NATO STANDARD

AOP-4496

FRAGMENT IMPACT TEST PROCEDURES FOR MUNITIONS

Edition A, Version 2

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NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION (NATO)

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NATO LETTER OF PROMULGATION

4 March 2022

1. The enclosed Allied Ordnance Publication AOP-4496, Edition A, Version 2, FRAGMENT IMPACT TEST PROCEDURES FOR MUNITIONS, which has been approved by the nations in the CNAD AMMUNITION SAFETY GROUP (CASG – AC/326), is promulgated herewith. The agreement of nations to use this publication is recorded in STANAG 4496.

2. AOP-4496, Edition A, Version 2, is effective upon receipt and supersedes AOP-4496, Edition A, Version 1, which shall be destroyed in accordance with the local procedure for the destruction of documents.

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4. This publication shall be handled in accordance with C-M(2002)60.

Dimitrios SIGOULAKIS
Major General, GR (A)
Director, NATO Standardization Office

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RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS

Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Document Database for the complete list of existing reservations.

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RECORD OF SPECIFIC RESERVATIONS

[nation]	[detail of reservation]
FRA	France reserves the right to use Method 2 for its own programmes.
USA	AOP-4496 fails to include text recognizing and incorporating United Nations (UN) Hazard Classification (HC) Division 1.6 article (or component level) fragment impact testing, which the United States of America may execute simultaneously with STANAG 4496 fragment impact testing for Insensitive Munitions (IM) and HC harmonization purposes. Specifically, the UN Series 7 type (l) test prescription requires a fragment impact velocity of 2530 ± 90 m/s, in alignment with the standard method (Method 1) prescribed within AOP-4496. Additionally, harmonized IM/HC testing requires test details (e.g., configurations, aim points, and shot lines) to be approved by national HC authorities prior to testing.
Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Document Database for the complete list of existing reservations.	

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CHAPTER 1 INTRODUCTION

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

A. Best Practices

B. Historical Overview

1.2 RELATED DOCUMENTS

STANAG 4439	Policy for Introduction and Assessment of Insensitive Munitions (IM)
AOP-39	Policy for Introduction and Assessment of Insensitive Munitions (IM)
SRD AOP-39.1	Guidance on the Organization, Conduct and Reporting of Full-scale Tests
STANAG 4496	Fragment Impact Test Procedures for Munitions
AASTP-03	Manual of NATO Safety Principles for the Hazard Classification of Military Ammunition and Explosives
United Nations	Manual of Tests and Criteria (ST/SG/AC.10/11)

1.3 AIM

The aim of this AOP is to specify the test requirements and procedures to provide evidence of the response of munitions and weapon systems to the threats represented from being impacted by a fragment.

1.4 AGREEMENT

1. Participating nations agree that the requirements and methods incorporated in this AOP will be used for determining the response of munitions and weapon systems to fragment impact.

2. Participating nations further agree that national standards, orders, manuals and instructions implementing this AOP will include a reference to the STANAG 4496 for purposes of identification.

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

1.5 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 Database (NATOTerm) that is available by reference for all Allied Publications.[1]

1.6 GENERAL

1. Effort to minimize the violence of the reaction of munitions impacted by a fragment is a continuing commitment of weapons designers in order that the safety of personnel and materiel will not be unduly jeopardized.

2. This AOP addresses the situation where munitions and weapon systems are impacted by a fragment. This can occur in peacetime as the result of an accident, dissident/saboteur activity, or on operations as a consequence of enemy action, which can result in a significant compromise of safety.

3. The objective of the Fragment Impact Test is to determine the response of the munition(s) when subjected to a fragment impact.

4. This test may also be used for Hazard Classification (HC) as required by AASTP-03 and UN Document ST/SG/AC.10/11 and any amendments thereto, and other applications not covered by these documents where the response of a munition to fragment impact is required to be known or assessed. If a test is to be used for Hazard Classification, an agreement must be reached between Hazard Classification and Safety Authorities on the required test, number of test items, their configuration (e.g. packaged or unpackaged), and the number of tests to be performed.

[1] https://nso.nato.int/natoterm/

1.7 TEST LIMITATIONS

1. The Fragment Impact Test is only designed to simulate a consistent shock condition that a munition might experience when exposed to a fragment from a munition reacting in the vicinity of it.

2. This test only represents a particular set of conditions as it is not possible to cater to the wide range of fragments, strike velocities or angles of attack in the real world.

3. Test items struck by a fragment at lower velocities may react more violently than the standard/alternate velocity.

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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 (e.g. live vs inert, pre-conditioning, packaged vs unpackaged, single vs multiple test items, All-Up-Round vs component level) as given in SRD AOP-39.1 Annex B shall be considered.

2.2 TEST DETAILS

2.2.1 Test Methods

There are two methods for performing the Fragment Impact Test for Munitions:

a. Method 1 (Standard) for determining the response of a munition to a high-velocity impact. The impact velocity of the standard test shall be 2530 ± 90 m/s.

b. Method 2 (Alternative) for determining the response of a munition when the THA dictates that impact by 2530 m/s fragments is of extremely low probability during the lifecycle of the munition. The impact velocity of the alternate method shall be 1830 ± 60 m/s.

2.2.2 Test Requirements

The test consists of impacting the munition with a representative fragment and recording its reaction(s). To ensure sufficient and uniform threat, the following requirements shall be met for all test methods.

a. **Characteristics of the Standard Fragment.**

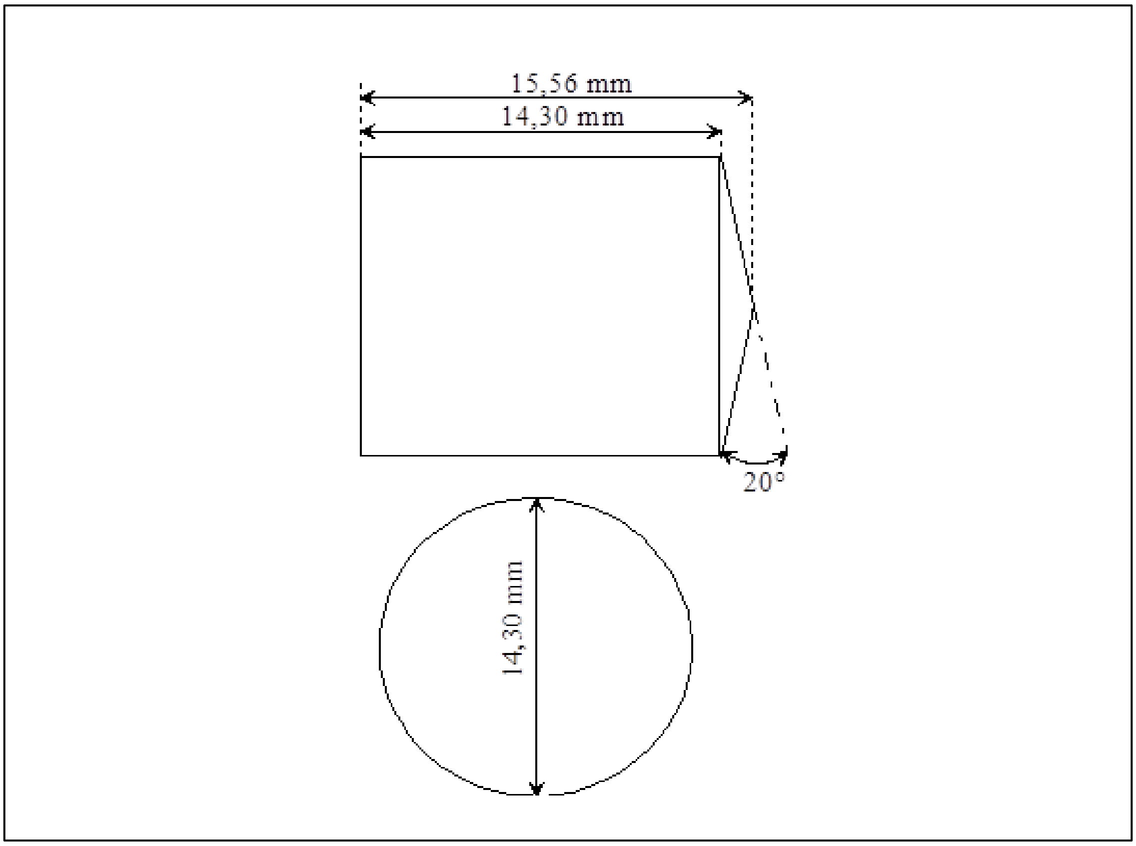

Figure 1: Standard Fragment

- Shape: A conical ended cylinder with the ratio $\frac{L\ (length)}{D\ (diameter)} > 1$ for stability.
- Tolerances: ± 0.05 mm and ± 0°30'
- Fragment Mass: 18.6 g
- Fragment material: A mild, carbon steel with a Brinell Hardness (HB) between 190 and 270

b. **Aim-Points Selection.** Aim-point shall be selected to create the most stressing condition on the target energetic. The aim-point shall also represent a credible exposure condition, based on the THA. Guidance for choosing the aim-point and shot-line can be found in SRD AOP-39.1. The aim-point and shot-line for each test should be approved by the National Authority prior to testing.

c. **Accuracy Requirement.** It shall be set to ensure the response mechanism under consideration is being tested. The required accuracy shall therefore be dependent on the geometry of the item under test. This shall be defined and recorded prior to testing and should be agreed to by the National Authority.

d. **Orientation of the Fragment at Impact.** The angular deviation (e.g. vector sum of yaw and pitch) for the threat fragment at impact shall be measured and recorded and should be limited to ± 10°.

e. **Firing Device.** To reduce the variability due to yaw, a gun system is recommended. The firing device will be chosen so as not to compromise interpretation of the response.

f. Methods shall be established to assure the fragment is aimed at the selected aim-point and that it follows the desired path through the munition.

2.2.3 Test Set-Up

1. The test item condition 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. The range from gun to target is to be determined by the test authorities, depending on accuracy and safety aspects.

3. Additional guidance on variations to the test conditions (positioning/orientation, aim-point/shot-line, restraints, conditioning, marking, reuse, etc.) as given in SRD AOP-39.1 Annex B shall be considered.

2.2.4 Number of Tests

Any of the selected two test methods shall be carried out twice for each selected sub-component of the munition: once against the main charge filling and once against the most sensitive component/energetic material (e.g. motor igniter, warhead booster). ‘Most sensitive component’ means the component which, if exposed to the threat, is likely to lead to the most violent response of the munition.

2.3 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 upon 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.

2.4 OBSERVATIONS AND RECORDS

Guidance on specific aspects of the conduct of testing, observations and data recording is discussed in more detail in SRD AOP-39.1. Unless noted as “optional”, for IM purposes, the following minimum observations shall be made and records kept. Test recommendations, records and observations for HC testing and assessment are included in the UN Manual of Tests and Criteria and the Globally Harmonized System of Classification and Labelling of Chemicals, and are not optional.

a. Test item identification and configuration (model, serial numbers, number of test items, etc.); Type of energetic material and weight; Listing of environmental preconditioning test performed; Spatial orientation of the test item.

b. Test setup/configuration: Type of procedure; Details of gun and fragment used; Brinell hardness of the fragment; Distance between gun and test item; 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.

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

d. Record of aim-point(s) selected, hit point (if possible) and whether the fragment exited from the test item or remained within it (if possible).

e. Impact velocity of the fragment and method of determination.

f. Accuracy at impact; Total angular deviation of the fragment at impact (e.g. vector sum of yaw and pitch); Estimated measurement uncertainties for: (a) the impact velocity, (b) impact location, and (c) total angular deviation.

g. Nature of any reactions by the Test Item.

h. Photo Imagery of the Test Item and the Test Setup before and after performing the test.

i. Nature and distribution of remains/residue and debris including: range, position, photographs, identification (as possible), and mass of each piece.

j. Meteorological data (wind speed, direction) during the test.

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

l. Audio and video records: A recording device shall be placed near the trial site to record all audio and enable correlation between visible events and indicated time.

m. Suitable Blast or overpressure gauges should be positioned around the test item to record pressure-time history with a record of gauge location and height.

n. Witness plates and screens (optional) as a measure of projection severity; Photographs of witness plates and screens (if used). Number and depth of penetrations in fragment recovery panels (if used).

o. A complete data record shall be compiled to include pressure, sound, imagery, fragmentation, debris and propulsion information.

2.5 EVALUATION OF TEST RESULTS

Policy and procedures for evaluation of test results are given in:

a. AOP-39, Policy for Introduction and Assessment of Insensitive Munitions (IM);

b. AASTP-03, Manual of NATO Safety Principles for the Hazard Classification of Military Ammunition and Explosives.

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ANNEX A BEST PRACTICES

There are currently no best practices identified.

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ANNEX B HISTORICAL OVERVIEW

B.1 REVISION PROCESS

B.1.1 IM Test AOP Standardization Working Group (2020-2021)

1. In the time between April 2020 and April 2021, AOP-39, -39.1, -4240, -4241, -4382, -4396, -4496, and -4526 have been revised. The objectives of these revisions, executed by the IM Test AOP Standardization Working Group, were:

   a. Fix grammatical and spelling mistakes, clerical errors, and enforce a uniform structure, format, and wording across all AOPs for the sake of readability and ease-of-use.

   b. Ensure that the AOPs only contain requirements.

2. Altering any technical content was not permitted, because the group aspired to merely update each AOP's Version and not release entirely new Editions.

3. To achieve the second goal, guidance and best practices were to be moved into the SRD AOP-39.1. However, accomplishing this was not entirely possible. It was agreed that all AOP-specific guidance remains in each AOP's Annex A, while all guidance that applied to two or more AOPs was marked to be moved into the SRD.

4. The IM Test AOP Standardization Working Group also made notes about topics that could potentially be discussed at future gatherings of each AOP's respective Custodian Working Group.

5. A total of 26 meetings took place, all of them virtually. The involved people were the Custodians of the various documents as well as representatives of MSIAC and AC/326 SG/B.

B.1.2 Creation of AOP-4496 Edition A

1. In 2010 NATO's Ammunition Safety Group (AC/326) empowered their munition Subgroup B (Ammunition Systems Design & Assessment) to establish Custodial Working Groups for each of the IM related STANAGs as a means of reviewing and updating the IM test requirements where needed. Several nations participated in these Working Groups to address the individual IM test requirements in succession, including Fast Heating, Bullet Impact, Shaped-Charge Jet Impact, Fragment Impact, Slow Heating and finally Sympathetic Reaction. Each topic required multiple meetings to produce the desired end product – a draft AOP document that contained the revised, updated test requirements. These new AOPs would then become companion documents to their respective STANAGs with the STANAG as the lead or referencing document only.

2. There were two Fragment Impact Custodial Working Group (FI CWG) meetings during the period January 2017 – April 2017. These meetings were conducted to review and update the test requirements of STANAG-4496 and create AOP-4496. The FI CWG deliberations included very lengthy discussions, sometimes supported by detailed technical investigations, on many topics related to this test and its procedural requirements.

B.1.3 Changes from STANAG 4496 Edition 1

1. This paragraph explains the regulatory changes between STANAG 4496 Edition 1 and AOP 4496 Edition A. These agreements are the successful results of discussions between members of the Fragment Impact Custodial Working Group (2016-2017).

2. Changes in Chapter 2 – Test Specifications:

   a. Paragraphs of STANAG 4496 Edition 1 which were not specific of the Fragment Impact were moved to SRD AOP-39.1.

   b. Additional details on the region of impact.

   c. Addition of a paragraph on an accuracy requirement. No requirement was mentioned in the STANAG 4496 Edition 1.

   d. Addition of a paragraph on the orientation of the fragment at impact. As the first step, the orientation of the fragment at impact shall be measured and recorded, and should be limited to ±10 °. In a next edition of AOP-4496, when all countries will have more data, the orientation of the fragment at impact will likely be mandatory limited to ±10 ° or to a more appropriate value

   e. Addition of a lower limit for the Brinell hardness of the fragment. In order to better standardize the Brinell hardness of the fragment, the lower limit of 190HB has been added. The value fits the lower limit value in the French regulation, and fits overall the lower limit value of all test centers.

3. Added in the Observations and records section of the AOP:

   a. Total angular deviation of the fragment at impact (e.g. vector sum of yaw and pitch).

   b. Accuracy at impact.

   c. Uncertainties for: (a) the impact velocity, (b) impact location, and (c) total angular deviation shall be measured.

4. Added in the annexes:

a. Addition of a paragraph on the historical overview of the Fragment Impact test (see next paragraph).

B.2 BACKGROUND AND TEST ORIGIN

B.2.1 Historical Overview of the Fragment

1. As part of the documentation for STANAG 4496 Fragment Impact Munitions Test Procedure, it is important to recognize the basis for previous decisions on the standard. To that end, this section covers some historical Fragment Impact (FI) information as well as the origin of the threat fragment characteristics and requirements that were first cited in the initial edition of STANAG 4496. Prior to the publication of the standard a variety of different test methodologies existed for evaluating Fragment Impact.

2. Number, size, shape, velocity, and the method for projecting the fragment(s) have long been the dominate considerations when discussing fragment impact testing. The earliest Fragment Impact safety requirement appeared in NAVSEA Instruction 8010.5 in 1985. Multiple half-inch square mild steel cubes were required to be projected at the test item with 3-5 hits recorded and a striking velocity of 8300 fps. This was intended to simulate general purpose bomb fragments. The most commonly used procedures in the 1980's and 90's relied on explosively projected the fragments, i.e., detonating a block of explosive with a mat of preformed fragments on the front face of the explosive charge. Neither number of fragment hits nor the fragment orientation were not controlled, leading to inconsistent test results. Starting in the mid-1990s the test methods were improved to use gas guns to launch individual fragments to the target.

3. The table below gives an overview of various NATO nations FI test policy and procedure requirements that were in place in 2001. This represented the Nations' baseline for the evolution of STANAG 4496.

Table B-1: Summary of policy and procedure requirement prior to 2001

	NATO	France Light Fragment	France Heavy Fragment	UK	US Preferred	US Alt #1
Geometry	Conical Tipped cylinder	Cube	Parallelepiped (sphere is used)	Cylinder Ø 12.7mm h=12.7mm	12. 7 mm cube	Conical tipped cylinder
Mass, g	16	20	250	13.5	16	16
# of Frags	1	3	1	1	2-5	1
Launcher Type	Undefined	Undefined	Smooth bore gun	RARDEN gun	Fragment Projector	Undefined (gun)
Velocity Range, m/s	2000	0<v<2000	0<v<1600	400<v<2500	2530 ± 90	1830 ± 60

B.2.2 Representative Threat Fragments

The archival data used to examine the generic threat fragment in STANAG 4496 are summarized in the tables below. The data in the first table, developed by Victor in the 1980s, includes the characteristics of typical fragments projected from several classes of munitions. It is important to note that approximately 26% of all fragments are greater than the average fragment mass, and therefore basing a threat fragment on average fragment mass represents neither the worst case nor the most credible one. The second table below shows fragment mass and velocity data for specific weapons were a “worst case” threat scenario.

Table B-2: Computed fragment characteristics (Mott and Gurney)

Threat Weapon	Mass	Ø	Source Velocity		Nominal Range [1]		Avg. Frag. Mass [2]	Frag. > 15g [3]	Cube Velocity of cube at Nominal Range	
	kg	cm	ft/s	(m/s)	ft	(m)	g	%	ft/s	(m/s)
Grenade	1.46	7.6	3700	(1128)	31	(9.4)	2.3	1.4	3191	(973)
Missile	32.8	17	5000	(1524)	125	(38.1)	3.0	2.6	2763	(842)
Artillery/ Missile	41.8	17	3890	(1186)	80	(24.4)	10.4	21.5	3216	(980)
Missile	100.4	32	5939	(1810)	135	(41.1)	4.3	5.5	3125	(952)
Missile/ Artillery	118.2	32	4920	(1500)	100	(30.5)	14.0	15.1	3876	(1181)
Missile	365.5	50	5188	(1581)	111	(33.8)	29.9	29.7	4235	(1291)
Missile	1003.	75	5814	(1772)	140	(42.7)	38.0	47.6	4500	(1372)

(1) Range at which main fragment beam delivers 3 fragments per square foot
(2) About 26% of fragments are larger than the average mass for each warhead
(3) Comparable to Army IM test fragment or Navy IM test fragment (16g)

Table B-3: Various munition fragment characteristics

Munition	Design fragment	
	Mass (g)	Velocity (m/s)
Mk81	12.76	2396
Mk82	18.43	2402
Mk117	38.61	2386
Mk83	52.16	2259
Mk84	63.79	2365
155mm M107	64.55	1030
8” M106	97.52	1152
105mm M1	13.13	1237

B.2.3 Velocity

During the time period in which the original Fragment Impact standard was written, the U.S. utilized the highest fragment velocity, 2530 m/s, which has now become the standard method. This fragment velocity, as defined in MIL-STD-2105B, originated from a US Navy survey dated 1987. The velocity chosen for the ½-inch steel cube was 8300 ft/s (2530 m/s) because it represented the upper range of the threat fragment velocity spectrum for a general-purpose bomb. MSIAC (NIMIC at the time) also looked as various munitions fragment velocities and reached a similar conclusion that 2530 m/s is at the very upper bound of possible threat fragments. It is also important to note that fragment velocities at about 2000 m/s were not observed for ground munitions. Additional work by MSIAC and also work done by J. Starkenburg indicates that fragment velocities for artillery type weapons may only near 2530 m/s when detonated in a stack configuration as initial fragment velocities for stacks of ammunition have been observed to be almost twice as high as for fragments from single-item ammunition.

B.2.4 Fragment Geometry

1. Because several Nations used differently shaped threat fragments, agreement on the shape of the threat fragment was critical for the STANAG test procedure. The cube shape resembles a preformed fragment present in many munitions, the lighter sphere shape is used in characterizing explosive formulations, and the conical typed cylinder was created to allow easier launch from a fragment gun. Although the cube most closely represents fragmentation, its angle of attack is not repeatable with face, edge and corner impacts resulting in significantly different shock loadings. Conversely, the advantage of spherical fragments is repeatability, however the spherical fragments were not perceived as a credible threat. Spherical fragments also require either a higher initial velocity or greater mass for the same input of shock duration to the target.

2. As seen in the figure below, the sphere had to be five times more massive than the NATO/MIL-STD-2105B alternate 1 fragment at 10° yaw, in order to maintain a given shock threshold. This was deemed too high for practical testing or to be representative of anything but rogue fragments.

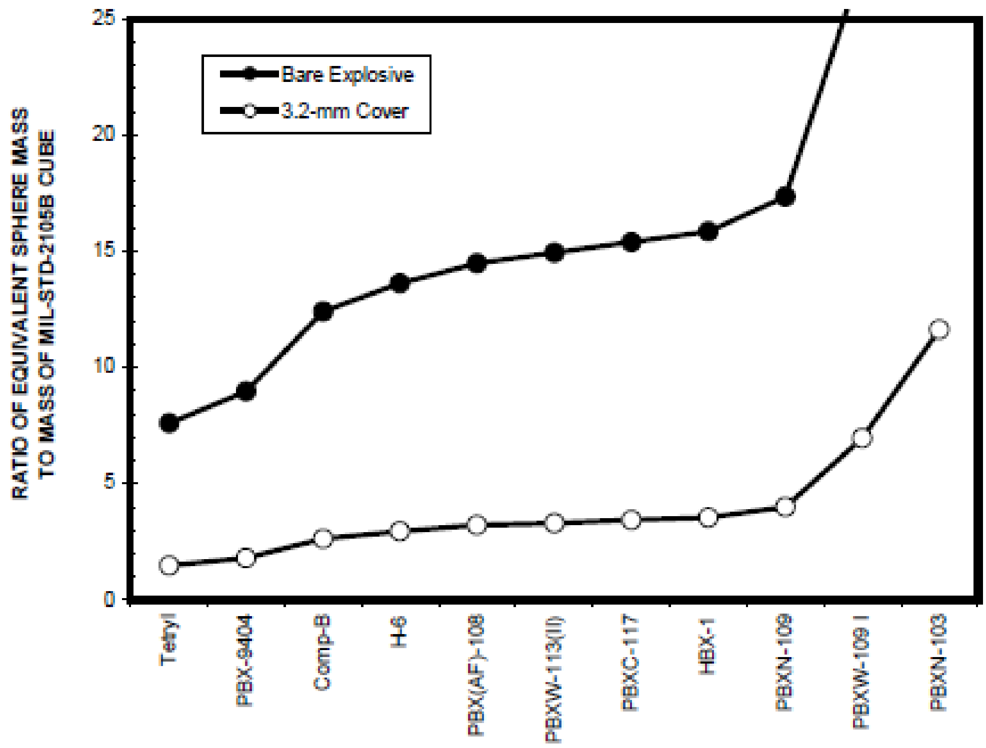
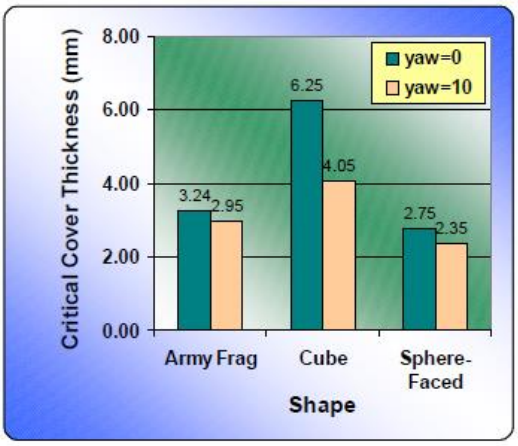


Figure B-1: The ratio of sphere mass and the mass of a 10° yawed cube that have the same critical velocity for detonation using the Jacobs-Roslund formula

3. Returning to look at the cube, the primary disadvantage remained repeatability. An issue which can be mitigated by using a conical tipped cylinder with its 160° included angle face (10° to normal). A cylinder with these characteristics is considered comparable to the cube because approximately 95 % of the time a randomly oriented cube will have an impact yaw of greater than 10° with the impact surface.

4. J. Starkenburg created the below figure which illustrates that a conical typed cylinder (denoted in the figure as Army Frag) significantly reduces yaw effects as compared to the cube.



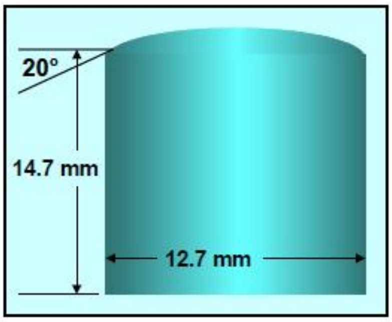


Figure B-2: Critical cover thickness as computed by CTH for a Comp-B target impacted at 1830 m/s.

5. In the end, it was determined that the conical tipped cylinder provided the best compromise between fragment realism and repeatability. However, the original authors of this STANAG wanted to ensure that the chosen NATO threat fragment maintained the shock generated by a cubical fragment. Looking back at Figure B-2, the NATO/ MIL-STD-2105B alternate 1 detonates at a lower cover plate thickness and represents a lower shock level than the cube. J. Starkenburg completed additional calculations proposing the current STANAG 4496 fragment shape and mass (18.6 g) as equivalent to the shock stimulus of the cube.

B.2.5 Multiple Fragments

In a threat scenario it is perhaps unrealistic to believe that a single fragment will be the only impact, therefore several legacy test procedures called for the impact of multiple fragments. However, for non-detonation reactions, the effect of multiple fragments is un-predictable, sometimes decreasing the reaction severity and sometimes increasing the reaction severity, providing no conclusive results. This gives no advantage to testing with multiple fragment projections. For Shock Detonation Transition (SDT) of damaged material, as in a rocket motor, it was decided that the reaction severity with multiple fragments was highly dependent on the degree of damage, the timing, and system conditions. It was felt that a multiple Fragment Impact test would not be repeatable enough to address these concerns, and furthermore that multiple impacts at a single velocity do not represent reality. For SDT of neat material, it was shown that any effects of multiple Fragments Impacts are unlikely since the fragments rapidly space out then quickly lose velocity with distance. The figure below shows that the fragment spacing reaches 3 fragment diameters at less than 13 m distance, so the effect of multiple Fragment Impact on SDT can be neglected.

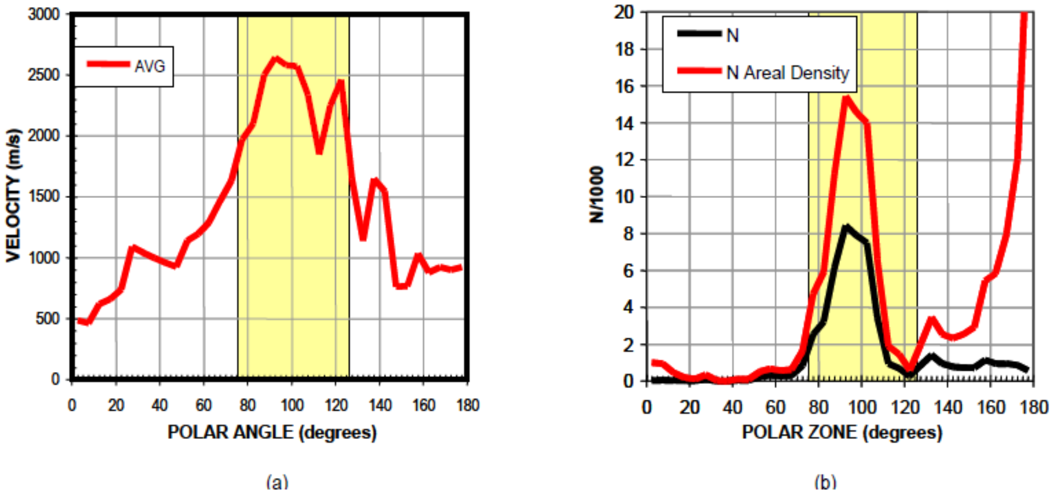


Figure B-3: (a) Velocity vs. Polar Zone; (b) Number of fragments vs. polar zone for a particular analogue system

B.3 REFERENCES

D. Pudlak, K. Tomasello, "Revisions and Improvements to the NATO Insensitive Munitions Test Doctrine Portfolio", NATO AC326 SG/B Spring Meeting, April 15-16, 2021

AOP-4496(A)(2)