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THE SMALL-SCALE GAP TEST (SSGT) AT PICATINNY ARSENAL

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The U.S. Army Combat Capabilities Development Command (DEVCOM) Armaments Center (AC), Picatinny Arsenal, NJ, has conducted the small-scale gap test (SSGT) on hundreds of explosive formulations in the last several decades. While test facilities and personnel have changed over this timeframe, the basic test method to assess shock sensitivity in this configuration has remained the same. DEVCOM AC's approach differs from the current governing document [Allied Ordnance Publication (AOP)-7]. This report will detail the key differences between the DEVOM AC method and AOP-7, Edition 2. Additionally, the output from varying explosive column heights in the donor charge was assessed and reported.

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INTRODUCTION

The small-scale gap test (SSGT) is a standard method of assessing the shock sensitivity of an explosive sample. Similar to other gap tests, such as the Naval Ordnance Laboratory (NOL)[1] large-scale gap test (LSGT), the experiment employs a standard donor explosive, an attenuator of some sort, an acceptor explosive, and a method of assessing the output of the acceptor explosive. The input to the acceptor explosive is adjusted based on the thickness of the attenuator material; in the U.S., this is generally poly(methyl methacrylate) (PMMA). A thicker attenuator material results in a less powerful shock experienced by the acceptor material and vice-versa. The output of the acceptor explosive is generally evaluated with a steel witness plate. In the case of the SSGT, a relatively thick steel plate is used. Detonation of the acceptor material results in a measureable dent in the steel plate.

The SSGT was initially standardized in 1959 at the NOL. By 1961, a few changes were made by the experimentalists; the brass specifications were changed for ease of procurement, donor explosive lot testing was made less stringent, donors were loaded flush to the top of the brass tubes, and the detonator was changed for improved safety. A comparison between the initial 1959 variant and the more standardized 1961 variant of the SSGT is shown in figure 1 (ref. 1).

[1] Naval Ordnance Laboratory, White Oak, MD.

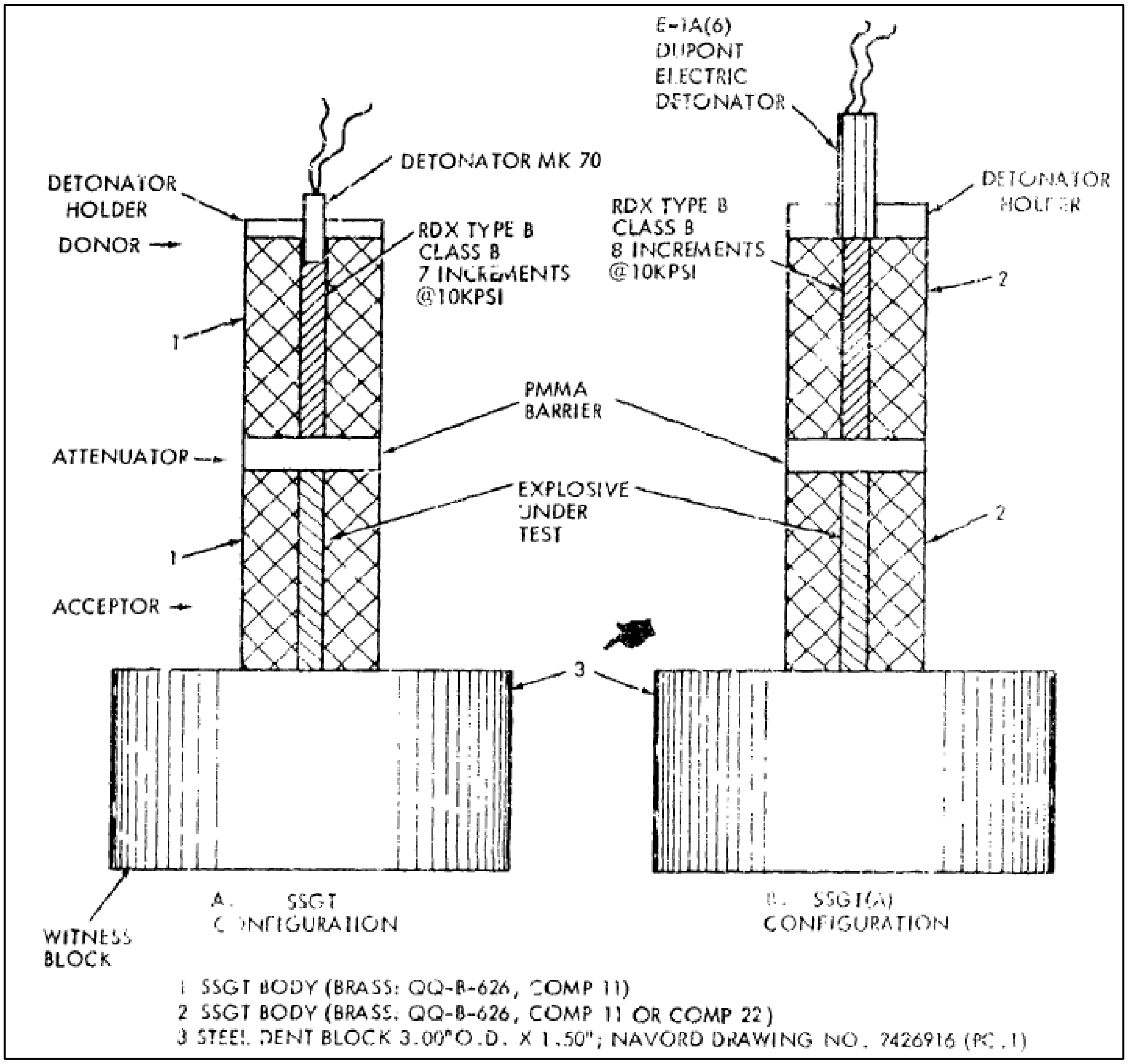

Figure 1
Comparison of NOL SSGT methods

The SSGT was integrated into MIL-STD-1751A (ref. 2), the Department of Defense (DoD) standard for safety and performance tests during the qualification of explosives. The MIL-STD test information sheet was based on the 1961 variant of the test and referenced the NOL technical report. Allied Ordnance Publication (AOP)-7 (ref. 3) integrated the SSGT into its test information sheets, as well, albeit with significantly less specifics on test protocol. When MIL-STD-1751A was discontinued, AOP-7, Edition 2, became the primary test method compendium for the U.S. qualification of explosives. There are key differences between the test methods that Picatinny Arsenal[2] employs and AOP-7, Edition 2.

[2] U.S. Army Combat Capabilities Development Command Armaments Center, Picatinny Arsenal, NJ.

SMALL-SCALE GAP TEST DONOR

Picatinny Arsenal has conducted hundreds, if not thousands, of SSGTs over the last several decades. To the authors' knowledge, there is no comprehensive, published database for these experiments nor published Picatinny Arsenal test procedures. At some point before 1983, the decision was made to switch from a neat RDX[3] binder to a Composition A-5 binder. Composition A-5 contains 1.0 to 1.5% stearic acid to improve the safety and ease of pressing operations. Picatinny Arsenal prepares thousands of Composition A-5 low density, 0.198-in. diameter pre-pellets at a high throughput pressing facility. Each of these 150-mg pre-pellets are considered one increment. Seven total increments are included into one SSGT donor. These increments are consolidated in three, 8,000-psi presses at the test site. First, two pre-pellets are added into the brass tube and consolidated. Next, three pre-pellets are added and consolidated. Finally, two more pre-pellets are added and consolidated. This results in a final measured donor density of 1.64 g/cm^3 and leaves a gap of approximately 0.2 in. from the top of the brass tube to the surface of the pressed Composition A-5. This empty space serves to loosely center the RP-87 exploding bridgewire (EBW) detonator. EBW detonators offer superior reliability and safety compared to traditional blasting caps, which contain primary explosives. A photograph of a Picatinny Arsenal donor charge is shown below in figure 2.

Figure 2
Picatinny Arsenal donor charge

MIL-STD-1751A, based off the NOL test report, specifically stated that eight total increments of neat RDX should be pressed at 10,000 psi: seven equal increments of 200 mg and an eighth top-off increment, resulting in a flush tube surface and a nominal density of 1.56 g/cm^3. An acrylic holder is required to center the detonator on the donor charge. It is assumed that AOP-7 recommends the same procedure given it references to both MIL-STD-1751A and the NOL technical report. However, AOP-7 does not specify the incremental loading or pressure. AOP-7 and MIL-STD-1751A both recommend a no. 6 commercial blasting cap or equivalent output, which is significantly larger than the RP-87 detonator.

The change from an embedded detonator to a flush surface mount detonator was made primarily based on safety. The Mk70 detonator was more likely to initiate from electrostatic discharge. The diameter of the proposed replacement detonator, a commercial no. 6 blasting cap, was larger than the 0.200-in. brass tube inner diameter for the donor explosive, so an additional increment was added to permit intimate contact between the detonator and RDX.

[3] 1,3,5-Trinitro-1,3,5-triazinane.

SMALL-SCALE GAP TEST WITNESS PLATE

MIL-STD-1751A, AOP-7 Edition 2, and the NOL technical report all note that the SSGT witness plate should be 3 in. in diameter by 1.5-in. thick mild steel. At some point, Picatinny Arsenal instead selected 1.25 in. diameter by 0.625-in. thick witness plates. To define the GO/NO-GO criterion, two tests are conducted with no attenuator between the donor and acceptor charges. The dents are measured and averaged. For all subsequent trials, if the dent equals or exceeds 50% of the baseline dent depth, the trial is considered a GO. Otherwise, the trial is considered a NO-GO.

In many cases, detonation reactions result in a slight bulging of the bottom of the witness plate and lead to some degree of inconsistency when measuring the dent depth. While most test series are completed with mostly binary trial results (nil dent or near 100% baseline dent), some materials exhibit longer run to detonation or quench times and yield dents that are 30 to 70% of the baseline dent depth. In most cases, the length to diameter ratio of the acceptor brass tube reduces or eliminates unsteady shock behavior in the acceptor explosive at the witness plate interface. Generally, the SSGT is only performed on high energy, very small critical diameter explosives. If there are concerns about the critical diameter of the formulation, a larger gap test is conducted to assess shock sensitivity, such as the insensitive high explosive (IHE) gap test or the LSGT. Bulging of the SSGT witness plates and the resulting measurement uncertainty can impact the 50% point but will tend to self-correct given the up-down test protocol of SSGT. Thicker witness plates should be considered in the future.

DONOR DENT EXPERIMENT

In order to test the repeatability of the Picatinny Arsenal donor system and determine the impact of adding another increment of Composition A-5, a series of donors with varying explosive fills were prepared and tested. Five charges at each of the following number of increments were pressed; 2, 4, 6, 7, and 8. For all but the 7 increment tubes, each pre-pellet (increment) was pressed one at a time at 8,000 psi. For the 7 increment tubes, the increments were pressed as standard Picatinny Arsenal donors as described previously (2-3-2). All 25 charges were initiated with RP-87 detonators and Picatinny Arsenal mild steel plates, 1.25 x 0.625 in., were used for dent measurement. Dent depth measurements were taken in triplicate by three individual operators. The average dent value with associated standard deviation for each donor system is shown in table 1. All measurements are also shown on a plot of dent depth versus increments in figure 3.

Table 1
Average dent depths versus number of increments

Increments	Average dent (in.)	σ (in.)
2	0.0520	0.0017
4	0.0644	0.0012
6	0.0679	0.0014
7	0.0670	0.0017
8	0.0680	0.0016

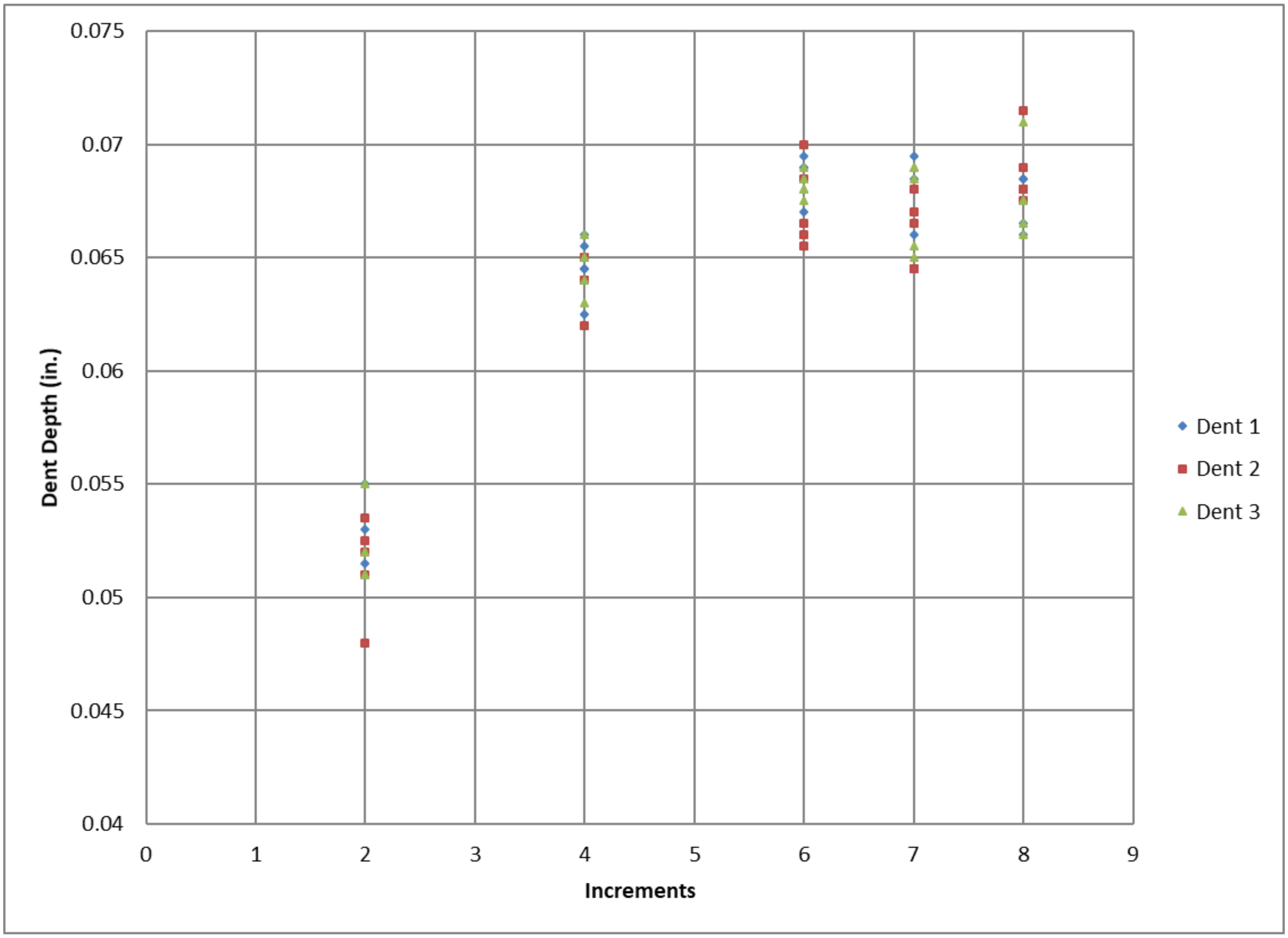

Figure 3
Dent depth versus increments

DISCUSSION

The mild steel witness plate dent depth increases significantly from 2 to 4 increments. A lesser, but still appreciable increase in dent depth occurs from 4 to 6 increments. The donor tubes containing 6, 7, and 8 increments yielded effectively the same dent measurements and are likely equivalent for use in this test. This justifies the Picatinny Arsenal method of leaving one increment out for both the convenience of locating the detonator and the safety benefit of avoiding a hands-on cutting operation to make the input end flush to the brass tube.

Jaguar version 20.0 (ref. 4) and Cheetah version 8.0 (ref. 5) both predict that Composition A-5 at 1.64 g/cm^3 yields significantly more output than neat RDX at 1.56 g/cm^3. It is not known why Picatinny Arsenal selected Composition A-5 and did not better match the density and therefore detonation pressure to the 1961 RDX standard. The different donor system allows relative comparisons between legacy formulations tested at Picatinny Arsenal but does not allow for comparisons with any other test facilities using the standard RDX donors. Additionally, per AOP-7, there are shock sensitivity requirements for materials characterized as booster explosives and a SSGT series of 20 trials at 4 decibangs (dBg) is typically called for.

Picatinny Arsenal's donor output is greater than the RDX standard, so any 4 dBg trials at Picatinny Arsenal have been overtests. Table 2 shows Jaguar and Cheetah comparisons at the Chapman-Jouguet (CJ) state.

Table 2
Cheetah and Jaguar CJ output estimates

Material	Code	Density	CJ pressure (kbar)	CJ detonation velocity (km/s)
RDX	Cheetah exp6i v8.0	1.56	249.1	7.82
RDX	Cheetah bkws	1.56	247.4	8.01
RDX	Jaguar	1.54	250.0	7.80
Comp A-5	Cheetah exp6i v8.0	1.64	272.3	8.09
Comp A-5	Cheetah bkws	1.64	272.6	8.30
Comp A-5	Jaguar	1.66	281.0	8.12

Over the last 15 years, Picatinny Arsenal has recommended adding Composition A-5 as an acceptable donor substitute in AOP-7. There have been several proposed revisions and one new proposed edition of AOP-7 since 2003; however, none have been ratified and promulgated. As of April 2020, the current approved AOP-7 document is Edition 2 dated June 2003. Adding the Picatinny Arsenal method into AOP-7 at this point, without additional test data comparing the neat RDX and Composition A-5 donor systems, would lead to confusion at test facilities and shock sensitivity data that could not be compared between the military services. The authors recommend at this time that a larger scale test be used for the purposes of U.S. qualification. The IHE gap test is commonly performed at all major DoD test laboratories, uses a commercially available booster, and requires substantially less explosive sample mass than LSGT.

CONCLUSIONS AND RECOMMENDATIONS

The Picatinny Arsenal[4]method of running the small-scale gap test (SSGT) is incompatible with U.S. national test standards and is incomparable to other Department of Defense test facilities. The deviations in the donor system are of primary concern. It is not known precisely when Picatinny Arsenal personnel switched from neat RDX[5] to Composition A-5 and the rationale behind the density selected. Testing has continued using these donors to maintain comparability to the substantial database of in-house SSGT results. For characterization purposes, the community has recently favored the insensitive high explosive (IHE) gap test, leading to few SSGTs performed on an annual basis at Picatinny Arsenal. This may be an ideal time to conduct the necessary research and development to propose a modern donor solution that better matches the legacy RDX standard.

If a change in donor is required in the future, a better match to detonative output to the 1.56 g/cm^3 RDX standard should be found. First, thermochemical codes such as Cheetah or Jaguar should be used to estimate the density of a readily available and safely pressable booster explosive. This could include explosives such as Composition A-5, Composition A-3, or PBXN-5. After selecting an explosive formulation and density, a pressing study should be completed to determine the necessary parameters to yield the target density. Donor assets should be prepared and evaluated using photonic Doppler velocimetry (PDV), comparing shock history through poly(methyl methacrylate) (PMMA) with several different attenuator thicknesses to the neat RDX standard. Once a satisfactory match is found, that donor system should be standardized to Picatinny Arsenal and reported to the community.

[4] U.S. Army Combat Capabilities Development Command Armaments Center, Picatinny Arsenal, NJ.
[5] 1,3,5-Trinitro-1,3,5-triazinane.

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