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DESIGN AND DEVELOPMENT OF PRECISION LINEAR SHAPED CHARGES

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The Precision Linear Shaped Charge (PLSC) design concept involves the independent fabrication and assembly of the liner (wedge of PLSC), the tamper/confinement, and explosive. The liner is the most important part of an LSC and should be fabricated by a more quality controlled, precise process than the tamper material. Also, this allows the liner material to be different from the tamper material. The explosive can be loaded into the liner and tamper as the last step in the assembly process rather than the first step as in conventional LSC designs. PLSC designs are shown to produce increased jet penetrations in given targets, more reproducible jet penetration, and more efficient explosive cross-sections using a minimum amount of explosive. The Linear Shaped Charge Analysis Program (LSCAP) being developed at Sandia National Laboratories has been used to assist in the design of PLSCs. LSCAP predictions for PLSC jet penetration in aluminum targets, jet tip velocities and jet-target impact angles are compared to measured data.

INTRODUCTION

Sandia National Laboratories (SNL)[1] is involved in the design of linear shaped charge (LSC) components varying in size from 10 to 300 grains per foot. These LSC components are required to perform such functions as rocket stage separation, parachute deployment, parachute system release, flight termination, system destruct and disablement. Most of the LSC components for these systems require precise and reproducible jet penetration using the minimum explosive and total component weights.

Sandia National Laboratories is currently involved in a task to design Precision Linear Shaped Charges (PLSC).[2-5] The sweeping detonation and 3-dimensional collapse process of an LSC is a complex phenomenon. The Linear Shaped Charge Analysis Program (LSCAP) is being developed at SNL to assist in the design of PLSC components. Analytical output from the LSCAP code is presented and compared to experimental data for various PLSC designs in the 20 to 25 grain per foot explosive loading range. The LSCAP code models the motion of the LSC liner elements due to explosive loading, jet and slug formation, jet breakup, and target penetration through application of a series of analytical approximations which are extensions of the standard 1-dimensional modeling techniques for conical shaped charges. The structure of the code is intended to allow flexibility in LSC design, target configurations and in modeling techniques.

MASTER

The analytical and experimental data presented includes LSC jet penetration in aluminum targets as a function of standoff, jet tip velocities and jet-target impact angles. The measured velocity and angle data were obtained using a Cordin Model 114 rotating mirror, camera at a turbine speed resulting in a 0.918-microsecond interframe time.

GENERAL LINEAR SHAPED CHARGE

The parameters or variables for a general linear shaped charge cross-section are illustrated in Figure 1. The large number of variables defining a cross-section makes the design of "the" optimum LSC a very difficult task.

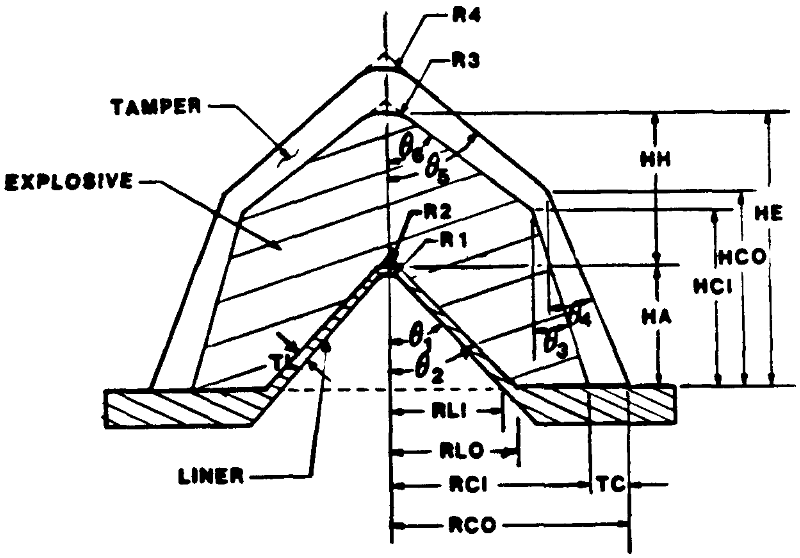

Figure 1. LSC Cross-Section Variables

The generic operational characteristics[3-8] of an LSC are shown in Figure 2.

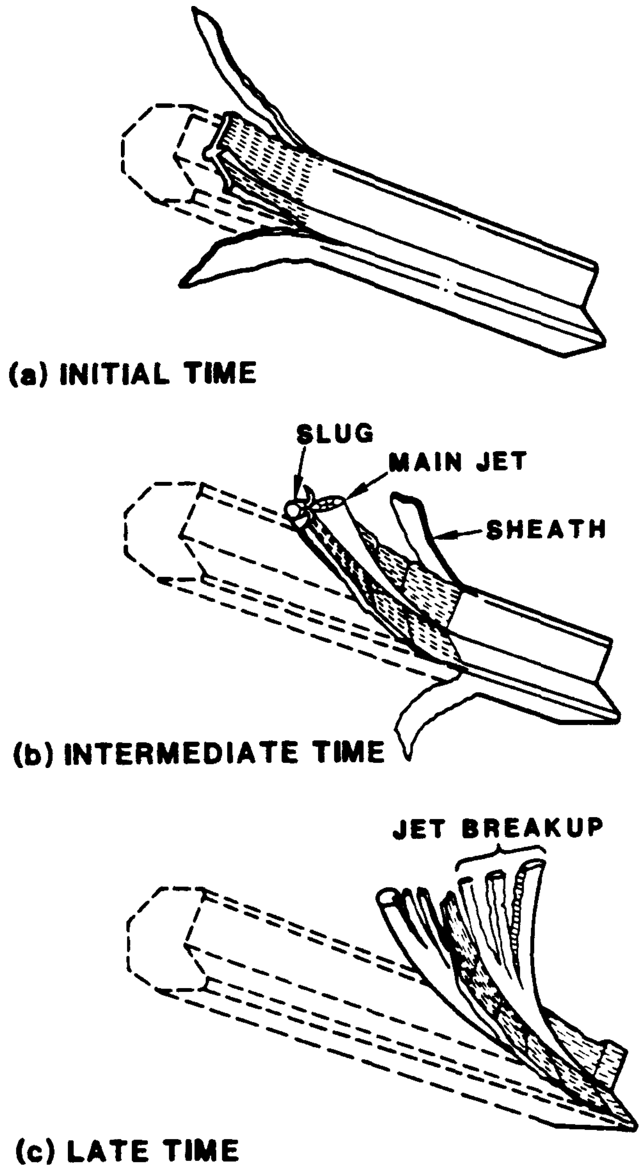

Figure 2. LSC Collapse and Jetting

A metal tube or sheath containing explosive is formed so that a wedge is created on one side. The LSC is typically point or end initiated and a detonation wave propagates along the axis. The wedge collapses on itself and forms a high velocity sheet of jet particles. In general the jet particles are not projected perpendicular to the original direction of the liner nor is the particle velocity perpendicular to the jet front.

The leading, relatively high velocity (3-5 mm/μs), main jet produces most of the jet penetration into the target. The slower (1-1.5 mm/μs), rear jet or slug is usually found embedded in the cavity generated in the target by the main jet. Severance of a finite thickness target results from both the penetration of the main jet and the fracture of the remaining target thickness. The fractured portion of the severed thickness usually varies and can be up to 50% depending on the target strength parameters.

CONVENTIONAL LINEAR SHAPED CHARGE

Typically, conventional LSCs are fabricated by loading a cylindrical tube with granular explosives, and then roll or swage forming the loaded tube to the familiar chevron configuration illustrated in Figure 3.

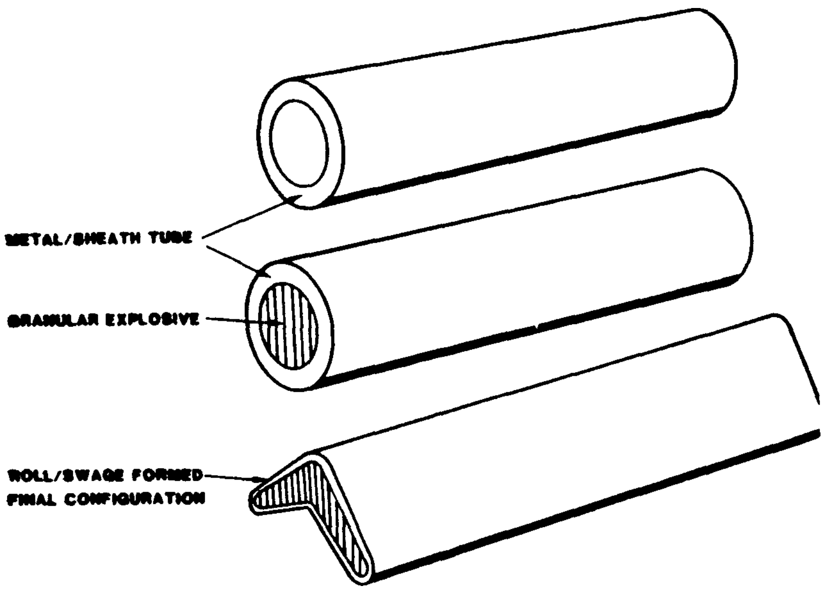

Figure 3. Conventional LSC Fabrication

Some of the disadvantages of conventional LSC designs are as follows:

1. Non-symmetrical cross-section,
2. Non-uniform explosive density,
3. Non-optimized explosive and sheath cross-sections, and
4. Historically designed for non-precise jet cutting.

The explosive and sheath cross-section of a conventional 25 grain per foot, aluminum sheathed LSC loaded with HNS II explosive is shown in Figure 4. Figure 5 illustrates the test to test variations in jet penetration of an aluminum target for the 25 grain per foot LSC shown in Figure 4.

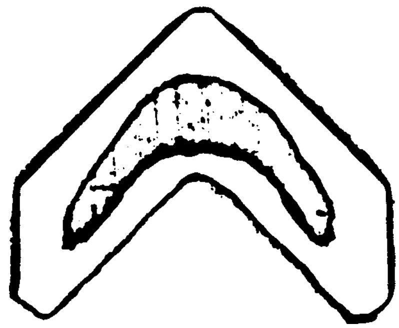

Figure 4. 25 gr/ft, HNS II, Al Sheathed LSC

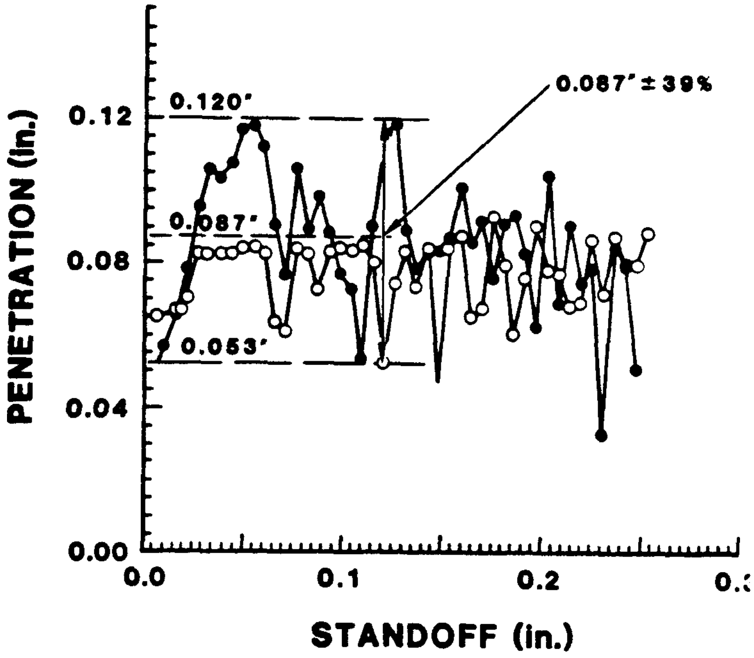

Figure 5. Reproducibility of 25 gr/ft LSC

PRECISION LINEAR SHAPED CHARGE

For PLSC the liner, explosive, and tamper materials can be assembled as illustrated in Figure 6.

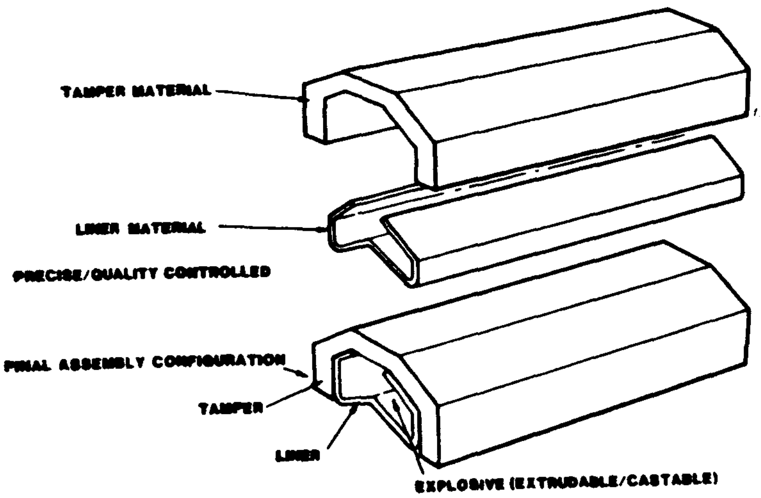

Figure 6. PLSC Fabrication

The liner, tamper and explosive are manufactured independently to allow the required control of fabrication methods which result in a more precise component. The quality control of the liner is most important in the performance of LSC devices.

An extrudable or castable explosive is loaded or assembled with the liner and tamper components after these other two components are fabricated. The explosive can be loaded using single or multiple extrusions or by "buttering," a "toothpaste" like application technique, if necessary. Assembly aids, such as the use of vacuum are also useful.

The LSCAP code has been used to improve the PLSC parameters. The explosive charge to liner mass ratio can be designed to optimize the transfer of energy from the detonation wave through the liner to the high-velocity jet. The explosive charge to tamper mass ratio can be designed to optimize the tamper material and thickness. The maximum tamper thickness is defined as that thickness beyond which no additional gain in the liner collapse velocity is obtained. The tamper can be made of a different material than that for the liner in order to:

1. Fit different configurations,
2. allow for buttering of explosive,
3. allow selection of tamping characteristics in material,
4. allow for built-in shock mitigation properties, and
5. allow for a built-in standoff housing free of foreign materials and water which degrade jet formation.

LINEAR SHAPED CHARGE ANALYSIS PROGRAM (LSCAP)

The modeling capabilities of the LSCAP code include:
1. Sweeping/tangential detonation propagation,
2. Jet-target impact angles,
3. Liner acceleration and velocity,
4. Jet formation process,
5. Jet penetration process including layered targets,
6. Jet breakup stress model, and
7. Target strength modeling.

The code is inexpensive relative to hydrocodes, can be easily used to conduct parametric studies, and is interactive.

The LSCAP modeling of half of an LSC cross-section is illustrated in Figure 7. Figure 8 shows sample LSCAP output illustrating an LSC with a variable standoff to an aluminum target, sweeping detonation, a jet front envelope of 26.7 degrees, jet particle path relative to the target, and a comparison of the predicted and experimental target-jet penetration at 8 and 24 microseconds, respectively.

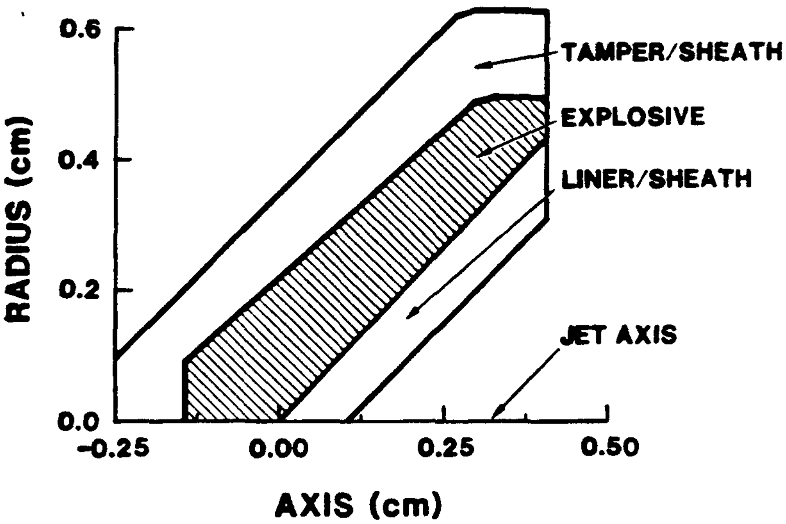

Figure 7. Model of LSC Cross-Section

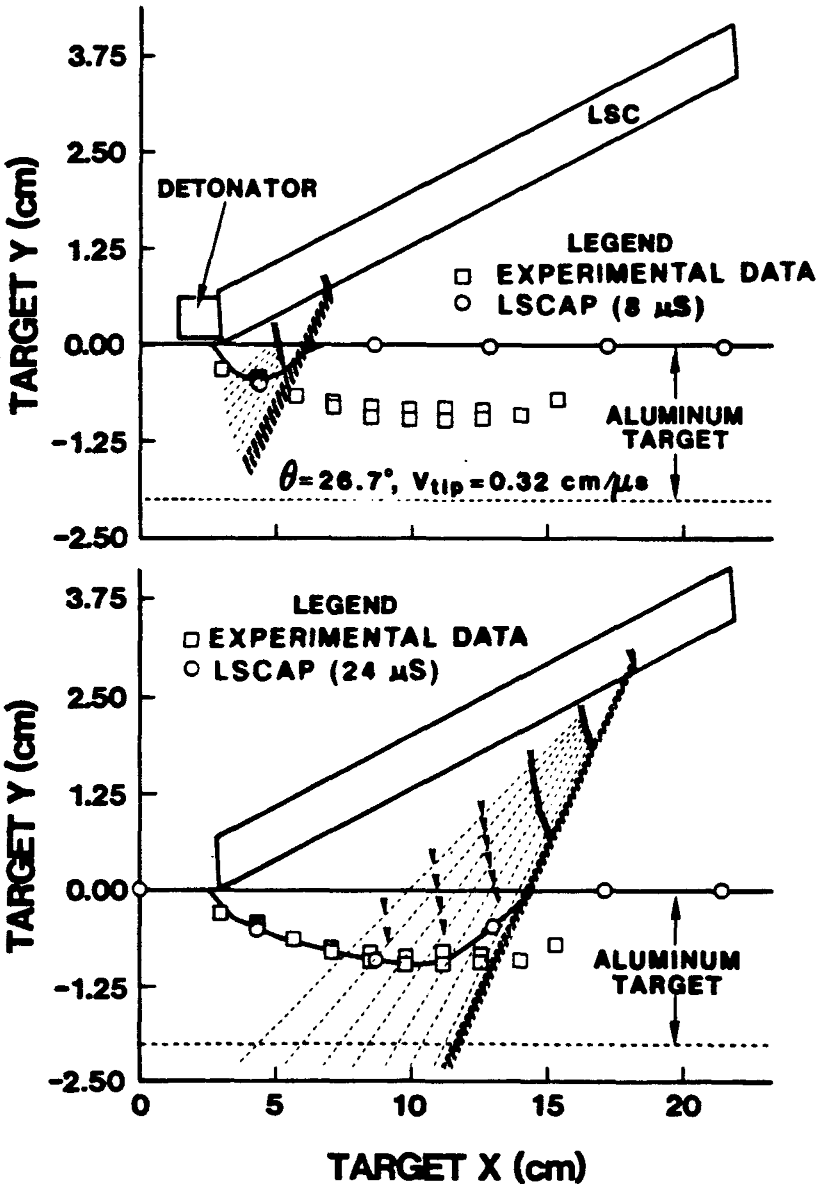

Figure 8. LSCAP Jet Penetration Graphics

RESULTS

A parametric study was conducted incorpcrating the 25 grain per foot (gr/ft), LX-13 explosive, flange PLSC designs similar to Figure 9 and with the following variables:

1. Explosives
   a. LX-13/XTX8003
   b. PBXN301
2. Liner materials
   a. Copper
   b. Aluminum
   c. Nickel
3. Tamper/confinement material
   a. Aluminum
4. PLSC Geometry
   a. Liner apex angles:
      70, 75, 90 & 105 degrees
   b. Liner thicknesses:
      .004, .007, .008, and .010 inches

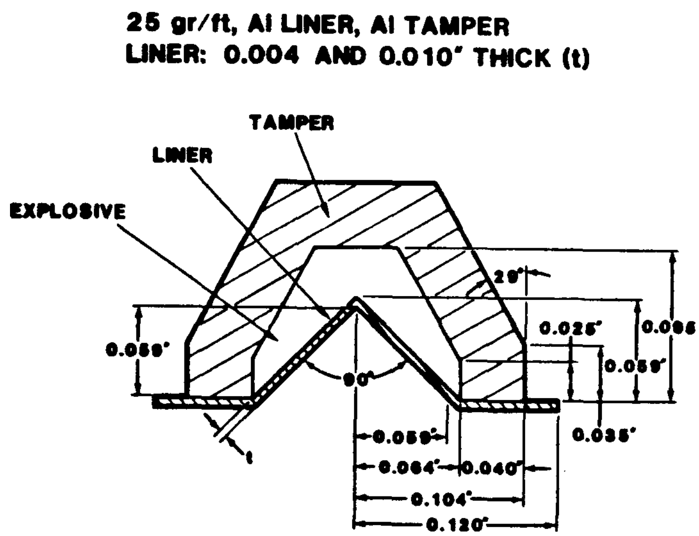

Figure 9. "Flange" PLSC Cross-Section

The PLSC materials, liner thickness (t), and apex angles (θ_a) were varied as listed in Table I. The PLSC jet tip velocity (V_j), jet envelope angle (θ), jet-target angle (α), jet penetration into an aluminum 6061-T6 target (P), and optimum standoff (S.O.) are listed in

Table I. The LSCAP predicted data are compared to the experimental values for most of the parameters. The effect on jet penetration versus standoff due to variations in some of the PLSC cross-section parameters are shown in Figures 10-14. The experimental data shown in Figures 10-14 were hand fitted to obtain the solid line curves.

Table I. LSCAP versus Experimental PLSC Parameter Comparisons

Liner Material	t (in.)	θ_a (in.)	V_j (cm/μs) Exp.	V_j (cm/μs) LSCAP	θ (deg) Exp.	θ (deg) LSCAP	α (deg) Exp.	α (deg) LSCAP	P (in.) Exp.	S.O. (in.) Exp.
Al	.004	70	.55	.65	49	55	62	63	.09	.07
Cu	.004	70	.36	.41	36	34	63	72	.11	.15
Al	.004	90	.42	.50	36	44	73	72	.11	.08
Cu	.004	90	.36	.33	27	27	77	77	.17	.10
Ni	.004	90	.28	.33	23	27	74	79	.13	.10
Al	.010	90	.32	.36	28	29	74	76	.15	.24
Cu	.010	90	.20	.20	16	16	78	82	.14	.19
Ni	.010	90	.17	.20	15	16	81	83	.09	.16
Al	.010	105	.28	.32	24	26	74	78	.13	.18
Cu	.010	105	.15	.17	15	13	86	83	.14	.21
Al	.004	105	.38	.46	31	37	84	75	.14	.11
Cu	.004	105	.26	.28	24	22	78	78	.16	.23
Cu	.010	70	.23	.25	19	20	80	81	.15	.18
Al	.010	70	--	.47	--	38	--	71	.18	.14

The effect of varying materials is illustrated in Figures 10 and 11 for a 90 degree apex angle with 0.004 and 0.010 inch thick liners, respectively. The effect of varying apex angles is illustrated in Figures 12 and 13 for 0.004 and 0.010 inch thick aluminum liners respectively. Figure 14 shows the penetration of 0.004 and 0.010 inch thick copper liners with apex angles of 70, 90, and 105 degrees.

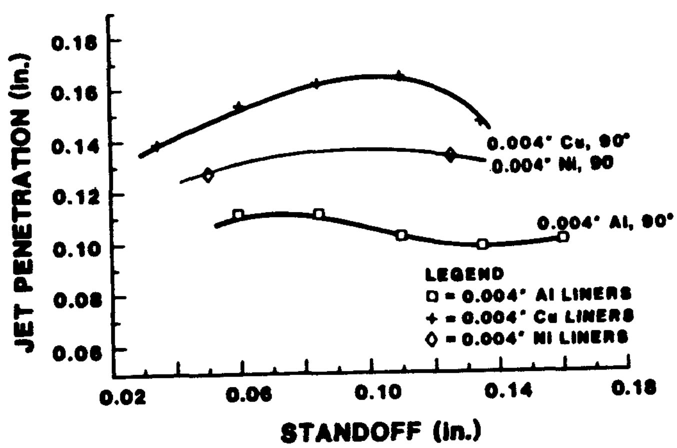

Figure 10. Effects of PLSC Liner Material (0.004" l

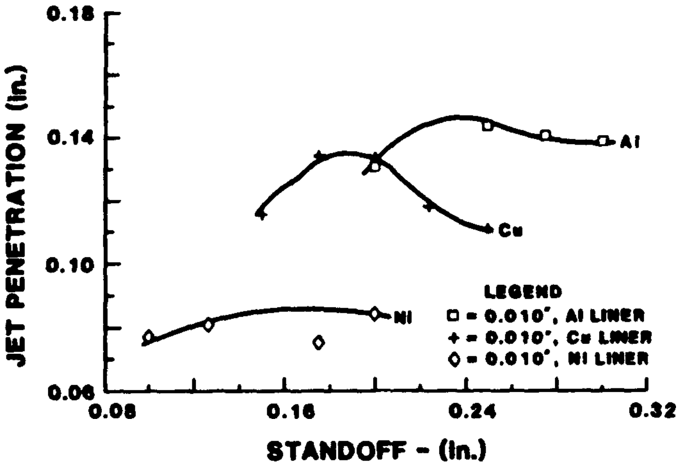

Figure 11. Effects PLSC Liner Material (0.010" liner, 90° apex)

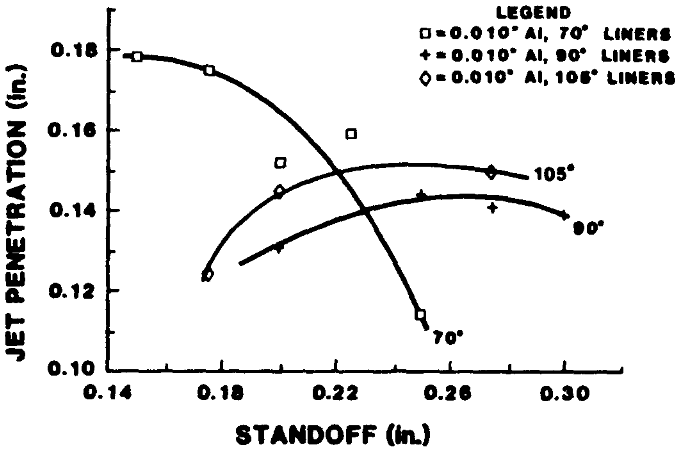

Figure 13. Effects of Al Liner Apex Angle (0.010" Al liner)

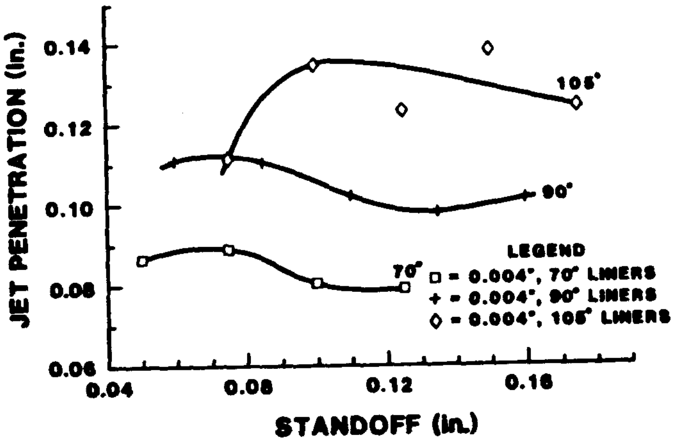

Figure 12. Effects of Al Liner Apex Angle (0.004" liner)

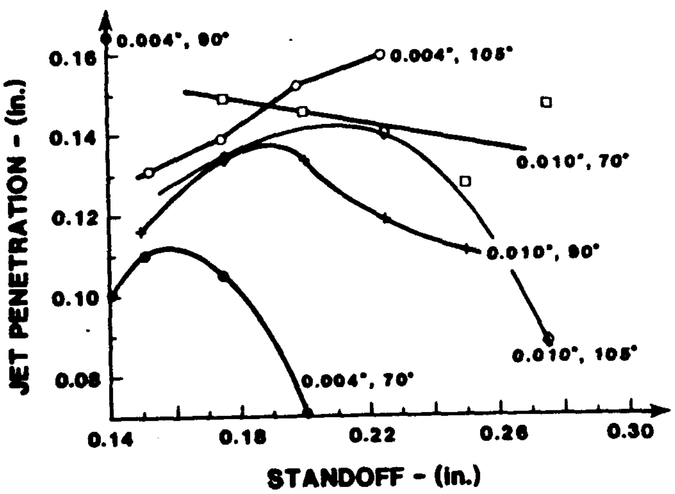

Figure 14. Effects of Cu Liner Angle & Thickness (0.004" and 0.010" liners)

Jet penetration versus standoff are illustrated in Figure 15 for the PLSC design shown in Figure 9 (0.010 inch thick liner) compared to the commercial LSC design shown in Figure 4. Both designs use aluminum liners (90 degree apex) and tampers. The LX-13 and HNS II explosives' metal driving ability is about the same.

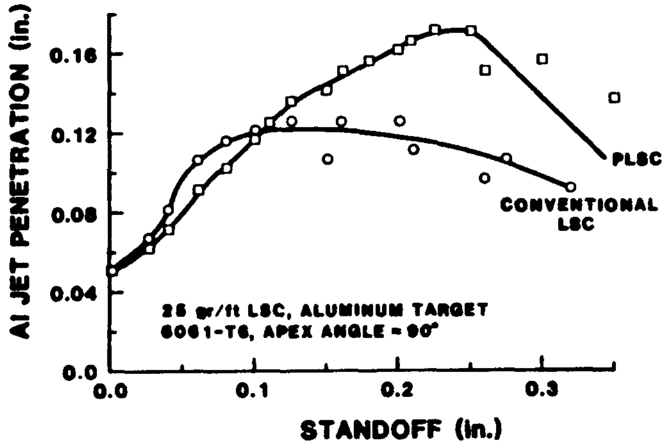

Figure 15. Measured PLSC versus LSC Data

Linear Shaped Charge Analysis Program predicted jet penetration versus standoff data are compared in Figure 16 to experimental data for the 25 gr/ft PLSC cross-section shown in Figure 9 using a 0.010 inch thick aluminum liner. The LSCAP predicted jet penetration versus standoff data are compared in Figure 18 to experimental data for the 20 gr/ft PLSC cross-section shown in Figure 17 using a 0.008 inch thick copper liner. The "W" liner configuration of the PLSC shown in Figure 17 can be more easily loaded with explosive than the PLSC shown in Figure 9. The reproducibility of jet penetration for one test versus position or distance along an aluminum 6061-T6 target is shown in Figure 19 for the 20 gr/ft PLSC cross-section of Figure 17 for both copper and aluminum liners 0.008 inch thick.

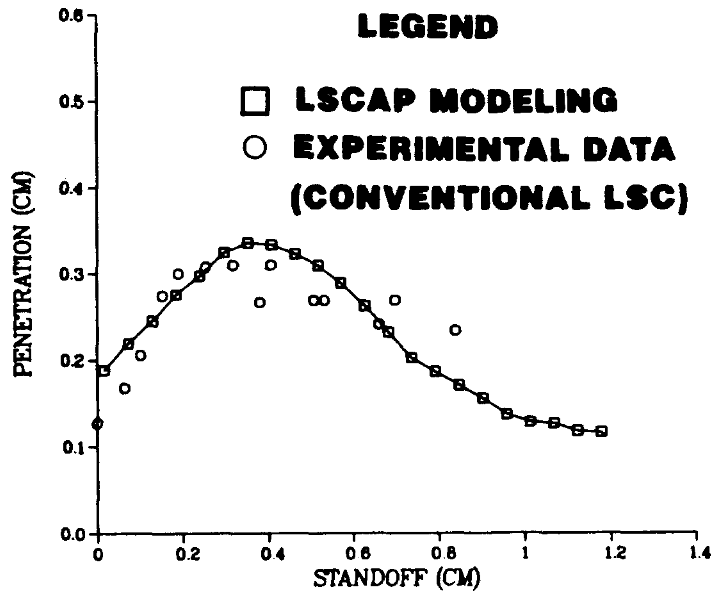

Figure 16. LSCAP versus Experimental Data (Fig. 9

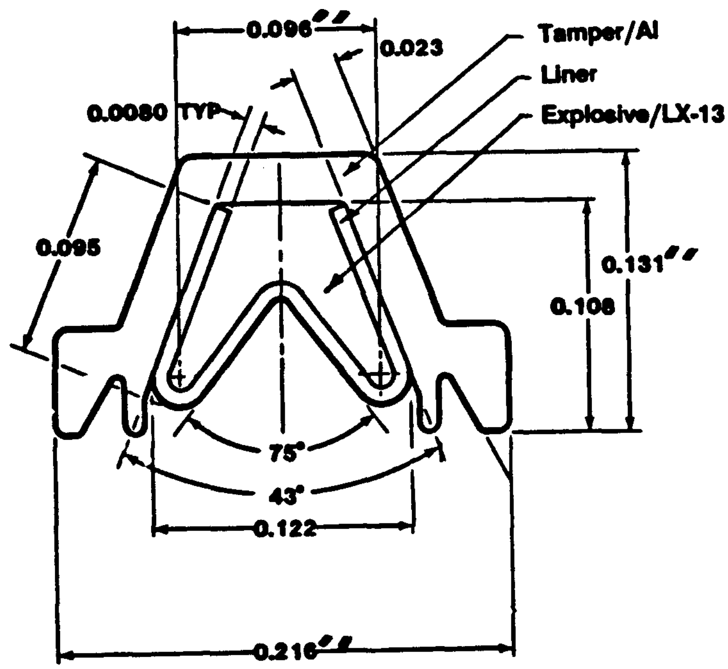

Figure 17. "W" PLSC Cross-Section

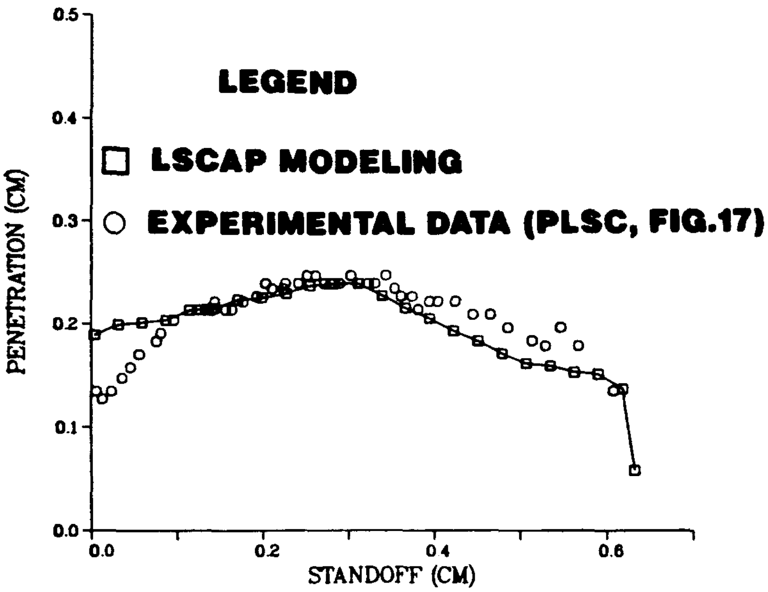

Figure 18. LSCAP versus Data (Fig. 17)

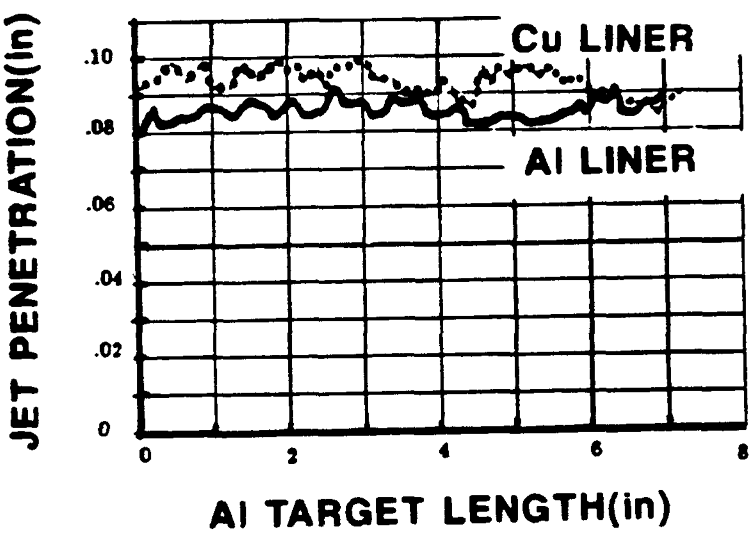

Figure 19. Reproducibility of PLSC (Fig. 17) (standoff = 0.100")

CONCLUSIONS

Precision Linear Shaped Charge liner, tamper, and explosive fabrication processes have been demonstrated to produce increased jet penetrations in aluminum targets, more reproducible jet penetrations, and more efficient explosive cross-sections compared to equivalent commercial LSCs.

The LSCAP predicted jet tip velocities are within 20 percent of the experimental values (Table I). The predicted jet envelope angles relative to the PLSC are within 20 percent of the photometrically measured values (Table I). The measured jet-target angles are within 11 percent of the predicted values (Table I). Data for copper and aluminum PLSC jet penetration into an aluminum target was presented demonstrating a 10 percent reproducibility for a given test (Figure 19). Data was presented to illustrate 40 percent improvement in jet penetration for a PLSC design compared to an equivalent 25 gr/ft conventional LSC design (Figure 16).

The data of Figures 10-14 illustrate that similar jet penetrations can be obtained from various PLSC designs. A parametric study with the LSCAP code to determine "the" optimum PLSC design is very difficult because of the large number of inter-related variables. This does, however, emphasize the importance of LSCAP in obtaining a more optimized design than is currently available from conventional LSC designs. Currently, LSCAP is the only known linear shaped charge code in the USA.

The PLSC designs similar to those presented here have recently been incorporated in Sandia National Laboratory (SNL) systems. The Explosive Subsystems Division plans to use PLSC designs in all future SNLA systems requiring jet severance of materials including Kevlar parachute suspension lines.

ACKNOWLEDGMENTS

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