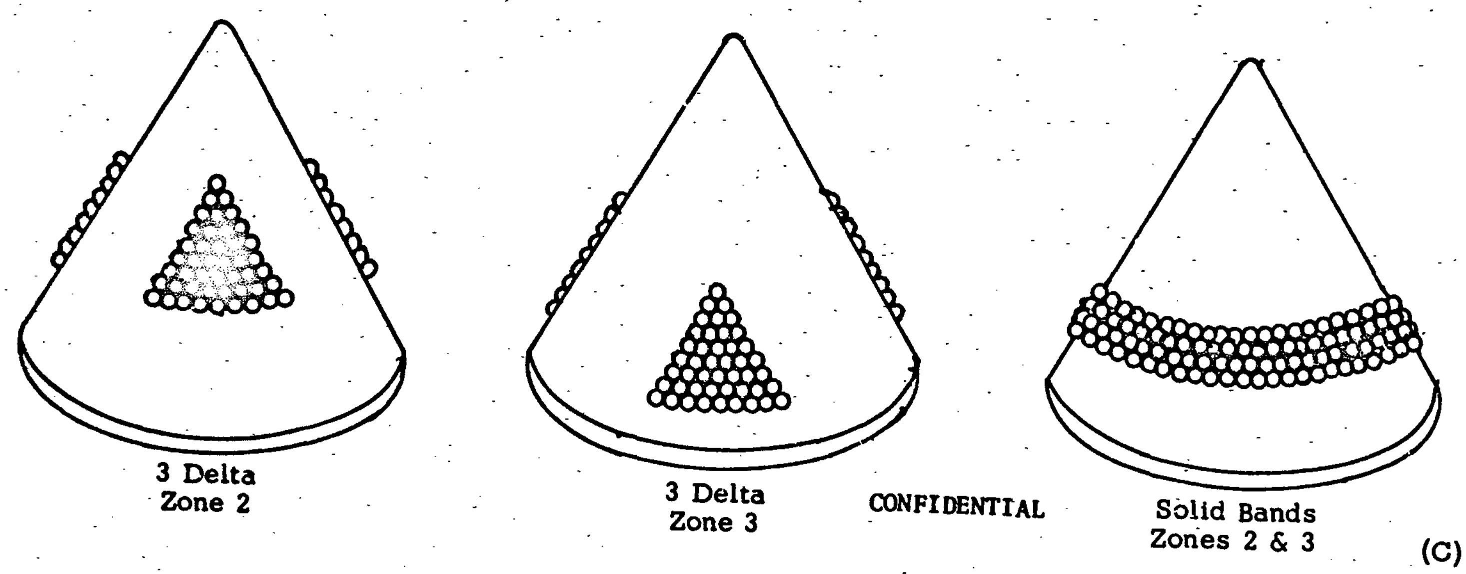
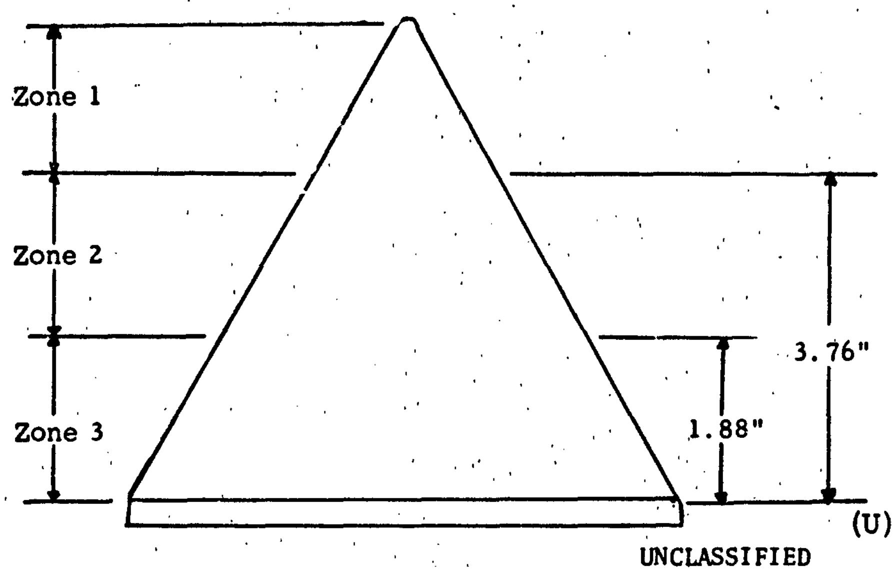


FIGURE 2 (C)

Follow-through Configurations (U)

the seeker section. The distance separating the warhead and seeker section was by necessity a part of the 17.8 ± 2.0 inches allowed for the warhead.



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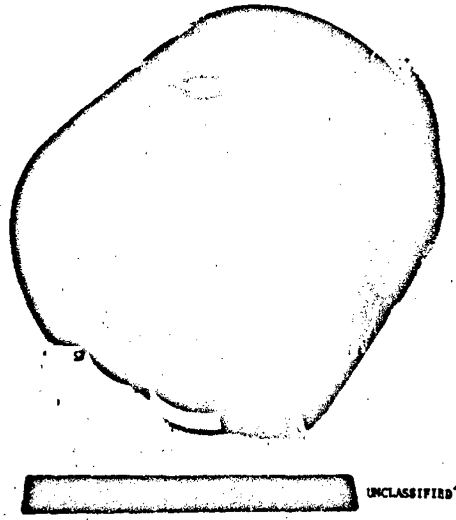


FIGURE 4 (U)

Seeker Optics and Platform (U)

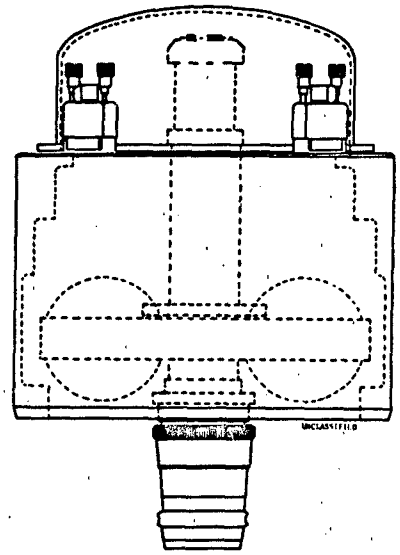


FIGURE 5 (U)

Representative Seeker Cross Section (U)

(U) After an assembly had been qualified, it was loaded with explosives. The density of the explosive was calculated as a means of determining whether cavities existed within the explosive casting.

h. Explosive Loading

(U) Extreme care was given to assure that proper explosive loading was accomplished. Because cavitation caused during the melt-pour explosive loading process could cause misleading results, close supervision was given to the melting process, pouring temperatures and the curing process. Two explosives, Composition B and Octol 75/25, were used during the study with most of the initial design evaluation being done with the Composition B explosive.

(U) The booster charge was a cylindrical pellet, 1.0 inch in diameter and 1.0 inch long. The RDX pellet, with graphite and wax, weighed 26 grams. The booster was inserted into a cavity concentrically located and machined into the explosive. Each booster pellet was press formed with a small cavity into which a No. 6 electric blasting cap was placed for detonating the test units.

i. Final Design Warhead

(C) A design change presented during the study was to reduce the warhead to a smaller diameter. The objective of this smaller warhead, either 6.50 or 6.625 inches outer diameter, was to allow the warhead to be installed within the missile airframe (Figure 7). The most apparent advantages to be gained with the smaller diameter warhead are:

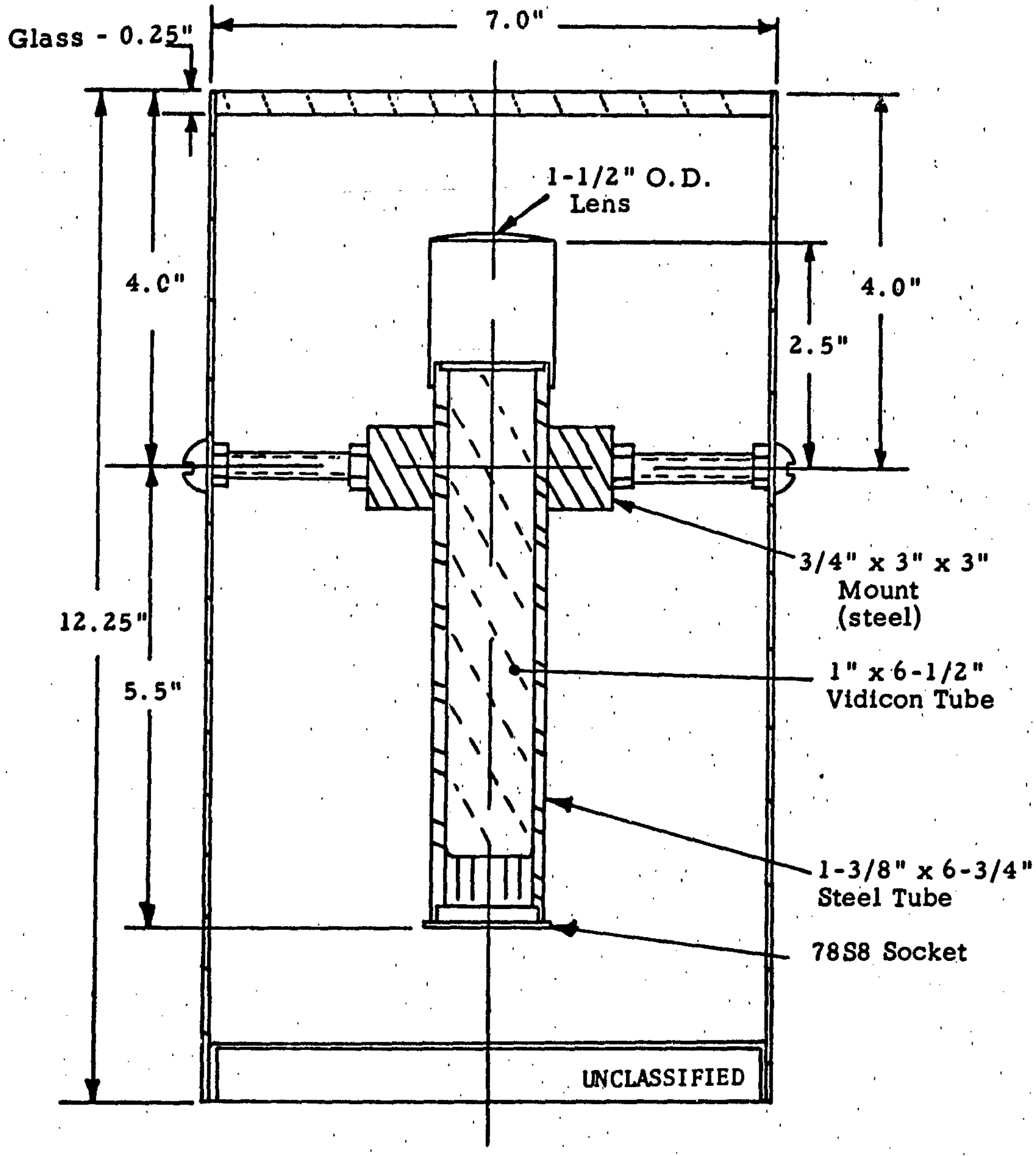
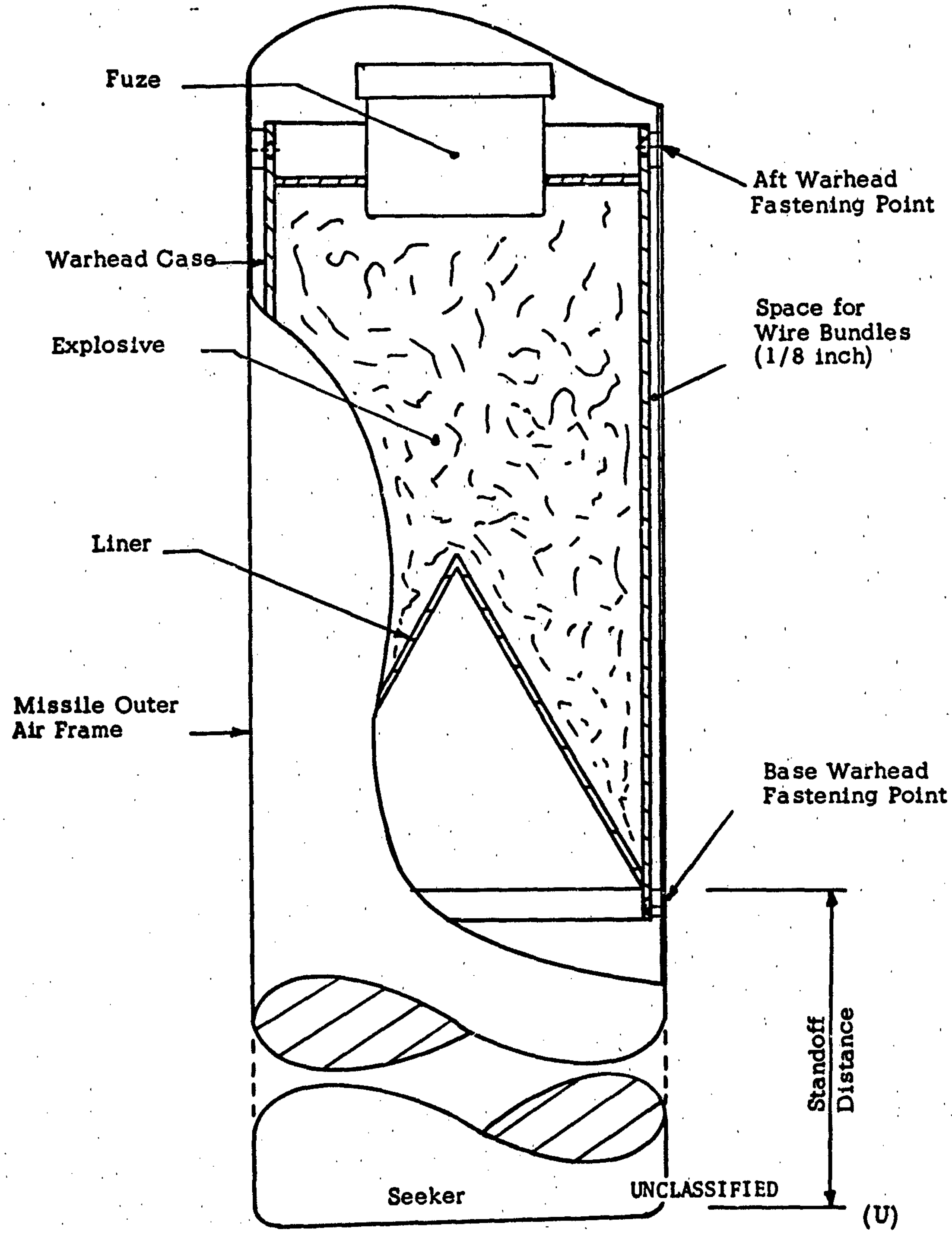


FIGURE 6 (U)

Simulated Seeker (U)



(U)

FIGURE 7 (U)

Cutaway of Insert Warhead Design (U)

(1) The airframe requires only one field break whereas two breaks would be required if the warhead case formed a part of the airframe.

(2) A space is provided through which the many control and signal wires required between the seeker section and the main guidance section may pass.

(U) 2. TESTING AND EVALUATING PROCEDURE

(C) Basically, two methods of test analysis were used during the course of this program. One method, the total penetration into semi-infinite mild steel target, was used to establish the basic shaped charge parameters (charge length, charge configuration, and liner thickness). Mild steel was used because it is much more readily available than armor and sufficiently similar to provide valid test results. The other method is best described as a beyond target effectiveness test. With this method the most complimentary standoff distance and follow-through particle configurations were selected. This test also provided a merit factor whereby the final design warhead could be evaluated for performance against different target thickness and for comparative performance with the XM131 (SHILLELAGH) warhead.

a. Total Penetration Test

(U) The semi-infinite target used consisted of several mild steel blocks stacked to a height of 35 inches (Figure 8 and 9). After each test, the hole diameter at the interface between each pair of the penetrated blocks was measured and recorded. Using this average diameter taken at the established increments of penetration depth, the volume was calculated.

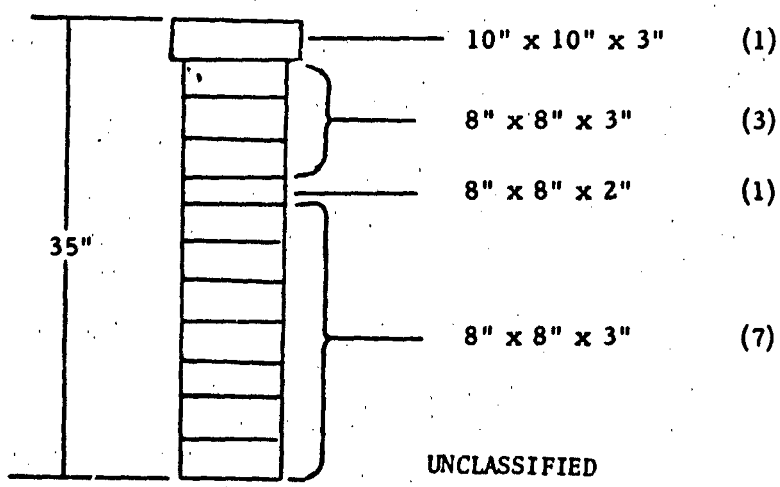


FIGURE 8 (U) (U)

Total Penetration Target (U)

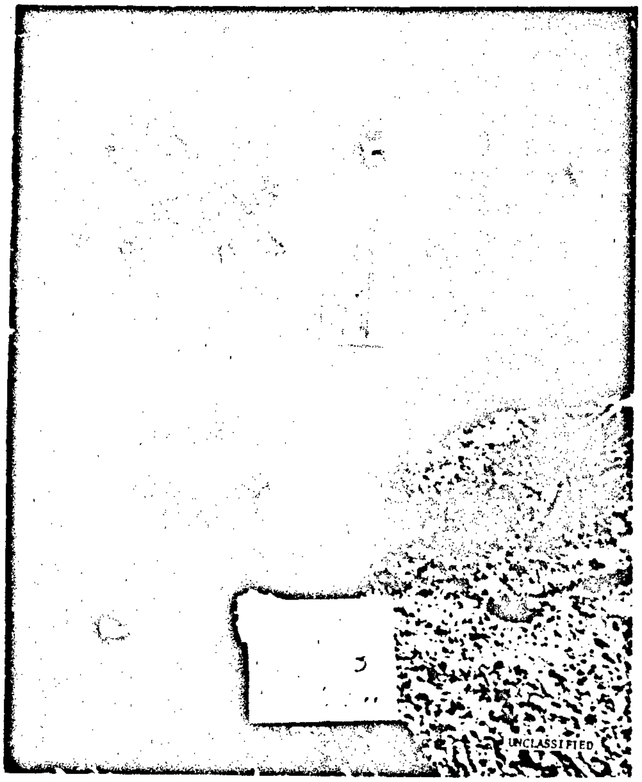


FIGURE 9 (U)

Total Penetration Test Arrangement (U)

(C) For evaluating the total penetration test, a design criteria of 14 inches of homogeneous armor was established. Since the target used in these tests was mild steel, an extensive literature search was made to determine a reliable armor/mild steel penetration ratio. This search revealed ratios ranging from 0.74 to 0.92 with these ratios being dependent on such variations as target material hardness and standoff distance. The relationship determined to best fit the conditions of tests in this study was:

$$P_A = 0.85\ P_S$$

where P_A = penetration into homogeneous armor

P_S = penetration into stacked mild steel plates

Using this ratio the penetration criteria into mild steel was set at 16.5 inches.

(U) The factors for evaluating the total penetration test were:

(1) Depth of penetration
(2) Volume of the penetration hole
(3) Overall penetration profile

The depth of penetration and penetration volume data are given in Tables IV, V, VI and VII in the Appendix.

b. Beyond Target Effectiveness Test

(C) To determine beyond target effectiveness, a test setup was required which would allow recovery of all the particles (follow-through, jet, and spall) which are projected beyond the target (Figure 10). A massive table was used to support the target, test unit, and a fiberboard screen located 24 inches below the target. Beneath this table a 300 gallon vat was filled with water to contain the jet and those particles traveling with the jet which passed through the fiberboard screen. For those particles contained in the fiberboard screen, the following data were recorded:

(1) Spatial distribution of the particles with respect to the charge axis.

(2) Depth of particle penetration into the fiberboard screen.

(3) Weight of each particle recovered from the screen.

(C) A computer program was written to reduce this data to provide the following information for the particles recovered in the fiberboard:

(1) The average penetration of the particles into mild steel as a function of the dispersion angle.

(2) Average impact velocity of the particles as a function of the dispersion angle.

(3) Azimuth octant distribution of the particles.

(4) Dispersion angle of the particle from the axis of the charge.

(5) The number of particles per dispersion degree.

(6) The number of particles per unit area as a function of the dispersion degree.

(7) Average personnel P_k (five-minute assault criteria) of the particles as a function of the dispersion angle.

(C) The above data taken into consideration with the data obtained from the penetration of the target and the efficiency of the follow-through particle allowed an overall evaluation of each design test fired. (The efficiency of the follow-through particle is the ratio of follow-through particles recovered beyond the target to those placed on the liner).

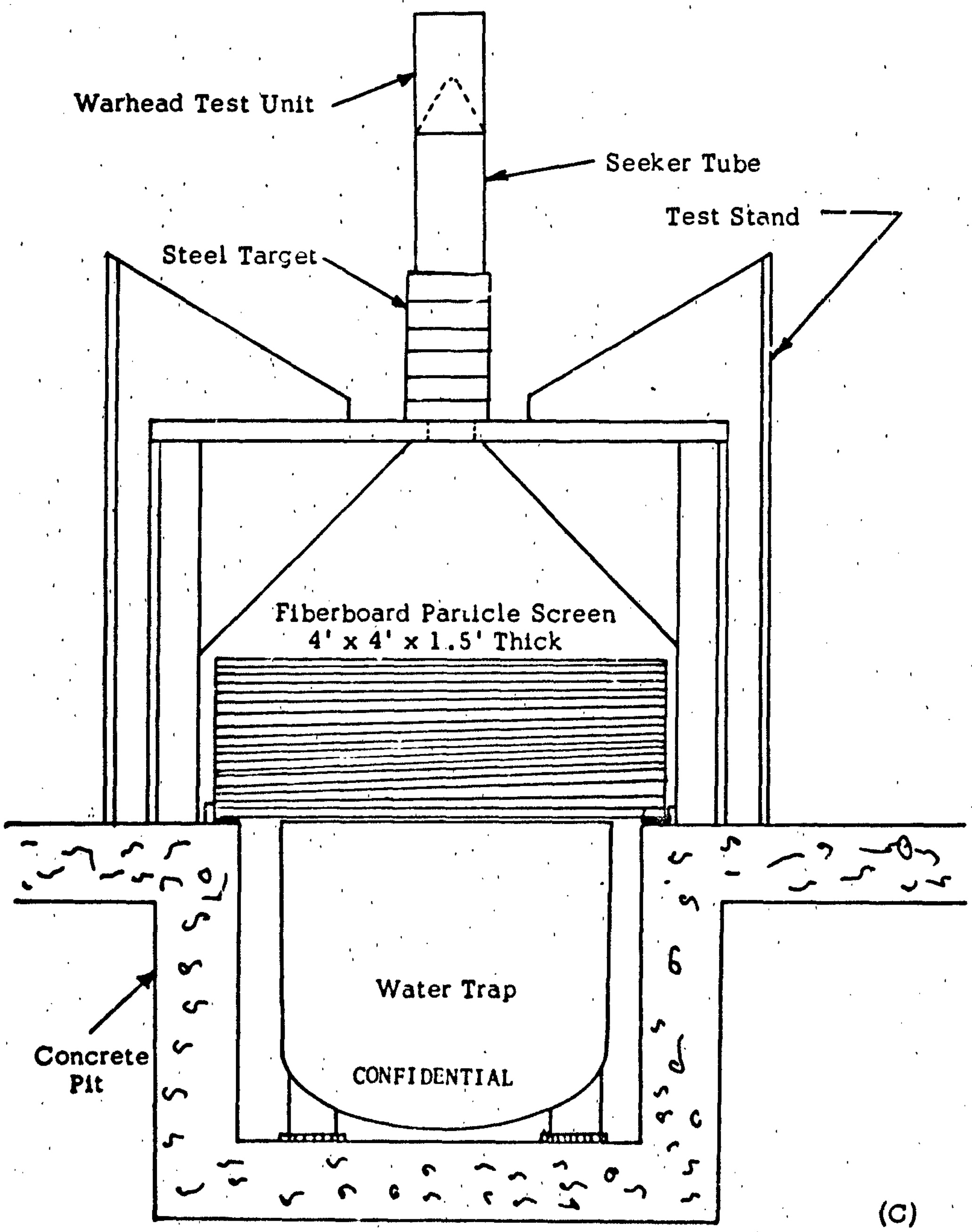


FIGURE 10 (C)

Effectiveness Test Setup

c. Warhead Fuzing System

(U) In order for the Air Force to perform the planned dynamic testing of the prototype warheads furnished as a part of this study, a fuzing system is required. To fulfill this requirement, a search of the literature and contacts directly with fuze manufacturers, were made to determine whether a fuze system was available which could be readily adapted to the "HORNET" warhead system. This search was based on the missile flight and design characteristics furnished by the "HORNET" Project Officer.

d. Case Fragment Lethal Area

(U) It was noted during the course of this study that the case breakup could add considerably to the lethality of the warhead. To verify this, an analysis of the lethal area of the warhead against armored personnel carriers and against one and one-half ton trucks was made. This was basically a theoretical study in which test result data of the fragment dispersion and density was utilized.

SECTION III

(U) RESULTS OF THE PROGRAM

(U) 1. PHASE I

(C) In this phase, a series of ten total penetration tests was performed. The purpose of this phase was to establish the level at which to set the factors of:

(1) Charge length (10 or 12 inches)
(2) Charge weight (with or without the aft body shaper)
(3) Liner thickness (0.062, 0.093, 0.125 or 0.188 inch)

The basic test unit design with a 3Δ-zone 2 follow-through configuration was used for all the tests in this series (Table I). The standoff distance was 17.0 inches.

(C) In this phase, Units 1 through 6 were to establish the liner thickness by evaluation of thickness of 0.062, 0.093 and 0.125 inch. Each liner thickness was test fired in both the 10 and 12-inch case without the aft body shaper. In these six tests the 0.125-inch liner provided the greatest penetration. There was no clear indication that thicker liner would not provide even greater penetration, however. To explore that possibility and better determine the location of the peak of the curve two additional test units were assembled. The two units were X-2 and X-3 having respective case lengths of 10 and 12 inches. The liner thickness in these units was 0.188 inch (Table II).

(C) Using the criteria given in the test procedure for evaluating total penetration tests, primarily the depth and hole volume, it was concluded the 0.125-inch liner thickness could be expected to provide the most effective performance (Tables IV, V and VI, Figure 11).

(C) Using this established liner thickness, Unit 7 (12-inch case length) and Unit 8 (10-inch case length) were assembled and loaded with the aft body shaper in place. Both these tests provided a considerable reduction in total penetration obtained as compared to that without the aft body shaper. A reduction of 13.7 percent was noted for the 10-inch case and 12.3 percent for the 12-inch case. The reduced penetration capabilities caused by the aft body shaper placed this design at a marginal level. Since the aft body shapers did not offer a significant advantage in meeting the weight requirement, it was determined not to use the aft body shaper. Since the weight limitation was not exceeded, it was determined to use the 12-inch case length which could be expected to provide a 7.3 percent greater penetration than the 10-inch case length.

(C) With the completion of this series of tests, it was determined that the selected design would have a case length of 12 inches and no body shaper. Also the liner thickness was set to be 0.125 inch for the next series of tests. This thickness was subject to change if in subsequent tests a follow-through configuration other than the 3Δ-zone 2 was selected. This did happen and will be discussed later in the Phase II section.

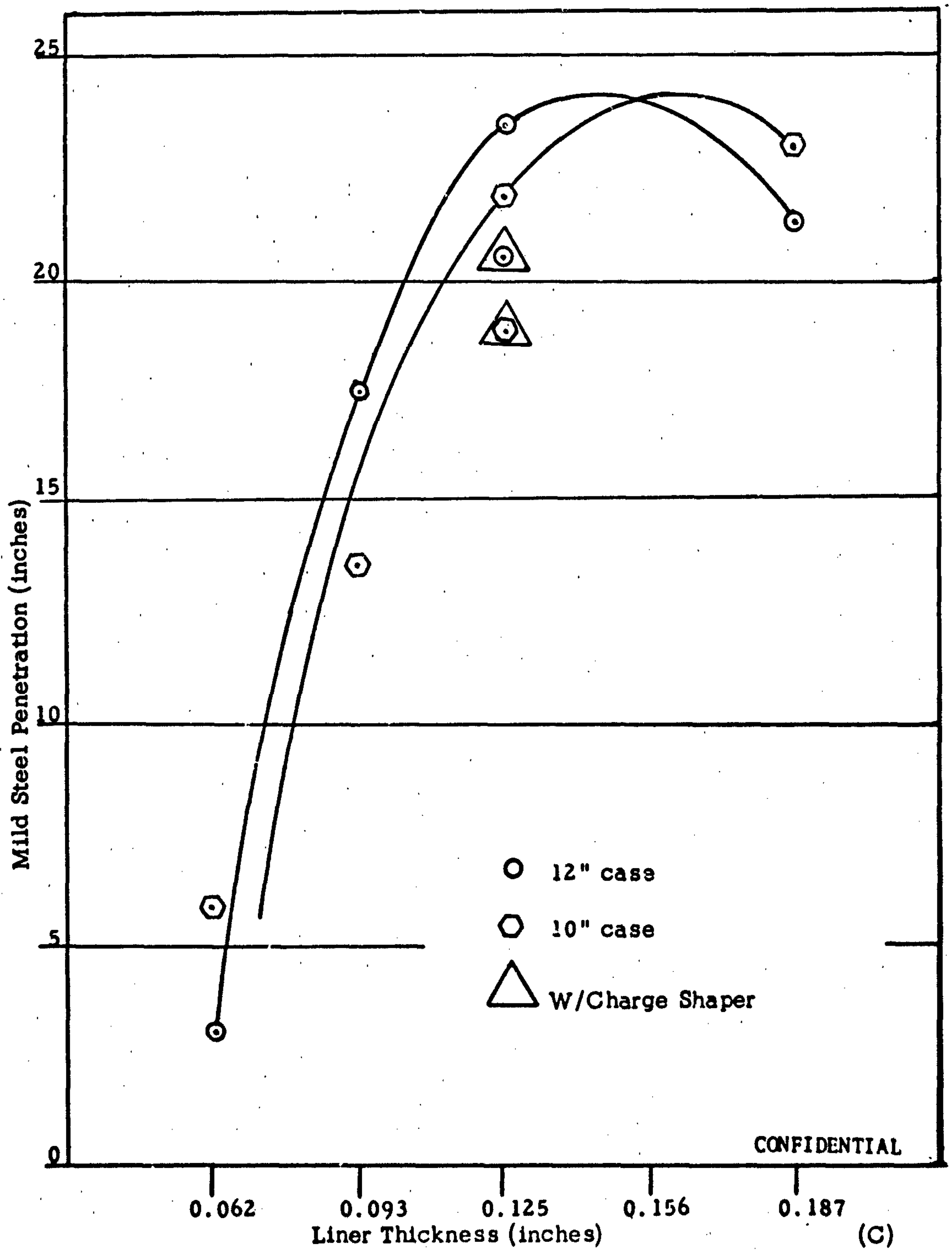


FIGURE 11 (C)

Infinite Target Penetration
Phase I Test (U)

(U) 2. PHASE II

(U) Considerable work was accomplished in Phase II. For clarity, the work has been divided into the following sections:

(C) a. Standoff Distance and Follow-through Configuration Parameters

The first series in this group included all the design combinations possible with the two evaluated factors (standoff and follow-through configuration) with each factor being considered at three levels. The assemblies used in this series were designated Units 9, 10 and 11 (3Δ-zone 2 configuration); Units 12, 13 and 14 (3Δ-zone 3 configuration); and Units 15, 16 and 17 (solid band-zones 2 and 3)(Tables I and II). The levels of standoff distance were 12, 17 and 22 inches. The 0.25-inch diameter carbon steel ball was the follow-through particle used in each configuration. The steel balls were attached to the liner with an epoxy resin.

(C) Each of these nine units was test fired to obtained beyond target effectiveness. The target for each test was ten inches of mild steel. After each test all the follow-through particles projected beyond the target were recovered. For those particles embedded in the fiberboard witness screen (except in the first three sheets) the appropriate location and weight information was recorded and later processed through a computer run which rendered a more definitive meaning to the particles (Table X). Those particles in the first three sheets were only considered in determining the total number of follow-through particles beyond the target. Also, after each test the dimensional data of the target penetration hole was recorded for over-all test unit analysis (Tables VIII and IX).

(C) To best evaluate the extensive data obtained on the nine units being considered, the three tests of each follow-through configuration were first analyzed as a group.

(C) Before considering the first group of three tests, a brief discussion of the method of evaluation is in order. As was presented earlier in this report, the computer analysis of the data recovered on the follow-through particles provided a considerable array of information relative to each particle. Of all the information provided by this analysis, the overall effectiveness of these particles is best presented by:

(1) The number of particles projected in each angle of dispersion from the axis

(2) Average personnel P_k (five minute assault criteria) of the particles as a function of the dispersion angle

To further simplify the presentation of this information, the two items above are combined to give the total P_k delivered in each five-degree increment of dispersion from the unit axis. After this comparative relation is established, it is much simpler to bring into consideration the related facts of total angle of dispersion, quantity of particles, average P_k of particles considered and distribution of these particles over the total dispersion angle. Realizing this review of data is limited to those follow-through particles which were captured in the fiberboard screen, it is also necessary to bring into consideration those particles which were traveling in and near the jet and also the pertinent target penetration data.

(S) Using the approach discussed above it is possible to graphically present the relative effect of the three evaluated standoff distances to the follow-through configuration. Considering first the 3Δ-zone 2 configuration (Figure 12) it can readily be determined that the 17-inch standoff is the best as it projected the most particles with the highest average P_k over the widest dispersion angle (nine particles with average P_k of 0.514 in fiberboard, overall efficiency 25 percent).

(S) The 3Δ-zone 3 configuration (Figure 13) is somewhat more difficult to analyze. There is no problem in eliminating the 22-inch standoff distance from consideration but the other two do have relative merits which must be weighed. Favoring the 12-inch standoff is the higher average P_k(.0497) but the average P_k obtained with the 17-inch standoff is only slightly less (.0475). The chief advantage of the 17-inch standoff is that more particles are transmitted and are better dispersed over the entire angle of dispersion.

(C) Using this same form of analysis for the solid band-zone 2 and 3 configuration (Figure 14) the 12-inch standoff is determined the most effective.

(C) The next step is to consider the results of these configurations at the best standoff in order to analyze the relative effectiveness of the configuration evaluated (Figure 15). If consideration of effectiveness is limited to only the follow-through particles, the solid band-zone 2 and 3 configuration is far superior. Only in total dispersion angle was the performance of the solid band configuration exceeded. However, the analysis of the target blocks and past experience with the solid band configuration gave rise to the presumption that the penetration capacity of this configuration would be less than the established criteria of 16.5-inch mild steel.

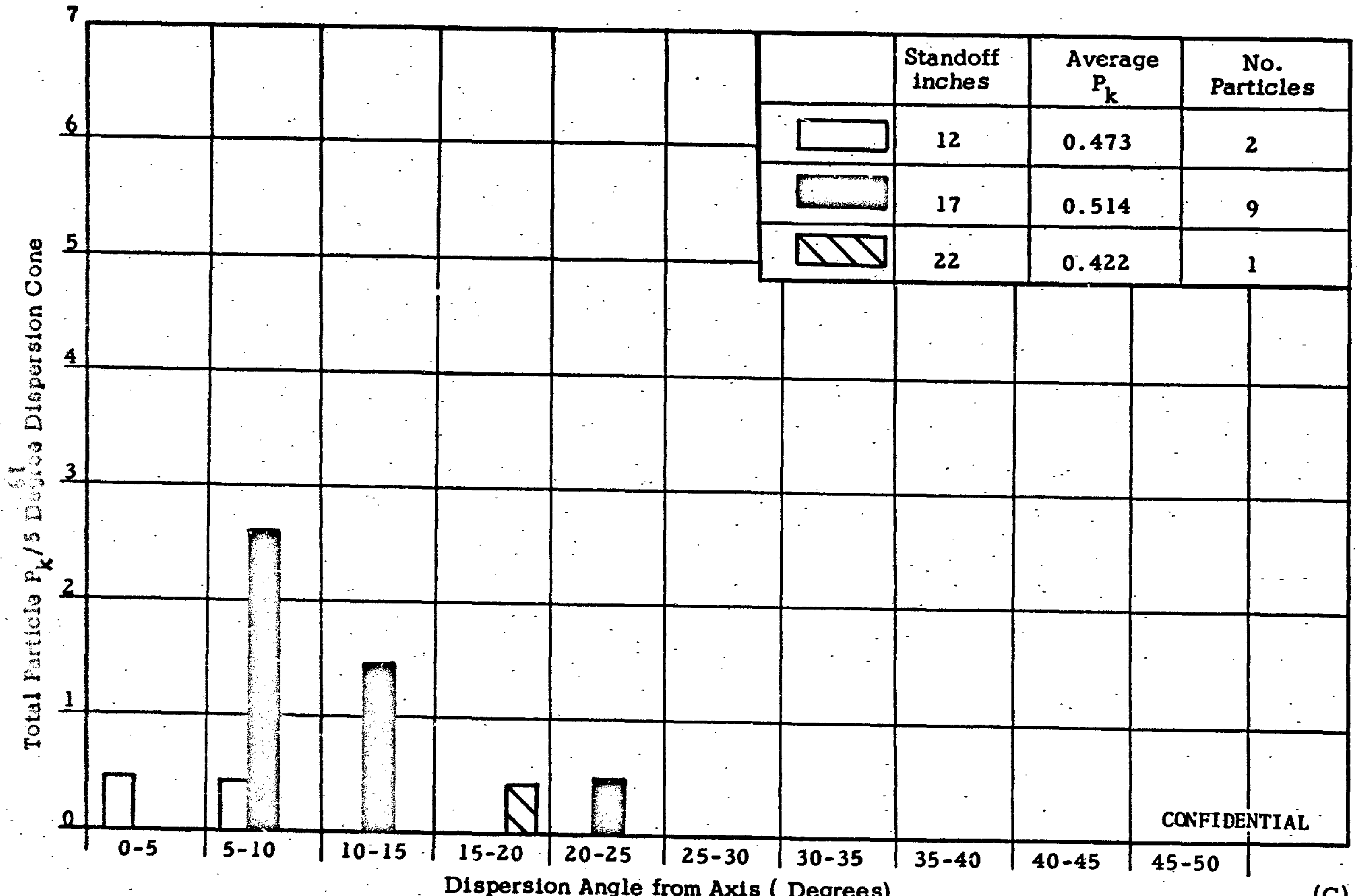
(C) b. Total Penetration of the Solid Band Configuration

Prior to selecting the follow-through configuration it was determined necessary to establish the penetration capabilities of the solid band-zone 2 and 3 configuration. For this test Unit X-8 was assembled and loaded (Table III). The results of this test verified the expected decrease in penetration. Whereas the 3Δ-zone 2 configuration had given a penetration of 23.5 inches, the penetration depth of the solid band-zone 2 and 3 configuration was 23 percent less at 18.1 inches. This did exceed the established criteria of 16.5 inches, but the margin of safety was not sufficient to select the solid band configuration unless the penetration could be improved.

(C) c. Other Follow-through Configurations Considered

From the review of the three best configurations it was apparent that a considerable gap existed between the degree of effectiveness obtained with the solid band configuration and the other two configurations evaluated. The objective of the next series of tests was to determine a configuration which would fall in this area of effectiveness while maintaining adequate penetration capacity.

(C) For this series the Units X-9, X-11 and X-15 were prepared (Table III). The follow-through configurations evaluated in this series were modifications of two of the three previously examined.



(C)

FIGURE 12 (C)

Effectiveness of 3△-Zone 2 (U)

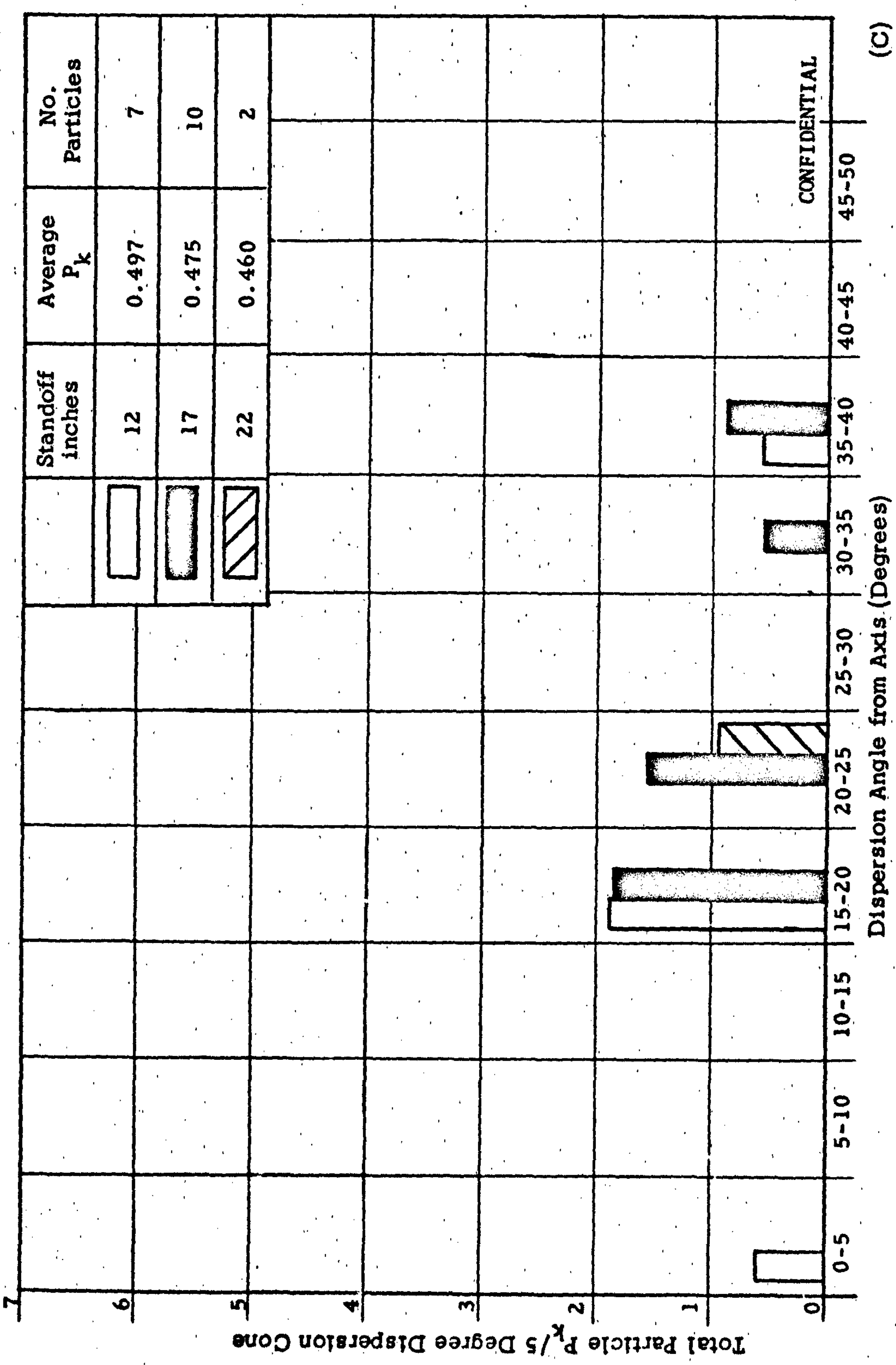
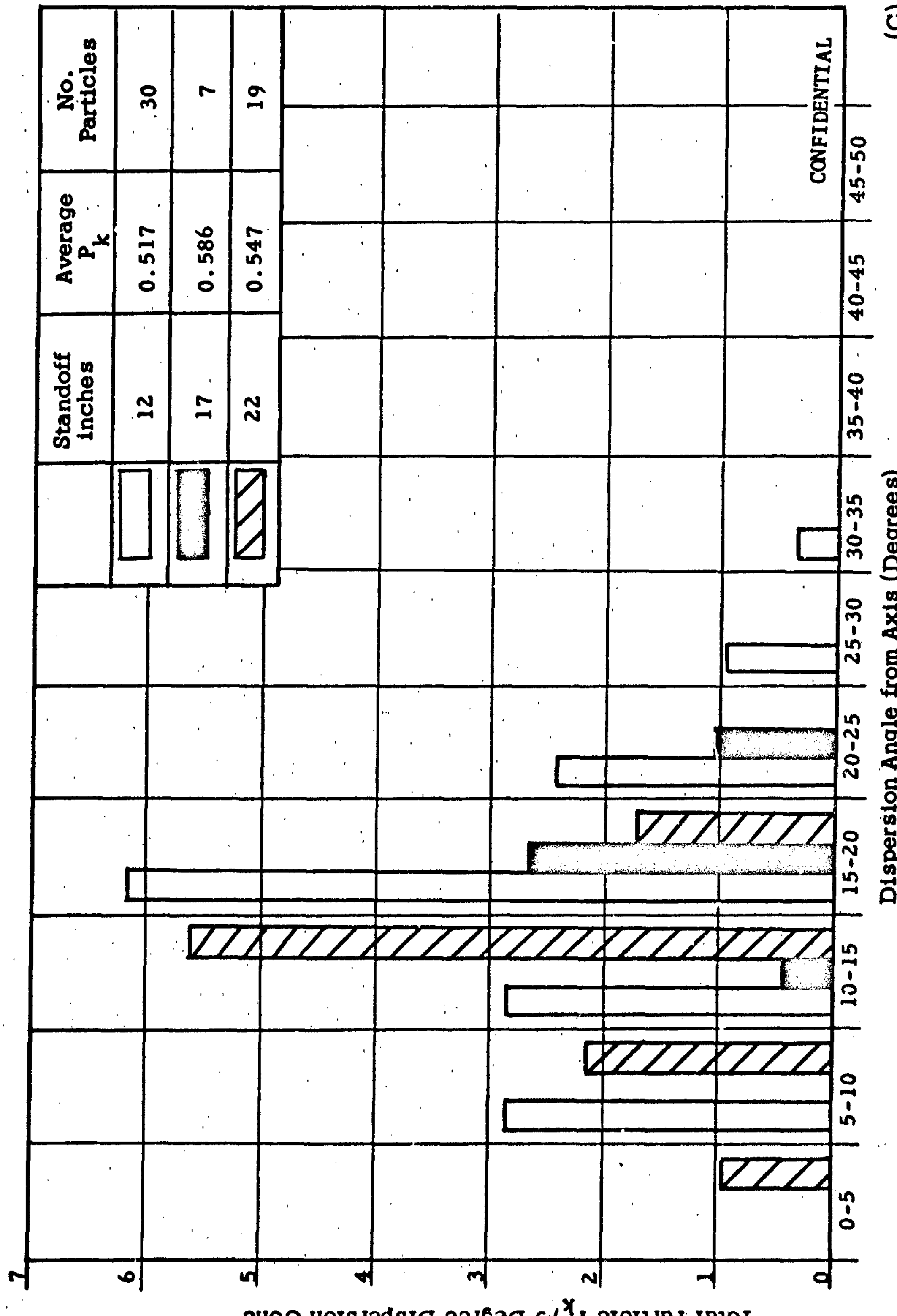


FIGURE 13 (C)

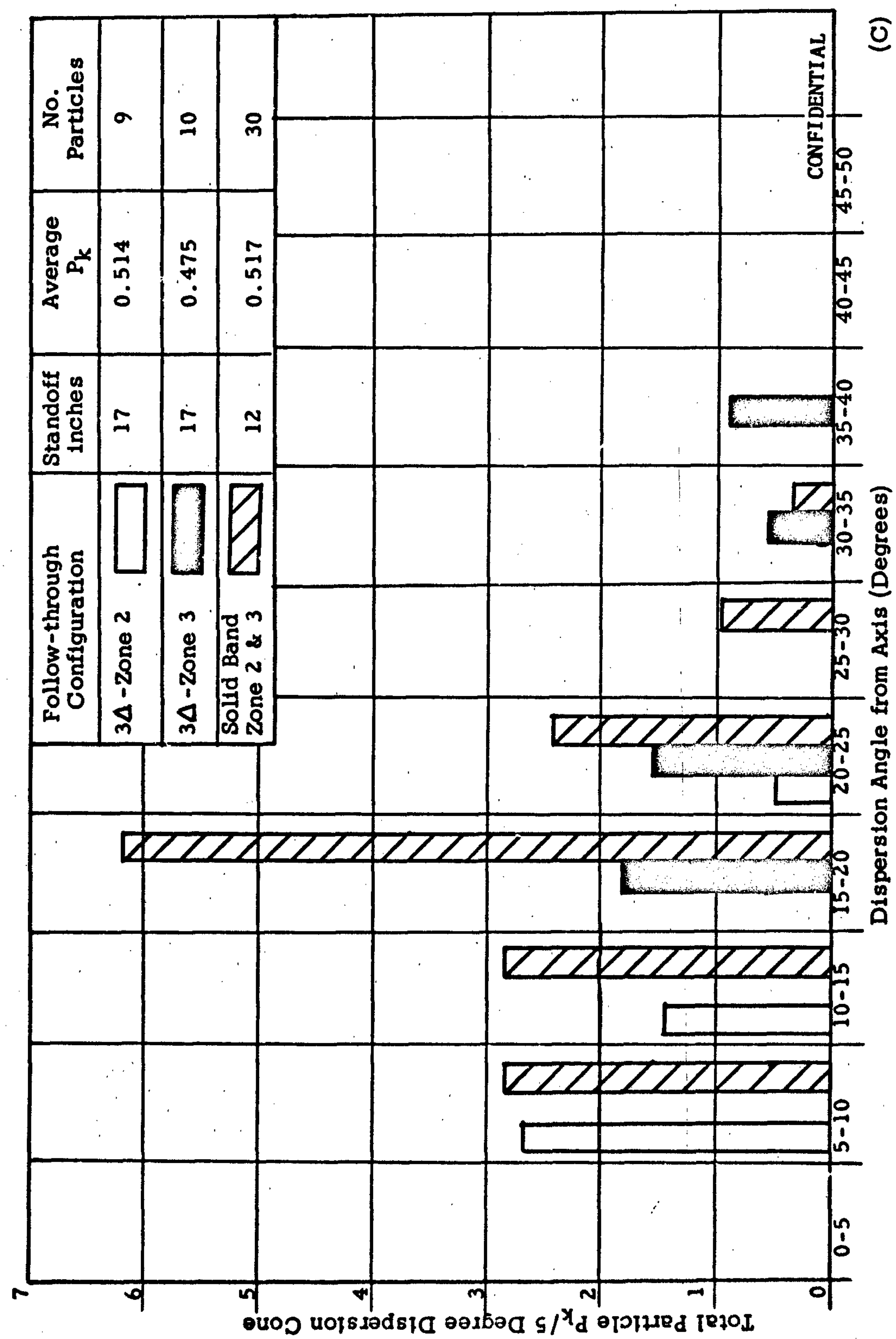
Effectiveness of 3Δ-Zone 3 (U)



(C)

FIGURE 14 (C)

Effectiveness of Solid Band-Zone 2 & 3 (U)



Follow-through Configuration		Standoff inches	Average P_k	No. Particles
3Δ-Zone 2	(open bar)	17	0.514	9
3Δ-Zone 3	(shaded bar)	17	0.475	10
Solid Band Zone 2 & 3	(hatched bar)	12	0.517	30

FIGURE 15 (C)

Effectiveness at Optimum Standoff (U)

(C) Units X-9 and X-11 evaluated modifications of the solid band-zone 2 and 3 configurations. One of the modified configurations (Unit X-11) had the steel balls placed on the same area of the cone in the same manner but a 0.188-inch steel ball was used in place of the 0.25-inch ball. This allowed the number of particles to be increased from 250 to 421. The configuration used with Unit X-9 was identical to the earlier solid band configurations except the particles were placed in a matrix of epoxy resin which was 80 percent bronze.

(C) The other configuration given additional study was the 3Δ-zone 3. Unit X-15 was test fired with the particles being placed in an epoxy resin matrix which was 80 percent aluminum.

(S) The three units were test fired under the same conditions as the previous follow-through effectiveness tests. These data were collected, processed and evaluated in the same manner as before (Tables IX and X, Figure 16). Weighing most heavily in favor of selecting the 3Δ-zone 3 configuration with the epoxy-aluminum matrix was the wide angle, even distribution pattern obtained. Other favorable factors were a high average P_k (0.513 for Unit X-15), high percentage of particles projected beyond the target (36 percent of total attached - 85 percent more than the same configuration without epoxy-aluminum matrix) and the penetration capability which was demonstrated in later tests.

(C) d. Penetration Capability of Selected Follow-through Configuration

The penetration capacity of the 3Δ-zone 3 follow-through configuration with aluminum matrix was demonstrated by the test firing of Unit X-16 (Table III and VII). The results of this test gave a total penetration depth of 21.3 inches -- 2.2 inches less than the best obtained with the 3Δ-zone 2 configuration.

(C) e. Verification of Liner Thickness

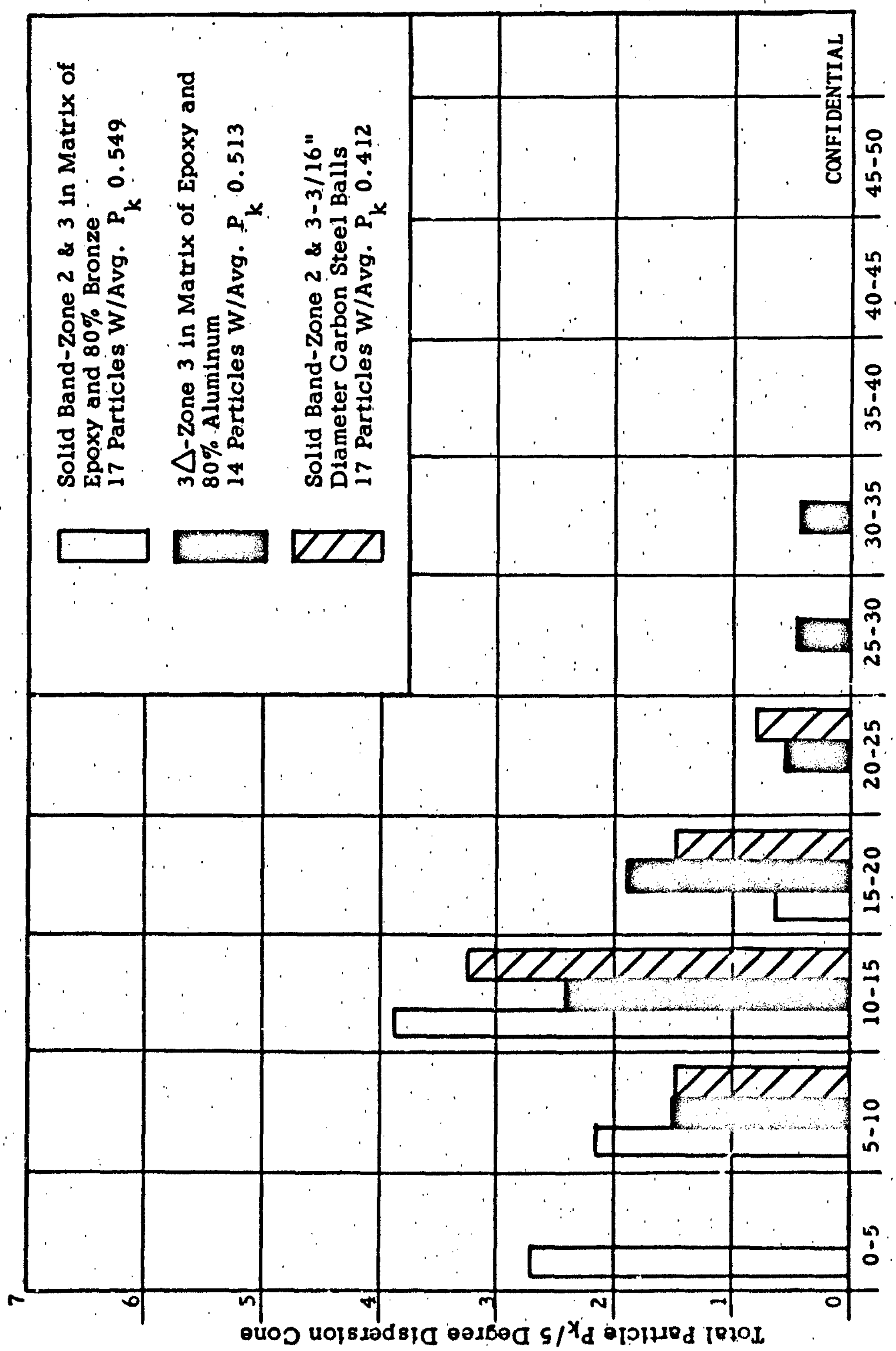
Noted earlier was the fact that the liner thickness determined in the Phase I study would be subject to verification if a follow-through configuration other than the 3Δ-zone 2 was selected. Initially it was intended to perform tests with the selected follow-through configuration on both the 0.062 and the 0.093-inch thick liners. Based on the poor performance of the 0.062-inch liner thickness to penetrate in the Phase I study, only the one test with a liner thickness of 0.093-inch was conducted.

(C) The penetration capacity with a liner thickness of 0.125 inch had been demonstrated to be sufficient; therefore, the liner thickness verification was the beyond target effectiveness test. The test was performed with Unit 19 (Table II).

(C) The results failed to show that the 0.093-inch liner thickness was any improvement over the 0.125-inch liner thickness (Table IX). Based on these results the liner thickness was set at 0.125 inch.

(C) f. Reduced Diameter of Test Unit

During the course of this program, a desire to reduce the outer diameter from 7.0 inches to either 6.625 or 6.50 inches was presented by the Air Force Project Officer. Three test units were assembled for total penetration tests to determine the effect of reducing the diameter (Units X-4, X-5 and X-6, Tables



(C)

FIGURE 16 (C)

Effectiveness of Modified Follow-through Configurations (U)

II and III). A second factor, case thickness, was also evaluated at 0.188 and 0.250 inches. All three units had the 3Δ-zone 2 follow-through configuration and were test fired at a standoff distance of 17 inches. The greatest penetration was obtained with the 6.50-inch case but the reduced size hole profile indicated the beyond target effectiveness would be inferior to the larger and more uniform penetration obtained with the design having a 6.625-inch case and 0.188-inch wall thickness (Figures 17 and 18). The case design of 6.625-inch outer diameter and wall thickness of 0.188 inch was recommended to the Project Officer and approved for use in the prototype warheads. To qualify the beyond target effectiveness of the reduced diameter charge, Unit X-12 was test fired for effectiveness (Tables IX and X). Prior to the test of Unit X-12, a casting void was noted in the Composition B, which without doubt contributed to the poor performance recorded.

(C) g. Evaluation of Explosives

Octol, with a higher detonating rate and density, is expected to offer a slightly greater depth of penetration. More important to a shaped charge of the follow-through design is the substantially larger hole diameter which can be expected.

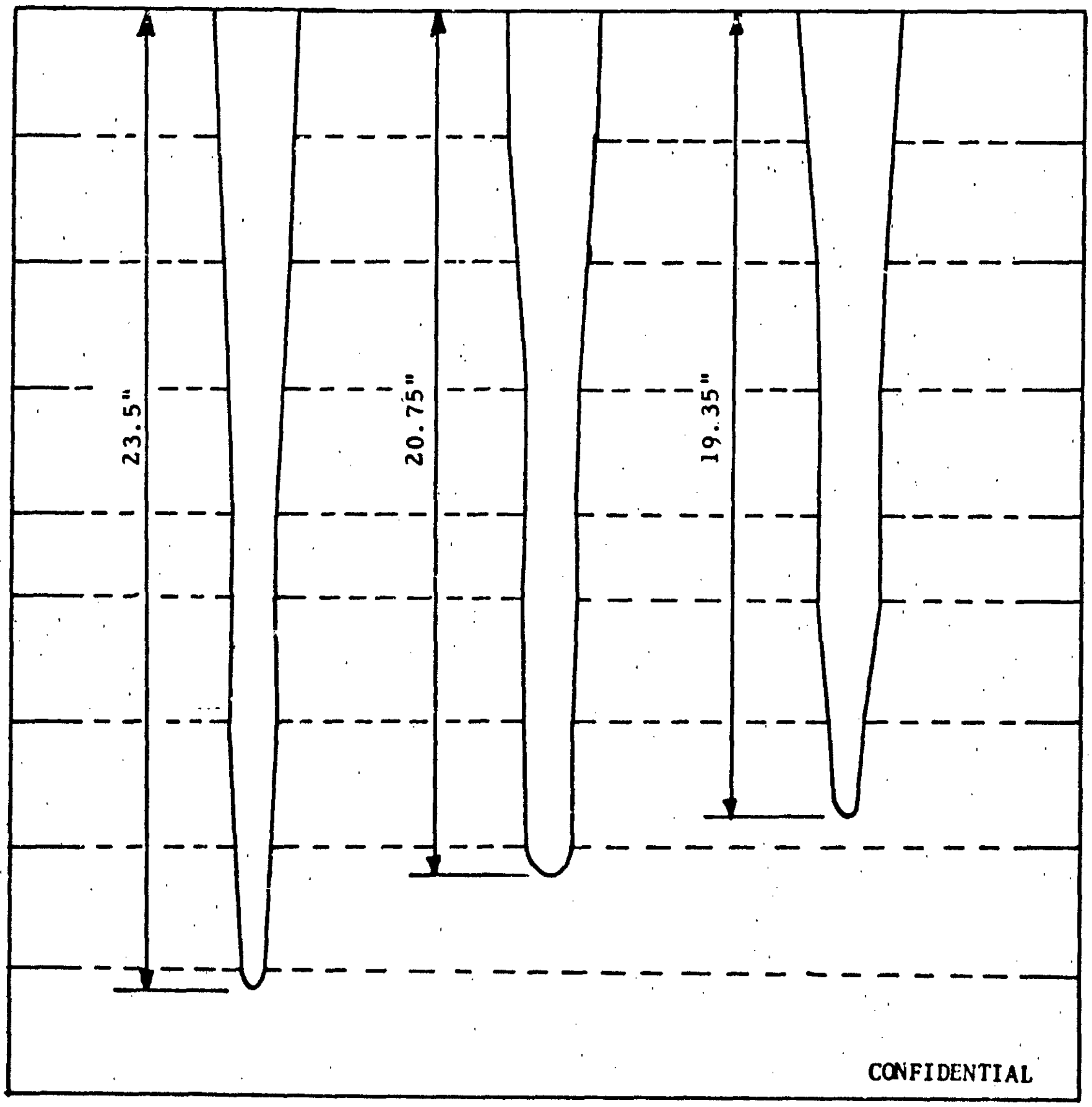
(C) To compare Octol to the Composition B used in the preliminary tests, two test units (X-13 and X-14 were assembled and loaded with Octol (Table III). Unit X-13 was test fired for beyond target effectiveness and is evaluated more completely below in the comparison of the XM131 Warhead. Unit X-14 was test fired for total penetration (Table VII). The depth of penetration obtained with Unit X-14 was 18 inches or 3.3 inches less than obtained with a like test unit configuration (Unit X-16) loaded with Composition B (Table VII). This substandard penetration was attributed to a poor casting of the explosive which resulted when the curing process was interrupted because of a violent electrical storm. Subsequent tests (Unit X-17) did demonstrate the performance of Octol to be as anticipated.

(C) h. Effectiveness Through Thicker and Thinner Targets

The standard target thickness used for the beyond target effectiveness test was 10 inches. It was desired to know to what extent an increase or decrease in target thickness would affect the follow-through particle effectiveness. To establish this, Units 20 and 21 were test fired for beyond target effectiveness through respective targets of 14 and 6 inches of mild steel. Comparing these results to those of a like test unit (X-13) fired through a 10-inch mild steel target, it is noted that both the quantity of particles and the average P_k of the particles are decreased with an increase of target thickness (Figure 19). No appreciable effect on angle of dispersion was noticed between the 6-inch and 10-inch target. The angle of dispersion from axis is 35° with the 10-inch target, 30° with the 6-inch target, whereas this angle was reduced to 20° with the 14-inch target.

(C) i. Comparison to the SM131 (SHILLELAGH) Warhead

Two XM131 Warheads were test fired under the same conditions as the follow-through warhead design. In both tests, the standoff distance was 17 inches and the simulated "HORNET" seeker section was located between the target and the warhead.

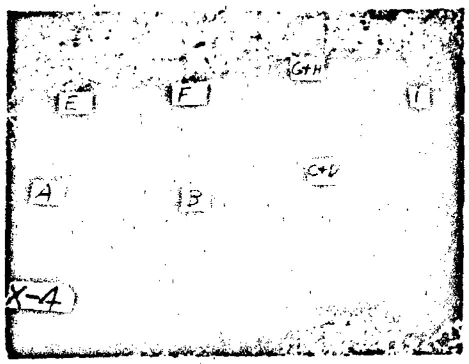


Unit X-4	Unit X-5	Unit X-6
6.50 Case Diameter	6.625 Case Diameter	6.625 Case Diameter
6.125 Cone Diameter	6.25 Cone Diameter	6.125 Cone Diameter

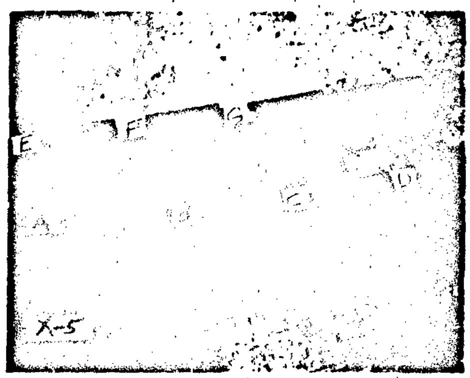
(C)

FIGURE 17 (C)

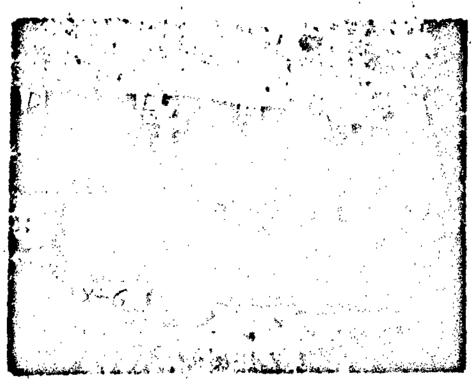
Reduced Case Diameter-Hole Profiles (U)



Unit X-4
6.50 Case Diameter and 6.125 Cone Diameter



Unit X-5
6.625 Case Diameter and 6.25 Cone Diameter



Unit X-6
6.625 Case Diameter and 6.125 Cone Diameter

FIGURE 18 (C)
Reduced Case Diameter Target Results (U)

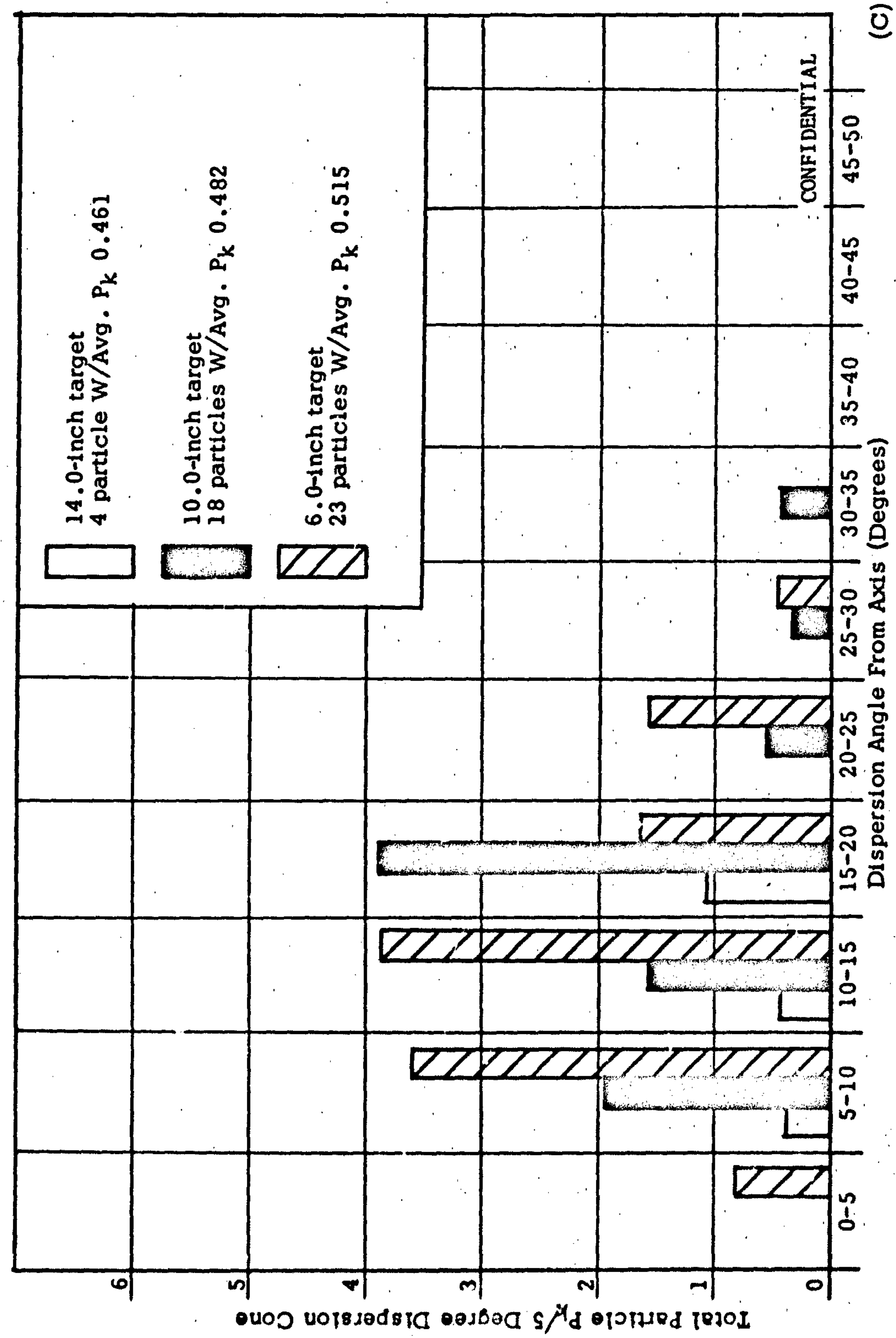


FIGURE 19 (C)

Effects of Target Thickness (U)

(C) The total penetration test with the XM131 Warhead (Unit S-2) provided a penetration of 18.25 inches into the mild steel as compared to 20.7 inches obtained with the prototype design "HORNET" Warhead. Although this is a small difference in the depth of penetration obtained with these two warheads, the advantage of the "HORNET" follow-through design is the much larger hole size.

(C) The advantages of the larger penetration hole are better shown in a comparison of the results of an XM131 Warhead (Unit S-1) and a follow-through design (Unit X-13) test fired for beyond target effectiveness (Figure 20). Only in the very small dispersion angle (0° to 10°) does the XM131 Warhead make a comparable showing to the follow-through design warhead. Over the remainder of the dispersion pattern the follow-through particles alone have nearly the same effectiveness as the XM131. This indicates that with complete suppression of spall, the follow-through design warhead would render nearly the same effectiveness expected from the XM131 Warhead without suppression of spall, when utilized in a delivery system of the "HORNET" concept (a seeker section between the warhead and target).

(C) Besides the effectiveness provided by those particles considered in the above discussion, there is another group of follow-through particles which must be considered when evaluating effectiveness. These are the particles which are projected through the fiberboard screen with the jet from the shaped charge and were captured in the water trap. Although these particles can offer little advantage as they are projected with the jet beyond the target, they do have an undetermined value as ricochet particles inside the target. There is usually a large percentage of the particles projected into the target which fall into this category. The particles traveling with the penetration jet can be expected to have a higher velocity than the particles recovered in the fiber screen, thus giving more value to the damage they can provide on ricochet.

(S) j. Preliminary Case Fragmentation Lethality Analysis

In order to predict as well as possible the fragmentation lethality of the "HORNET" Warhead an analysis was perfromed using some experimental data compiled together with some calculated data. In particular, the fragments' initial velocity was calculated using Gurney's formula for cylinders and was found to range between 7195 and 7600 feet per second. Furthermore, the fragment size distribution was calculated using a formula by Gurney and Sarmousokis, BRL Report 448. The weight of the case was used to determine the total weight of all fragments. The fragment angular dispersion and spatial density were determined from a test shot where 4' x 10' x 1/4" steel witness plates were used to count fragment impacts and their locations (Figure 21). All of these data were keypunched in the proper format to be processed by the warhead lethality program in use at Eglin Air Force Base, Florida. This program computes the kill probability against various targets at a grid of points on the ground around the missile impact and from these numbers computes lethal area, a mathematical index of the warhead lethality or effectiveness. Using vulnerability data on armored personnel carriers and one and one-half ton cargo trucks, the Analysis and Effectiveness Branch, Ballistics Division, Air Force Armament Laboratory at Eglin AFB, computed the lethal areas of the "HORNET" Warhead against these targets. The lethal area against the armored personnel carriers was 250 square feet and against the truck was 750 square feet. This is roughly represented by saying that the kill probability is .37 at 8.9 feet for the armored personnel carriers and at 15.5 feet for the truck.

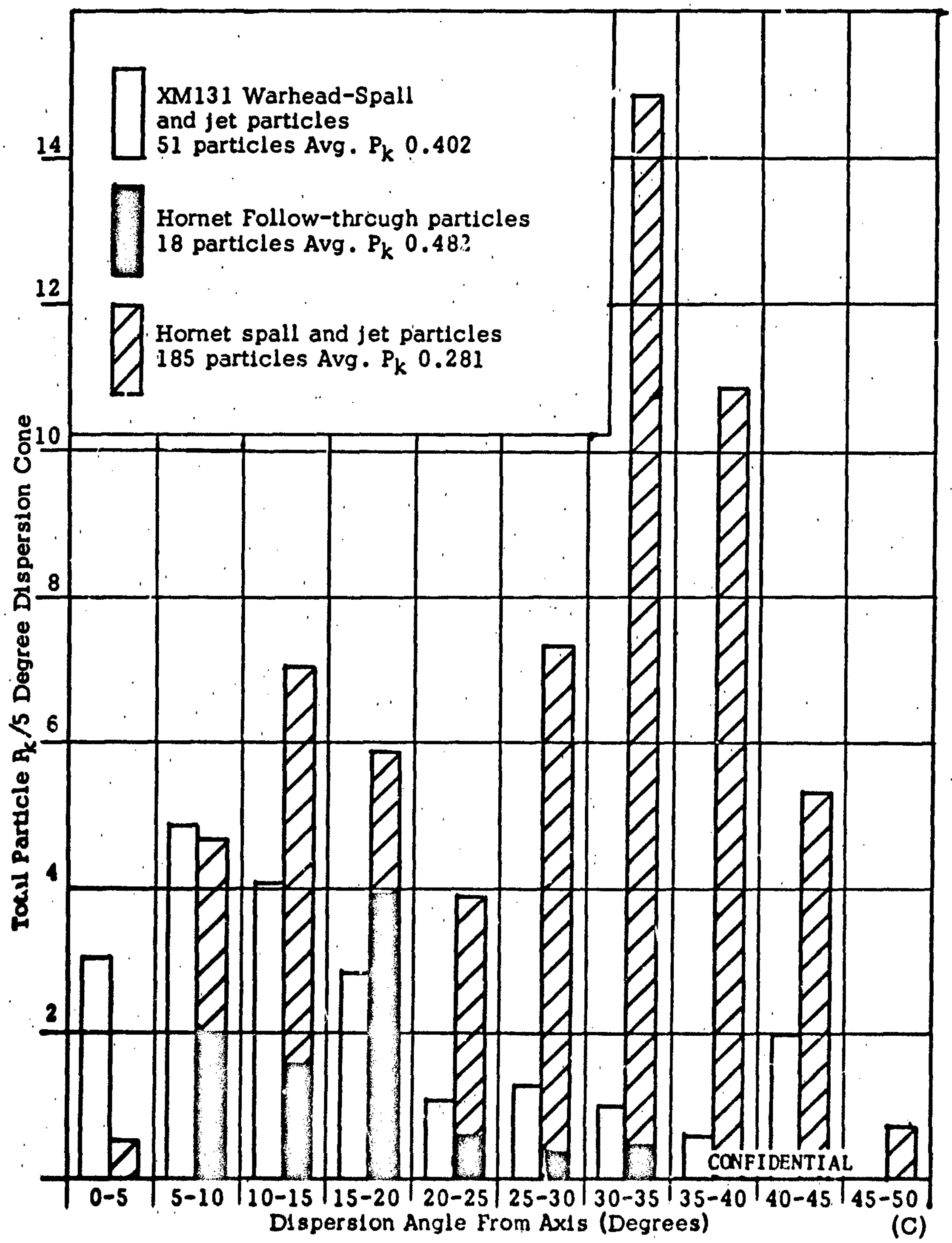


FIGURE 20 (C)

Comparison of Geyond Target Effectiveness-Hornet-XM131 Warhead (U)

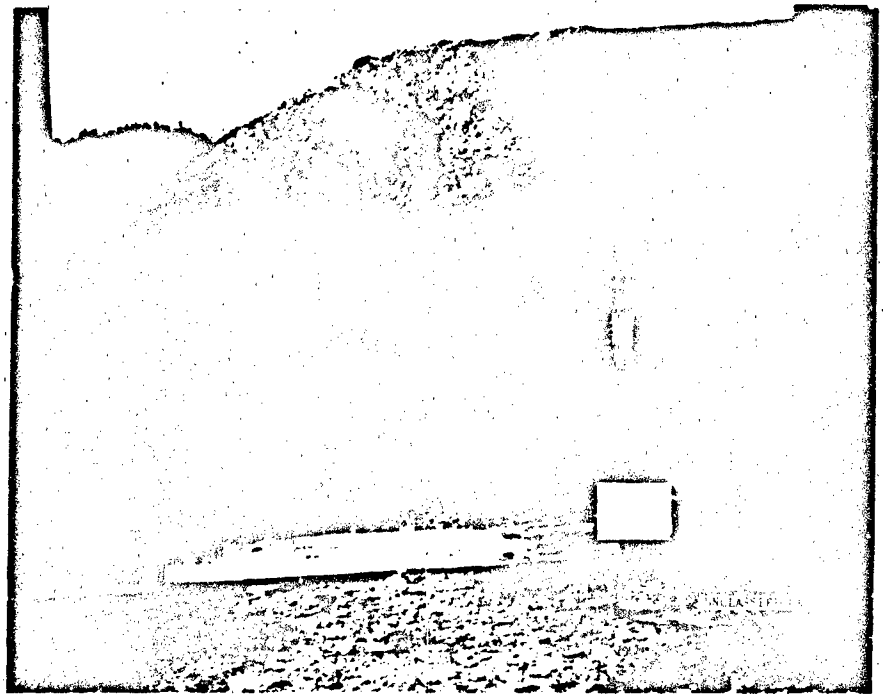


FIGURE 21 (U)

Case Fragmentation Test Arrangement

(C) k. Degradation Caused by the Seeker Section

As pointed out early in this report, the location of the seeker section of the "HORNET" guidance systems did offer an undesirable condition under which the shaped charge warhead must function. To establish the extent to which this seeker section did degrade the shape charge performance, two total penetration tests were made, one with the seeker in place (Unit X-7) and one without a seeker (Unit X-1) (Tables II and III) In both tests the 10-inch case was used and follow-through particles were not placed on the liner. A penetration of 30.5 inches into the mild steel target was obtained without the seeker whereas the test with the seeker in place reduced the depth of penetration by 22 percent to 23.8 inches (Tables V and VI).

(C) It is also apparent that some decrease in penetration capacity is caused by adding the follow-through particles to the charge liner. This decrease can be exemplified by comparing the depth of penetration obtained from Units X-7 and 6. These are like test units except for the addition of follow-through particles to the liner in Unit 6 The total penetration with Unit 6 was 21.9 inches, 1.9 inches less than without follow-through placed on the liner (Table V). It should be recognized that even with this decrease in penetration, the warhead is capable of defeating heavy armor.

(C) l. Fuze System

During the course of this study, a joint effort was undertaken with the Air Force Project Officer to locate an available fuzing system which could be used with the warhead as a part of the "HORNET" missile system. Several systems were found which had the general requirements, but usually were disqualified, at least for consideration for use in the feasibility demonstration vehicle by the short (200 millisecond) thrust period of the present motor. In correspondence with the Borg-Warner Ordnance Department, it was determined the T1403 fuze could be modified to meet this short thrust period without an extensive redesign program. A modified T1403 will function on the available power supply of the "HORNET" missile, and provides for a safe separation, time delayed arm signal and a self destruct signal. Upon tentative approval of the T1403 fuze by the Project Officer, the prototype warheads were designed to accept this fuze. No modification program for the T1403 fuze was authorized or undertaken, however. Dummy shapes, machined to the dimensions of the T1403, were used to show fuze installation.

(C) m. Prototype Warhead

The three prototype warheads furnished as a part of this program are designed to be inserted within the outer shell of the "HORNET" Missile with the base of the warhead liner to be located 17 inches from the leading surface of the missile. Provision has been made for fastening the warhead in place by eight threaded attachment points, four on each end of the warhead. The aft end of the warhead is provided with the necessary hardware to hold and lock in position the T1403 fuze (Figure 22). The total weight of each warhead is 40 pounds of which 19.3 pounds is the explosive, Octol 75/25.

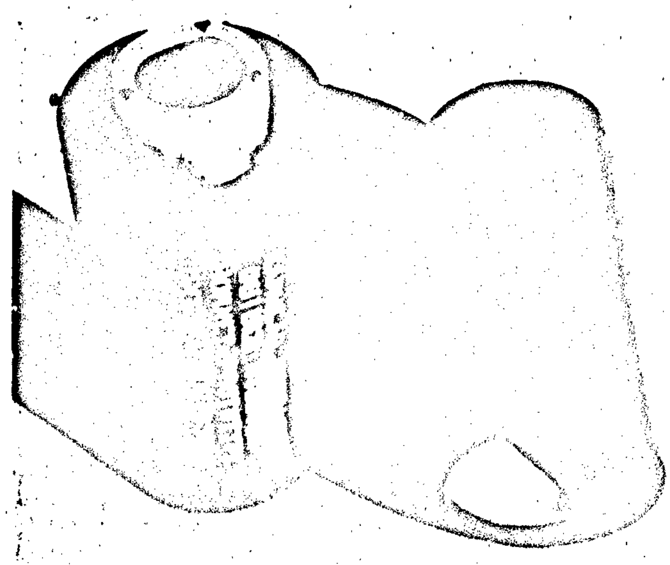


FIGURE 22 (U)

Prototype Warhead (U)

SECTION IV

(U) CONCLUSION AND RECOMMENDATION

(S) The results from this study are decisive in establishing a follow-through shaped charge warhead design that can be employed with the "HORNET" Missile. The warhead has demonstrated the capability to defeat the seeker section of the missile guidance and heavy armor. The penetration capacity of this warhead is adequate to perforate that armor which has a 0.99 probability of being encountered given a random hit on the presented area of interior volume of the JS-3 tank. The assurance of heavy damage to this interior volume was demonstrated by the large number of 0.250-inch diameter carbon steel balls delivered beyond the target as follow-through particles. Also to be expected is a high degree of damage to the interior from spall when spall is not suppressed. This was indicated by the large hole diameter provided by the penetration jet---greater than one-inch diameter at fourteen inches of armor penetration. An additional benefit which was obtained from this study was a highly effective case fragmentation. An analysis of case fragmentation showed a lethal area of 250 square feet for an APC and 750 square feet for a one and one-half ton truck.

(C) It is recommended that a more extensive study program be undertaken to qualify the parameters evaluated with a higher degree of confidence than obtained with the limited number of tests in this study. Although this program has adequately established the feasibility of employing the shaped charge follow-through warhead with the "HORNET" Missile, it cannot be considered to have adequately established the design parameters. Other recommended objectives of future programs are:

(C) a. Incorporating incendiary follow-through particles. These particles could be expected to be projected as efficiently and well-dispersed as the carbon steel particles. In addition to impact damage, these particles would greatly increase the probability of fire inside the tank.

(C) b. Extensive evaluation of the warhead case aimed at increasing the ratio of particle effectiveness to case weight without decreasing the penetration performance.

APPENDIX

TABLES

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(C) TABLE I

(U) Test Unit Assembly Data

	Liner 60° copper		Follow-through: Particles Steel balls		Follow-through: Configuration		Case Steel tubing			Explosive		Total weight lb.
Unit No.	Thickness in.	Dia. in.	No.	Dia. in.	Zone	Type	Dia. in.	Length in.	Thickness in.	Type	Weight lb.	
1	0.062	6.5	135	0.25	2	3Δ	7.0	12	0.250	Comp B	18.88	39.44
2	0.062	6.5	135	0.25	2	3Δ	7.0	10	0.250	Comp B	15.75	30.81
3	0.093	6.5	135	0.25	2	3Δ	7.0	12	0.250	Comp B	19.75	40.00
4	0.093	6.5	135	0.25	2	3Δ	7.0	10	0.250	Comp B	15.81	33.12
4A	0.093	6.5	135	0.25	2	3Δ	7.0	10	0.250	Comp B	15.75	33.06
5	0.125	6.5	135	0.25	2	3Δ	7.0	12	0.250	Comp B	19.50	40.38
6	0.125	6.5	135	0.25	2	3Δ	7.0	10	0.250	Comp B	15.69	33.44
7	0.125	6.5	135	0.25	2	3Δ	7.0	12	0.250	Comp B	16.44	40.50
8	0.125	6.5	135	0.25	2	3Δ	7.0	10	0.250	Comp B	12.25	33.25
9	0.125	6.5	135	0.25	2	3Δ	7.0	12	0.250	Comp B	19.94	40.69
10	0.125	6.5	135	0.25	2	3Δ	7.0	12	0.250	Comp B	19.94	40.56
11	0.125	6.5	135	0.25	2	3Δ	7.0	12	0.250	Comp B	20.00	40.62
12	0.125	6.5	135	0.25	3	3Δ	7.0	12	0.250	Comp B	20.00	40.81

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(C) TABLE II

(U) Test Unit Assembly Data

	Liner 60° copper		Fo[illegible]				Case Steel tubing			Explosive		Total weight lb.
			Particles Steel ba[illegible]		C[illegible]guration							
Unit No.	Thickness in.	Dia. in.	No.	Dia. in.	Zone	Type	Dia. in.	Length in.	Thickness in.	Type	Weight lb.	
13	0.125	6.5	135	0.25	3	3△	7.0	12	0.250	Comp B	20.00	40.81
14	0.125	6.5	135	0.25	3	3△	7.0	12	0.250	Comp B	19.94	40.63
15	0.125	6.5	250	0.25	2&3	Solid band	7.0	12	0.250	Comp B	20.00	40.69
16	0.125	6.5	250	0.25	2&3	Solid band	7.0	12	0.250	Comp B	20.00	40.75
17	0.125	6.5	250	0.25	2&3	Solid band	7.0	12	0.250	Comp B	20.06	40.87
19	0.093	6.5	135	0.25	3	3△ 2	7.0	12	0.250	Comp B	19.75	40.00
20	0.125	6.5	135	0.25	3	3△ 2	7.0	12	0.250	Comp B	20.06	40.94
21	0.125	6.5	135	0.25	3	3△ 2	7.0	12	[illegible]	Comp B	19.88	40.75
X-1	0.125	6.5	---	---	---	---	7.0	10	0.250	Comp B	15.69	33.19
X-2	0.188	6.5	135	0.25	2	3△	[illegible]	[illegible]	0.250	Comp B	15.50	34.63
X-3	0.188	6.5	135	0.25	2	3△	[illegible]	[illegible]	0.250	Comp B	19.50	41.69
X-4	0.125	6.12	135	0.25	2	3△	[illegible]	12	0.188	Comp B	17.59	32.75
X-5	0.125	6.25	135	0.25	2	3△	6.[illegible]25	12	[illegible]	Comp B	18.32	34.125

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(C) TABLE III

(U) Test Unit Assembly Data

Unit No.	Liner 60° copper: Thickness in.	Liner 60° copper: Dia. in.	Follow-through: Particles Steel balls: No.	Follow-through: Particles Steel balls: Dia. in.	Follow-through: Configuration: Zone	Follow-through: Configuration: Type	Case Steel tubing: Dia. in.	Case Steel tubing: Length in.	Case Steel tubing: Thickness in.	Explosive: Type	Explosive: Weight lb.	Total weight lb.
X- 6	0.125	6.12	135	0.25	2	3△	6.625	12	0.250	Comp B	18.57	38.375
X- 7	0.125	6.50	---	---	---	---	7.0	10	0.250	Comp B	15.82	33.315
X- 8	0.125	6.50	253	0.25	2&3	Solid band	7.0	12	0.250	Comp B	20.19	41.562
X- 9	0.125	6.50	253	0.25	2&3	Solid band [1]	7.0	12	0.250	Comp B	19.94	41.560
X-11	0.125	6.50	421	0.188	2&3	Solid band	7.0	12	0.250	Comp B	20.13	41.380
X-12	0.125	6.25	135	0.25	3	3△ [2]	6.625	12	0.188	Comp B	18.35	34.100
X-13	0.125	6.50	135	0.25	3	3△ [2]	7.0	12	0.250	OCTOL	21.00	41.880
X-14	0.125	6.50	135	0.25	3	3△ [2]	7.0	12	0.250	OCTOL	21.56	42.810
X-15	0.125	6.50	135	0.25	3	3△ [2]	7.0	12	0.250	Comp B	20.19	41.310
X-16	0.125	6.50	135	0.25	3	3△ [2]	7.0	12	0.250	Comp B	20.06	41.060
X-17	0.125	6.25	135	0.25	3	3△ [2]	6.625	12	0.188	OCTOL	18.75	35.375
S-1-2	XM 131 WARHEAD (SHILLELAGH)											

[1] Particles in matrix of 80% bronze epoxy
[2] Particles in matrix of 80% aluminum epoxy

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(C) TABLE IV

(U) Total Penetration Data

Unit no.	1		2		3		4A		5			
Standoff (in.)	17		17		17		17		17			
	Hole Diam. (in.)	Residual vol. (in.^{3})	Hole Diam. (in.)	Residual vol. (in.^{3})	Hole Diam. (in.)	Residual vol. (in.^{3})	Hole Diam. (in.)	Residual vol. (in.^{3})	Hole Diam. (in.)	Residual vol. (in.^{3})	Hole Diam. (in.)	Residual vol. (in.^{3})
Depth of Penetration (in.) 0	2.35	4.856	2.4	12.835	2.30	45.7	2.53	33.081	2.4	46.346		
3	0.5	0.074	1.9	1.948	2.48	32.275	1.81	22.004	2.15	34.156		
6	---	---	---	---	1.93	20.876	1.77	14.457	1.98	24.137		
9	---	---	---	---	1.56	13.751	1.61	7.731	1.55	16.821		
12	---	---	---	---	1.59	7.873	1.85	.672	1.33	11.954		
14	---	---	---	---	1.30	2.964	---	---	1.23	8.125		
17	---	---	---	---	0.91	.082	---	---	1.33	4.296		
20	---	---	---	---	---	---	---	---	1.00	1.113		
23	---	---	---	---	---	---	---	---	0.38	0.023		
26												
29												
32												
Total Penetration (ins.)	4.50		5.75		17.50		13.5		23.5			
Total Volume (cu. in.)	4.86		12.84		45.70		33.08		46.35			
Area of Hole at 14 ins. (sq. in.)	---		---		1.33		---		1.19			

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(C) TABLE V

(U) Total Penetration Data

Unit no.	6		7		8		X-1		X-2			
Standoff (in.)	17		17		17		17		17			
	Hole Diam. (in.)	Residual vol. (in.^{3})	Hole Diam. (in.)	Residual vol. (in.^{3})	Hole Diam. (in.)	Residual vol. (in.^{3})	Hole Diam. (in.)	Residual vol. (in.^{3})	Hole Diam. (in.)	Residual vol. (in.^{3})	Hole Diam. (in.)	Residual vol. (in.^{3})
Depth of Penetration (in.) 0	1.75	43.433	2.50	48.035	2.20	32.617	4.10	100.428	2.55	42.215		
3	2.05	34.931	2.13	35.440	1.61	24.059	3.18	69.228	1.86	30.766		
6	1.76	26.373	1.82	26.300	1.50	18.355	2.85	47.822	1.68	23.389		
9	1.50	20.106	1.50	19.830	1.48	13.144	2.13	33.222	1.39	17.841		
12	1.39	15.197	1.45	14.705	1.38	8.361	1.70	24.586	1.18	13.953		
14	1.33	10.865	1.88	8.197	1.43	3.745	1.43	18.819	1.33	10.244		
17	1.88	4.836	1.28	2.355	0.98	.354	1.38	14.171	1.19	6.506		
20	0.90	0.302	0.70	.058	---	---	1.33	9.848	1.53	2.151		
23	---	---	---	---	---	---	1.25	5.929	0.38	---		
26	---	---	---	---	---	---	1.28	2.161	---	---		
29	---	---	---	---	---	---	0.59	0.102	---	---		
32												
Total Penetration (ins.)	21.9		20.6		18.9		30.5		23.0			
Total Volume (cu. in.)	43.43		48.04		32.62		100.43		42.22			
Area of Hole at 14 ins. (sq. in.)	1.39		2.78		1.61		1.60		1.39			

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(C) TABLE VI

(U) Total Penetration Data

Unit no.		X-3		X-4		X-5		X-6		X-7			
Standoff (in.)		17		17		17		17		17			
		Hole Diam. (in.)	Residual vol. (in^3)	Hole Diam. (in.)	Residual vol. (in^3)	Hole Diam. (in.)	Residual vol. (in^3)	Hole Diam. (in.)	Residual vol. (in^3)	Hole Diam. (in.)	Residual vol. (in^3)	Hole Diam. (in.)	Residual vol. (in^3)
Depth of Penetration (in.)	0	2.25	45.315	2.09	34.748	2.19	41.248	2.57	42.734	3.5	64.885		
	3	2.08	34.278	1.91	25.329	2.13	30.261	2.13	29.730	2.37	44.600		
	6	1.99	24.526	1.63	17.952	1.73	21.490	1.77	20.676	2.17	32.466		
	9	1.63	16.811	1.36	12.689	1.34	15.942	1.50	14.381	1.68	23.740		
	12	1.33	11.653	1.08	9.184	1.26	11.962	1.54	8.941	1.49	17.825		
	14	1.30	7.581	1.06	6.488	1.35	7.952	1.53	3.392	1.45	12.736		
	17	1.34	3.478	1.19	3.508	1.31	3.787	0.77	.273	1.48	7.682		
	20	1.00	.255	0.84	1.082	1.18	.137	---	---	1.37	2.901		
	23	---	---	0.50	.025	---	---	---	---	0.81	.103		
	26												
	29												
	32												
Total Penetration (ins.)		21.3		23.5		20.75			19.35		23.8		
Total Volume (cu. in.)		45.32		34.75		41.25			42.73		64.89		
Area of Hole at 14 ins. (sq. in.)		1.33		0.89		1.43			1.84		1.65		

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(C) TABLE VII

(U) Total Penetration Data

Unit no.	X-8		X-14		X-16		X-17		S-2			
Standoff (in.)	17		17		17		17		17			
	Hole Diam. (in.)	Resi-dual vol. (in.^{3})	Hole Diam. (in.)	Resi-dual vol. (in.^{3})	Hole Diam. (in.)	Resi-dual vol. (in.^{3})	Hole Diam. (in.)	Resi-dual vol. (in.^{3})	Hole Diam. (in.)	Resi-dual vol. (in.^{3})	Hole Diam. (in.)	Resi-dual vol. (in.^{3})
Depth of Penetration (in.) 0	2.4	34.702	2.35	49.880	2.65	59.101	1.98	42.669	1.48	22.477		
3	1.64	25.093	2.33	36.987	2.37	44.266	2.03	33.203	1.56	17.037		
6	1.23	20.244	2.25	24.638	2.28	31.537	2.00	23.642	1.43	11.774		
9	1.78	14.910	1.88	14.596	2.03	20.601	1.61	15.970	1.18	7.763		
12	1.40	8.957	1.45	8.068	1.55	13.056	1.4	10.636	0.91	5.192		
14	1.58	3.730	1.5	2.945	1.36	8.071	1.31	6.313	0.90	3.263		
17	0.88	.167	0.7	.096	1.34	3.779	1.13	2.808	1.30	.414		
20	---	---	---	---	1.09	.303	1.00	.137	---	---		
23												
26												
29												
32												
Total Penetration (ins.)	18.10		18.00		21.30		20.70		18.25			
Total Volume (cu. in.)	34.70		49.88		59.10		42.67		22.48			
Area of Hole at 14 ins. (sq. in.)	1.96		1.77		1.45		1.36		0.64			

(C) TABLE VIII

(U) Result of Effectiveness Test

Unit number		9	10	11	12	13	14	15	16	17
Standoff (in.)		12	17	22	12	17	22	12	17	22
		Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)
Depth of Penetration (in.)	0	3.15	2.70	2.28	3.83	2.40	2.06	1.95	1.38	2.60
	3	2.50	2.30	2.05	2.88	2.08	2.00	1.93	1.93	1.60
	5	1.85	2.00	1.99	1.83	2.01	1.85	1.93	1.65	1.42
	6	---	---	---	---	---	---	---	---	---
	7	1.23	1.75	1.45	1.23	1.95	1.70	1.49	1.38	1.25
	8	---	---	---	---	---	---	---	---	---
	10	1.80	2.30	1.68	2.00	2.15	2.05	1.90	1.98	1.47
	11	---	---	---	---	---	---	---	---	---
	14	---	---	---	---	---	---	---	---	---
Target thickness (in.)		10	10	10	10	10	10	10	10	10
Total volume (cu. in.)		33.01	24.11	22.25	40.93	34.39	23.76	21.27	13.04	12.61
Area of Exit Hole (sq. in.)		2.54	4.15	2.22	3.14	3.63	3.30	2.83	3.08	1.70
Number of particles of follow-through projected beyond target		12	34	4	23	26	14	52	74	69

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(C) TABLE IX

(U) Result of Effectiveness Test

Unit number		19	20	12	X-9	X-11	X-12	X-13	X-15	S-1
Standoff (in.)		17	17	17	17	17	17	17	17	17
		Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)	Hole Diameter (in.)
Depth of Penetration (in.)	0	2.70	2.07	2.53	2.53	2.10	1.85	2.45	2.48	1.60
	3	2.48	2.30	2.25	2.08	1.35	1.81	2.30	2.54	1.60
	5	1.99	---	---	2.08	1.24	1.64	2.65	2.64	1.45
	6	---	2.00	2.85	---	---	---	---	---	---
	7	1.90	---	---	1.73	1.59	1.50	2.05	2.16	1.23
	8	---	1.70	---	---	---	---	---	---	---
	10	2.0	---	---	1.13	2.85	2.08	2.20	1.93	1.50
	11	---	1.41	---	---	---	---	---	---	---
	14	---	1.60	---	---	---	---	---	---	---
Target thickness (in.)		10	14	6	10	10	10	10	10	10
Total volume (cu. in.)		30.83	38.53	28.74	28.71	24.09	23.95	42.12	43.98	16.79
Area of Exit Hole (sq. in.)		3.14	2.01	6.38	1.00	6.38	3.40	3.80	2.92	1.77
Number of particles of follow-through projected beyond target		41	28	56	65	75	17	36	48	---

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(C) TABLE X

(U) Beyond Target Effectiveness of Follow-Through Particles

Dispersion angle	Number	Average P_k	Average mild steel penetration (in.)	Average velocity (ft./sec.)
		Unit 9		
4	1	0.487	0.071	1163
7	1	0.460	0.082	1585
		Unit 10		
6	1	0.481	0.093	1839
7	2	0.538	0.106	1858
8	1	0.538	0.096	1613
9	1	0.591	0.109	1705
11	2	0.469	0.088	1748
13	1	0.502	0.135	3176
21	1	0.499	0.098	1890
		Unit 11		
15	1	0.422	0.070	1408
		Unit 12		
4	1	0.576	0.128	2313
16	1	0.313	0.056	1398
18	1	0.441	0.060	1016
19	1	0.537	0.087	1399
20	1	0.579	0.101	1566
37	1	0.533	0.085	1351

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(C) TABLE X (Cont'd)

(U) Beyond Target Effectiveness of Follow-Through Particles

Dispersion angle	Number	Average P_k	Average mild steel penetration (in.)	Average velocity (ft./sec.)
		Unit 13		
16	1	0.445	0.060	995
17	2	0.456	0.066	1088
18	1	0.450	0.060	991
21	1	0.436	0.060	1049
22	1	0.591	0.125	2129
24	1	0.506	0.076	1237
34	1	0.525	0.083	1323
36	1	0.457	0.068	1177
38	1	0.426	0.053	882
		Unit 14		
21	1	0.372	0.059	1234
23	1	0.549	0.090	1409

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(C) TABLE X (Cont'd)

(U) Beyond Target Effectiveness of Follow-Through Particles

Dispersion angle	Number	Average P_k	Average mild steel penetration (in.)	Average velocity (ft./sec.)
		Unit 15		
6	1	0.645	0.132	1991
7	2	0.562	0.112	1922
8	2	0.534	0.100	1632
11	1	0.417	0.070	1405
12	1	0.625	0.132	2125
13	1	0.659	0.145	2217
14	2	0.565	0.103	1674
16	1	0.615	0.123	1932
17	3	0.540	0.102	1727
19	4	0.511	0.100	1792
20	4	0.470	0.101	1985
21	2	0.500	0.103	1839
22	1	0.565	0.101	1636
23	1	0.349	0.070	1794
25	1	0.510	0.077	1234
26	1	0.653	0.142	2183
28	1	0.291	0.058	1639
32	1	0.303	0.073	2259

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(C) TABLE X (Cont'd)

(U) Beyond Target Effectiveness of Follow-Through Particles

Dispersion angle	Number	Average P_k	Average mild steel penetration (in.)	Average velocity (ft./sec.)
		Unit 16		
14	1	0.433	0.071	1371
16	1	0.755	0.212	3090
17	2	0.703	0.198	3270
20	1	0.490	0.074	1235
21	1	0.487	0.075	1259
22	1	0.534	0.088	1437
		Unit 17		
3	1	0.586	0.108	1706
5	1	0.381	0.068	1511
7	1	0.521	0.084	1374
8	2	0.532	0.095	1520
9	1	0.536	0.085	1336
12	2	0.482	0.072	1185
13	4	0.584	0.107	1673
14	2	0.543	0.092	1486
15	2	0.600	0.116	1851
16	1	0.633	0.134	2127
18	2	0.540	0.104	1806

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(C) TABLE X (Cont'd)

(U) Beyond Target Effectiveness of Follow-Through Particles

Dispersion angle	Number	Average P_k	Average mild steel penetration (in.)	Average velocity (ft./sec.)
		Unit 19		
8	1	0.518	0.084	1388
10	1	0.496	0.104	2125
11	4	0.609	0.118	1826
13	1	0.625	0.122	1862
14	1	0.612	0.122	1934
16	1	0.600	0.111	1726
18	1	0.477	0.073	1259
26	1	0.539	0.090	1474
		Unit 20		
9	1	0.380	0.068	1533
14	1	0.440	0.059	998
16	1	0.488	0.073	1210
17	1	0.534	0.087	1390

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(C) TABLE X (Cont'd)

(U) Beyond Target Effectiveness of Follow-Through Particles

Dispersion angle	Number	Average P_k	Average mild steel penetration (in.)	Average velocity (ft./sec.)
Unit 21				
5	1	0.783	0.237	3380
7	1	0.614	0.120	1868
8	2	0.403	0.057	1070
9	1	0.415	0.110	2987
10	3	0.591	0.122	1909
11	6	0.551	0.113	1915
12	1	0.535	0.085	1354
16	1	0.300	0.055	1449
17	1	0.452	0.060	983
19	2	0.420	0.072	1431
21	1	0.542	0.089	1408
23	1	0.456	0.062	1018
25	1	0.544	0.090	1449
33	1	0.474	0.067	1095
Unit X-2				
3	1	0.678	0.153	2304
4	2	0.562	0.096	1508
5	2	0.451	0.081	1634
6	2	0.568	0.097	1503
10	2	0.503	0.078	1259
12	2	0.444	0.076	1436
13	3	0.615	0.110	1813
14	1	0.475	0.072	1233
15	1	0.644	0.134	2058
17	1	0.630	0.124	1878

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(C) TABLE X (Cont'd)

(U) Beyond Target Effectiveness of Follow-Through Particles

Dispersion angle	Number	Average P_k	Average mild steel penetration (in.)	Average velocity (ft./sec.)
Unit X-11				
7	2	0.488	0.113	2475
8	1	0.517	0.115	2333
11	3	0.445	0.099	2285
12	2	0.447	0.081	1613
14	1	0.306	0.066	1903
15	2	0.356	0.079	2093
16	1	0.359	0.057	1236
17	2	0.324	0.056	1378
19	1	0.477	0.096	1963
23	2	0.386	0.071	1612
Unit X-12				
18	1	0.510	0.086	1483
34	1	0.520	0.082	1341

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(C) TABLE X (Concl'd)

(U) Beyond Target Effectiveness of Follow-Through Particles

Dispersion angle	Number	Average P_k	Average mild steel penetration (in.)	Average velocity (ft./sec.)
		Unit X-15		
7	1	0.567	0.097	1509
8	1	0.446	0.058	960
10	1	0.487	0.072	1181
11	1	0.458	0.071	1268
12	1	0.683	0.156	2333
13	1	0.507	0.106	2101
15	2	0.381	0.085	2206
18	2	0.687	0.159	2378
19	1	0.516	0.109	2127
24	1	0.522	0.100	1844
26	1	0.448	0.087	1827
35	1	0.425	0.066	1257

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(C) TABLE XI

(U) Beyond Target Effectiveness - Hornet and XM131 Warheads

Unit No.	S-1				X-13 Follow-Through				X-13 Spall			
Angle of Dispersion	Number	Average P_k	Average Mild Steel Penetration (in.)	Average Velocity (ft/sec)	Number	Average P_k	Average Mild Steel Penetration (in.)	Average Velocity (ft/sec)	Number	Average P_k	Average Mild Steel Penetration (in.)	Average Velocity (ft/sec)
1												
2									1	0.181	0.112	7373
3	2	0.327	0.086	2813								
4	3	0.554	0.114	1980					1	0.301	0.065	1873
5	2	0.351	0.077	1972								
6	4	0.539	0.137	2424								
7	3	0.183	0.057	2710					3	0.403	0.081	1965
8	1	0.201	0.061	2544	1	0.645	0.132	1994	2	0.459	0.119	3986
9	2	0.523	0.121	2552	2	0.419	0.086	1960	1	---	0.080	8260
10	1	0.890	0.183	1478	1	0.447	0.070	1300	2	0.283	0.059	1749
11	3	0.517	0.105	2484					5	0.255	0.067	2497
12	1	0.358	0.056	1211					4	0.306	0.063	1746
13	1	0.343	0.056	1272	2	0.564	0.114	1904	4	0.269	0.070	2346
14	3	0.607	0.086	1319					3	0.310	0.066	1898
15					1	0.410	0.070	1455	2	0.472	0.072	1239
16					2	0.508	0.085	1446	4	0.138	0.053	2631
17					2	0.459	0.084	1665	1	---	0.047	3291
18	1	0.776	0.070	468	1	0.574	0.100	1563	1	0.111	0.050	2596
19	4	0.462	0.079	2553	1	0.577	0.100	1557				
20	1	0.192	0.052	2128	2	0.402	0.065	1340	5	0.224	0.073	3057
21	1	0.059	0.049	2982					1	0.285	0.088	3283
22	1	0.215	0.054	1941	1	0.546	0.089	1405	6	0.144	0.064	3228
23	1	0.065	0.060	4073					2	0.242	0.092	4141
24	1	0.146	0.052	2463					3	0.275	0.082	2980
25	2	0.271	0.063	2027					4	0.212	0.077	3233
26									4	0.248	0.089	3867
27									6	0.207	0.072	3113
28	2	0.161	0.060	2798					6	0.261	0.072	2678
29	1	0.074	0.052	3124	1	0.353	0.106	3468	3	0.378	0.077	1928
30	2	0.432	0.063	1564					9	0.221	0.066	2593
31	1	0.093	0.053	3064					10	0.279	0.081	2906
32									7	0.269	0.070	2150
33									12	0.250	0.073	2842
34									10	0.300	0.071	2221
35	2	0.426	0.066	1676	1	0.416	0.091	2201	12	0.310	0.077	2373
36									8	0.275	0.074	2608
37	1	0.551	0.086	1307					5	0.326	0.077	2189
38									5	0.249	0.068	2467
39									8	0.333	0.076	2167
40									9	0.341	0.071	1903
41	2	0.639	0.077	864					5	0.443	0.085	1774
42	1	0.713	0.096	978					1	0.393	0.070	1523
43									5	0.356	0.081	2165
44									3	0.129	0.069	1896
45												
46												
47									2	[illegible]	0.081	2164

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13. ABSTRACT (C) The feasibility of incorporating a follow-through shaped charge warhead in the Hornet Anti-tank Missile has been shown. The guidance system concept used with the Hornet Missile required a target seeker to be located in the forward, leading section of the missile. This requirement not only prohibits the placing of the warhead in the most orthodox location, but places an added burden on the warhead in that the seeker section must be penetrated prior to the target. The warhead design obtained from this study is capable of defeating the seeker and heavy armor. An additional advantage of the design is that a large number of 0.250-inch diameter steel balls are projected beyond the armor as follow-through particles.

(C) In this study the basis for evaluation was the effectiveness of the warhead after first defeating seeker section. To increase this effectiveness, pre-shaped follow-through fragments were incorporated in the warhead. These particles were attached to the liner between the liner and the explosive based on the concept that the particles will follow the shaped charge jet through the target perforation. The fragments projected through the perforation not only increased the beyond armor lethality, but assured the presence of lethal particles beyond the armor even when spallation is controlled.

(C) During this study it has been demonstrated that the warhead design provided from this study has a penetration capacity greater than required to penetrate that armor which is 0.99 probable of being encountered given a random hit on the presented area of interior volume of the JS/3 tank. Of the follow-through particles (0.250-inch diameter carbon steel balls) incorporated in the warhead, thirty percent can be projected beyond the target in a dispersion pattern having an included angle of greater than 70 degrees.

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[redacted] Security Classification [redacted]

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Air-to-surface						
Anti-tank						
Lined charge						
Warhead						
Follow-through						

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