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Optimized Conical Shaped Charge Design Using the SCAP Code

Manuel G. Vigil

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OPTIMIZED CONICAL SHAPED CHARGE DESIGN USING THE SCAP CODE

Manuel G. Vigil
Explosive Subsystems Division

Sandia National Laboratories
Albuquerque, NM 87185-5800

ABSTRACT

The Shaped Charge Analysis Program (SCAP) is used to analytically model and optimize the design of Conical Shaped Charges (CSC). A variety of existing CSCs are initially modeled with the SCAP code and the predicted jet tip velocities, jet penetrations, and optimum standoffs are compared to previously published experimental results. The CSCs vary in size from 0.69 inch (1.75 cm) to 9.125 inch (23.18 cm) conical liner inside diameter. Two liner materials (copper and steel) and several explosives (Octol, Comp B, PBX-9501) are included in the CSCs modeled. The target material was mild steel. A parametric study was conducted using the SCAP code to obtain the optimum design for a 3.86 inch (9.8 cm) CSC. The variables optimized in this study included the CSC apex angle, conical liner thickness, explosive height, optimum standoff, tamper/confinement thickness, and explosive width. The non-dimensionalized jet penetration to diameter ratio versus the above parameters are graphically presented.

Prepared at Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550, for the United States Department of Energy under Contract DE-AC04-76DP00789

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OPTIMIZED CONICAL SHAPED CHARGE DESIGN USING THE SCAP CODE

Introduction

The Shaped Charge Analysis Program (SCAP)¹ is used to analytically model and optimize the design of Conical Shaped Charges (CSC). SCAP is an interactive modeling code developed (Robinson, 1985) at Sandia National Laboratories for the purpose of assisting in the design of conical shaped charge components. Design requirements for Sandia applications need not correspond to typical conventional shaped charge requirements. Miniaturized components, specialized materials and non-standard designs open the way for possible unique modeling requirements. The need for an in-house Sandia code with maximum modeling flexibility and ease of use has led to the development of SCAP.

SCAP is user friendly and very inexpensive to run. It is designed for flexibility in shaped charge device configuration, choice of competing modeling techniques, and implementation of new models for various parts of conical shaped charge jet formation and penetration phenomena. The code at present contains models for liner acceleration, jet formation, jet stretching and breakup, jet penetration and confinement motion. Different models are available for some portions of the code and may be chosen via a menu format. Few *a priori* assumptions are built into the code with the intent that the program structure should allow the modeling of devices of nonstandard design. The code is conceptually simple and well structured.

The SCAP code was used to model some existing conical shaped charges (CSC) of various sizes and materials. The resultant analytical penetration versus standoff and jet tip velocities are compared to experimental data. The CSCs vary in size from 0.69 inch (1.75 cm) to 9.125 inch (23.18 cm) conical liner inside diameter. Copper and steel liner materials and Octol, Comp B and PBX-9501 explosives are included in the CSCs modeled. The target material was mild steel.

Additionally, a parameteric study was conducted with the code to determine the optimum design for a CSC with a copper liner. The CSC variables optimized in this study included liner apex angle, liner thickness, explosive height, tamper/confinement thickness, explosive width and standoff. For the optimized CSC design, jet penetration data are presented for the secondary explosives LX-13/XTX-8003, Comp B, Octol, PBX-9501, and RDX. The CSC jet penetration versus standoff data are presented for both copper and steel liners.

SCAP Theory

The basic modeling theory and format for the SCAP code are described in References 1-3. The SCAP code was developed at Sandia National Laboratories¹ to provide design guidance for CSC components. The SCAP code includes the following features:

1. Interactive,
2. Modeling flexibility,
3. Ease of use,
4. User friendly,
5. Analytical code,
6. Fortran 77 computer language,
7. Currently run on VAX computer,
8. Inexpensive (compared to hydro-codes),
9. Competing modeling techniques,
10. Liner acceleration modeling,
11. Jet formation modeling,
12. Jet stretching and breakup modeling,
13. Jet penetration modeling,
14. Tamping or confinement modeling
15. Menu format,
16. Hardcopy output listing and plotted output, and
17. Movie output of jet formation process using
DISSPLA plotting package.

The code does not include detailed equation of state material description capability. However, the code is very useful in establishing a preliminary design of a CSC and for parametric studies. Conducting parametric studies of CSC designs with hydro-codes is not normally affordable. The current version of the code is called XSCAP20 and is an updated version of the SCAP 1.0¹ version.

Background

It is assumed that the reader has some knowledge of the functioning of conical shaped charges. Chou and Flis, Reference 4, present a review of recent developments in shaped charge technology and include ninety-nine references on the theory of shaped charges.

The relatively long high velocity metallic jet produced by the explosively collapsed conical liner is useful for many applications because of its good penetration capability. CSCs have historically found utility in many applications including oil well perforating, underwater trenching, demolition, mining work, and conventional military applications requiring the penetration of various barriers.

Analytical-Experimental Comparisons

A general cross-section with the many variables required to model a CSC are shown and defined in Figure 1. The SCAP code was used to model the CSCs with liner, explosives and tamper parameters as listed in Table AI in Appendix A. The cross-sections for the CSCs listed in Table AI are shown in Figures A1-A5 in Appendix A. The SCAP input parameter data files are listed in Tables AIII - AVII. The parameters listed in Tables AIII - AVII are described and defined in Reference 1. The SCAP modeled half cross-sections (assuming symmetry) are shown in Figures A6-A10. The SCAP code jet penetration into mild steel versus standoff output are compared to experimental data in Figures A11-A15. The analytical (SCAP) data is in good agreement with the experimental data. The maximum jet penetration and optimum standoff values from Figures A11-A15 were tabulated in Table AII for the above five CSCs. The analytical-experimental values of the jet tip velocities are also listed in Table AII. The calculated and experimental jet tip velocities agree within 10%.

CSC Geometrical Parametric Study

The optimal design of a CSC can become very complex because of the many geometric material variables involved as illustrated in Figure 1. Therefore, conducting a parametric study to determine the optimum value for each of the variables shown in Figure 1 is not a trivial matter. Ideally, one would like to vary one variable at a time while holding the remaining variables constant in determining the optimum value. However, the order for varying each of the variables and the fixed value for the remaining variables is not obvious.

The procedure used to obtain the results for the parametric study was to initially fix the SCAP input variables listed in Table I. Octol is a secondary explosive with relatively high metal driving ability. Copper conical liners have a reasonably high density and are very ductile, thus producing the relatively long jets necessary for

- RLI - LINER INNER RADIUS**
- RLO - LINER OUTER RADIUS**
- RCI - CONFINEMENT/SHEATH INNER RADIUS**
- RCO - CONFINEMENT/SHEATH OUTER RADIUS**
- HI - LINER INNER HEIGHT**
- HA - LINER ACTUAL HEIGHT**
- H - LINER THEORETICAL APEX HEIGHT**
- HCI - CONFINEMENT/SHEATH INNER HEIGHT**
- HCO - CONFINEMENT/SHEATH OUTER HEIGHT**
- HE - EXPLOSIVE HEIGHT**
- HH - EXPLOSIVE HEIGHT ABOVE APEX**
- TL - LINER THICKNESS**
- TC - CONFINEMENT/SHEATH THICKNESS**
- R1 - LINER INNER APEX RADIUS**
- R2 - LINER OUTER APEX RADIUS**
- θ_1 - LINER INNER APEX HALF ANGLE**
- θ_2 - LINER OUTER APEX HALF ANGLE**
- θ_3 - CONFINEMENT/SHEATH INNER APEX HALF ANGLE**
- θ_4 - CONFINEMENT/SHEATH OUTER APEX HALF ANGLE**

Figure 1. General Conical Shaped Charge Cross-section

TABLE I.

Fixed SCAP Variables for CSC Geometrical Parameter Study

Explosive:

1. Octol
2. 1.81 g/cc
3. 0.848 cm/microsecond
4. Gurney Velocity $(2E)^{0.5} = 0.278$ cm/microsecond
5. Explosive Exponent = 2.79

Conical Liner:

1. Copper
2. Inside Cone Diameter = 9.8 cm (1 CD)
3. 8.96 g/cc
4. Bulk Sound Speed = 0.394 cm/microsecond

Target:

1. Mild Steel
2. 7.86 g/cc

Tamper/Explosive Confinement Casing:

1. Aluminum
2. 2.7 g/cc

SCAP Model Options (Reference 1)

1. Units - centimeter, gram, microsecond
2. Gurney liner acceleration (A) profile (4)
3. Gurney zoning (1) - radial zones
4. Jet collapse point (IAXIS, 2) - off axis ad hoc model (YCLPS > 0)
5. Interpolation type (IINTER, 2) - quadratic interpolation
6. Detonation modeling (ISMDDET, 1) - point detonation
7. Jet breakup modeling (IBREAK, 3) - dynamic yield stress model
8. Geometry (2) - CSC
9. Number of zones - 70
10. Cutoff ratio for no jet criteria - 1.0
11. Dynamic yield stress for jet (copper) - .0022 Mb
12. No. of coefficients to define liner - 4
13. IBREAK = 3 Coefficient - 5.0
14. No. of confinement coefficients - 8
15. Initiation point radius for CSC - 0.0
16. Total number of standoffs of interest - 20
17. Number of target layers - 1
18. Target layer UMIN - 0.14 cm/microsecond

maximum penetration. The target and tamper/confinement are arbitrarily chosen as mild steel and aluminum, respectively. The CSC inside diameter was arbitrarily chosen as 3.86 inches ($D = CD = 9.8$ cm) representing an intermediate sized CSC. Figure 2 illustrates the basic CSC cross-section configuration considered initially. The CSC parameters that were varied in this study are shown in Figure 2.

Liner Apex Angle:

Based on previous experience from experimental studies with small CSCs⁵ at Sandia National Laboratories, the following initial values for explosive height (H), liner thickness (t), tamper/confinement thickness (T_c) and explosive width (W_e) were chosen:

1. $H = 2 CD = 2D$
2. $t = 0.01 CD = 0.01D$
3. $T_c = 0.02 CD = 0.02D$
4. $W_e = \text{Liner Outside Diameter}$

The liner apex angle β was then varied between 20 and 120 degrees. The jet penetration to diameter ratio (P/D) as a function of liner apex angle (Beta) and standoff (S.O. in cone diameters) data are shown in Figure 3 and Table II. The curves for P/D versus Beta were identical for standoff (S.O.) between 4 and 6 cone diameters. Maximum P/D values then steadily decreased beyond standoffs by 6 cone diameters. The additional curves for standoffs greater than 4 cone diameters were not shown. However, for all standoffs, the optimum liner apex angle (Beta) was about 45 degrees, and this value was used for the remainder of this parametric study. Bi-conic and trumpet liner configurations⁵ have been shown to improve jet penetration, however, only conical liner geometries were considered in this study.

Liner Thickness:

The liner thickness (t) was next varied between 0.25% and 5% of the cone inside diameter (D). The resultant jet penetration to diameter ratio (P/D) versus liner thickness to diameter ratio (t/D) are shown in Figure 4. The optimum liner thickness occurs at about a value of 0.01D or about 1% of the cone diameter. The explosive width, jet penetration, optimum standoff, and jet tip velocity data are listed in Table III. The jet tip velocity versus liner thickness is shown in Figure 5.

Figure 2. Basic Conical Shaped Charge Cross-section

FIGURE 3. CONICAL SHAPED CHARGE JET PENETRATION TO DIAMETER RATIO VERSUS CONICAL LINER APEX ANGLE AND STANDOFF(S.O.)

TABLE II.

Jet Penetration Versus Standoff and Apex Angle

Jet Penetration (CD)								
Standoff (CD)	Liner Apex Angle (degrees)							
	20	30	45	60	75	90	105	120
0	2.3	2.9	3.7	2.2	1.5	1.0	0.7	0.5
1	3.8	4.0	4.7	3.8	3.0	2.3	1.9	1.5
2	4.1	4.5	5.2	4.3	3.7	3.3	2.9	2.7
3	4.5	4.8	5.5	4.6	4.0	3.6	3.2	3.0
4	4.5	4.9	5.7	4.7	4.1	3.6	3.2	2.9
6	4.4	4.9	5.7	4.7	3.9	3.3	2.8	2.3
8	4.0	4.6	5.5	4.4	3.5	2.9	2.2	1.8

CD = Liner Cone Inside Diameter (9.8 cm)

FIGURE 4. CONICAL SHAPED CHARGE JET PENETRATION TO DIAMETER RATIO
VERSUS LINER THICKNESS TO DIAMETER RATIO

TABLE III.

CSC Jet Penetration and Liner Thickness Data

CD = Cone Inside Diameter (9.8 cm)

Optimum Standoff = 52.6 cm (8.4 CD)

<u>LINER THICKNESS</u>		<u>JET PENETRATION</u>		<u>JET TIP VELOCITY</u>
(cm)	(CD)	(cm)	(CD)	(cm/ μ S)
.0246	.0025	39.0	3.97	.833
.0492	.0050	49.7	5.06	.842
.0980	.0100	56.5	5.75	.799
.1970	.0200	51.3	5.22	.675
.2950	.0300	46.7	4.75	.602
.3930	.0400	42.9	4.36	.551
.4920	.0500	39.4	4.00	.511

FIGURE 5. CONICAL SHAPED CHARGE JET TIP VELOCITY VERSUS LINER THICKNESS TO DIAMETER RATIO

Explosive Height:

Using a liner apex angle of 45 degrees and a liner thickness of $0.01D$, the explosive height (H) was varied between $0.5D$ and $3D$. The resultant P/D versus H/D data are shown in Figure 6. The jet penetration increases as the explosive height increases, however, there is no significant increase in jet penetration for explosive heights greater than about $1.5D$. Therefore, a value for H of $1.5D$ to $2D$ appears to be sufficient. The explosive height, jet penetration, and jet tip velocity are listed in Table IV. The jet tip velocity does not vary significantly with explosive height. In the SCAP code, the explosive height only effects the liner collapse angle. The smaller values of H result in larger collapse angles and, therefore, lower jet tip velocities.

Tamper/Confinement Thickness:

Using a liner apex angle of 45 degrees, liner thickness of $0.01D$ (1%), and an explosive height of ($2D$), the aluminum tamper/confinement thickness (T_c) was varied from 0 to $0.09D$. The resultant P/D versus T_c/D data are shown in Figure 7. The jet penetration increases as the tamper thickness increases, however, there is only a 4% increase of P/D for a tamper thickness increase from 0 to $0.09D$. The tamper thickness and jet penetration data are listed in Table V. The jet tip velocity did not vary significantly. The weight penalty using a very thick tamper could not be justified for the relatively small increase in P/D . A minimum rigid casing is, however, necessary to house the explosive and attach to the liner and to survive environmental requirements. Therefore, a tamper thickness of $0.02D$ was chosen.

Explosive Width:

Using a liner apex angle (Beta) of 45 degrees, liner thickness (t) of $0.01D$, explosive height (H) of $2D$, and a tamper thickness (T_c) of $0.02D$, the explosive width (W_e) was varied from $1.05D$ to $1.41D$. The resultant P/D versus W_e/D data are shown in Figure 8. The P/D values increase significantly (38%) from 5.8 to 8 for W_e/D values from $1.05D$ to $1.41D$, respectively. Therefore, the value of W_e selected will be more dependant on explosive and total component weight and shock-shrapnel constraints. The explosive width, jet penetration, optimum standoff and jet tip velocity values are listed in Table VI. The jet tip velocity (V_j) versus explosive width to diameter ratio (W_e/D) data are shown in Figure 9. For values of (W_e/D) > 1 , significant forward explosive detonation gas product venting could occur which might degrade the performance of Gurney modeling. Therefore, the significant gain in penetration for larger W_e/D values may not be realized.

FIGURE 6. CONICAL SHAPED CHARGE JET PENETRATION TO DIAMETER RATIO
 VERSUS EXPLOSIVE HEIGHT TO DIAMETER RATIO

TABLE IV.

CSC Jet Penetration and Explosive Height Data

CD = Cone Inside Diameter (9.8 cm)

Optimum Standoff = 52.6 cm (8.4 CD)

<u>EXPLOSIVE HEIGHT</u>		<u>JET PENETRATION</u>		<u>JET TIP VELOCITY</u>
(cm)	(CD)	(cm)	(CD)	(cm/ μ S)
4.9	0.5	38.9	3.96	.777
9.8	1.0	53.2	5.41	.831
14.7	1.5	56.9	5.79	.832
19.6	2.0	57.5	5.85	.832
26.5	2.5	57.6	5.86	.840
29.4	3.0	57.6	5.86	.843
49.0	5.0	57.0	5.80	.845

FIGURE 7. CONICAL SHAPED CHARGE JET PENETRATION TO DIAMETER RATIO
VERSUS TAMPER THICKNESS TO DIAMETER RATIO

TABLE V.

CSC Jet Penetration and Tamper Case Thickness Data

Explosive length = 2 CD = 19.66 cm,

CD = Cone Inside Diameter (9.8 cm)

Jet Tip Velocity = (0.837 - 0.844 cm/microsecond)

Tamper Thick		Jet Penetration	
(cm)	(CD)	(cm)	(CD)
.0005	.00005	57.3	5.83
.0050	.00050	57.4	5.83
.0898	.00910	57.6	5.84
.1290	.01300	57.4	5.86
.2230	.02300	58.3	5.93
.8680	.08800	60.1	6.11

FIGURE 8. CONICAL SHAPED CHARGE JET PENETRATION TO DIAMETER RATIO
 VERSUS EXPLOSIVE WIDTH TO DIAMETER RATIO

TABLE VI.

CSC Jet Penetration and Explosive Width Data
CD = Cone Inside Diameter (9.8 cm)

<u>EXPLOSIVE HEIGHT</u>		<u>JET PENETRATION</u>		<u>OPTIMUM STANDOFF</u>		<u>JET TIP VELOCITY</u>
(cm)	(CD)	(cm)	(CD)	(cm)	(cd)	(cm/ μ S)
10.2	1.04	56.9	5.79	52.6	5.35	0.805
10.5	1.07	58.6	5.96	52.6	5.35	0.810
11.0	1.12	61.6	6.27	63.2	6.43	0.818
11.5	1.17	64.6	6.57	63.2	6.43	0.826
12.0	1.22	67.6	6.88	63.2	6.43	0.833
14.0	1.42	75.8	7.99	105.0	10.6	0.855

FIGURE 9. CONICAL SHAPED CHARGE JET TIP VELOCITY VERSUS
 EXPLOSIVE WIDTH TO DIAMETER RATIO

Summary of Geometrical Parameters Study

The geometrically optimized CSC for the fixed parameters listed in Table I should be configured as shown in Figure 10. The 1.21D vertical height for the tamper and 22.5 degree upper taper of the tamper were found to be near optimum if a centered single point detonation of the explosive is assumed.

Using a copper liner, a secondary explosive with properties similar to Octol, and an aluminum (or some equivalent weight and thickness of a different material) tamper, the optimized configuration shown in Figure 10 can be scaled to any diameter CSC desired to obtain scaled penetrations into mild steel targets. Dimensional analysis and similarity methods ⁶⁻¹¹ have been used to derive scaling laws that are commonly accepted and have been verified experimentally.

Different CSC Liner Materials

The optimized CSC configuration shown in Figure 10 was used to briefly investigate the effect of liner material. The CSC cone diameter was fixed at 3.86 inch (9.8 cm). Copper and steel liners were evaluated. The jet penetration to diameter ratio (P/D) versus standoff to diameter ratio are compared for copper and steel liners in Figure 11. Density, bulk sound speed, maximum jet penetration, optimum standoff, and jet tip velocity are compared for copper and steel liners in Table VII. Larger liner densities relative to the target density have been demonstrated ¹ to produce greater jet penetrations for equal jet tip velocities and jet lengths. However, the higher liner densities usually result in larger liner mass to explosive ratios and, therefore, lower conical liner collapse velocities which produce lower jet tip velocities and potentially less penetration.

Since only a relatively small percentage of the liner thickness forms the high velocity penetrating jet,⁵ high density material (platinum, gold, etc.) plating of low density (aluminum for example) material would be very desirable.³ This would produce a multi-layered liner³ which would be much more efficient for a given CSC configuration. However, the cost of materials and liner forming processes usually prohibit the use of multi-layered liners. The use of single layered liners of depleted uranium and tantalum has been shown to be very effective. More dense liners than copper or steel were not evaluated because a good estimate of the minimum jet penetration velocities for those materials in steel or other targets were not available. The XSCAP20 code is currently being improved to include jet-target yield strength models that will not require the minimum jet penetration velocity as input.

FIGURE 11. CONICAL SHAPED CHARGE JET PENETRATION TO DIAMETER RATIO VERSUS STANDOFF TO DIAMETER RATIO

TABLE VII.
Copper Versus Steel Liner Data
CD = D = 9.8 cm, Octol Explosive, Aluminum Tamper
Configuration - Figure 10

Liner Material	Density (g/CC)	Bulk Sound Speed (cm/ μ S)	Max Jet Penetration (cm) (CD)		Optimum Standoff (cm) (CD)		Jet Tip Velocity (cm/ μ S)	SCAP Variables		
								TBCON	YLIN	UMIN (cm/ μ S)
Copper	8.96	0.394	56.8	5.8	52.6	5.4	0.805	5	.0022	.14
Steel	7.86	0.456	43.1	4.4	42.5	4.3	0.826	7	.0079	.14

TBCON - Jet breakup - yield stress model constant

YLIN - Dynamic yield stress of jet material

UMIN - Minimum jet penetration velocity

Different CSC Explosives

The explosives listed in Table VIII were modeled in the CSC configuration shown in Figure 10. The SCAP input parameters required are also listed in Table VIII. The jet penetration to diameter ratio (P/D) versus Gurney Velocity¹² (explosive ability to drive metal) data are shown in Figure 12 for the different explosives listed in Table VIII. Clearly, the higher the Gurney velocity, the larger the jet penetration. The P/D versus jet tip velocity (V_j) data are shown in Figure 13 for the same explosives. Again, the higher the jet tip velocity the larger the jet penetration. The P/D versus jet tip to Gurney velocity ratio (V_j/V_g) are illustrated in Figure 14. The higher (V_j/V_g) ratios produce the larger jet penetration.

SCAP Code Sample Output

A sample graphic output for the 3.86 inch (9.8 cm) diameter CSC is included in Appendix B. The initial cross-section modeled in SCAP code is illustrated in Figure B1. Tamper and liner material velocities versus initial material position are shown in Figures B2 and B3. The accumulated jet mass, momentum, kinetic energy and breakup time versus jet velocity are shown in Figures B4 - B7. Jet penetration versus time and velocity are shown in Figures B8 - B12 for standoffs of 0, 21.1, 63.2, 105, and 189 cm, respectively. The detonation wave propagation, conical liner collapse, jet and slug formation, and tamper-explosive detonation product gas expansion are graphically illustrated in Figures B13 - B16. A description of some of the CSC/jet parameter data found in Appendix B is presented in Reference 1. Several graphs are new and have never been documented.

Conclusions

The SCAP code has been shown to be a useful tool in the design of conical shaped charges (CSC). Parametric studies of CSC designs can be quickly and inexpensively conducted with the SCAP code. The code generated jet penetration versus standoff and jet tip velocity were shown to compare well with experimental data.

The CSC geometrical parametric study for a copper liner, aluminum tamper, and a secondary explosive (Octol) produced the following optimal CSC design parameters relative to the conical liner inside diameter (D):

1. Apex angle = 45 degrees,
2. Liner thickness = $0.01D$,
3. Explosive height = $(1.5D - 2D)$,
4. Tamper thickness = $0.02D$,
5. Explosive width = $(1D - 1.4D)$
6. Optimum standoff = $(2D-6D)$

Using similar liner, explosive and tamper materials, the optimal geometry shown in Figure 10 can be scaled to any diameter (D) CSC to produce a scaled jet penetration in mild steel targets.

TABLE VIII.

Conical Shaped Charge Explosive Parameters

Explosive	Density (g/cc)	D_e (cm/ μ S)	V_g (CM/ μ S)	Gamma	V_g/D_e
LX-13	1.53	0.726	0.240	2.77	0.331
Octol	1.81	0.848	0.278	2.79	0.328
Comp B	1.72	0.802	0.272	2.76	0.339
PBX-9501	1.84	0.883	0.290	2.66	0.328
RDX	1.80	0.880	0.286	2.82	0.325

D_e = Detonation velocity
 $V_g = (2E)^{0.5}$ = Gurney velocity
 gamma = Explosive Exponent

FIGURE 12. CONICAL SHAPED CHARGE JET PENETRATION TO DIAMETER RATIO VERSUS GURNEY VELOCITY AND EXPLOSIVE

FIGURE 13. CONICAL SHAPED CHARGE JET PENETRATION TO DIAMETER RATIO VERSUS JET TIP VELOCITY AND EXPLOSIVE

FIGURE 14. CONICAL SHAPED CHARGE JET PENETRATION TO DIAMETER RATIO
VERSUS JET TO GURNEY VELOCITY AND EXPLOSIVE

TABLE IX.

Conical Shaped Charge Jet Penetration versus Standoff and Explosive Data

Liner: Copper, 45 degree apex angle, .098 in thick, 8.90 g/cc, 9.8 cm I.D.
 Tamper: Aluminum, 2.7 g/cc,
 Target: Milt Steel, 7.86 g/cc
 CD = Cone Inside Diameter (9.8 cm)

Explosive	V_g (g/cc)	V_j (cm/ μ S)	Jet Penetration		Optimum Standoff		V_j/V_g
			(CM)	(CD)	(cm)	(CD)	
LX-13	0.240	0.650	42.6	4.33	42.1	4.28	2.708
Comp B	0.272	0.749	51.4	5.23	52.6	5.35	2.754
Octol	0.278	0.787	54.3	5.52	52.6	5.35	2.831
RDX	0.286	0.814	56.3	5.73	52.6	5.35	2.846
PBX-9501	0.290	0.812	56.3	5.72	52.6	5.35	2.800

$V_g = (2E)^{0.5} =$ Gurney velocity

$V_j =$ Jet tip velocity

APPENDIX A

Section I. Selected CSC Analytical Experimental Parameters

Section II. SCAP Input Parameter Data File

Section III. CSC Cross-sections

Section IV. SCAP Model of Cross-section

**Sectuib V. SCAP Code Jet Penetration Versus Standoff
Output Compared to Experimental Data**

APPENDIX A

Section I

Selected CSC Analytical-Experimental Parameters

TABLE A I.

Conical Shaped Charge (CSC) Measured Parameters

LINER					EXPLOSIVE				TAMPER	
<u>D</u> <u>(in)</u>	<u>Material</u>	<u>Thick</u> <u>(in)</u>	<u>Apex</u> <u>Angle</u> <u>(deg)</u>	<u>Height</u> <u>(in)</u>	<u>Type</u>	<u>Weight</u> <u>(lb)</u>	<u>Dia</u> <u>(in)</u>	<u>Height</u> <u>(in)</u>	<u>Material</u>	<u>Thick</u> <u>(in)</u>
0.690	COPPER	.030	42	1.10	PBX-9501	0.60	.69	1.51	PMMA	.250
3.230	COPPER	.081	42	3.84	OCTOL	1.90	3.20	5.51	AL	.090
3.860	COPPER	.082	42	4.75	OCTOL	3.54	3.86	7.45	AL	.080
4.660	COPPER	.105	60	4.10	OCTOL	5.33	4.87	6.70	AL	.065
9.125	STEEL	.158	60	7.25	COMP B	30.00	9.13	15.50	STEEL	.024

TABLE A II.

Conical Shaped Charge (CSC) Analytical (SCAP) - Experimental Parameters

D (in.)	Tip Velocity (in/ μ s)		OSO (in.)		P (in)	
	Meas.	SCAP	Meas.	SCAP	Meas.	SCAP
.690	0.620	.564	*	16.0	*	14.5
3.200	0.838	.800	20.5	17.7	17.5	18.1
3.860	*	.837	30.0	20.7	22.5	22.6
4.660	*	.775	32.0	24.9	25.0	24.3
9.125	0.700	.694	*	31.0	30.0	29.7

- * - No data available
D - CSC Conical liner inside diameter
OSO - Optimum Standoff
P - CSC jet penetration

APPENDIX A

Section II

**SCAP Input Parameter Data Files
(Detailed discussion in Reference 1)**

TABLE AIII.

3.86 Inch I.D. CSC SCAP Input Data File

7-JUN-88 - 14:28:31 - XSCAP 2.0

```

INPUT DECK -          DRAG42CUST.DAT  THIS FILE -          DRAG42CUST.LIS

MASS      LENGTH      TIME      IACCEL IGURZN  IAXIS IINTER ISMDET IBREAK
GM         CM         MICROSEC      4      1      2      2      1      3

IGEOM  NZ      ETYPE      DEXP      VDET      RT2E      GAMMA
  2  70 OCTOL      1.810E+00 8.480E-01 2.780E-01 2.790E+00

      DLIN      VBLKL      CUTJET      TB      T1      YLIN      NL      TBCON
  8.960E+00 3.940E-01 1.000E+00 1.250E+02 2.250E+02 2.200E-03      4 5.000E+00
LINER PARAMETERS
  2.250E+01 4.902E+00 2.250E+01 5.105E+00

      DCON      NC
  2.700E+00      4
CONFINEMENT PARAMETERS
  0.000E+00 5.105E+00 0.000E+00 5.105E+00

      HDET      RDET      H      SOFMIN      SOFMAX      NSOFF      NTL
  1.960E+01 0.000E+00 1.232E+01 0.000E+00 2.000E+02      20      1

      DTAR      THICK      UMIN      HOLEC      VMIN
  7.860E+00 8.500E+01 1.400E-01 5.400E+00 0.000E+00

CPRINT  CPLIT  CSHADE  CMOVIE  XMAX      XMIN      YMAX      XYFAC
PRINT   NOPLT  SPARSE  NOMOVIE  3.784E+01-7.070E+00 1.041E+01 1.000E+00

CSETUP  CCNVEL  CJTVEL  CAJTMS  CAJTMM  CAJTKE  CBREAK  CPNSFF
NOPLT   NOPLT  NOPLT  NOPLT  NOPLT  NOPLT  NOPLT  NOPLT

CPDETL  CSOUT*  *      *      *      *
NONE

CSNPST  NPP      TOUT
NOSNAP  0      2.000E+01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

```

TABLE A IV.

4.66 Inch I.D. CSC SCAP Input Data File

7-JUN-88 - 14:35:38 - XSCAP 2.0

```

INPUT DECK -      TOW80CUST.DAT  THIS FILE -      TOW80CUST.LIS

MASS      LENGTH  TIME      IACCEL IGURZN  IAXIS  IINTER ISMDET IBREAK
GM         CM      MICROSEC      4      1      2      2      1      3

IGEOM  NZ      ETYPE      DEXP      VDET      RT2E      GAMMA
  2  70 OCTOL      1.010E+00 8.480E-01 2.800E-01 3.070E+00

      DLIN      VBLKL      CUTJET      TB      T1      YLIN      NL      TBCON
8.960E+00 3.940E-01 1.000E+00 1.700E+02 2.250E+02 2.200E-03      4 5.000E+00
LINER PARAMETERS
3.000E+01 0.185E+00 3.000E+01 0.350E+00

      DCON      NC
2.700E+00      8
CONFINEMENT PARAMETERS
0.000E+00 0.450E+00 0.000E+00 0.704E+00 1.700E+01 1.700E+01 2.100E+01 2.100E+01

      HDET      RDET      H      SOFMIN      SOFMAX      NSOFF      NTL
2.360E+01 0.000E+00 1.100E+01 0.000E+00 2.000E+02      20      1

      DTAR      THICK      UMIN      HOLEC      VMIN
7.860E+00 9.500E+01 1.400E-01 5.400E+00 0.000E+00

CPRINT  CPLOT  CSHADE  CMOVIE  XMAX      XMIN      YMAX      XYFAC
PRINT   PLOT   SPARSE  NOMOVIE 3.940E+01-8.990E+00 1.270E+01 1.000E+00

CSETUP  CCNVEL  CJTVEL  CAJTMS  CAJTM  CAJTKE  CBREAK  CPNSFF
PLOT    NOPLOT NOPLOT  NOPLOT NOPLOT NOPLOT  NOPLOT  NOPLOT

CPDETL  CSOUT*  *      *      *      *
NONE

CSNPST  NPP      TOUT
NOSNAP  0      0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

```

TABLE AV.

9.125 Inch I.D. CSC SCAP Input Data File

M3STEEL.DAT - 7-JUN-88 - 14:40:52 - XSCAP 2.0

```

INPUT DECK -      M3STEEL.DAT      THIS FILE -      M3STEEL.LIS

MASS      LENGTH  TIME      IACCEL IGURZN  IAXIS  IINTER ISMDET IBREAK
GM         CM      MICROSEC    4        1        2        2        1        3

IGEOM  NZ      ETYPE      DEXP      VDET      RT2E      GAMMA
  2   52  COMP  8      1.720E+00  7.990E-01  2.680E-01  2.990E+00

      DLIN      VBLKL      CUTJET      TB      T1      YLIN      NL      TBCON
  7.860E+00  4.570E-01  1.000E+00  2.250E+02  2.250E+02  7.900E-03      4  7.000E+00
LINER PARAMETERS
  3.000E+01  1.205E+01  3.000E+01  1.251E+01

      DCON      NC
  7.860E+00      8
CONFINEMENT PARAMETERS
  0.000E+00  1.251E+01  0.000E+00  1.258E+01  1.760E+01  1.762E+01  3.000E+01  3.000E+01

      HDET      RDET      H      SOFMIN      SOFMAX      NSOFF      NTL
  3.050E+01  0.000E+00  1.850E+01  0.000E+00  2.500E+02      20      1

      DTAR      THICK      UMIN      HOLEC      VMIN
  7.860E+00  1.000E+02  1.700E-01  5.400E+00  0.000E+00

CPRINT  CPLLOT  CSHADE  CMOVIE  XMAX      XMIN      YMAX      XYFAC
PRINT   PLOT   SPARSE  NOMOVIE  6.574E+01 -1.120E+01  2.510E+01  1.000E+00

CSETUP  CCNVEL  CJTVEL  CAJTMS  CAJTMM  CAJTKE  CBREAK  CPNSFF
PLOT    NOPLLOT NOPLLOT NOPLLOT NOPLLOT NOPLLOT NOPLLOT NOPLLOT

CPDETL  CSOUT*  *   *   *   *
NONE

CSNPST  NPP      TOUT
NOSNAP  0        0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00

```

TABLE A VI.

3.23 Inch I.D. SCAP Input Data File

302CU42ST.DAT - 7-JUN-88 - 14:42:50 - XSCAP 2.0

```

INPUT DECK -          302CU42ST.DAT   THIS FILE -          302CU42ST.LIS

MASS      LENGTH  TIME      IACCEL IGURZN  IAXIS IINTER ISMDET IBREAK
GM         CM      MICROSEC      4      1      2      2      1      3

IGEOM  NZ      ETYPE      DEXP      VDET      RT2E      GAMMA
  2  39 OCTOL      1.810E+00 8.480E-01 2.780E-01 2.770E+00

      DLIN      VBLKL      CUTJET      TB      T1      YLIN      NL      TBCON
  8.960E+00 3.940E-01 1.000E+00 1.030E+02 1.030E+02 2.200E-03      4 5.000E+00
LINER PARAMETERS
  2.100E+01 4.102E+00 2.100E+01 4.318E+00

      DCON      NC
  2.700E+00      8
CONFINEMENT PARAMETERS
  0.000E+00 4.318E+00 0.000E+00 4.547E+00 9.700E+00 1.089E+01 2.100E+01 2.100E+01

      HDET      RDET      H      SOFMIN      SOFMAX      NSOFF      NTL
  1.397E+01 0.000E+00 1.112E+01 0.000E+00 1.400E+02      20      1

      DTAR      THICK      UMIN      HOLEC      VMIN
  7.800E+00 6.000E+01 1.400E-01 5.400E+00 0.000E+00

CPRINT  CPLOT  CSHADE  CMOVIE  XMAX  XMIN  YMAX  XYFAC
PRINT   PLOT   SPARSE  NOMOVIE  2.794E+01-2.720E+00 9.094E+00 1.000E+00

CSETUP  CCNVEL  CJTVEL  CAJTMS  CAJTM  CAJTKE  CBREAK  CPNSFF
PLOT    NOPLOT  PLOT    NOPLOT  NOPLOT  NOPLOT  NOPLOT  NOPLOT

CPDETL  CSOUT*  *      *      *      *
NONE

CSNPST  NPP      TOUT
NOSNAP  0        1.500E+01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

```

TABLE A VII.

0.69 Inch I.D. SCAP Input Data File

69CU42STPB.DAT - 7-JUN-88 - 14:44:18 - XSCAP 2.0

```

INPUT DECK -      69CU42STPB.DAT  THIS FILE -      69CU42STPB.LIS

MASS      LENGTH  TIME      IACCEL IGURZN  IAXIS  IINTER ISMDET IBREAK
GM         CM      MICROSEC      4      1      2      2      1      3

IGEOM  NZ      ETYPE      DEXP      VDET      RT2E      GAMMA
  2  20 PBX9501  1.840E+00 8.830E-01 2.860E-01 2.860E+00

      DLIN      VBLKL      CUTJET      TB      T1      YLIN      NL      TBCON
8.980E+00 3.940E-01 1.000E+00 2.800E+01 1.000E+04 2.200E-03      4 5.000E+00
LINER PARAMETERS
2.100E+01 9.340E-01 2.100E+01 1.010E+00

      DCON      NC
1.180E+00      8
CONFINEMENT PARAMETERS
0.000E+00 1.270E+00 0.000E+00 1.905E+00 1.600E+00 3.980E+00 2.100E+01 0.000E+00

      HDET      RDET      H      SOFMIN      SOFMAX      NSOFF      NTL
3.980E+00 0.000E+00 2.200E+00 0.000E+00 4.000E+01      20      1

      DTAR      THICK      UMIN      HOLEC      VMIN
7.860E+00 2.000E+01 1.400E-01 5.000E+00 0.000E+00

CPRINT  CPlot  CSHADE  CMOVIE  XMAX      XMIN      YMAX      XYFAC
PRINT   PLOT   SPARSE  NOMOVIE  0.000E+00 0.000E+00 0.000E+00 0.000E+00

CSETUP  CCNVEL  CJTVEL  CAJTMS  CAJTM  CAJTKE  CBREAK  CPNSFF
PLOT    NOPLT   PLOT    NOPLT   NOPLT   NOPLT   NOPLT   NOPLT

CPDETL  CSOUT*  *      *      *      *
NONE

CSNPST  NPP      TOUT
NOSNAP  0      0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

```


APPENDIX A

Section III

Selected CSC Cross-sections

Figure A1. 3.86 Inch Diameter CSC Cross-Section

Figure A2. 4.66 Inch Diameter CSC Cross-Section

Figure A 3. M3 9.125 Inch Diameter CSC Cross-Section

Figure A4. 3.23 Inch Diameter Conical Shaped Charge Cross-section

Figure A5. 0.69 Inch Diameter CSC Cross-section

APPENDIX A

Section IV

SCAP CSC Modeling Cross-sections

Figure A6. 3.86 Inch I.D. CSC

Figure A7. 4.87 Inch I.D. CSC

Figure A8. M3 9.125 Inch I.D. CSC

Figure A9. 3.23 Inch I.D. CSC

Figure A10. 0.69 Inch I.D. CSC

APPENDIX A

Section V

SCAP Code Jet Penetration Versus Standoff Output Compared to Experimental Data

Figure A11. CSC Jet Penetration Versus Standoff Analytical-Experimental Comparison

Figure A12. CSC Jet Penetration Versus Standoff Analytical-Experimental Comparison

Figure A13. M3 CSC Jet Penetration Versus Standoff Analytical-Experimental Comparison

Figure A15. .69 Inch Diameter CSC Jet Penetration Versus Standoff
Analytical-Experimental Comparison

APPENDIX B

Sample SCAP Code Graphical Output of Selected CSC

Figure B1. CSC XCAP Code Modeling Cross-Section

7-JUN-88 - 14:47:31 - XSCAP 2.0

Figure B2. Tamper Case Velocity Versus Case Initial Position

Figure B3. Material Velocities Versus Initial Liner Height Position

7-JUN-88 - 14:47:31 - XSCAP 2.0

Figure B4. Jet Mass Versus Jet Velocity

Figure B5. Jet Momentum Versus Jet Velocity

7-JUN-88 - 14:47:31 - XSCAP 2.0

Figure B6. Jet Kinetic Energy Versus Jet Velocity

7-JUN-88 - 14:47:31 - XSCAP 2.0

Figure B7. Jet Breakup Time Versus Jet Velocity

7-JUN-88 - 14:47:31 - XSCAP 2.0
PENETRATION AT 0.000E+00 (CM) STANDOFF

Figure B8. Jet Penetration Versus Time and Velocity at Zero CM Standoff

7-JUN-88 - 14:47:31 - XSCAP 2.0
PENETRATION AT 21.1 (CM) STANDOFF

Figure B9. Jet Penetration Versus Time and Velocity at 21.1 CM Standoff

7-JUN-88 - 14:47:31 - XSCAP 2.0
PENETRATION AT 63.2 (CM) STANDOFF

Figure B10. Jet Penetration Versus Time and Velocity at 63.2 CM Standoff

Figure B11. Jet Penetration Versus Time and Velocity at 105 CM Standoff

7-JUN-88 - 14:47:31 - XSCAP 2.0
 PENETRATION AT 189. (CM) STANDOFF

Figure B12. Jet Penetration Versus Time and Velocity at 189 CM Standoff

Figure B13. Detonation Wave at Liner Apex

7-JUN-88 - 14:05:16 - XSCAP 2.0
TIME = 20.0 MICROSEC

Figure B14. Detonation Process Almost Completed

Figure B15. Jet, Slug, Detonation Product Gases at 60 Microseconds

7-JUN-88 - 14:05:16 - XSCAP 2.0
TIME = 100. MICROSEC

Figure B16. CSC Jet at Near Maximum Length

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2513	T. L. Garcia	7133	S. R. Kurowski
2514	P. L. Stanton	7170	R. D. Bentley
2514	L. L. Bonzon	7173	G. L. West
2515	P. D. Wilcox	7173	H. D. Smith
2515	M. R. Kopczewski	7533	F. H. Mathews
2542	W. N. Sullivan	7533	J. P. Weber
2600	L. D. Bertholf	7535	D. C. Bickel
3141	S. A. Landenberger (5)	8524	P. W. Dean
3151	W. I. Klein (3)		