NATO STANDARD

AOP-4526

SHAPED CHARGE JET MUNITION TEST PROCEDURE

Edition A, Version 1
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NORTH ATLANTIC TREATY ORGANIZATION

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NATO LETTER OF PROMULGATION

20 November 2018

1. The enclosed Allied Ordnance Publication AOP-4526, Edition A, Version 1, SHAPED CHARGE JET MUNITION TEST PROCEDURES, which has been approved by the nations in the CNAD Ammunition Safety Group, is promulgated herewith. The agreement of nations to use this publication is recorded in STANAG 4526.

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Director, NATO Standardization Office

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RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS
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RECORD OF SPECIFIC RESERVATIONS

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When reviewing requirements for this test, SRD AOP 39.1 should first be read for guidance in the organization, responsibilities and conduct of full scale testing.

1.1. ANNEXES

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B. Shaped Charge CCEB 62 (French)
C. Historical Overview

1.2. AIM

The aim of this Standard is to specify the test requirements and procedures to provide evidence of the reaction of munitions and weapon systems to the threats represented from being struck by a shaped charge weapon.

1.3. AGREEMENT

1. Participating nations agree that the requirements and procedures incorporated in this Standard will be used for assessing the reaction, if any, of munitions and weapon systems to impact by a shaped charge jet represented by the most prevalent threat currently the RPG or more appropriate threat.

2. Participating nations further agree that national standards, orders, manuals and instructions implementing this AOP will include a reference to the STANAG 4526 for purposes of identification.

3. No departure may be made from this agreement without consultation with the NATO Tasking Authorities/Delegated Tasking Authorities (TA/DTAs). Nations may propose changes at any time to the TA/DTAs where they will be processed in the same manner as the original agreement.

4. This Standard is supported by the guidance in SRD AOP 39.1 that makes recommendations on the organisation, conduct and reporting of the tests in this and other full scale tests Standards.

1.4. DEFINITIONS

For the purpose of this document, definitions of terms to be used to describe test details and events are given in the NATO Terminology Management System that is available by reference for all Allied Publications.

1.5. GENERAL

1. Minimizing the reaction of ordnance to shaped charge jet impact is an ongoing commitment of weapons designers to ensure that the safety of personnel and materiel will not be unduly jeopardized.

2. This Standard addresses the situation where munitions and weapon systems may be struck by a shaped charge projectile most probably whilst on operations. This can have a significant consequence for personnel and equipment from the response of their own munitions and weapon systems to such a threat.

3. Other tests may be required to evaluate the response of munitions in tactical situations, such as when stowed on armored vehicles.

1.6. DETAILS OF THE AGREEMENT

1. This Standard provides guidance and procedures for Shaped Charge Jet testing. Testing should be conducted by participating nations as a part of the Insensitive Munition (IM) assessment of munitions where required by STANAG 4439, Policy for Introduction, Assessment and Testing for Insensitive Munitions.

2. This Standard specifies 2 test procedures:

   a. A standard test procedure for determining the degree of reaction, if any, of a munition when hit by a Shaped Charge Jet (SCJ), characteristic of a Rocket Propelled Grenade (RPG).

   b. An alternative test procedure for determining the degree of reaction, if any, of a munition when hit by a specific alternate threat shaped charge jet supported by means of a Threat Hazard Assessment (THA).

CHAPTER 2 TEST SPECIFICATIONS

2.1. TEST ITEM CONFIGURATION

1. The test item configuration shall be the final production standard and in accordance with the condition as appropriate to the life cycle phase represented by the test, or representative as approved by the national authority.

2. Guidance on variations to the production standard and condition (like; live vs inert, pre-conditioning, packaged vs unpackaged, All Up Round vs Components) as given in SRD AOP 39.1 Annex B shall be considered.

2.2. TEST TYPES

There are two methods for performing the Shaped Charge Jet Test; a “Standard Test” and an “Alternative Test”. For the selected test, subject the munition in either a logistical and/or tactical configuration, to a jet from a shaped charge, as documented in an approved test plan.

a. Method 1 (Standard Threat Test): Using the general guidance specified herein, subject the test item to the jet from a shaped charge representing the rocket propelled grenades, as described in Section 2.5.1, method 1, of this document. The complete characterization of the jet used for the test shall be conducted to meet the requirements of this AOP, and shall be provided or referenced. Examples of tests fulfilling these requirements can be found in the annexes.

b. Method 2 (Alternative Threat Test): Using the general guidance specified herein, subject a test item to a well characterized shaped charge jet as documented in a THA. The jet should be fully characterized and reported, as documented in sections 2.5.1, method 2.

2.3. TEST CONDITIONS

1. The test item state and orientation shall be applied in coherence with the life cycle phase represented by the test, or representative as approved by the national authority.

2. Methods shall be established to assure the jet is aimed at the selected aimpoint and that the jet follows the desired path through the munition. Base the shotline on the THA, and in general, select it to produce the worst case reaction while remaining consistent with the THA. Subjected to this constraint, the likelihood of getting a violent response, will normally be maximized by choosing a shot line, which provides the longest possible path length through the energetic material. However,

unlikely shotlines should be avoided, which are aimed at components that are quite small when compared to the bulk of the explosive, propellant or aimed at unlikely angles. Prior to testing, shotlines should be agreed to by the appropriate authorities. In this regard, the following considerations may apply: if the energetic material contains a cavity of significant size (such as the bore of a rocket motor), aim the jet to pass perpendicularly through the cavity. (It has been observed that such cavities can promote the occurrence of violent reactions).'

3. Additional guidance on variations to the test conditions (like; positioning/orientation, aimpoint/shotline, restraints, conditioning, marking, re-use) as given in SRD AOP 39.1 Annex B shall be considered.

2.4. SHAPED CHARGE

1. The shaped charge will be produced in a precise manner ensuring that all components are properly located, and that the charge is axially symmetric. Dimensional tolerances shall be selected such that a consistent straight jet is achieved. The explosive charge diameter shall be between 61mm and 95mm, with an explosive fill performance, detonation velocity and Gurney energy, between COMP B and Pure HMX at TMD. The charge liner shall be made from a high quality oxygen free copper and described. Initiation methods will be specified to assure consistent and strong symmetric initiation. The method for positioning the shaped charge shall not destabilize the jet formation (e.g. avoid using high density materials placed asymmetrically on the perimeter of the charge).

2. The shaped charge shall be designed such that the output after a conditioning plate, represents the performance of a shoulder launched rocket propelled grenade. The performance parameters considered shall include the diameter and velocity both at the tip and along the jet. The characterization shall include information as to the placement that replicates the standoff of the RPG threat (for Method 1).

2.5. JET CHARACTERISTIC REQUIREMENTS

2.5.1. Characterization of the Shaped Charge Jet

1. Shaped charge jets that comply entirely with examples found in the Annexes of this AOP, are fully characterized and do not require additional documentation. Characterization of the SCJ shall be documented in a technical report available to national IM panels.

2. For Method 1, the following guidelines shall be met:

   a. Distances between the shaped charge, the conditioning plate, and the test object shall be documented.

   b. A conditioning plate of suitable uniform thickness to remove the first part of the jet, must be used. Parts of the munitions normal configuration, such as armor and packaging, shall not be used as conditioning plates.

c. Jet diameter at the target (2.5 - 3.5mm)

d. V^2d at the target (between 120 and 140 $mm^3/\mu s^2$)

e. A jet straightness exhibiting less than ½ of a jet diameter deviation at a 20 charge diameter standoff is desired.

f. Breakup characterization of the SCJ shall be documented.

3. For Method 2, the following data shall be reported as a minimum:

a. Distances between the shaped charge, the conditioning plate, and the test object.

b. Conditioning plate materials and thickness, if used. Parts of the munitions normal configuration, such as armor and packaging, shall not be used as conditioning plates.

c. Jet diameter at the target

d. V^2d at the target

e. Jet straightness and diameter deviation at an appropriate distance.

f. Breakup characterization of the SCJ.

2.5.2. Measurements

1. Jet diameters shall be measured as shown in Figure 2-1. The larger sections are due to phenomenon such as the slow moving jet at the tip from real geometric liner designs, being impacted by faster following sections of the jet (reverse velocity gradient). These sections will be reduced or stripped by the conditioning plate. Efforts should be made to reduce or eliminate spall from conditioning plates impacting the test item.

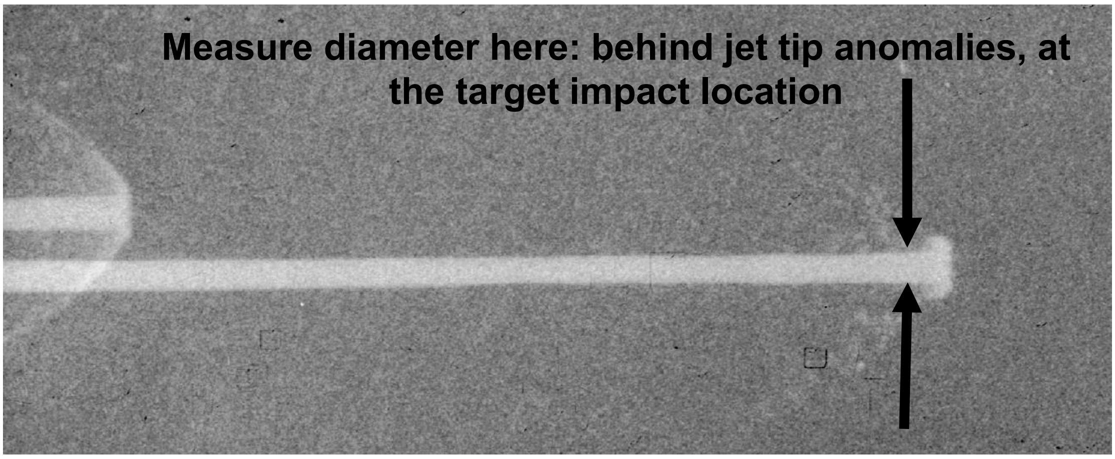

Figure 2-1. Jet Diameters

2. Primary Jet parameters should be measured by using appropriate test instrumentation such as flash radiography. Calibration rods can be used to assist in accurate measurement. Computer modeling can be used for supporting data.

2.5.3. Shotline

Methods shall be established to assure the jet is aimed at the selected aimpoint and that the jet follows the desired path through the munition. Base the shotline on the THA, and in general, select it to produce the worst case reaction while remaining consistent with the THA. Subjected to this constraint, the likelihood of getting a violent response, will normally be maximized by choosing a shot line, which provides the longest possible path length through the energetic material. However, unlikely shotlines should be avoided, which are aimed at components that are quite small when compared to the bulk of the explosive, propellant or aimed at unlikely angles. Prior to testing, shotlines should be agreed to by the appropriate authorities. In this regard, the following considerations may apply: if the energetic material contains a cavity of significant size (such as the bore of a rocket motor), aim the jet to pass perpendicularly through the cavity. (It has been observed that such cavities can promote the occurrence of violent reactions).

2.6. DOCUMENTATION AND COMPLIANCE

1. A test directive, test plan and test report shall be produced and shall be agreed by the national authority. Guidance on completion of documentation, responsibilities for completion and review are discussed in detail in SRD AOP 39.1.

2. It is essential that the test is conducted in accordance with the Test Directive; one of the responsibilities of the Project Team is to confirm compliance.

3. Where deviations from the agreed Test Directive and Test Plan or the procedure agreed at the Trial Readiness Review prove necessary, these must be approved on behalf of the review body by the appropriate Project Team representative, taking advice as necessary from the safety advisor and technical specialists.

2.7. OBSERVATIONS AND RECORDS

1. Guidance on specific aspects of the conduct of testing, observations and data recording is discussed in more detail in SRD AOP 39.1. The following minimum observations must be made and records kept:

a. Test setup/configuration: Type of procedure, details of shaped charge, jet characteristics and conditioning plate; Method of mounting and/or restraint; Distances from the test item to any protective wall or enclosure; Identification and location of any other instrumentation if used.

b. Record of aim point(s) selected.

c. Record of events against time from the order to fire to the end of the test.

d. Nature of any reactions by the test item.

e. Imagery shall be recorded.

f. Meteorological data.

g. Indication of propulsion (video or other suitable means).

h. Microphone or other suitable listening device should be placed near the trial site to record audible events. The audio record shall be a sound track on the motion picture film or on the videotape to enable correlation with visible events and indicated time.

i. Suitable blast or pressure gauges should be positioned around the test item and the location and height of the gauges recorded.

j. Fragment recovery and mapping.

k. Witness screens as a measure of projection severity (optional).

2.8. EVALUATION OF TEST RESULTS

1. Guidance is provided by:

a. STANAG 4439, Policy for Introduction, Assessment and Testing for Insensitive Munitions.

b. AOP-39, Guidance on the Development, Assessment and Testing of Insensitive Munitions.

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ANNEX A SHAPED CHARGE 81 MM, LX-14 (USA)

A.1. INTRODUCTION

The U.S. DoD has developed a standardized shaped charge jet attack configuration to represent standard rocket propelled grenade (RPG) attacks based on the RPG-7 rocket launcher. Figure A-1 presents the U.S. developed RPG IM threat test configuration and 81 mm LX-14 shaped charge warhead used to represent RPG attacks.

A.2. SHAPED CHARGE

The 81 mm shaped charge is comprised of a high precision forged and machined liner made from C101 Oxygen Free Copper (OFE, UNS C10100) and a bare billet LX-14 configuration that has been pressed to a minimum density of 1.815 g/cm^3 and is machined to final dimensions. Figure A-2 presents a drawing of the 81 mm shaped charge copper liner. Experimental characterization of the LX-14 81 mm shaped charge included jet characterization using long standoff x-rays. The x-rays were taken up to a 24 charge diameter standoff in order to assure jet characterization for the fully particulated jet. Figure A-3 presents CALE high rate continuum modeling of the accumulated jet mass characteristics for RPG IM threat test. Figure A-4 presents the resulting shaped charge jet x-rays. A jet tip velocity of 6.2 km/s was measured, which agrees with CALE hydrocode modeling results. The jet characteristics were reduced using a digitizing light table and ARDEC developed software. Figure A-5 presents the shaped charge characterization jet length vs. jet velocity for the fully particulated jet. Figure A-6 presents the shaped charge characterization jet diameter vs. jet velocity for the fully particulated jet. The presented jet diameter is measured as the largest diameter of each jet particle. Figure A-7 presents the shaped charge jet characterization jet break-up time vs. jet velocity. The break-up time is calculated using the particulated jet length velocity profile and the known standoff from the original warhead position. The results are relatively consistent and indicative of a high precision shaped charge built using a high quality liner made from relatively pure copper.

A.3. CONDITONING PLATE

The RPG IM threat test configuration has been developed so the back of the Al conditioning plate represents the probe nose position of the RPG. As shown in Figure 8, the back of the Al conditioning plate is placed in the geometric position to represent the RPG attack probe nose position. Figure A-9 presents a drawing of the Al conditioning plate.

A.4. SETUP

To facilitate testing, a set of standardized test configuration hardware has been developed as shown in Figures A-9, A-10, A-11, A-12, A-13 and A-14. Although this hardware is not required to achieve the standardized RPG threat testing

configuration, it can greatly facilitate the testing. Figure 9 provides photographs of the LX-14 loaded
81 mm shaped charge and the shaped charge in the test assembly configuration. As shown in Figures A-10, A-11 and A-12, the standardized configuration hardware is based around an acrylic holder. The acrylic holder that is made by clamping two acrylic triangles together. The corners of the acrylic triangles are drilled and tapped in order to provide threaded holes for clamping using threaded rods. The space between the triangles is adjusted to allow for the 4" aluminum cylinder and 2" air gap positioning, as well as to ensure that components are level and aligned. For testing, an approximate ½" of standoff clearance is left between the aluminum cylinder face and the target test article. If the standardized test configuration hardware is being used in the vertical position, then the threaded leveling rods (3) from Figure A-10 are used to ensure proper alignment. If the standardized test configuration hardware is being used in the horizontal position, then the threaded leveling rods (4) from Figure A-10 are used to ensure proper alignment. If the aluminum spall produced by the shaped charge jet Al conditioning plate perforation is of concern, a stripper plate can be used to prevent the Al spall from impacting the test article, as well as to achieve the 1/2" gap between the Al conditioning plate and the target test article. A stripper plate design and assembly configuration is shown in Figures A-10 and A-15 shows a jet diameter measurement used to calculate the Held's parameter, at the test item impact position. The resulting calculated V^2d is 119.8 $mm^3/\mu s^2$, based on an averaged measured jet diameter of 3.04 mm and a measured jet tip velocity of 6.28 $mm/\mu s$.

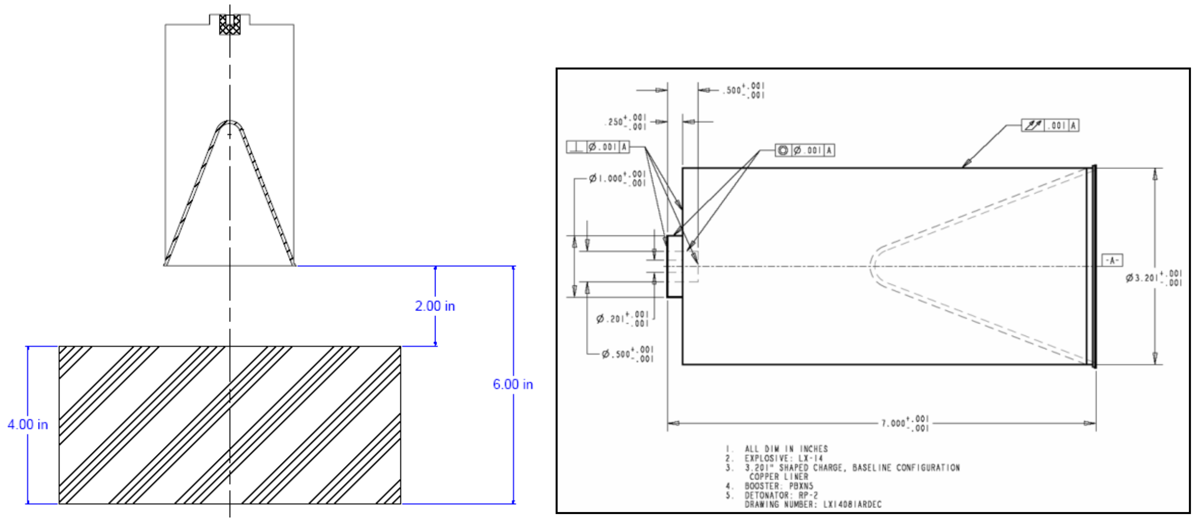


Figure A-1. IM RPG threat test configuration (left) and warhead (right).

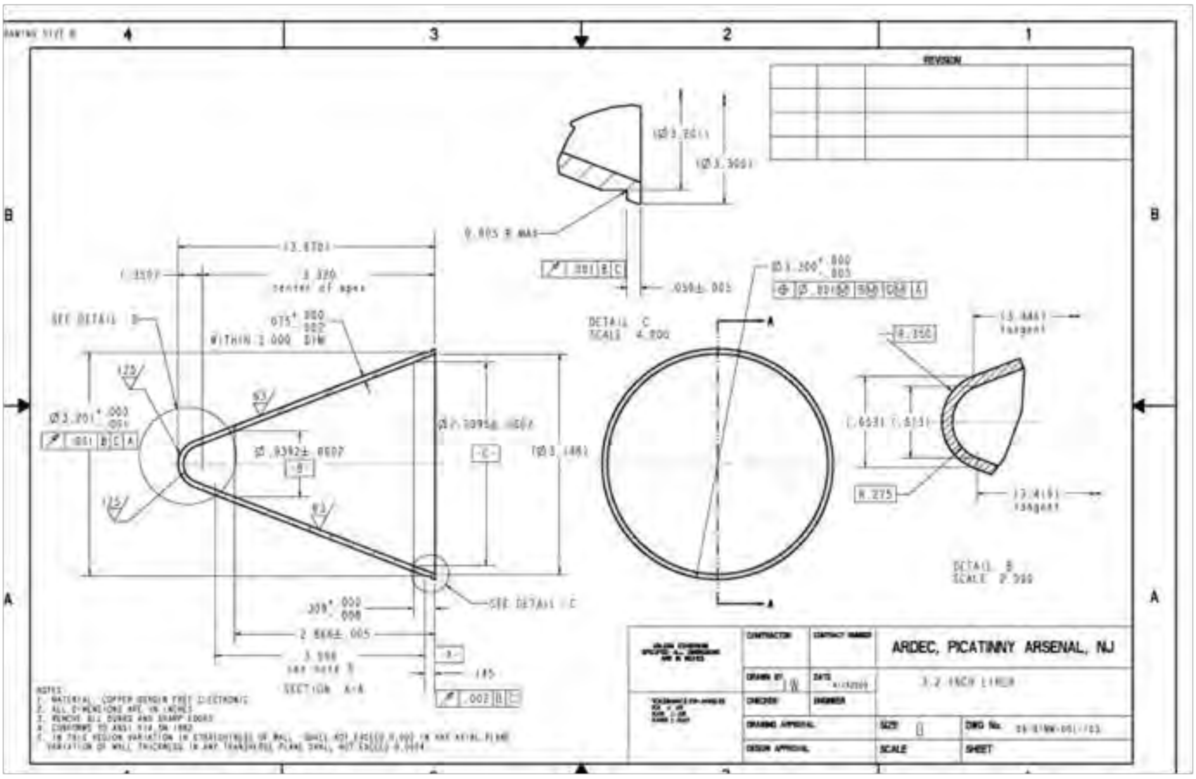


Figure A-2. Liner drawing

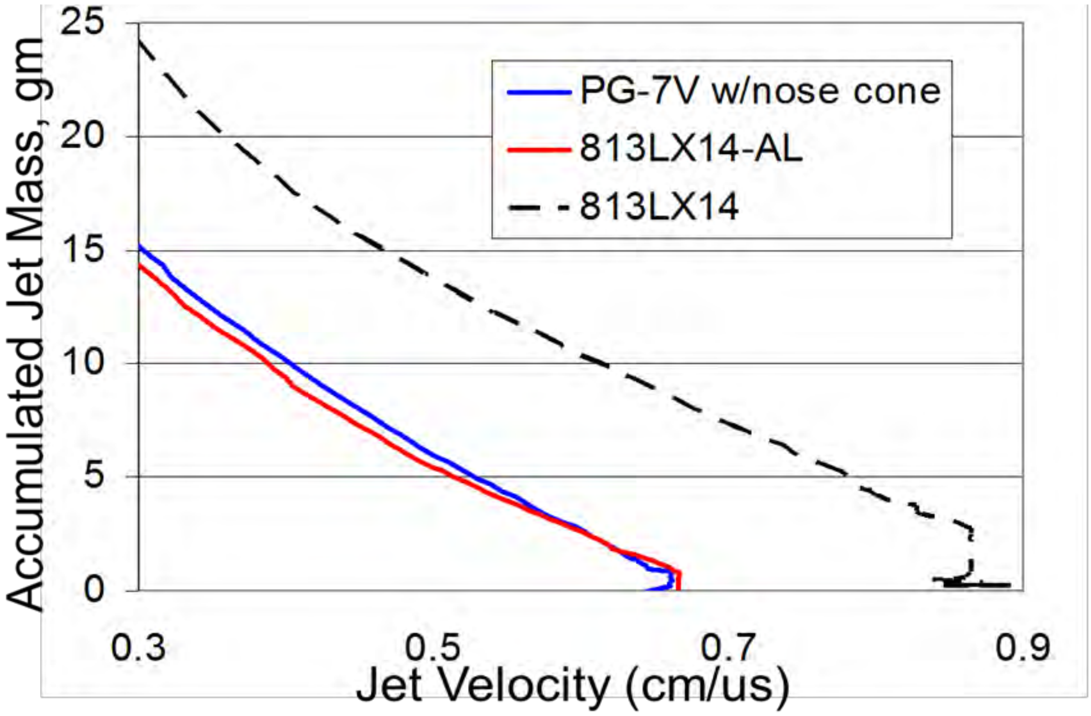


Figure A-3. CALE modeling used for RPG IM threat test development based on a standard LX-14 loaded 81 mm shaped charge.

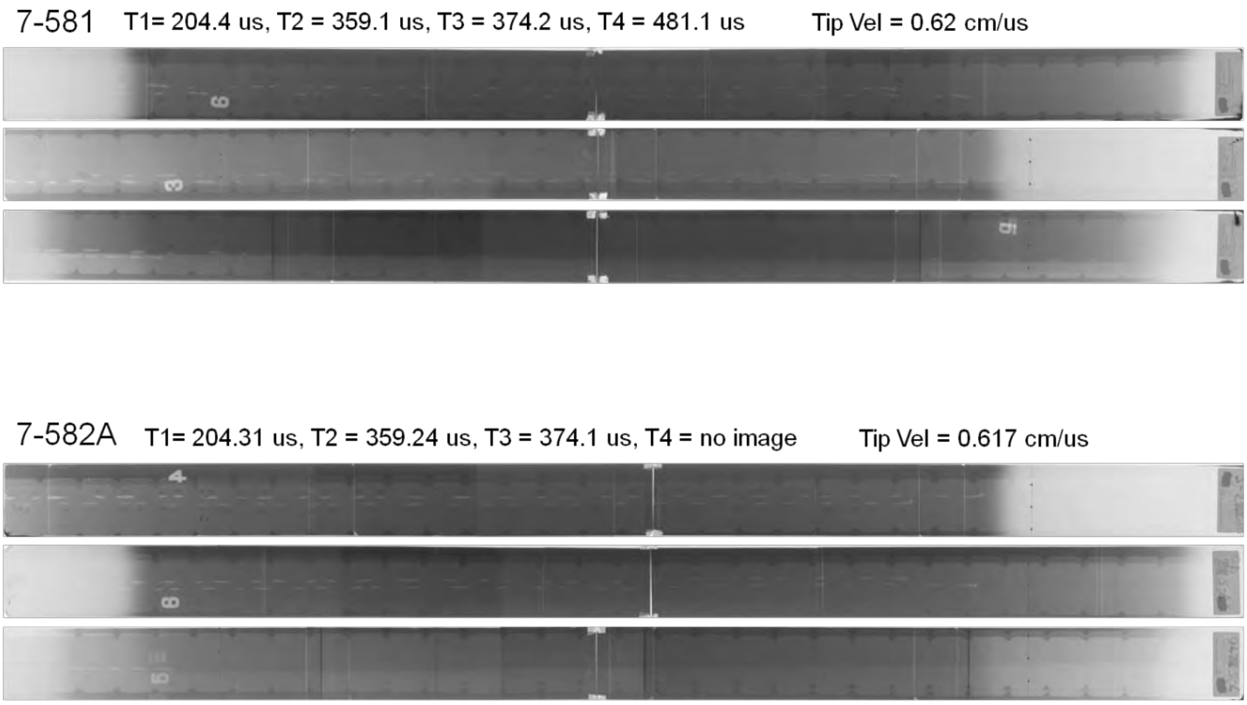


Figure A-4. Shaped charge jet characterization long standoff x-rays.

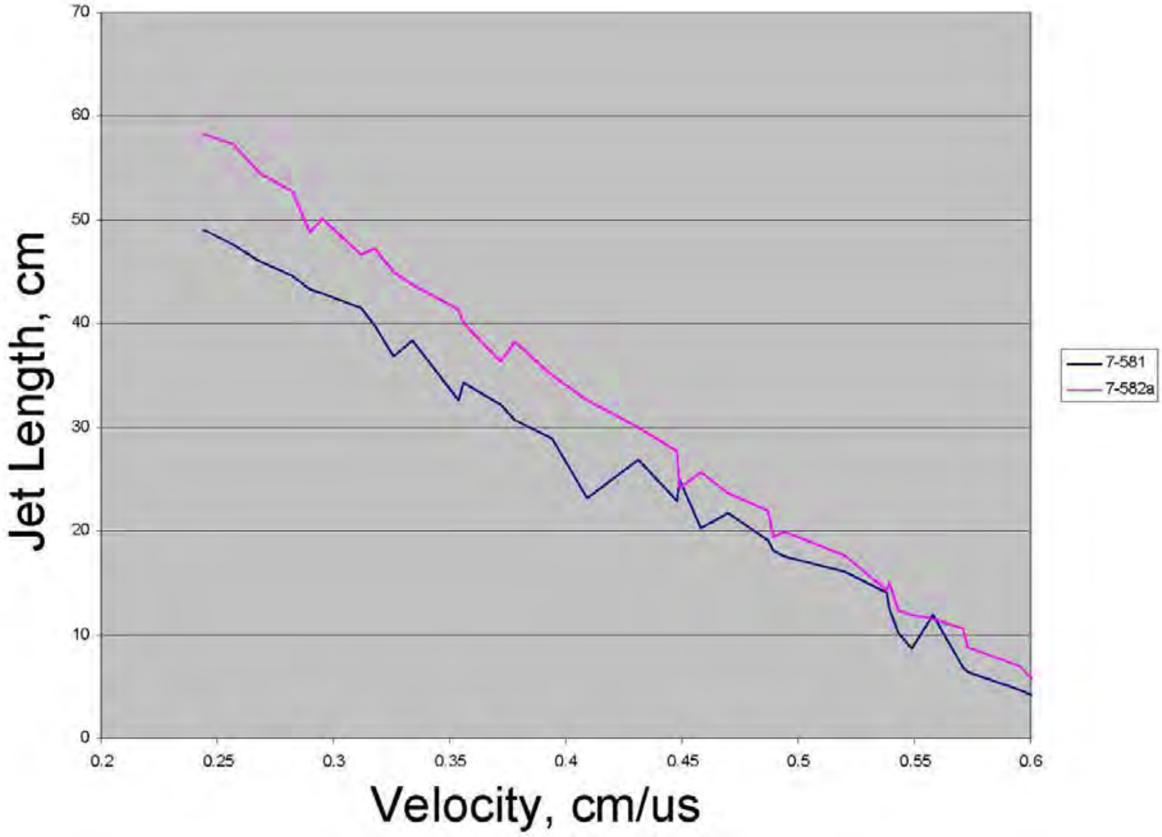


Figure A-5. Shaped charge characterization jet length vs. jet velocity.

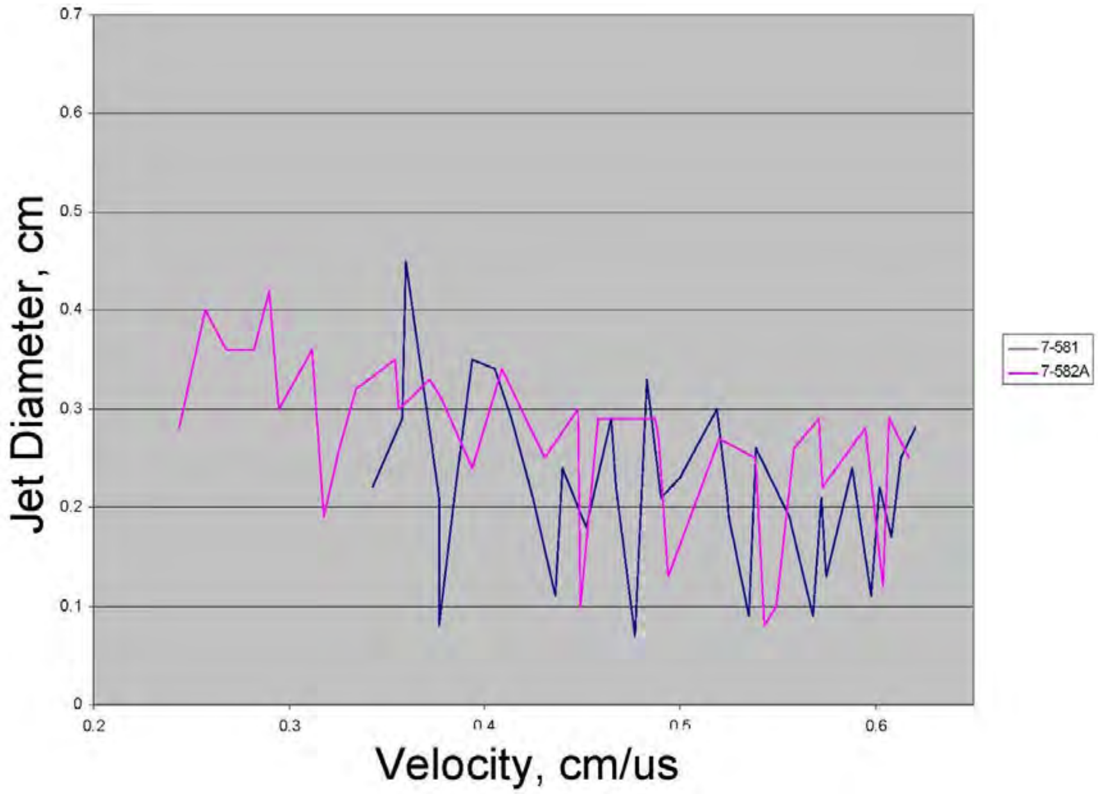


Figure A-6. Shaped charge characterization jet diameter vs. jet velocity.

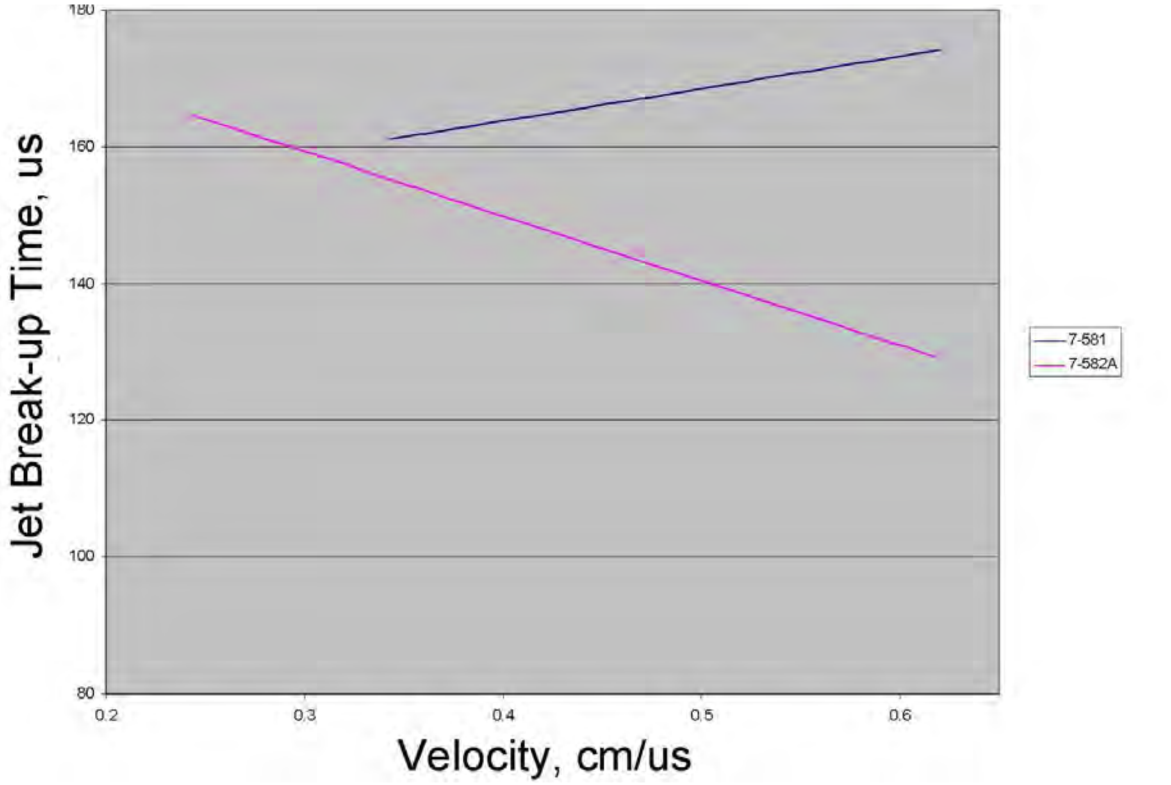


Figure A-7. Shaped charge jet characterization jet break-up time vs. jet velocity.

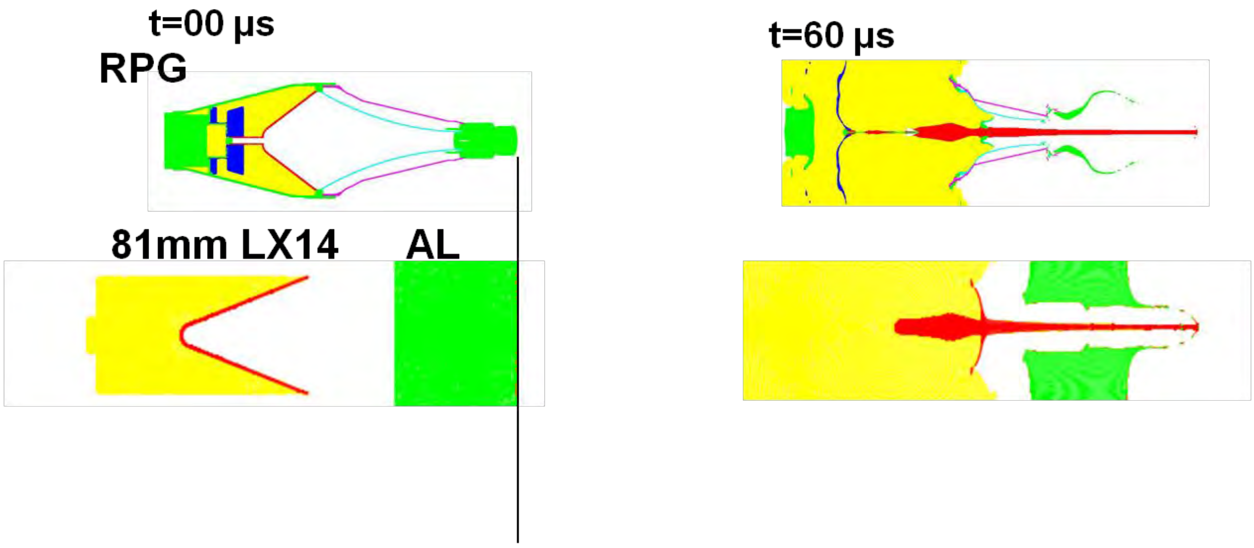


Figure A-8. The back of the Al conditioning plate represents probe nose position of the RPG.

For IM threat testing, place the back of the Al conditioning plate in the geometric position to represent RPG attack probe nose position.

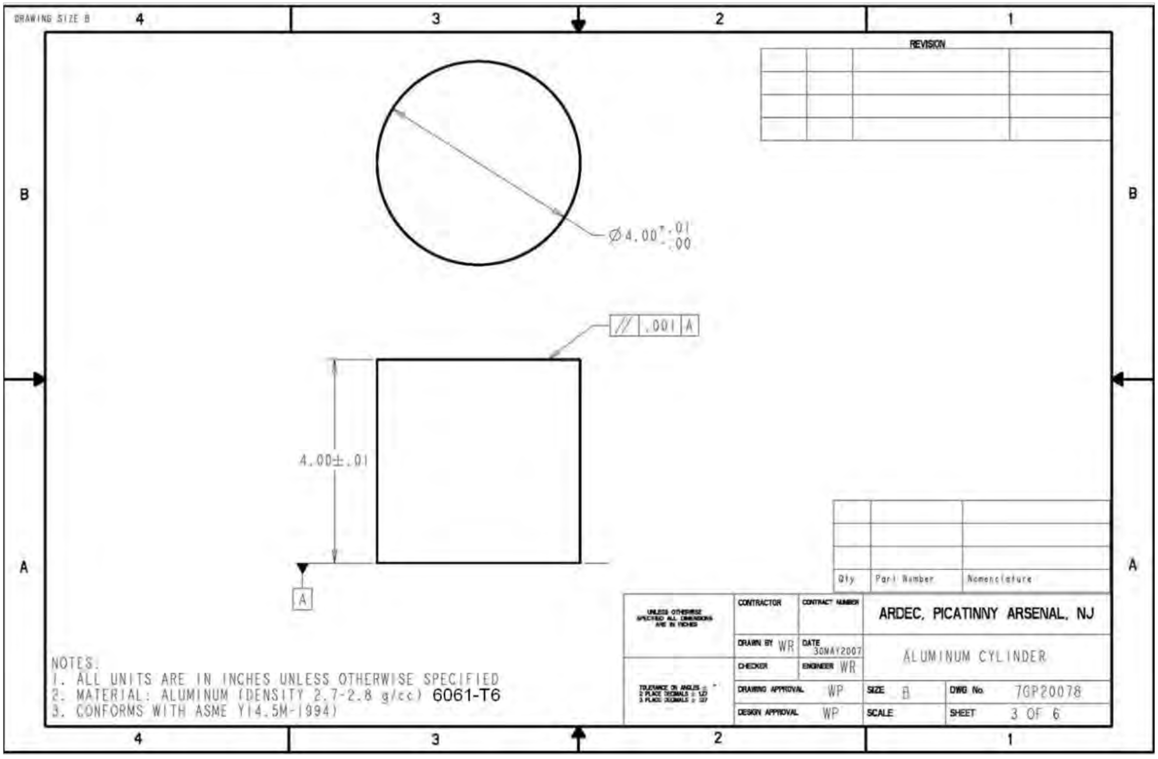


Figure A-9. Aluminum conditioning plate drawing.

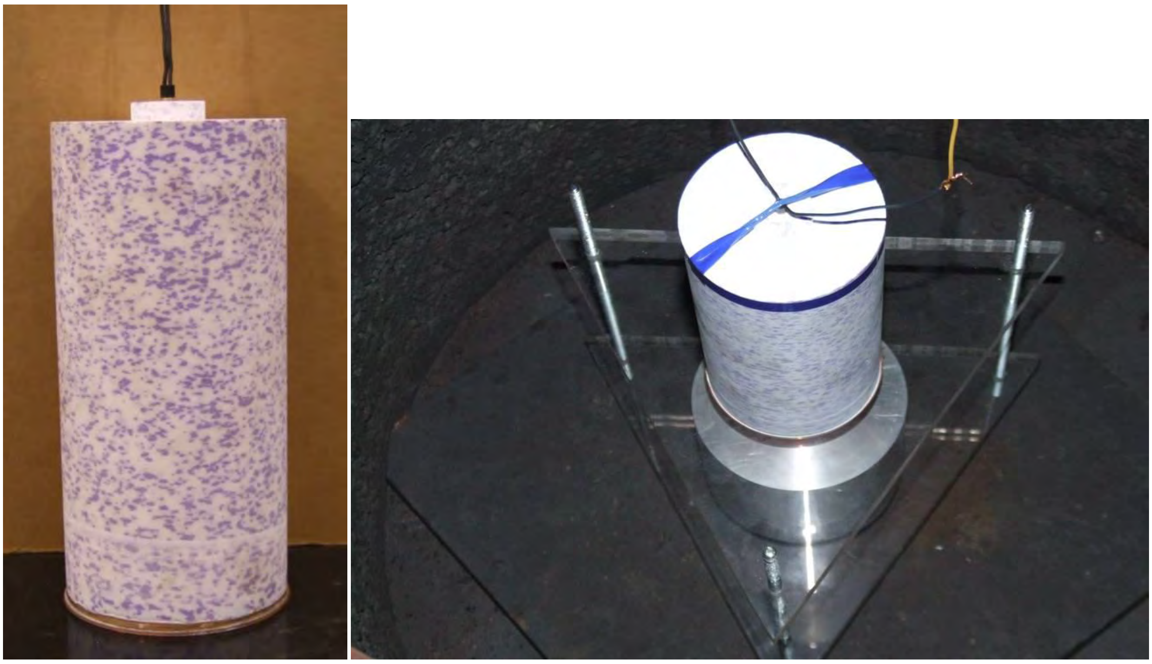


Figure A-10. Shaped charge (left) is typically assembled into a test configuration using a set of standardized hardware.

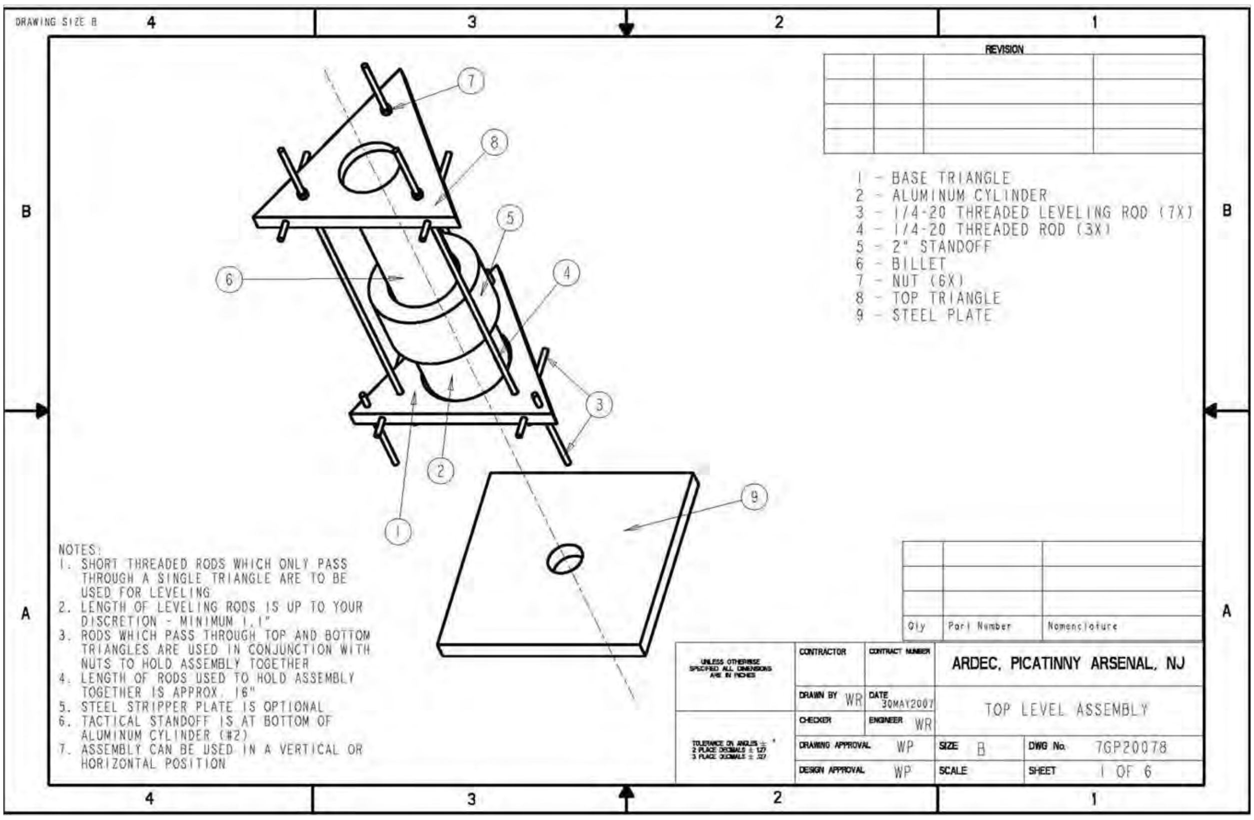


Figure A-11. Standardized test assembly and hardware.

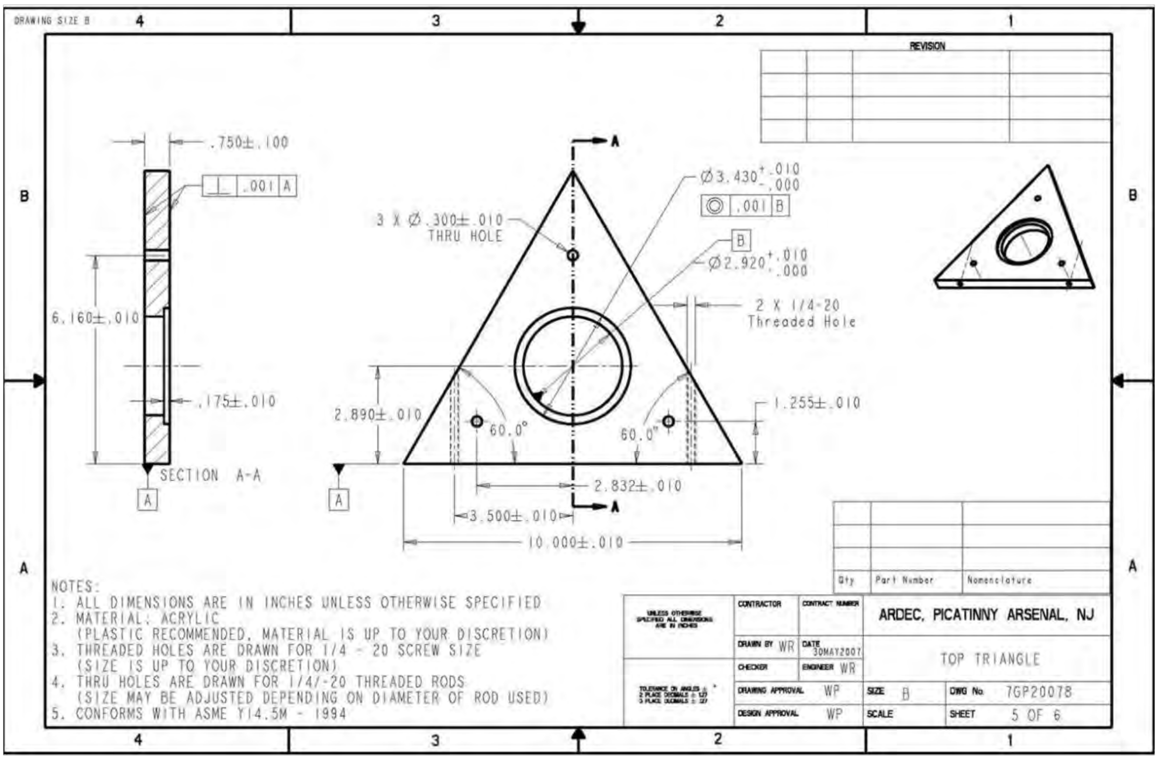


Figure A-12. Assembly hardware drawing.

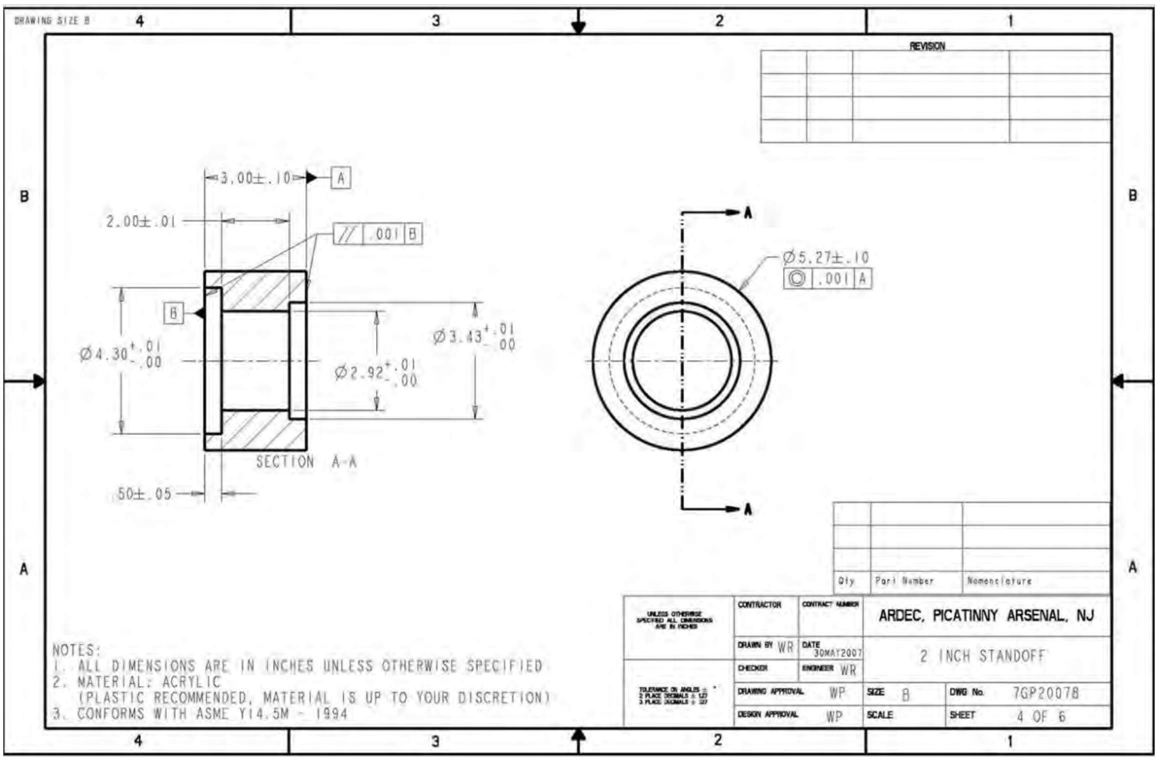


Figure A-13. Assembly hardware drawing.

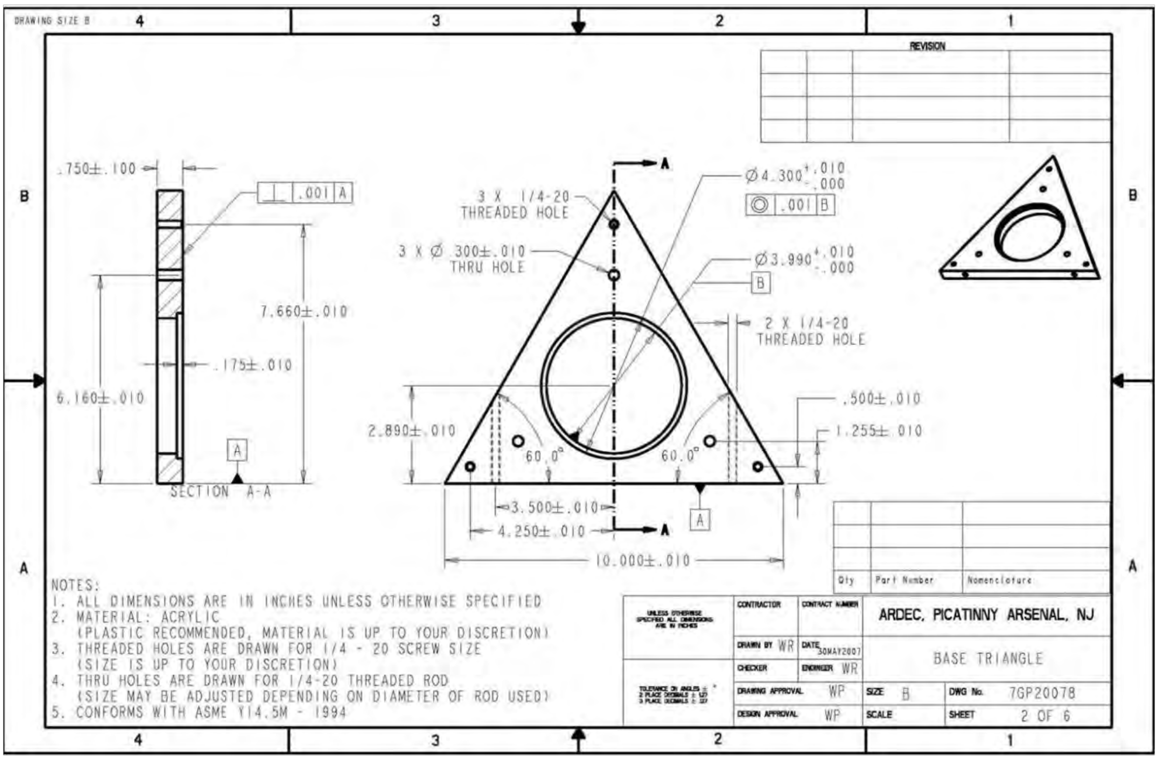


Figure A-14. Assembly hardware drawing.

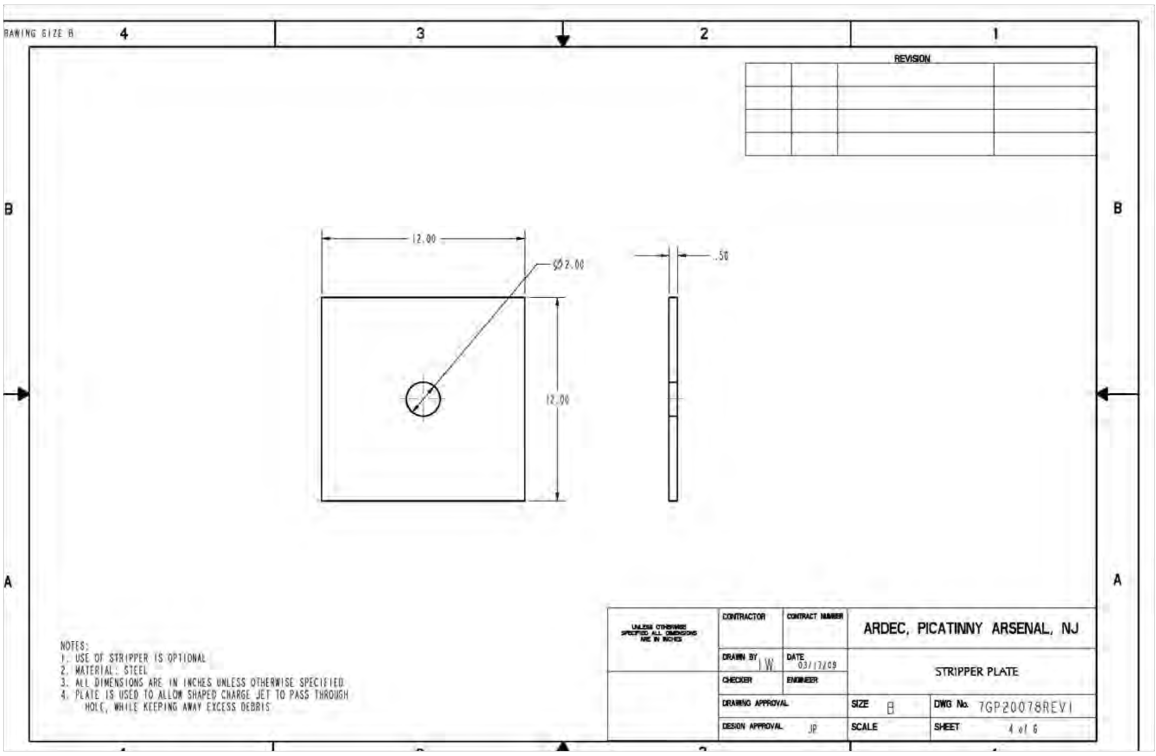


Figure A-15. Stripper plate hardware drawing.

ANNEX B SHAPED CHARGE CCEB 62

B.1. INTRODUCTION

1. CCEB 62 is the French standardized shaped charge for Insensitive Munitions signature assessment in agreement with MoD Instruction N°211893/DEF/DGA/INSP/IPE issued on 21 July 2011. It is initiated with a Nexter M720 Explosive Bridgewire Detonator.

2. This charge was selected for several reasons. On the one hand, CCEB 62 is representative of the standard rocket propelled grenades threat. On the other hand, this charge has been used for many years mainly in the field of armour studies (CCEB 62 is a French acronym for “shaped charge for armour studies of 62 mm”). This charge has thus been designed to be highly reproducible as shown on Figure B-1 by the jet straightness at long stand-off.

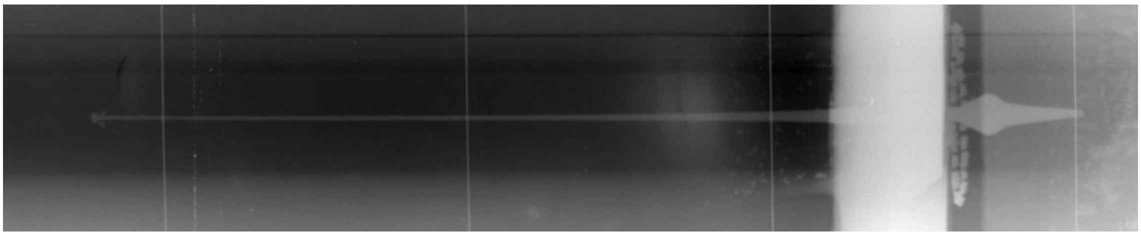
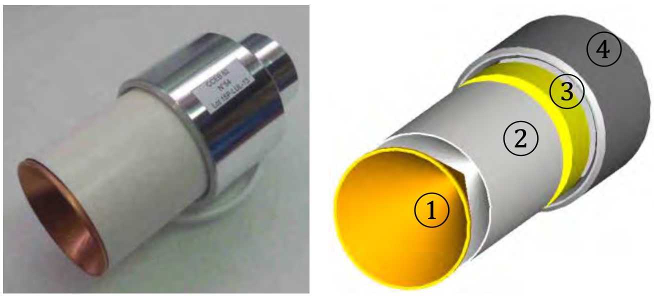


Figure B-1. CCEB62 Jet Characterization at Long Stand-off X-ray (around 7 Calibers)

B.2. SHAPED CHARGE

1. The CCEB 62 shaped charge consists in an Oxygen-Free High thermal Conductivity (OFHC) copper liner and an explosive charge as presented on Figure B-2a. The main explosive charge and booster are manufactured with the help of an isostatic process; an accurate machining step is needed to ensure the required final dimensions. A drawing of the charge is presented on Figure B-2b.



① Liner: OFHC copper

② Main explosive: HMX-based composition

③Booster: RDX-based composition

④ Fixing device: 7000 series aluminum alloy

Figure B-2a. French Reference Shaped Charge CCEB 62 for IM Tests

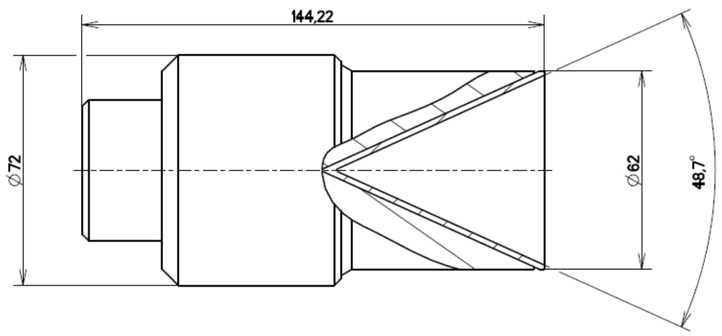


Figure B-2b. French Reference Shaped Charge CCEB 62 Drawing

2. The charge manufacturer reference is:

Code	F0531	**Reference**	82108633000	**Index**	A

3. A jet characterization has been performed and consisted in the full jet particulation observation, the V^2d determination and the penetration reproducibility validation.

4. Figure B-3 presents the shaped charge characterization - jet length vs. jet velocity (when fully particulated). Jet particles having a velocity lower than 3000 m/s are not presented here.

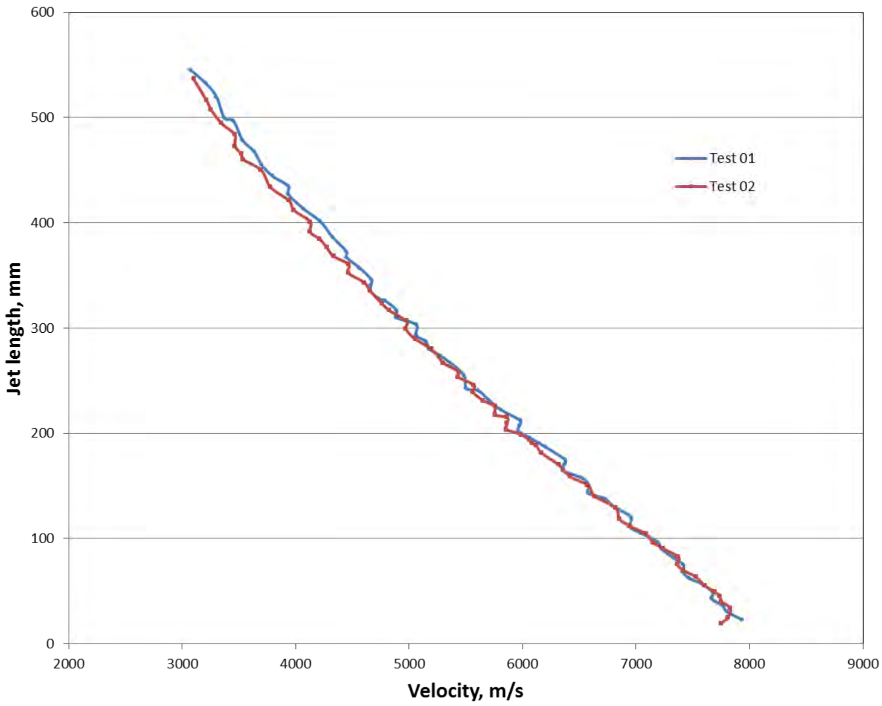


Figure B-3. CCEB 62 Characterization Jet Length vs. Jet Velocity

5. Concerning the V^2d evaluation, several configurations were tested in order to select the best configuration. The set-up used for those tests is presented on Figure B-4. The jet characteristics were determined using X-ray pictures. The acquisition was started with a contact gauge located on the front side of the conditioning plate. The delays were adjusted to observe the jet at two relevant positions. The analyzed parameters were the stand-off (s/o) and the conditioning plate definition. The following configurations were considered:

a. Two values for the stand-off (s/o): 0.5 and 2 calibers;

b. Two types of conditioning plates: mild steel and mild steel + High Density Polyethylene (HDPE);

c. Various thicknesses for the conditioning plates.

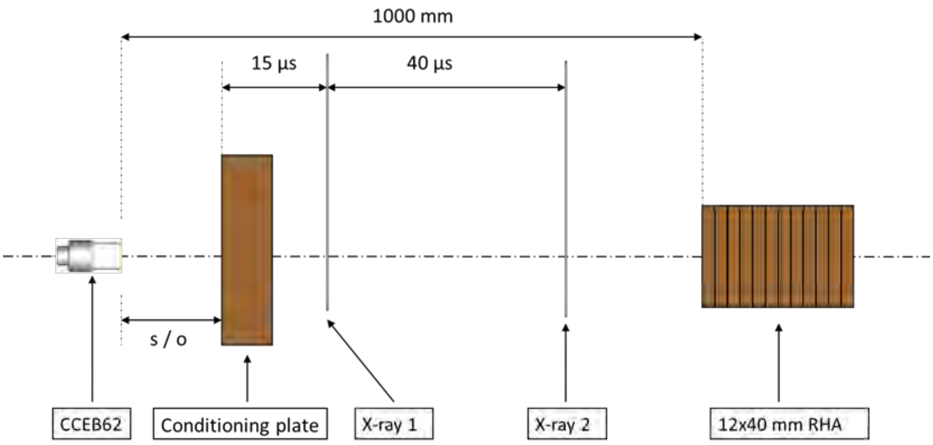


Figure B-4. Experimental Set-up Used for CCEB62 Jet Characterization

6. The tests highlighted that a proper evaluation of the V^2d value requires a relevant and accurate measurement of the jet diameter. The front jet element shape depends on the characteristics of the conditioning plate (thickness, material…). Figure B-5 presents the influence of the conditioning plate definition on the front jet element shape. Examples 1 and 2 show two configurations considered as unsatisfactory as the jet tip is disturbed and two different diameters could be assessed for the jet. Example 3 provides a configuration limiting these discrepancies. In this configuration, the collapse area in front of the jet is reduced and the jet diameter is easier to identify.

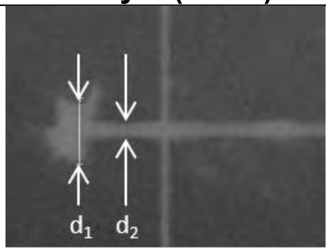
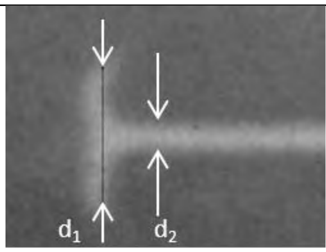
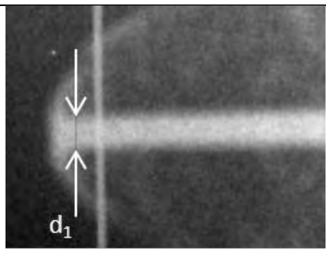
Example	s/o and conditioning plate	X-ray 1 (8 cal.)
1	2 cal. / 10 mm mild steel	
2	2 cal. / 10 mm mild steel + 25 mm HDPE	
3	0.5 cal. / 10 mm mild steel + 50 mm HDPE	

Figure B-5. Examples of the Influence of the Conditioning Plate Definition on the Front Jet Element Shape

7. At last, the reproducibility of the charge was validated through penetration tests in Rolled Homogeneous Armour (RHA) steel plates. Eight shaped charges were used and the measurements indicated a narrow deviation (2.6%) around the mean value.

B.3. FRENCH REFERENCE TEST CONFIGURATION FOR SHAPED CHARGE JET

The French test configuration used for the IM evaluation of munition reaction to shaped charge jet aggression is presented in Figure B-6. The conditioning plate is made of the assembly of a 50 mm HDPE plate (density ~ 1) and a 10 mm mild steel type C35 plate. The lateral dimensions of the plates are 250 x 250 mm. The HDPE plate is placed at the back of the steel plate in order to prevent debris (spall effects) from impacting the test article. The stand-off distance between the shaped charge and the conditioning plate is 0.5 caliber (31 mm). The distance between the back of the conditioning plate and the tested munition is 0.75 caliber (46 mm). In this configuration, the velocity of the front jet element is of 7025 m/s and the diameter of the jet is of 2.7 mm (± 0.2 mm). This results in a mean V^2d value of 133 $mm^3/\mu s^2$.

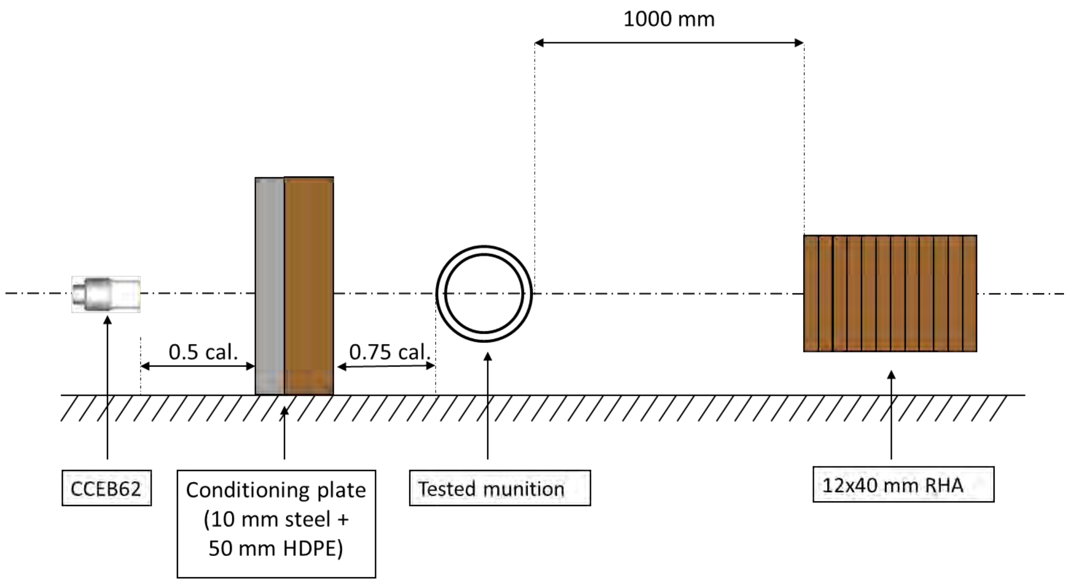


Figure B-6. Recommended Set-up for IM Shaped Charge Jet Test with the CCEB62

ANNEX C HISTORICAL OVERVIEW

1. In order to facilitate a beneficial exchange of information between nations, some standardization, as well as characterization of the tests is desirable. For the shaped charge jet munitions test procedure, each member nation had been creating and adopting their own standards because the previous STANAG 4526 was dated and had lost relevance. For example it referenced US Rockeye Shaped Charge, which is no longer used by any member nation.

2. In meetings and a workshop used in developing the new document, most member nations confirmed some form of the RPG-7 as the predominant threat. This munition, and copies, is produced and sold by many countries and is encountered in a multitude of scenarios. Therefore this document uses the RPG-7 as the representative threat and maintains and documents the French and US test standards that replicate this threat. Additionally this document defines the jet characterization and test configurations so that other test arrangements and hardware can be developed that meet the standard. An alternative threat variation is allowed, based upon a threat hazard Assessment (THA).

3. The development of this document utilized the current understanding of shaped charges and shaped charge initiation was utilized. Criteria, known as the Held criteria has been developed to evaluate the initiability of an explosive impacted by a shaped charge. The Held criteria is the velocity of the jet squared times the diameter (V^2d). Many conditions modify this criteria; confinement and to the extent as to how the Held criteria is extrapolated. Additionally, two different shaped charges which deliver the same V^2d on the outside of a munition or its shielding, may deliver very different reactions when the jet reaches the energetic material. Consequently, full characterization of the jet used was required.

4. To achieve the desired jet characteristics and remove jet tip anomalies and debris, it is necessary to adjust the jet velocity from the shaped charge by using conditioning plates between the shaped charge and the test munition.

5. The following test methods and sections were removed as they were no longer being used for IM evaluation:

a. Bomblet Shaped Charge.

b. Rockeye Shaped Charge.

c. Anti-Tank Missile.

d. Ballistic Pendulum.

6. Additionally the old, inaccurate V^2d table of Held's Criteria (V^2d) for various shaped charges that could not be verified was removed.

AOP-4526(A)(1)