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A STUDY OF MACRO-PARTICLE ACCELERATION WITH SEQUENCED HIGH EXPLOSIVE IMPULSES

Optimization of Single Stage Geometry

by

WARREN E. FOGG

July 1963

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Pitman-Dunn Institute for Research
Philadelphia, Pa. 19137

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ABSTRACT

A single stage high explosive system for accelerating macroparticles has been designed and tested in order to investigate the various parameters.

Velocities to 7500 fps were achieved with an aluminum projectile weighing approximately 4.5 grams. Damage to the projectiles became so great (mass losses to 40 percent) that the program was halted.

Suggestions are made to show how the methods of acoustical impedance matching could help prevent projectile break-up.

INTRODUCTION

It was desired to identify the sensitive variables in a single stage, explosive, shaped charge system which would be used as the first stage of a sequenced system for obtaining hypervelocity projectiles. The apparent simplicity of using sequenced explosive impulses from unlined shaped charges to attain hypervelocity projectiles (20,000 fps and greater) has aroused a great deal of interest at this installation. Previous efforts resulted in preliminary models of both a single and a two-stage launcher system.*

The results were encouraging. Velocities to 6,000 fps were achieved with the single stage launcher, and the two-stage system gave a boost of 40 to 50 percent to projectiles (4.0 to 4.5 gm) moving with an initial velocity of 4,000 fps. The recovered projectiles showed only slight evidence of mass loss and deformation due to action of the gaseous jet.

However, the results did show a serious shot-to-shot velocity variation with the single stage launchers. This could not be tolerated due to the precise timing which would be necessary for the second and successive stages.

The study reported here was undertaken as part of an effort to arrive at a single stage geometry which would give a maximum projectile velocity with a minimum shot-to-shot variation.

METHOD

The launcher designed for this study is shown in Figure 1. The lead encasement was cast around the steel barrel and a mandrel which formed the charge cavity and the launcher angle. The mandrels, one for each of the individual launcher angles, were machined with a tailpiece which supported the barrel during casting. This method was relatively inexpensive and assured good alignment between the charge and the barrel. The launchers weighed approximately 30 pounds, which was enough so that no elaborate anchoring fixtures were required. Most of the lead was recovered after firing and was re-used in the casting process.

Initially, it was intended that charges of various diameters would be investigated, but as the testing progressed, it was decided that no advantage would be gained by changing the charge size.

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*C.W.Fleischer, "A Projectile Launching System for Hyperballistic Studies," Proceedings of the First Army Science Conference, June 1957.

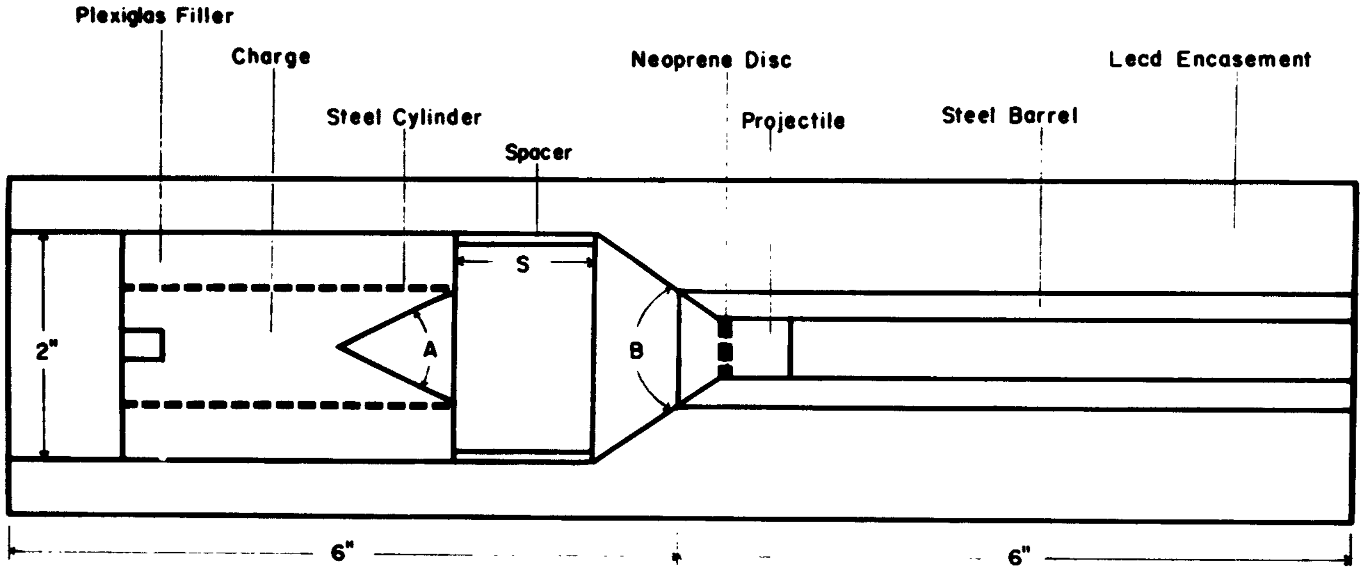

Figure 1. Single Stage High Explosive System

The charges used (1 inch in diameter and cast of 60/40 pentolite) were maintained at a constant weight of 69 grams.* To maintain the constant weight, the charge length was varied when the angle (A) changed. The charges were recessed along the axis at the rear to accept a tetryl booster pellet (1/4 inch diameter by 3/8 inch long). Detonation was initiated with a No. 6 blasting cap butted against the booster pellet.

The projectiles were machined from aluminum round stock to a nominal size of 1/2 inch diameter by 1/2 inch long. Since the barrels were made of steel tubing, as received, it was necessary to machine each projectile to fit a specific test barrel. Friction fit was maintained. The projectiles were partially protected with 1/8 inch thick neoprene discs which weighed 0.7 gram.

The standoff distance (S) was measured between the bases of the charge angle (A) and the launcher angle (B). At distances greater than zero it was maintained with steel spacers of the appropriate axial length.

Velocities were measured over a 2-foot base line. Velocity screens, continuous conductors printed on paper and connected electrically to an oscilloscope, were placed at the appropriate points to detect passage of the projectile. A voltage drop was indicated on the oscilloscope as each screen was broken by the projectile. The length of time necessary for the projectile to traverse the base line distance was measured with the sweep frequency of the oscilloscope. A Polaroid camera, attached to the oscilloscope, provided a permanent record.

The projectiles were recovered by firing into a box of sawdust. Deceleration in this manner did not damage the projectile.

Originally it was intended to fire a minimum of three tests for each change of one of the parameters (A, B, or S) while holding the other two constant. As the testing progressed, much greater projectile damage was encountered than had been expected. The program was halted so that studies of the damage and methods of preventing it could be made.

EXPLORATORY TESTS

During the testing program, brief exploratory tests were conducted in an effort to either gain a velocity increase or prevent

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*This weight was based on a charge 3 inches long with cone angle (A) of 60°.

excessive projectile damage. The results are not conclusive, but they are included for a matter of record and to give some indication of trends that were observed.

The launcher was modified by eliminating the angle B. This allowed a further check on the effects of standoff distance. However, velocities increased and projectile damage was extreme and, therefore, the short standoffs cannot be used until a method is devised for protecting the projectiles.

Smaller steel projectiles were tested to increase the velocity. Drill rod (1/4 inch by 1/4 inch) and 1/4 inch diameter bearings were tried. The cylinders were nested in one end of an aluminum projectile, and nylon sabots were machined for the bearings. The velocities achieved, 7,000 to 9,000 fps, were satisfactory and the bearings suffered only slight damage. However, mass loss of the cylinders ranged between 16 and 50 percent.

Attempts to decrease projectile damage by using stronger material were equally unsuccessful. Steel cylinders (1/2 inch by 1/2 inch) and 1/2 inch diameter steel bearings were tried. The velocities decreased sharply due to the increased projectile mass, and mass loss ranged between 50 and 80 percent. The cylinders had been treated so that their tensile strength was approximately 250,000 psi.

Preliminary investigations to test the method of acoustic impedance mismatching were made. A pad or pads of different materials whose acoustic impedance differed greatly from that of aluminum was/were placed between the projectile and charge. The following materials were used either singly or in combinations: 1/8 inch aluminum discs, 1/2 inch aluminum slugs, 1/2 inch cellular aluminum slugs, 1/8 inch and 1/4 inch neoprene discs, 1/8 inch and 1/4 inch nylon discs, 1/2 inch glass slugs, and 1/8 inch lead discs. None of these was entirely satisfactory. The loss of mass still averaged 60 percent, and the velocities decreased with each increase of additional mass to be accelerated. Combinations of aluminum and nylon showed the most promise.

RESULTS AND CONCLUSIONS

The individual test conditions, comparison of projectile weight before and after firing, and the recorded velocities are given in Table I. Figure 2 shows a sampling of the recovered projectiles.

Although the testing was conducted in the open atmosphere, no efforts were made to establish data for drag reduction. However,

TABLE I. Recorded Projectile Velocities and Comparison of Projectile Weights Before and After Firing

			Projectile Weight (gm)		
Test No.	B (°)	S (in.)	Before Firing	After Recovery	Velocity x 10^{-3} (fps)
			Change Angle = 60°		
1	60	0	4.2		7.50
2	60	0	4.2		7.02
3	60	0	4.2		7.27
4	45	0	4.2	3.9	7.02
5	45	0	4.2		5.59
6	45	0	4.2		7.41
7	45	0	4.2		7.09
8	30	0	4.5	3.5	7.14
9	30	0	4.5	3.6	6.89
10	30	0	4.5	3.7	7.02
11	60	0.5	4.4	3.7	5.00
12	60	0.5	4.4	3.8	6.45
13	60	0.5	4.4	3.7	5.80
14	60	0.5	4.4	3.9	5.88
15	60	0.5	4.4	4.0	4.63
16	45	0.5	4.5	3.6	6.25
17	45	0.5	4.5	3.6	6.35
18	45	0.5	4.5	3.7	6.34
19	30	0.5	4.4	3.7	6.90
20	30	0.5	4.4	3.8	6.67
21	60	1.0	4.4	3.9	5.24
22	60	1.0	4.5	3.8	5.17
23	60	1.0	4.5	3.6	5.26
24	60	1.0	4.5	3.8	5.33
25	45	1.0	4.4	3.8	5.68
26	45	1.0	4.4	3.9	5.56
27	45	1.0	4.4		5.59
28	30	1.0	4.4	2.8	6.35
29	30	1.0	4.4	3.8	6.12
30	30	1.0	4.4	3.6	6.01
31	30	1.0	4.4	3.6	5.95
32	30	1.0	4.4	3.8	5.36
			Charge Angle = 45°		
33	45	0	4.4		6.49
34	45	0	4.4	3.7	7.29
35	45	0	4.4	3.5	7.18
36	45	0	4.4	3.7	5.65
37	45	0	4.4	3.8	6.67
38	45	0.5	4.5	3.5	5.60
39	45	0.5	4.5	3.6	5.00
40	45	0.5	4.5	3.7	5.80
41	45	1.0	4.4		5.36
42	45	1.0	4.4	3.7	5.71
43	45	1.0	4.4	3.8	5.48
44	45	1.0	4.4	3.7	5.29
			Charge Angle = 30°		
45	30	0	4.5	3.5	5.88
46	30	0	4.5	3.6	5.88
47	30	0	4.5	3.7	6.15
48	30	1.0	4.5	3.7	5.18
49	30	1.0	4.5	3.6	5.20
50	30	1.0	4.5	3.5	5.48

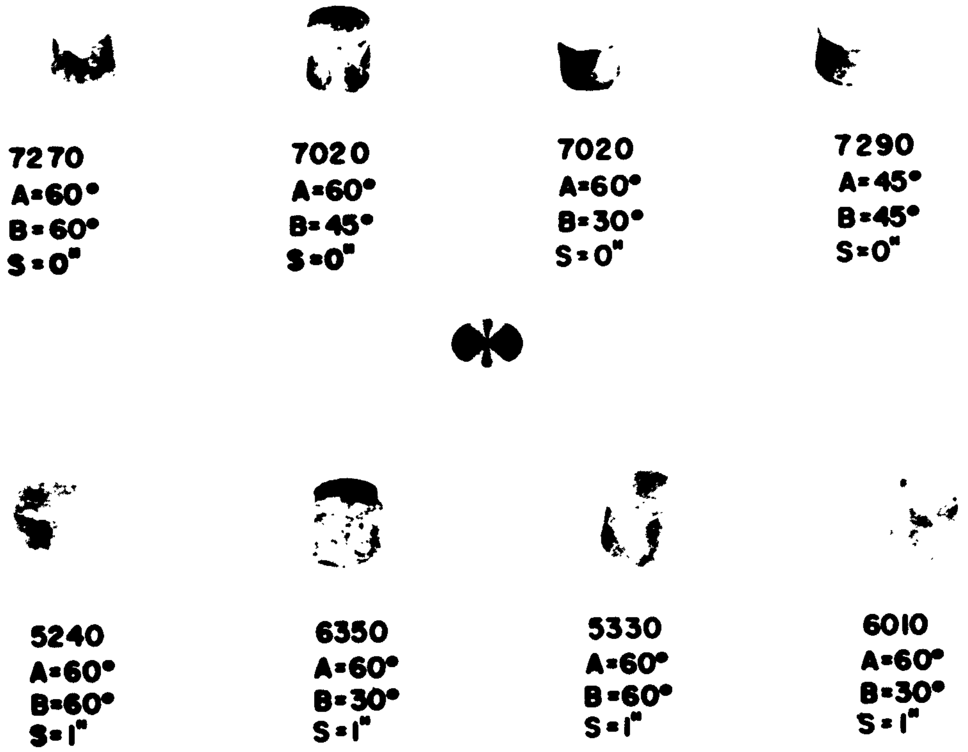

Figure 2. Sampling of the Recovered Projectiles shown with an Unfired Slug for comparison
(Velocities in fps and other test conditions are given)

to gain some insight as to how much reduction might have been experienced, the standard equation

$$v = v_o \exp -(\rho d^2 K_d z/M)$$

was applied to samples of the test firings using the values:

$\rho = 4.35 \times 10^{-5}$ lb/in.^{3}

z = 2 feet, and

K_d varied between 0.1 and 1.0.

The maximum reduction was found to be three percent.

Figures 3 through 6 show the average recorded velocities plotted against the effective standoff, Se. Se is defined as the distance between the bases of the projectile and the charge angle. From an examination of these figures one can infer that the maximum velocity will be achieved with a set of parameters in which the charge angle (A) equals 60°.

The function of the launcher angle (B) and its relation to the standoff distance is least understood. The effective standoff (Se) increased when B was decreased. It was expected that projectile velocities would decrease with increasing standoff, but Figure 5 shows that this is not always true. This graphs shows a decided velocity increase in two cases when B is decreased while holding A and S constant. Apparently there is some additional focusing of the peripheral gases which is due to angle B and which is dependent upon the standoff distance.

The shot-to-shot velocity variation within the different groupings might present a problem when successive stages are added, but this would depend upon the configuration chosen.

The amount of damage suffered by the projectiles is so serious, it warrants special attention. It arises from two separate and distinct sources. The first, erosion due to the jet itself, is apparently of little consequence. The major damage is due to scabbing of the projectile material. The longitudinal compression pulse, produced in the projectile upon impact by the jet, traverses the material and gives rise to a reflected tensile stress pulse at the front surface. The superposition of these two pulses exceeds the tensile strength of the material and, therefore, the projectile is literally torn apart. The mechanism as presented here is highly simplified, but the results suggest that a careful analysis of the stress wave propagation, interaction, etc, within the system is necessary.

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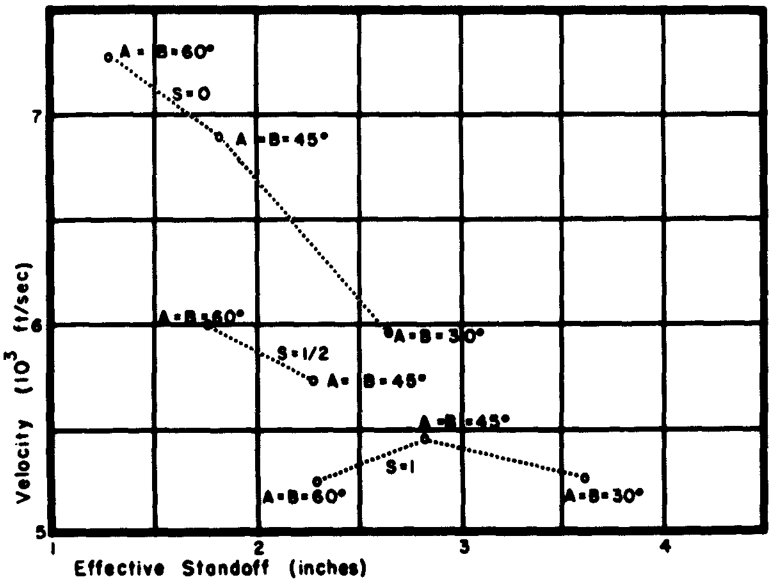

Figure 3. Plot showing how both Velocity and Effective Standoff vary with Changes in the Angle when the Charge and Launcher Angles are Equal

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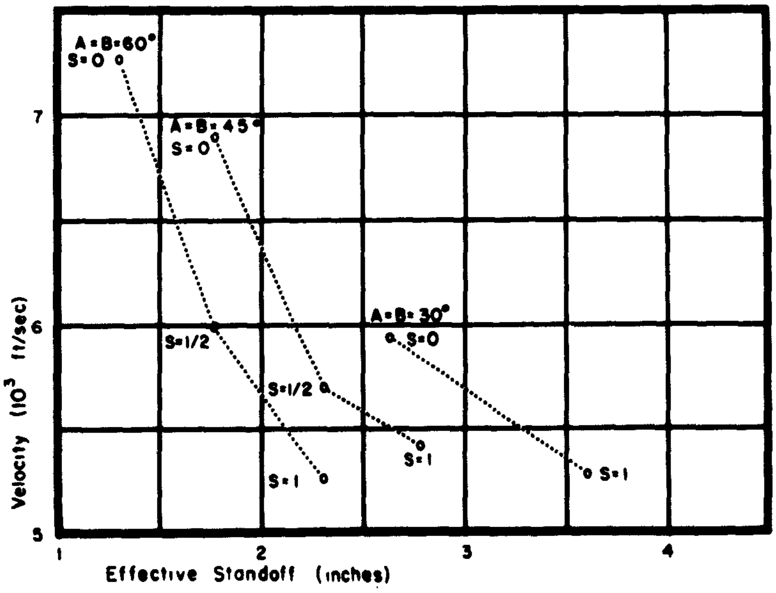

Figure 4. Data of Figure 3 plotted to emphasize the Effects of varying only Standoff Distance

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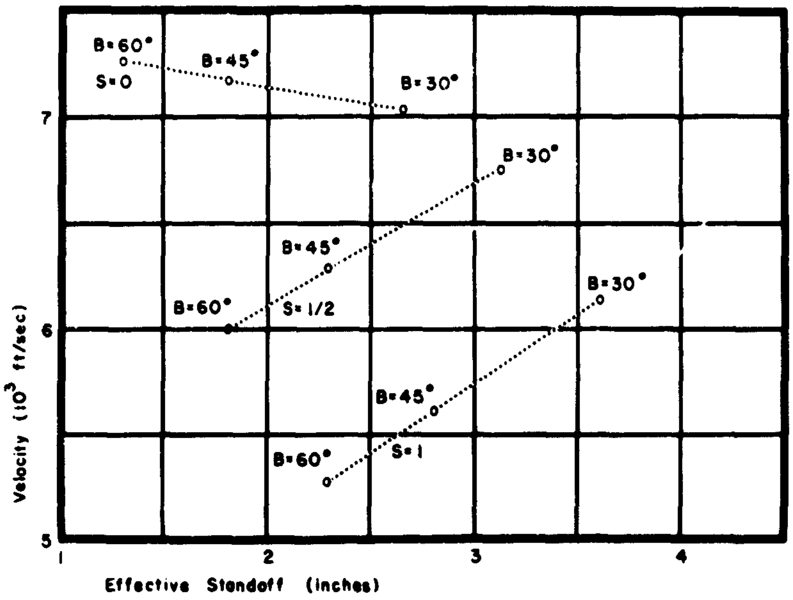

Figure 5. Plot showing how Variations of Launcher Angle effect both Velocity and Effective Standoff
(Charge Angle is 60° throughout.)

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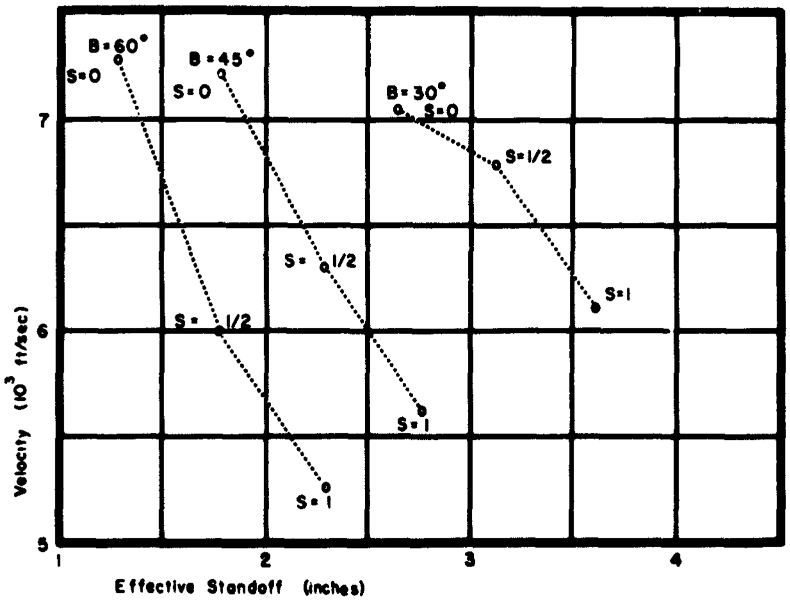

Figure 6. Data of Figure 5 plotted to show Effects of varying only Standoff Distance
(Charge Angle is 60° throughout.)

FUTURE WORK

Additional effort should be directed primarily toward a means of preventing excessive projectile damage. A solution now under consideration would make use of the concept of acoustical impedance matching or, rather, controlled mismatching.

Ordinarily, impedance matching is used to prevent scabbing from the reverse side of a material which receives a sharp impulsive load. This is accomplished by backing the primary material with another which has the same acoustical impedance, or nearly so. The stress pulse produced upon impact then continues through the material and across the boundary with little or no reflected pulse arising; thus, fracture is prevented.

It is assumed that the reverse procedure can be adapted to the launching system. A pad or pads of different materials, greatly mismatched in acoustical impedance, placed between the projectile and charge would absorb or attenuate the initial peak pulse. The amplitude of the transmitted pulse would be less than that required to form a reflected pulse within the projectile sufficient to cause fracture. This padding would also prevent erosion of the projectile due to action of the jet.

In addition, high speed framing camera observation of the jet formation and propagation would undoubtedly yield valuable information for selection of an optimum S and B.

Finally, precisely cast charges should be tested for their effect on the shot-to-shot velocity variation. The charges used here were obtained from a small company (primarily concerned with commercial applications) which does not have facilities for controlled precision casting.

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lw pp incl tables & illus; OMS Code 5520.11.434; DA Proj 50201008

Unclassified Report

A single stage high explosive system for accelerating macro-particles has been designed and tested in order to investigate the various parameters. Velocities to 7500 fps were achieved with an aluminum projectile weighing approx 4.5 grams. Damage to the projectiles became so great (mass losses to 40 percent) that the program was halted.

Suggestions are made to show how the methods of acoustical impedance matching could help prevent projectile break-up.

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1. Macro-particle Acceleration
2. Shaped Charges
3. Explosive Devices

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FRANKFORD ARSENAL, Research and Development Group, Pitman-Dunn Institute for Research, Philadelphia, Pa., 19137

FA Rpt M64-5-1, Jul 63, "A STUDY OF MACRO-PARTICLE ACCELERATION WITH SEQUENCED HIGH EXPLOSIVE IMPULSES - Optimization of Single Stage Geometry," by Warren B. Fogg
lw pp incl tables & illus; OMS Code 5520.11.434; DA Proj 50201008

Unclassified Report

A single stage high explosive system for accelerating macro-particles has been designed and tested in order to investigate the various parameters. Velocities to 7500 fps were achieved with an aluminum projectile weighing approx 4.5 grams. Damage to the projectiles became so great (mass losses to 40 percent) that the program was halted.

Suggestions are made to show how the methods of acoustical impedance matching could help prevent projectile break-up.

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1. Macro-particle Acceleration
2. Shaped Charges
3. Explosive Devices

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