U. S. Army Ordnance
Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland
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EXPLOSIVES RESEARCH CENTER

STRESS WAVES IN BOUNDED MEDIA

Quarterly Report
March 1, 1966 to May 31, 1966

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Prepared for:

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STRESS WAVES IN BOUNDED MEDIA

Introduction

Studies related to the energy transfer phenomena using the two dimensional slab geometry have been continued. One phase of the work deals with metal plates propelled by various composite explosive combinations consisting of two components. By utilizing explosives having different detonation rates an oblique detonation front can be induced and maintained in the lower velocity component. An enhancement in energy transfer was observed when the plate was coupled to the low-velocity element. The other phase involves the use of flat composite plates composed of a plastic-metal plate combination propelled by a single explosive. Energy transfer to the outer plate was more efficient when the explosive was coupled to the metallic component of the target.

Penetration and hole volume data are presented for 1.100-inch base diameter shaped charges using precision copper cones with Composition B (Comp B) and nitroglycerin-ethylene glycol dinitrate (NG-EGDN) explosives. The reproducibility in the NG-EGDN penetration data is observed to be very good.

Energy Transfer Studies in the Slab Geometry Using Composite Explosives

Energy coupling experiments have been carried out using an explosive system consisting of a slab-like arrangement of two different explosive materials that were coupled to form a unit charge. A typical charge-plate assembly is shown in figure 1; each explosive component has a thickness of 1/2 inch, a width of 3 inches and a length of 7-1/2 inches. Three explosive arrangements were used that consisted of Comp B and nitromethane (NM), trinitrotoluene (TNT), or NG-EGDN. These were coupled to 3-inch wide x 6-inch long copper plates for all shots; the thickness of the copper plate (t) was adjusted to provide a constant C/M ratio. Separate trials were made with the plate in contact with both explosive components in each explosive system. Two similar firings were made for each explosive plate combination.

The plate departure angles and variation as determined from flash radiographs are presented in table 1. The calculated plate velocities and the plate energies per unit explosive mass are also presented. The results may be summarized as follows: (1) Tests with each of the composite explosive systems show that the plate velocity is greater when the plate is coupled to the explosive component having the lower detonation velocity. (2) The difference in plate velocities for a reversal of the plate position for a given composite explosive configuration, increases as the difference in the detonation velocities between the explosive components increases. For example, the detonation velocities for Comp B, NG-EGDN, TNT, and NM decrease in the order listed. The Comp B - NM arrangement produces plate velocities of 1.40 mm/μsec with the Comp B coupled to the plate and 1.59 mm/μsec for a reversal in the plate position -- an increase of about 14 percent. The Comp B - TNT and Comp B - NG-EGDN configurations produce successively smaller increases of about 5% and 2% respectively, where 2% is on the order of experimental error. (3) The energy per unit explosive mass (E_p/C) is somewhat enhanced through the use of composite explosives. For example, the Comp B - NM → plate configuration yields an E_p/C value of 816 jouled/g, whereas, in previously reported data[1], an E_p/C value of 717 joules/g was obtained for a Comp B - copper plate combination having nearly the same dimensions and an identical C/M ratio.

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[1] Watson, R. W., K. R. Becker, and F. C. Gibson. Stress Waves in Bounded Media. Bureau of Mines Quarterly Report, U. S. Army Ordnance, Aberdeen Proving Ground, Md., December 1, 1965 to February 28, 1966.

An explanation of the mechanism involved is to be found in the structure of the detonation fronts. Radiographs of the detonation structures for the three composite explosive systems are presented in figure 2. The width of the explosive systems was reduced from three inches to one inch to improve picture detail. Each radiograph clearly shows that the detonation front, for the explosive component used in association with Comp B, is decidedly canted relative to the front observed in the Comp B. Furthermore, the obliquity of the front becomes progressively more pronounced as the difference between the detonation velocities of the two explosive components increases. The angular displacements of the fronts measured from the normal direction of propagation front for Comp B are roughly 73°, 60°, and 53° for NG-EGDN, TNT, and NM, respectively. These agree well with the theoretical values of 74°, 61°, and 54° calculated from the relationship $\sin \theta = \frac{D_1}{D_2}$ where $D_2 > D_1$.

The significant result of this work is that the effectiveness of the wave shaping technique used here could possibly be increased resulting in further gains in the energy transfer process. Other explosive combinations that would provide a greater difference in detonation rates with a corresponding reduction in the value of angel θ, are being explored for this purpose.

Energy Transfer Studies in the Slab Geometry Using Composite Plates

Previously reported studies[2] in this area indicate that, for a composite target consisting of a metal - metal combination, the energy transferred from the explosive was the same regardless of which metal component was in contact with the explosive. In

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[2] See work cited in footnote 1.

addition, the energy transfer for the composite case agreed very well with that obtained for a single copper target used in an equivalent C/M system.

A more recent series of energy coupling experiments using a metal-plastic plate combination have been completed. Two different plate configurations consisting of 1/8-inch thick slabs of polyethylene coupled either to copper or aluminum plates were employed. One-inch thick Comp B slabs were used throughout all tests and a C/M value of 1.55 was maintained by adjusting the thickness of the metal component of the composite plate system. The explosive charges were 3 inches wide and 7-1/2 inches long; the plates were of the same width and were 6 inches long.

Radiographs of the propelled plates indicated a separation of the metallic and plastic plate components for the two cases where the explosive was coupled to the metal. The separation is illustrated in figure 3 which is a radiograph of an aluminum-polyethylene combination. No separation was evident for the two cases where the explosive was coupled to the plastic plate component.

The data for the metal-plastic experiment are given in table 2; uncertainties in the plate velocities are about 4 percent. The data may be summarized as follows: (1) For the two configurations where the explosive was coupled to the plastic component, the metal plate velocities were 1.55 mm/μsec and 1.49 mm/μsec for copper and aluminum, respectively; this is not a significant difference. No separation was noted and the velocity of the plastic plate is assumed to be the same as the metal plate. (2) For the other two configurations, where the explosive was coupled to the metal components, the velocity of the copper plate was 1.63 mm/μsec as opposed to 1.53 mm/μsec for the aluminum plate; a small, but significant, impedance effect that is consistent with previous results. The plastic plates for these two arrangements were both separated from their metallic components and had the same velocity (1.77 mm/μsec).

It appears therefore that the energy transferred from the explosive to the composite plate is greater when the explosive is coupled to the metallic element; this applies for the composite plate elements considered individually or collectively. Also, the copper coupling is slightly more efficient than the aluminum coupling. This suggests that a three plate system consisting of a metal-plastic metal combination might lead to a gain in the energy transferred to the outer metallic element. Experiments have been designed to explore this possibility.

Investigations of Shaped Charge Performance Using Liquid and Solid Explosives

A program involving tests with precision copper cones, using both solid and liquid explosive systems has been initiated. Penetration and hole volume data have been accumulated for 1.100-inch base diameter, precision copper cones confined in steel charge bodies. The cone had an apex angle of 42° and wall thickness of 27.5 mils; both the cones and steel charge bodies were supplied by Firestone.

All charges were fired at a standoff of ten cone diameters (11.0 inches) into stacks of 4 x 4 x 1-inch thick 2024-T3 aluminum targets. A low density target material was selected in order to obtain larger values of penetration and corresponding variability than would be obtained with steel targets which are ordinarily used in shaped charge work. Details of the charge assembly and experimental set-up are presented in figure 4.

A first group of firings (I) was made for Comp B and NG-EGDN explosives using a 3/4-inch explosive head and initiating with a shorter booster (1/4-inch long) than is shown in the figure. The results, in table 3, indicate an average penetration of 6.30 inches for five Comp B firings with a total spread of 0.9 inch. Only two NG-EGDN firings are given here because some difficulty was experienced in the initiating system (possibly wetting of the booster) and several firings resulted in low-order detonation with no penetration. The two successful shots gave an average penetration of 6.80 inches with a spread of 0.8 inch.

Subsequently, a second set of firings (group II) was conducted with the initiating system shown in figure 4. In addition, extra precautions were made to prevent booster wetting. The explosive head was also increased from 3/4 inch to 1-1/16 inches.

Data for both Comp B and NG-EGDN are also summarized in table 3. The five NG-EGDN trials produced individual penetrations of 6.41, 6.65, 6.28, 6.37, and 6.29 for an average of 6.40 inches with an unusually low variation -- the total spread was only 0.38 inch. For the Comp B firings the observed penetrations were 5.70, 6.82, 7.30, 6.55, and 8.10 inches; thus, the increase in the explosive head appears to have increased the average penetration by about 1/2 inch from 6.30 to 6.89 inches. The spread in this case was 2.40 inches. The hole volume data for this group correlated with the penetration data; average hole volumes of 13.2 cc and 12.4 cc were obtained for the Comp B and NG-EGDN data, respectively. Thus, while the charges loaded with Comp B gave superior performance in terms of the average penetration depth, the use of a homogeneous liquid explosive resulted in a considerable improvement in the reproducibility. It may be speculated that the homogeneous system tends to minimize perturbations in the collapse process arising from the irregularities that may be present in the detonation front of a crystalline solid explosive.

TABLE 1. - Energy transfer characteristics for flat plates coupled to composite explosive slabs

Configuration	Plate Thickness (in)	Departure Angle (deg)	Spread (deg)	V_n (mm/μsec)	E_p/C (joules/g)
NM - Comp B → plate	0.104	10.3	0.3	1.40	632
Comp B - NM → plate	0.104	11.7	0.3	1.59	816
TNT - Comp B → plate	0.120	11.1	0.1	1.51	736
Comp B - TNT → plate	0.120	11.7	0.2	1.59	816
NG-EGDN - Comp B → plate	0.119	11.7	0.2	1.59	816
Comp B - NG-EGDN → plate	0.119	12.0	0.1	1.63	858

V_n = normal component of plate velocity.

E_p/C = plate energy per unit explosive mass.

C/M = charge mass/plate mass = 1.55 throughout all firings.

TABLE 2. - Energy transfer characteristics for composite flat plates coupled to explosive slabs

Configuration	Departure Angle (deg)		Spread (deg)		V_n (mm/µsec)		E_p/C (joules/g)	
	Metal	Plastic	Metal	Plastic	Metal	Plastic	Metal	Plastic
Comp B → plastic-copper	11.4	11.4	0.1	-	1.55	1.55	698	80
Comp B → copper-plastic	12.0	13.1	0.5	0.6	1.63	1.77	767	105
Comp B → plastic-aluminum	11.0	11.0	0.2	-	1.49	1.49	645	74
Comp B → aluminum-plastic	11.3	13.1	0.2	0.4	1.53	1.77	674	105

Departure angles were measured from radiographs of the propelled plates.

V_n = calculated normal component of plate velocity.

C/M = 1.55 for all configurations; copper plates were 0.112-inch thick and aluminum plates 0.369-inch thick.

Two identical trials were conducted for each configuration.

TABLE 3. - Summary of penetration and hole volume data for 1.100-inch base diameter copper cones fired into aluminum targets

Group	Explosive	Trials	Average Penetration (in)	Variation Spread (in)	Average Hole Volume (cc)	Variation Spread (cc)
I	Comp B	5	6.30	0.90	10.0	2.4
I	NG-EGDN	2	6.80	0.80	10.1	0.9
II	Comp B	5	6.89	2.40	13.2	0.8
II	NG-EGDN	5	6.40	0.38	12.4	2.5

Group I firings utilized a 3/4-inch explosive head and a 1/2-inch diameter x 1/4-inch long tetryl booster.

Group II firings utilized a 1-1/16-inch explosive head and 1/2-inch diameter x 1/4-inch long tetryl booster.

Spread is the difference between the highest and lowest value.

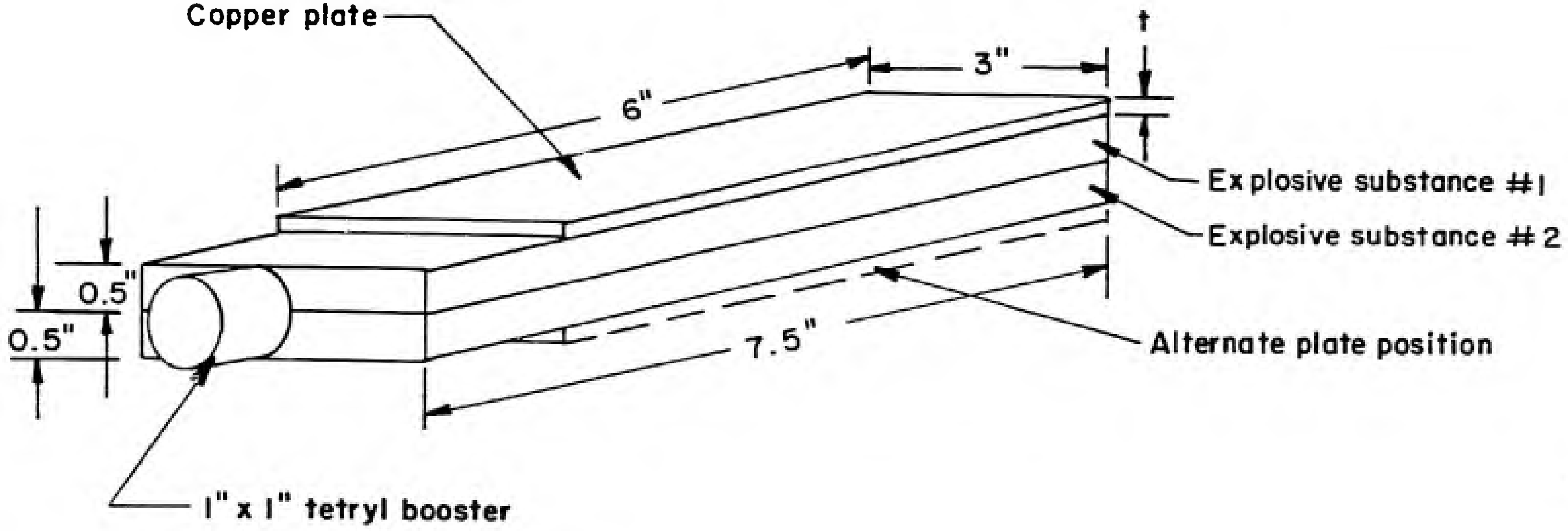

FIGURE 1. - Sketch of a typical composite explosive-plate assembly.

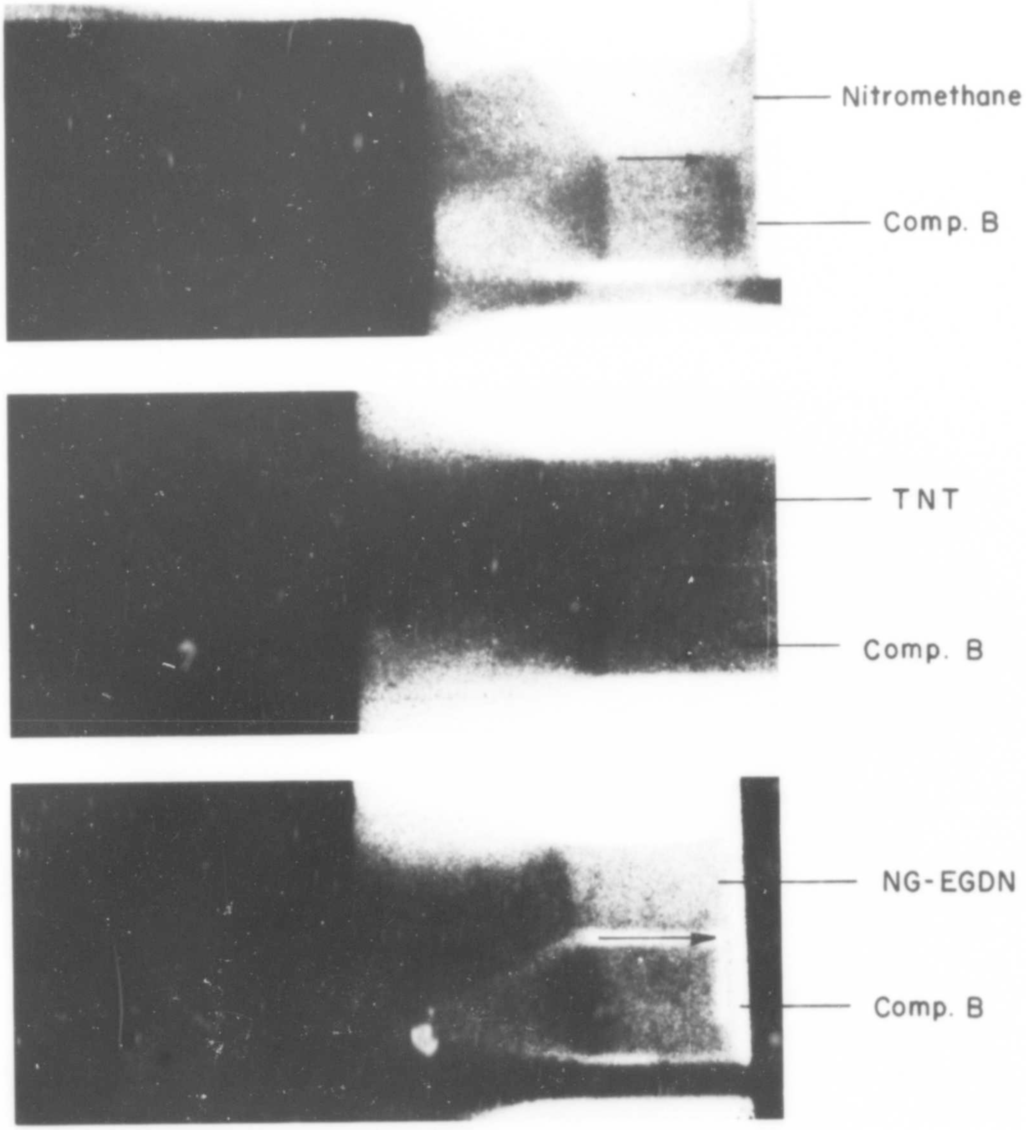

FIGURE 2. - Flash radiographs comparing detonation fronts for various composite explosive configurations.

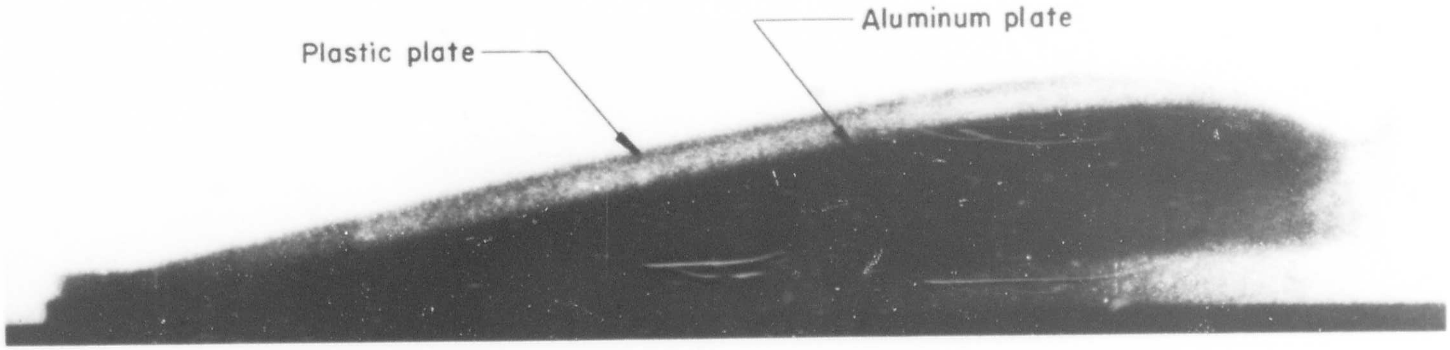

FIGURE 3. - Radiograph of a propelled composite plate.

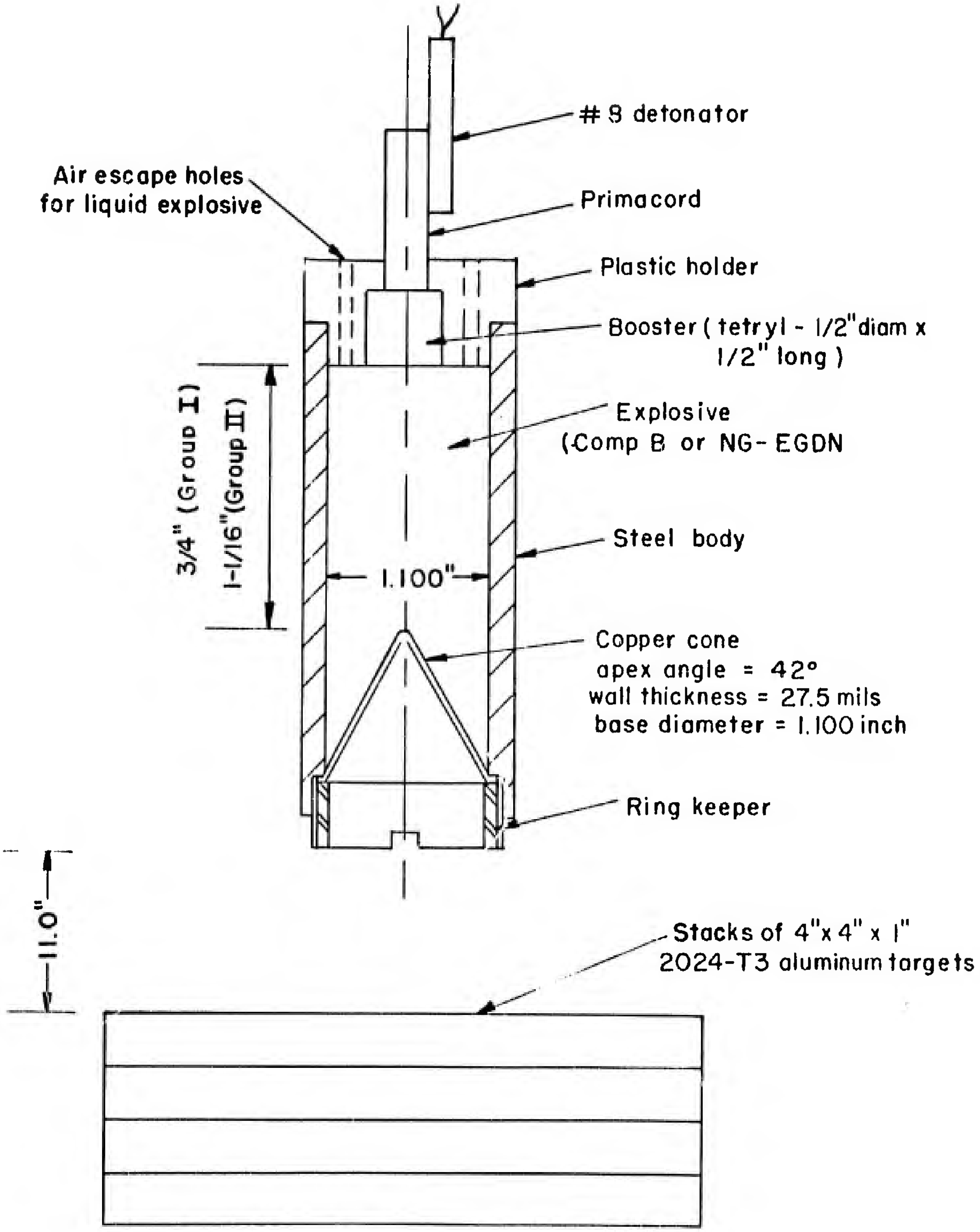

FIGURE 4. - Sketch of set-up for precision cone firings.