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SOME ASPECTS OF SHAPED CHARGE JET DIRECT IMPACT UPON A PROPELLANT BED

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MAY 1992

U.S. ARMY LABORATORY COMMAND

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The response of candidate low vulnerability ammunition (LOVA) propellants to a Shaped Charge Jet Direct Impact (SCJDI) is evaluated with tests which are designed in such a way as to constitute a sequence in which the test severity increases at each step. A propellant is rejected if it fails to pass a test along the way. If it passes, it is "eligible" for the next (more severe) tests in the sequence.

This report deals with one test of this sequence. Here, the response of the propellant charge is first evaluated by using a witness plate. If the propellant shows a moderate level of response, a more quantitative evaluation is performed with an instrumented block equipped with pressure gages.

Following changes in the test configuration, the amount of propellant under test was significantly reduced. In spite of this reduction, a propellant candidate showed a much *increased* level of response to the SCJDI.

A study was undertaken in order to determine which test configuration parameter was affecting the outcome of the test.

The geometry of the test configuration was hypothesized to be the most important because of suspected wave reflections. Recommendations concerning the operating procedures for the SCJDI test are provided.

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1. INTRODUCTION

The survivability of an armored weapon system depends, among other factors, upon the vulnerability of its onboard ammunition (Rocchio, Reeves, and May 1975). Armored weapon systems typically carry high explosive (HE) rounds that are composed of a propellant charge and a warhead. The overall vulnerability of an HE round has been found to depend largely upon the vulnerability of the propellant charge (for uncompartmentalized ammunition or for ammunition which is compartmentalized and protected against warhead sympathetic detonation). This is because the energy density of the propellant and of the HE are comparable, the mass of propellant is larger, the geometric cross section is greater, and the cartridge case is thinner than the HE warhead case (Reeves 1970).

The threats to the ammunition have been separated into two groups (Rocchio 1980): 1) spall (thermal) and 2) kinetic energy (KE) penetrator or shaped charge (SC) jet (shock impact). The vulnerability of a propellant can be evaluated in terms of its response to these threats. Such an evaluation requires a wide variety of tests (Gerri 1980; Heimerl 1989). The work described in this report involves the assessment of a propellant's response to a shaped charge jet direct impact (SCJDI).

The effects of the propellant's reaction upon impact by a shaped charge jet may be evaluated through measurements of the blast overpressure produced by this reaction (Gerri, to be published). However, direct air blast measurements seem to be rather difficult to interpret in a reliable manner, at least in the manner in which they have been performed (Devynck, Bonanno, and Heimerl, to be published).

Therefore, another test was developed with the incorporation of an instrumented block equipped with two pressure gages that allow the recording of the pressure history in the propellant bed (Bonanno, Heimerl, and Devynck 1988). However, because these gages could be damaged if the propellant's reaction was very violent, the instrumented block test is performed only on propellants that are known to react in a relatively mild manner. An estimate of the level of response of a given propellant is provided by a simpler version of this test in which the instrumented block is replaced by a 1-cm-thick steel witness plate. The damage to the plate caused by the propellant's reaction and measured by the maximum plate depression can be empirically correlated with the violence of the response.

Because it is presently the only test in which a pressure history of the propellant bed can be obtained, the instrumented block test could become a valuable tool for LOVA propellant designers. The first step is to validate and understand the test itself by performing a series of experiments with several propellants in order to build a database for future comparisons. The list of propellants to be tested was established in the last quarter of 1989. Actual tests started shortly thereafter, and some unexpected results were obtained with a propellant candidate of the HELP1 family. This report presents these unexpected results and provides their explanation: under certain circumstances related to the test's geometric configuration, some phenomena may modify the propellant's response. First, the "symmetry effect" is observed when the shot centerline is exactly halfway between two reflecting surfaces. Second, the "proximity effect" appears when the shot centerline is very close to a reflecting surface.

2. TEST DESCRIPTIONS

2.1 Instrumented Block Test. Figure 1 shows a schematic of the test configuration and Figure 2 shows the block detail.

The propellant to be tested is contained in a cylindrical case whose material and vertical dimension may vary from test to test. This propellant-filled case is placed vertically on a steel block in which a cavity and two pressure ports have been machined to accommodate piezoelectric gages. For this test, the relatively small cavity in the block is also filled with propellant; thus, the cavity is an extension of the case in which pressure measurements can be made.

The propellant charge is confined by the cylindrical case itself; the instrumented block at the bottom; and a 52-kg, 10-cm-thick rolled homogeneous armor (RHA) confinement block at the top. In the original design of this test, the purpose of this confinement block was to simulate the effect of the crimping force in a real round of ammunition and to provide a method for estimating the impulse produced by the propellant's reaction (Wise and Ewing 1981).

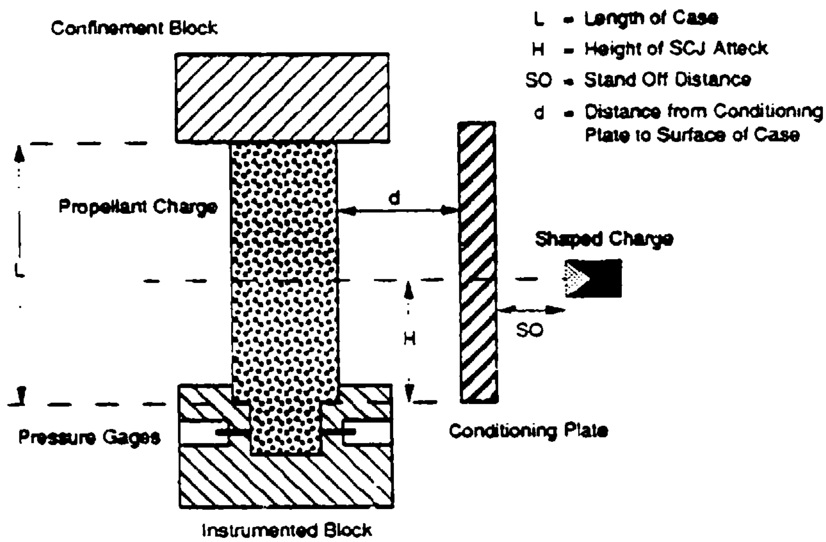


Figure 1. Schematic of the Instrumented Block Test Setup.

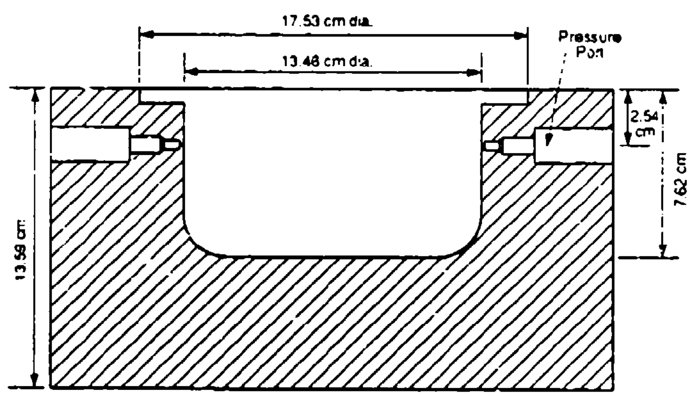


Figure 2. Schematic of the Instrumented Block That Holds the Two Pressure Gages.

The 81-mm BRL precision shaped charge is placed on a wooden stand in such a manner that its axis is horizontal and intersects the case's vertical axis 12.5 cm from the bottom of the case. (It must be noted, however, that the bottom of the case is not the bottom of the propellant charge since there is an additional volume of propellant in the block's cavity below the bottom of the case.) The jet is conditioned by a 5-cm RHA plate. The dimensions of the conditioning plate (30 cm x 60 cm) are such that it offers some protection from the blast due to the shaped charge's explosive. The stand-off between the shaped charge and the conditioning plate is equal to 2 cone diameters (CD), and the distance between the wall of the propellant-filled case and the conditioning plate is 12.5 cm.

2.2 Witness Plate Test. The witness plate test is used as a preliminary screening test to determine whether a propellant can be subjected to the instrumented block test (Figure 1) without creating a risk of substantial damage to the block and/or the pressure gages.

A s[illegible] of this test configuration is given in Figure 3. The test setup is similar to that of the instrumented block test. The instrumented block of Figure 2 is replaced by a 1-cm-thick mild steel plate that rests upon two square pieces of 5-cm RHA used to support the witness plate. The confinement at the bottom of the propellant charge is then achieved by the witness plate. The shaped charge jet shot centerline is still at 12.5 cm above the bottom of the case (in the witness plate configuration, the bottom of the case is also the bottom of the propellant charge). Therefore, the shot centerline is, in fact, at 12.5 cm above the witness plate.

3. TEST RESULTS

Various types of propellants were part of the test plan established to calibrate the instrumented block test. They included conventional, nitrocellulose-based compositions such as M30; and novel, nitramine-based compositions, such as HELP1 (HELP = High Energy LOVA Prototype). The first propellant to be tested was from the HELP1 family. In the following sections of this report, several lot numbers will be mentioned and we will use their abbreviated form for convenience. Table 1 lists these lot numbers, their abbreviated forms, and their dimensions.

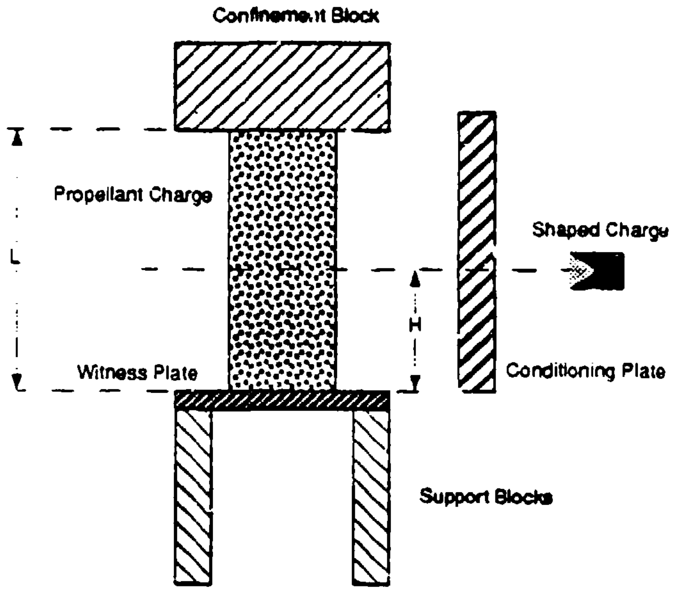


Figure 3. Schematic of the Witness Plate Test Setup.

Three of these propellant lots (those identified as "HELP1" in Table 1) were manufactured as nominal replicates (i.e., lots 132 and 133 were supposed to replicate the earlier lot 204). However, lot 132 was inadvertently cut about 2.5 mm too short (Table 1).

Table 1. Dimensions and Abbreviations of the HELP1 Propellant Lots (19-Perf Granular)

Lot Number		Length (mm)	Diameter (mm)	Average Web (mm)
Full	Abbreviated			
HELP1-1188-133	133	13.54	9.25	1.27
HELP1-1088-132	132	10.11	8.94	1.27
HELP1-0987-204	204	12.55	9.17	1.24
NGP89006-BL1RD	BL1	14.10	8.79	1.14

3.1 Initial Observations. In a preliminary test series, the instrumented block test result for lot 132 yielded a maximum block pressure of about 450 MPa (this shot is shown in Table 2, Test 1). In the configuration used, the propellant was encased in a 15-cm-dia by 40-cm-long PVC pipe. The case was completely filled with propellant (i.e., no ullage), and the charge weight was 8.6 kg.

The test series described in this report is a continuation of the above series; however, the test configurations have been somewhat modified, as shown in Table 2, shots 2 to 10, and as discussed below. First of all, in order to save scarce and expensive prototype propellant, the diameter of the PVC pipe was reduced from 15 cm to 10 cm, and the length from 40 cm to 25 cm. Moreover, it was decided to load the case with the interior ballistic loading density determined from actual gun firings. This loading procedure resulted in the presence of a ullage at the top of the charge.

In order to verify whether this change in configuration had any effect on the outcome of the instrumented block test, the first experiment of the series was performed on lot 133 in the 10-cm by 25-cm PVC pipe. In this test (test 2), the propellant weight was 2.4 kg—which means that, when compared to Test 1 with lot 132, the charge weight was reduced by nearly 70%.

This reduction in propellant mass led us to suspect that the observed level of response would be no greater, and perhaps a great deal less, than that observed with lot 132. On the contrary, the propellant reacted very violently—the pressure recordings showed pressures in excess of 700 MPa, both gages were destroyed, and the instrumented block severely damaged.

Between test 1 and test 2, several test parameters had been changed. These parameters included 1) bed diameter; 2) bed length; 3) charge weight; and 4) presence of an ullage. Parameters 1, 2, and 3 all had a smaller value, and, therefore, these variations were expected to lead to a lower response. Thus, we hypothesized that, because of the presence of an ullage, propellant grains might be impacting the confinement block and that resulting grain fractures could lead to higher surface areas for combustion and thus to higher pressures.

Table 2. Summary of the Witness Plate and Instrumented Block Test Data

						Case					
Test Number	Shot Number	Propellant Type	Lot Number	Charge Weight (kg)	Ullage	Material	Diameter (cm)	Length (cm)	Confinement Block	Test Type*	Results
1	834301	HELP1	HELP1-1088-132	8.6	N	PVC	15	40	Y	I	450 MPa
2	922001	HELP1	HELP1-1188-133	2.4	Y	PVC	10	25	Y	I	Very Violent
3	922701	JA2	RAD-PE-472-124	8.6	Y	PVC	15	40	Y	I	55 MPa
4	922801	JA2	RAD-PE-472-124	2.3	N	PVC	10	25	Y	I	20 MPa
5	922901	HELP1	HELP1-0987-204	2.4	Y	PVC	10	25	Y	I	Very Violent
6	923301	HELP1	HELP1-0987-204	2.8	Y	Steel	12.7	25	Y	W	Very Violent
7	923302	HELP1	HELP1-0987-204	2.1	N	PVC	10	25	Y	W	Very Violent
8	923401	HELP1	HELP1-1188-133	7.6	N	PVC	15	40	Y	W	Mild
9	923402	HELP1	55% 133/45% 204	4.8	N	PVC	15	25	Y	W	Very Violent
10	925401	HELP1	HELP1-1188-133	2.5	N	PVC	15	25	N	W	Mild

* I: instrumented block
W: witness plate

To verify this hypothesis, two shots were made in the two different loading configurations described previously. However, in order to avoid any catastrophic effects to the experimental fixtures, these shots were conducted with a propellant that is known to give mild responses when hit by a shaped charge jet, namely, JA2 [lot No. = RAD-PE-472-124].

The maximum pressure recorded for JA2 in the 15-cm by 40-cm case (test 3) was 55 MPa; in the 10-cm by 25-cm case (test 4), it was 20 MPa. This result showed that the differences observed with HELP1 were not necessarily related to the presence of an ullage in the case.

It was then decided to repeat the test in which a violent response was observed with HELP1 in order to check whether this result was consistently observed. The test was conducted with lot 204 (test 5) and gave a response that could be described as even more violent than previously observed in the same test configuration with lot 133. Both pressure gages were ejected from the pressure ports, and no signal was recorded. The instrumented block was severely damaged, and the confinement block was launched from the test site. It was later recovered about 30 m from the firing barricade. This suggested an influence of the nature of the propellant and/or of the geometry of the test, particularly the ullage, for the HELP1 propellant.

Because of the severe damage to the instrumented block, it was decided to use only the witness plate test (see Figure 3) and to evaluate the response of the propellant by analysis of the damage to the plate.

3.2 Test Sequence. A test matrix was designed in order to isolate the influence of each parameter that was suspected of playing a role in the observed phenomenon. These parameters, mentioned in Section 3.1, are repeated below:

Ullage in the propellant charge (i.e., loading density)
Case diameter
Case material
Case length.

The method used in designing the test matrix was to define a baseline configuration and then to perform tests in configurations that differed from this baseline by varying one parameter at a time. The baseline configuration was chosen to be the one that had given the mild response (test 1), that is:

Case material: PVC

Case diameter: 15 cm

Ullage: No

Case length: 40 cm.

The test configuration that had given the violent responses (test 2) (10 cm by 25 cm and ullage) is referred to as the modified configuration.

For all tests, the propellant charge was to be taken from one of the lots listed in Table 1 and the 52-kg confinement block was to be used. The test matrix is summarized in Table 3 in which the parameter of interest for each test is highlighted by means of a grayed box. The experimental data, tests 6–10, are given in Table 2.

Table 3. Test Matrix

	Baseline	Modified			Repeat Baseline		
Test # From Table 2	1	2–5	6	7	8	9	10
Case Diameter (cm)	15	10	12.7	10	15	15	15
Case Length (cm)	40	25	25	25	40	25	25
Case Material	PVC	PVC	Steel	PVC	PVC	PVC	PVC
Ullage	N	Y	Y	N	N	N	N
Confinement Block	Y	Y	Y	Y	Y	Y	N
Results[a]	NV	V	V	V	NV	V	NV

[a] V: Violent NV: not violent

3.2.1 Case Material. The nature of the case material was considered first. If the case material were important, the greater confinement of steel over PVC should lead to a more violent response. A test was performed in which the propellant was contained in a 25-cm-long section of a 105-mm steel case. The average diameter of this steel case is 12.5 cm. With the interior ballistic loading density, there resulted a charge weight of 2.8 kg. The propellant used in this test was lot 204 (test 6).

The witness plate was perforated, and the confinement block was again projected about 6 m into the air. This was an indication that the propellant's reaction was very violent, at about the same level of violence as tests 2 and 5 (the duplicated HELP1 tests with the instrumented block). It was concluded that the case material did not have a major influence on the violence of the reaction.

3.2.2 Ullage. Next, the influence of the ullage was investigated (test 7) by filling up the 10-cm by 25-cm PVC pipe with propellant (lot 204). The charge weight was 2.1 kg. This charge weight is smaller than the one given in the tests performed in a 10-cm by 25-cm PVC pipe with a ullage. (This is because these previous tests were instrumented block tests and additional propellant was required to fill the block's cavity.)

The observed reaction was again very violent—the witness plate was perforated, and the confinement block flew to an estimated height of 15 m. Since it went out of the field of view of the video camera, its height had to be estimated from the total time the block was airborne.

This test provided two types of information—first, the presence or absence of ullage did not seem to affect the propellant's response; and second, the violent response observed when using HELP1 in the 10-cm by 25-cm PVC pipe was repeatable.

3.2.3 Case Length. The test performed to check the influence of the case length was also used to verify whether the response observed in test 1 (instrumented block), with lot 132 in a 15-cm by 40-cm PVC pipe, was repeatable. If this replicate of test 1 gave a violent response, it would mean that the mild result for test 1 observed was an exception (due to some mishap) and that the propellants of this particular chemical family would, in general, react violently in this test. The propellant used for this test was lot 133. A charge weight of

7.6 kg completely filled the 15-cm by 40-cm PVC pipe (test 8). Since this was a witness plate test, there were no pressure measurements available. However, since the plate was bent (about 7 cm) and a fairly large number of unburnt propellant grains were found at the test site after the shot, the observed response was judged mild and similar to that of the original test. This indicated that the mild response of test 1 was not due to some mishap but was indeed repeatable. It also indicated that the case length was the test parameter most likely correlated with the propellant's response. However, in order to fully isolate parameters, it was necessary to run one more test in which only the length would be changed in the above test configuration.

A 25-cm-long by 15-cm-dia PVC pipe was chosen to determine whether the length or the diameter of the case was the predominant factor affecting the response of the propellant charge.

For lack of a sufficient amount of a unique propellant lot, the propellant used in this test was a mix of lots 133 and 204, a reasonable choice since these propellant lots have nominally identical dimensions (see Table 1). The charge weight was 4.8 kg (there was no ullage in this test), and the weight ratio of the mix was 55% (lot 133): 45% (lot 204).

This test (test 9) gave a response that was the most violent of this series. The witness plate was shattered, and only small fragments of it were recovered. The reaction was probably close to a detonation, as witnessed by the deep imprints left in the range base plate that supports the test fixture. The confinement block flew to an estimated height of 30 m. It was recovered bent and bearing imprints from the impacts of propellant grains.

At this point, it became clear that the loading configuration was affecting the outcome of the test and, of all the parameters involved, the length of the charge (or the L/D ratio) seemed to be the most likely parameter to explain the observed results.

4. DISCUSSION

Thorough analysis of the data obtained from the tests described in this report highlighted the fact that, in all these tests, the shot centerline (i.e., the axis of the shaped charge jet) was 12.5 cm above the bottom of the case. Thus, the shot centerline had been exactly at the mid-plane of the charge when a 25-cm-long tube was used. This observation suggested the hypothesis that the symmetrical aspect of this configuration might contribute to the observed phenomenon. More precisely, since various types of wave structures are known to exist in propellant beds disturbed by a shaped charge jet (Ramsay 1990; Watson, Serrano, and Pilarski 1991), it was hypothesized that, upon impact into the propellant charge, two reactive waves are created that travel through the propellant bed, one upward and the other one downward.

The downward wave is reflected by the witness plate, and the upward wave is reflected by the confinement block. Then these reflected waves travel back through the bed and eventually meet and recombine somewhere in the propellant bed. In the situation where the shot centerline is at the mid-plane of the charge, the reflected waves are likely to meet and recombine near the mid-plane of the charge since the distances traveled by each wave are approximately equal. But the propellant bed in the vicinity of the mid-plane has been highly perturbed by the impact of the shaped charge jet. In fact, the reflected waves travel through "processed" nonvirgin material (as schematically illustrated in Figure 4). It seems reasonable to assume that the recombination of the waves could generate a very violent reaction. This phenomenon would not necessarily occur in the 40-cm-long tube, either because the waves would be out of phase, or because the waves would have traveled sufficiently far to decay below some critical amplitude.

One way to partially verify this hypothesis was to perform a test in a 25-cm-long tube without the confinement block at the top of the charge. This eliminates the surface upon which the upward-bound wave is supposed to reflect. It is not possible to eliminate the witness plate since it provides both the physical support for the test charge and the means of evaluation of the test's outcome.

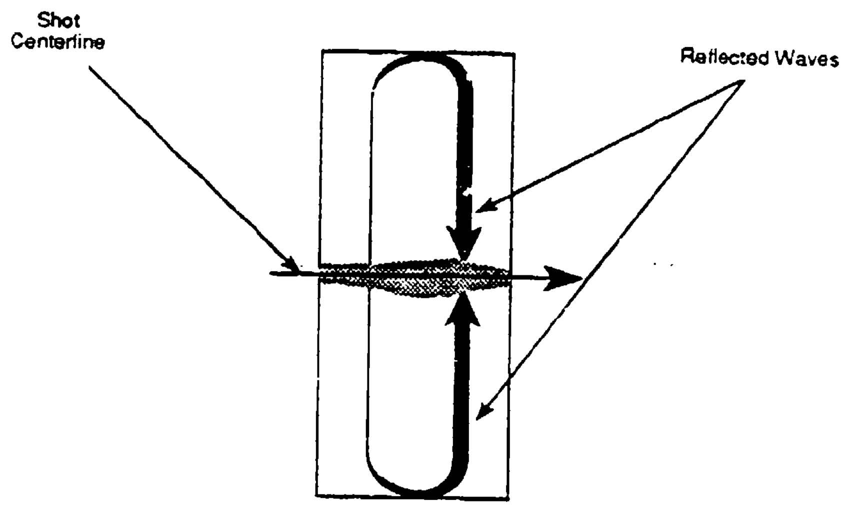


Figure 4. Schematic Representation of the Symmetry Hypothesis.

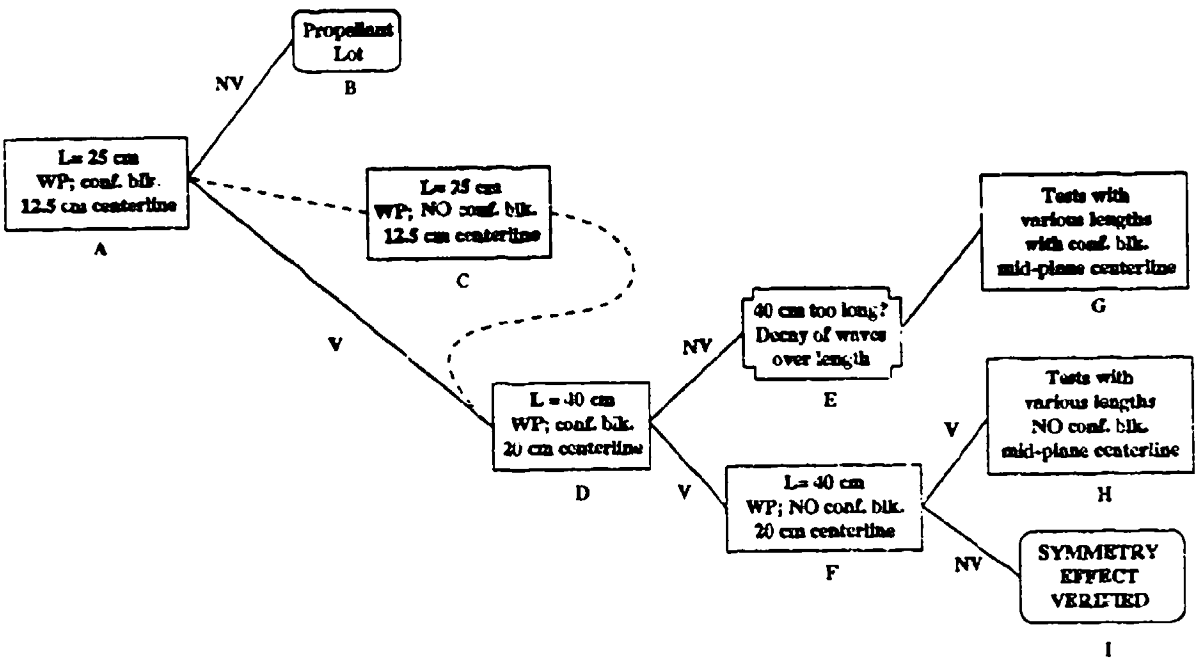
This test (test 10) was performed immediately following the above test series. As was mentioned before, all the propellant from lots 132, 133, and 204 had been used, but considering the importance of the verification of the above hypothesis, we decided to download some existing test rounds to obtain the additional propellant (here lot 133) necessary to conduct this test.

A 15-cm by 25-cm PVC pipe was fully loaded (i.e., no ullage) with 4.5 kg of lot 133. The confinement block was replaced in this configuration by a simple wooden plug that played the role of retainer for the propellant. The plug did not allow reflection of a pressure wave. This test (test 10) gave a mild response (i.e., the witness plate was simply bent about 7 cm) which was very similar to the mild result in test 8 with the 15-cm by 40-cm PVC pipe.

This result provided support for what we began to call the "symmetry effect" hypothesis. However, additional data were needed in order to confirm this hypothesis, and an additional test plan was designed to provide these data.

5. TESTS TO CONFIRM THE SYMMETRY HYPOTHESIS

5.1 Test Tree. In order to confirm the symmetry hypothesis, a test sequence was designed in the form of a "test tree" in which each test led to another depending upon whether the response was violent (V) or not violent (NV). This test tree is shown in Figure 5.



NOTE: WP (WITNESS PLATE)

Figure 5. "Test Tree" to Confirm the Symmetry Hypothesis.

The first test of the test tree, A, was to be a duplicate of the test in the modified configuration, to check the repeatability of the results because a different lot of HELP1 had to be used for availability reasons. If this test gave a mild response, B (i.e., different from what had previously been observed in the same configuration with a similar propellant from a different lot), this would mean that the propellant lot was responsible for the observed results, and further investigation would then be required.

On the other hand, if the first test brought a confirmation of previous results, the next logical step would be a test in a symmetrical configuration with the confinement block but with a longer pipe, D. A 40-cm-long pipe would then be used with a 20-cm shot centerline. We also considered conducting a test similar to A, but without the confinement block, in order to verify the contribution of the confinement block to the hypothesized symmetry effect, C.

The propellant's response to D would be either violent or not. If not violent, we could hypothesize that the 40-cm length was sufficient to allow the waves to decay in such a way that they would not recombine in a destructive manner, E. Additional tests with various lengths would then be required in order to determine the critical length above which the phenomenon could not be observed, G.

A violent response in D would constitute a first step in the confirmation of the symmetry hypothesis and led to a test in an identical configuration save for the absence of the confinement block, F.

Again, the response to 6 could be violent or not. If it were violent, the hypothesis of a critical length above which the effect could not be observed would have to be verified by performing tests with various lengths and without the confinement block, H.

On the other hand, if the propellant's response in E were mild, the symmetry effect would be confirmed, I.

5.2 <u>Confirmation Test Results</u>. For this test series, a substitute propellant lot had to be found. A lot of similar composition and dimensions was the HELP1 lot designated NGP89006-BL1RD (abbreviated as BL1) and was used. The finished dimensions of this lot are given in Table 1.

In the test series conducted with BL1, a 15-cm PVC pipe was used in all tests. The case length, the height of the shot centerline, and the presence/absence of the confinement block were the parameters of interest. The results for the tests in this series are described in detail in the following paragraphs and have been summarized in Table 4.

Table 4. Summary of the Witness Plate Test Data for the BL1 Propellant Lot

Test Number	Shot Number	Case Length (cm)	Shot Centerline (cm)	Charge Weight (kg)	Confinement Block	Max. Plate Depression (cm)	Result
11	012201	40	12.5	7.3	Y	9.5	Mild
12	012202	25	12.5	4.5	Y	13.5	"Mildly Violent"
13	012301	25	12.5	4.5	N	—	Violent
14	012302	40	20	7.3	N	7.5	Mild
15	012303	40	20	7.3	Y	—	Very Violent
16	013701	20	10	3.6	N	—	Extremely Violent
17	013702	33	16.5	5.9	N	10.5	Mild
18	015601	40	10	7.3	N		Very Violent

A preliminary repeatability test (test 11) was performed in order to check that the BL1 propellant selected gave a mild response like test 8 (see Table 3) in the baseline configuration. The test in the 40-cm PVC pipe with the confinement block gave a mild response, which allowed the test series of Figure 5 to be pursued with BL1.

The test in a 25-cm pipe with the shot centerline at 12.5 cm was performed (test 12) with the purpose of checking the reproducibility of earlier violent results (test 7). This test gave a response that was described as "mildly violent"—the witness plate was not perforated, as in previous violent reactions, but the deformation was significant (13.5 cm). There were marks on it that indicated that it had been projected toward the ground with great force.

The aforementioned tests 11 and 12 were conducted with the confinement block on top of the propellant charge. Since the hypothesis of the symmetry effect implied that this confinement block would play a very important role in the phenomenon, the test in the 25-cm pipe with the shot centerline at 12.5 cm and without the confinement block was inserted into the test sequence to confirm the importance of the confinement block in the suspected phenomenon. This test was performed (test 13) and gave a violent response. This result did not seem to support the symmetry hypothesis, but it was observed that the 25-cm length, or for that matter, the 12.5-cm height of the shot centerline, might be such that the incident shock wave produced by the jet's impact had not yet decayed (see Figure 6). Thus, there

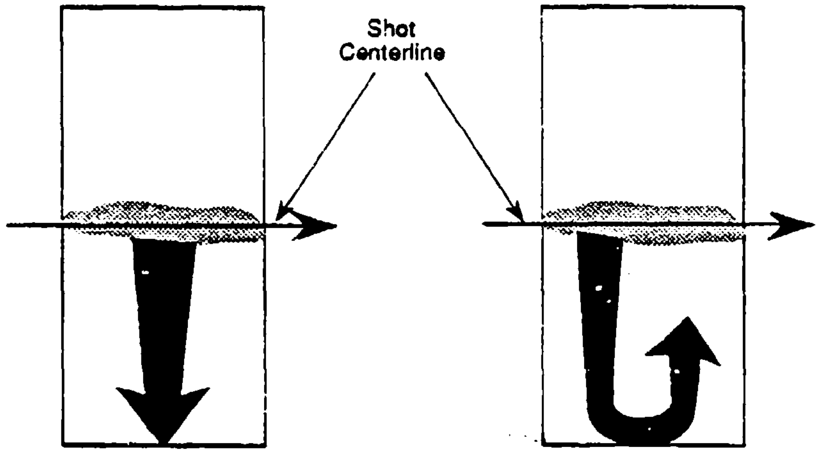


Figure 6. Schematic Representation of the Proximity Hypothesis.

would be no need for recombination of waves in order for a violent reaction to occur. If this were true, then we had observed yet another effect in addition to the symmetry effect.

This aspect of the hypothesis was verified with tests in a 40-cm pipe with the shot centerline at 20 cm, the first of which was preformed without the confinement block. This configuration gave a mild response (test 14).

The test performed in a similar configuration, but with the confinement block, gave a very violent response (test 15).

These results confirmed the symmetry effect, but it was also suspected from the result of test 13 that another effect was probably associated with it in some instances.

6. ADDITIONAL HYPOTHESIS

The suspected additional effect could be expressed as follows. Below a certain distance from the shot centerline, the observed reaction is always violent because the wave produced in the propellant charge by the shaped charge jet's impact is still very strong and has not yet decayed. In other words, there was, in addition to the symmetry effect, a "proximity effect" (i.e., proximity of the jet to the witness plate). If this were true, then there must be a critical distance below which this effect must occur and above which this proximity effect would not be observed.

To determine this critical height, several tests were performed, all without the confinement block since we then know that the confinement block was crucial for the symmetry effect and its presence would have created conditions detrimental to the observation of the proximity effect. All tests were done using 15-cm-diameter PVC pipe as the case material.

The first one of these additional tests involved a 20-cm-long pipe with the shot centerline at 10 cm. This test gave an extremely violent response (test 16). The next test was then done in a 33-cm-long pipe with the shot centerline at 16.5 cm. The observed response was mild, which seemed to indicate that the 16.5-cm shot centerline was above the critical distance of the proximity effect for a propellant of the HELP1 formulation (test 17).

These results supported the proximity hypothesis. In order to provide further support, it appeared desirable to consider a configuration known to give a mild response and to make the proximity effect dominate. Thus, a 40-cm-long tube without confinement block was selected, with a 10-cm shot centerline rather than the previous 12.5 cm. The prediction was that the reaction should be violent if the proximity hypothesis were correct.

This test was performed (test 18), and the propellant's response was very violent. Since it was known that in a 40-cm-long pipe with a shot centerline at 12.5 cm and a confinement block, the response was mild (test 11). This last result could be seen as a confirmation of the proximity effect. It could be said that, with propellants of the HELP1 family, 12.5 cm was the distance below which the proximity effect prevailed in these test configurations.

However, the results of the tests performed with the 12.5-cm shot centerline with HELP1 propellants showed that the propellant's response in this configuration could be either mild or violent. Other parameters could also affect the outcome of the test. One of these parameters, for example, is the interaction of the shaped charge jet and the conditioning plate, with the possible resulting deviation of the jet. The 12.5-cm distance could then be viewed as being contained in a threshold region where results could be either mild or violent, depending on conditions that cannot be controlled. It seemed safe then to assume that the 10-cm distance was lower and the 16.5-cm one higher than the critical "proximity distance" for HELP1.

7. TEST CONFIGURATION RECOMMENDATIONS

The observed phenomena (i.e., the symmetry effect and the proximity effect) can be summarized graphically, as shown in Figure 7. In a 40-cm pipe with the confinement block, a mild response at the 20-cm shot centerline and a violent one at the 12.5-cm shot centerline are the expression of the symmetry effect. Without the confinement block, the mild response at the 12.5-cm shot centerline and the violent one at the 10-cm shot centerline are related to the proximity effect.

In order to design a test that would adequately measure the level of response of candidate propellants to a shaped charge jet direct attack, it is necessary to eliminate both symmetry and proximity effects from the test configuration. The occurrence of these effects is closely related to a geometric configuration that has a very low probability of being encountered in the field. A perfectly symmetrical hit is very unlikely; moreover, the reflecting surfaces in an actual round of ammunition are not planar and therefore unlikely to produce the wave reflections that were inferred from some of the above test observations.

Some guidelines for the design of the test configuration for the instrumented block and witness plate tests can therefore be expressed as follows:

- no confinement block to eliminate multiple reflections and thus the occurrence of the symmetry affect;
- case length such that the amount of propellant is sufficient to allow the test configuration to realistically simulate an actual round; here a length of 30 cm was selected for HELP1;
- shot centerline sufficiently far from the witness plate to ensure that it is out of the threshold zone for the proximity effect mentioned above; here a distance of 17.5 cm was selected for HELP1;

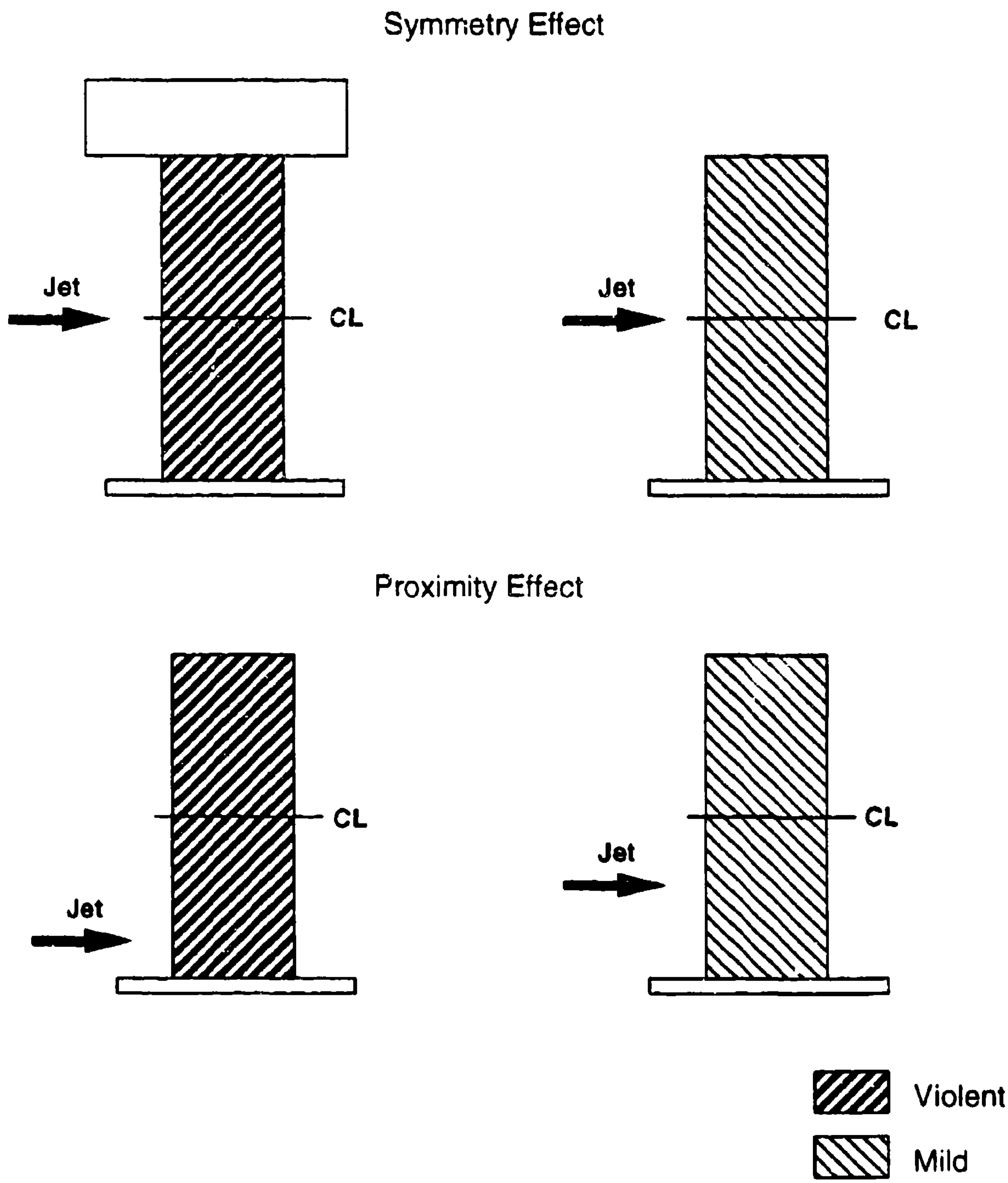


Figure 7. Summary of the Symmetry and Proximity Effects.

- case diameter such that it is equal to or greater than the case diameter of actual rounds to ensure that the path traveled by the jet through the propellant bed (and thus the deposited KE [Majerus and Merendino 1978]) is at least equal to that encountered by an actual round—here a diameter of 15 cm, used in the above tests, was selected.

Finally, it was necessary to check whether this suggested configuration provides an adequate means of discriminating a propellant's response.

A final test series was conducted with several propellants known to give very different responses (namely M30, HELP1, and JA2) in order of decreasing expected level of response. The results of this final test series are presented in Table 5.

Table 5. Summary of the Witness Plate Test Data in the Recommended Test Configuration

Test Number	Shot Number	Propellant Type	Lot Number	Case Length (cm)	Shot Centerline (cm)	Charge Weight (kg)	Confinement Block	Max. Plate Depression (cm)
19	102301	HELP1	NGP89006-BL1RD	30	17.5	5.5	N	7.5
20	102302	M30	RAD-86C070534	30	17.5	5.5	N	10.5
21	102303	JA2	RAD-PD-041-2	30	10	5.5	N	7.9
22	102401	JA2	RAD-PD-041-2	30	6.5	5.5	N	9.9

The first two test (tests 19 and 20) were intended as a validation of the recommended test configuration. The selected configuration would not create any destructive effects with HELP1, but it had to be determined that the response observed with a more sensitive propellant, (namely, M30) would be significantly higher, enough to differentiate the propellants in terms of their respective levels of response, but yet without creating any damaging effects. This was verified as the plate's deformation was sensibly larger with M30, and the response of M30 in this test could still be described as mild (identical to test 17, Table 4).

The next two tests (test 21 and 22) were conducted with JA2 propellant. The purpose of these tests was to check whether the proximity effect could be induced in a propellant that is known to give very mild responses. The test with a 6.5-cm shot centerline yielded a higher plate deformation (9.9 cm) than the test with the 10-cm shot centerline (plate deformation: 7.9 cm). These results provided further confirmation of the proximity effect.

8. CONCLUSIONS

A phenomenon that seemed at first to reflect a propellant's strange behavior (a lesser charge contained in a smaller container gave a much more violent response) was explained by the fact that the test configuration that gave the higher response had a symmetrical aspect that created conditions favorable for the support of a "symmetry effect." In the course of verifying the symmetry effect, another independent effect was discovered. This other effect was called the "proximity effect" because it was observed when a reflecting surface (in these tests, the witness plate) was located too close to the shaped charge jet shot centerline. Both of these effects are pictorially summarized in Figure 8.

Since these effects appeared to be related to the test's geometric configuration, and are unlikely to appear in actual field conditions, recommendations were provided to eliminate, by design, the conditions favorable to their occurrence. The preferred test configuration would have the propellant encased in a 15-cm-dia, 30-cm-long PVC pipe, with no confinement at the top, and the shaped charge jet shot centerline 17.5 cm above the bottom of the case.

This configuration was used in tests with JA2, HELP1, and M30 propellants. It was found to produce test results that are free of the aforementioned effects and to provide an effective means of comparison between these propellants. It can thus be used as a starting point for future tests with other propellants. One of the objectives of future tests will then be to check for these effects at more than one height. Additional investigations could also be made to study the influence of the bed diameter, or that of geometric intrusions in the bed (e.g., projectile tail), since the internal geometry of a recent KE or HEAT cartridge case is quite complex.

Finally, the possibility of using the proximity effect to differentiate propellants by determining the critical proximity distance for each propellant, and using it as a ranking criterion, could be investigated.

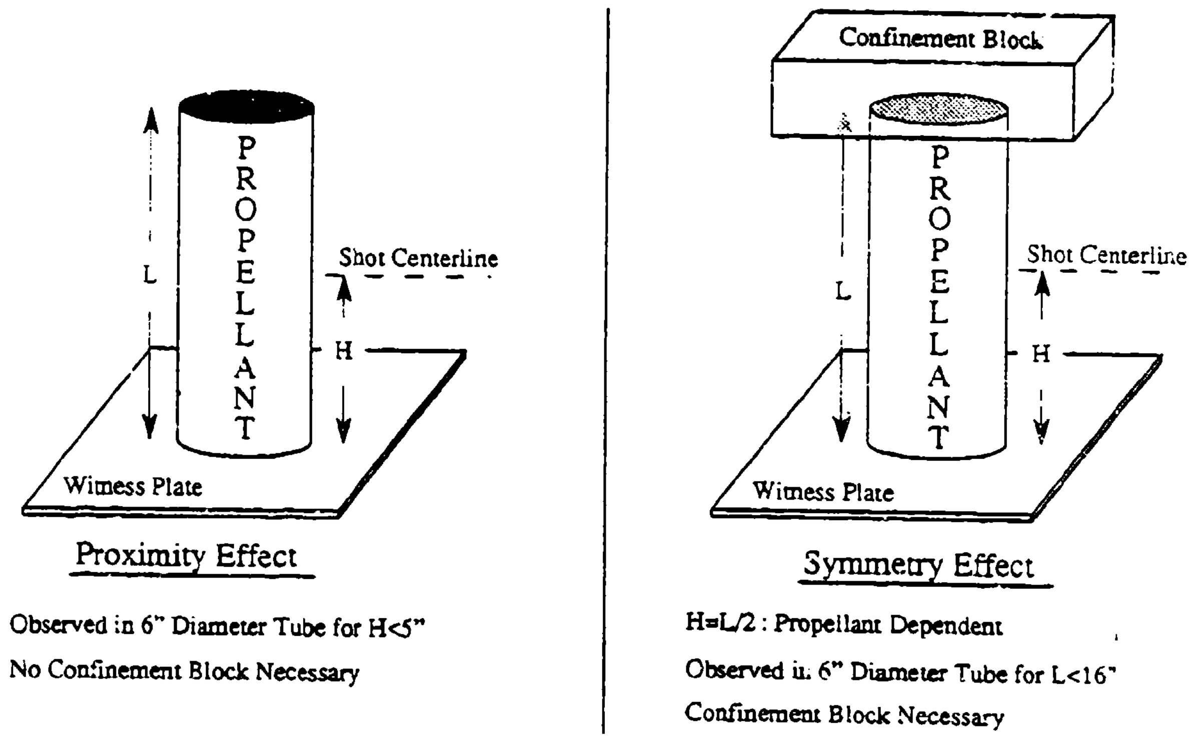


Figure 8. Pictorial Representation of the Conclusions.

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