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Review and Update of Insensitive Munitions Test Procedures

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NATO Insensitive Munitions policy is currently mandated by Standardization Agreement (STANAG) STANAG 4439, Policy for the Introduction and Assessment of Insensitive Munitions (IM), currently at Edition 3 promulgated on 17 March 2010. STANAG 4439 has been updated twice since the last IM full-scale test STANAG was promulgated on 13 December 2006. As a result, a lack of consistency had developed between the policy in STANAG 4439 and the full-scale test STANAGs. Under direction of the NATO CNAD Ammunition Safety Group, Custodian Working Groups were organized to review and update the NATO STANAG 4439 and the full-scale test STANAGs. This task was substantial involving significant technical updates as well as rewriting documents in accordance with the new NATO policy on standard structure and format. Standards now consist of two documents: the covering document, STANAG and an Allied Ordnance Publication (AOP) which contains the test procedure and the technical details. This paper describes the progress of the Custodian Working Groups (CWG) in completing reviews and updates of the Bullet Attack, Fast Heating, Shaped Charge Jet and Fragment Impact full-scale test STANAGs, which were promulgated in November 2018 and March 2019. The Slow Heating and Sympathetic Reaction full-scale test STANAGs are currently being reviewed and updated. A summary of document status is given in Figure 1 which presents a timeline for the IM STANAG and AOP evolutions. This report describes what has changed in these standards, including the new format and testing procedures technical changes. It should be noted that NATO standards follow a review cycle which seeks to implement best practice as it develops, which means that further changes can be expected in the future. Indeed, the ongoing harmonization of IM and Hazard Classification (HC) effort will likely result in further consequential changes in the not too distant future. The paper finishes with a short overview of how this effort is progressing and what it may mean for the future.

BACKGROUND

Figure 1 shows the timeline for promulgation of previous and planned future NATO IM, as well as HC, related documents. Of note is that the last update of any the full-scale test policy documents was in 2006 with the majority last updated in 2004. STANAG 4439 has been updated twice since the last full-scale test STANAG was promulgated, which included additional requirements and guidance with respect to test conduct that should have resulted in consequential changes for the full-scale testing STANAGS.
As a result, a lack of consistency has developed between the policy in STANAG 4439 and the full-scale test STANAGs. As a consequence, Edition 3 of AOP-39 (Annex H) updated requirements and guidance for the conduct of all the full-scale tests were often overlooked as

they were not referenced by the full-scale test STANAGs, or other relevant NATO documents (including AASTP-3 on HC).
A number of other factors also led to the current review of all test related standards and guidance. There have been pressures to change full-scale test procedures to reflect more efficient testing methods and to take into account our improved understanding of threats and munition response. Recent changes in approach and policy on NATO documents led to an opportunity to review and restructure all the IM policy documents. A review was also undertaken of the Response Descriptors detailed in AOP-39 and the UN Recommendations on the Transportation of Dangerous Goods – Manual of tests and Criteria (ST/SG/AC.10/11/Rev.6 Appendix 8) back in 2013. This provided an opportunity to determine whether earlier changes made in 2009 had satisfactorily addressed needs by analyzing experience by nations conducting subsequent assessments.
The updated full-scale test Standards have, or are being written to comply with NATO policy consisting of a covering STANAG and an associated AOP for each full-scale test. All the full-scale test documents are developed to have a consistent structure and standard. A new class of NATO document, a Standards Related Document (SRD) allows all common information to be contained in a single reference document. It was decided by the Custodian and working group that an SRD would be drafted to support STANAG 4439 and AOP-39. This resulted in creation of AOP.39.1 Guidance on the Organization, Conduct and Reporting of Full Scale Tests, Edition A Version 1, May 2018. This was undertaken to also address the concern that AOP – Annex H was being overlooked and it was the intention that test guidance be removed from AOP-39 into this new document. It is noted that the removal of this Annex has yet to be completed resulting is some duplication of guidance. It is intended that this will be addressed as part of the IM/HC Harmonization effort referred to later in this paper.

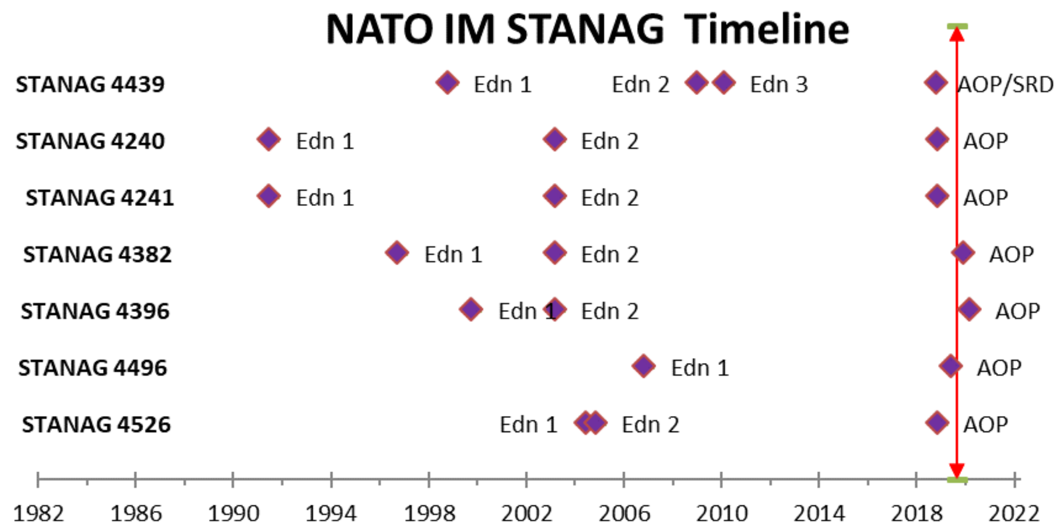

Figure 1. IM STANAG and AOP Timeline

The following sections summarize the main changes which have been made which is followed by the rational per test procedure.

FULL SCALE TESTING ALLIED STANDARDS

AOP-4240 – Fast Heating Changes

The updated AOP 4240 includes a number of changes, the most significant of which is the addition of a new Test Method 3: Fuel Burner Fire.

Annex A describes Test Method 1: Large Pool Fire. An additional two thermocouples are now required, bring the total to six, to allow two additional thermocouples to be placed above and below the test item. Previously, the flame temperature was required to reach 550°C in the order of 30 seconds after ignition as measured by any two of four flame thermocouples. The updated test requires that the flame temperature shall reach 550°C in under 30 seconds after ignition as measured by all of the valid thermocouples. An average flame temperature of at least 800°C, as measured by all of the valid external thermocouples, is still required.

Annex B describes Test Method 2: Mini Pool Fire. It also now requires 6 thermocouples, the two additional thermocouples to be placed above and below the test item. Previously, the flame temperature was required to reach 550°C in the order of 30 seconds after ignition as measured by any two of four flame thermocouples. The updated test requires that the flame temperature shall reach 550°C under 30 seconds after ignition as measured by all of the valid thermocouples. Previously, a test was considered valid if either the store has reacted, or the arithmetic mean temperature of the four thermocouples reaches 800°C within two minutes. The updated test requires that an average flame temperature of at least 800°C, as measured by all of the valid external thermocouples, be achieved.

Annex C describes the new Test Method 3: Fuel Burner Fire. This new test method has been introduced to allow other hydrocarbon fuels to be used by test centers when undertaking a Fast Heating Test. Research has shown that gaseous fuels (e.g. propane) can produce comparable absolute temperatures and heat fluxes to those of a pool of burning liquid hydrocarbon fuel. Testing and modelling has shown that the radiative and convective components of both gaseous propane and liquid hydrocarbon fuels are not always equivalent, but the total heating of the test item is comparable when the correct test setup is used. Figure 2 presents a photograph of a fast heating test propane burner. The test description test setup and configuration, instrumentation and test requirements are similar to Test Method 1. However there is a required test calibration that includes heat flux measurements. Items may only be tested in a "hearth" region that meets these requirements:

- The average temperature must be greater than 800°C and reach 550°C within 30 seconds of ignition:
- Heating must be uniform.
- The total absorbed heat flux, as measured by a device of specified dimensions, must be greater than 80 kW/m^2 when averaged over a minimum 30-second period after a minimum temperature of 800°C is achieved.

Annex C provides specific details of how to perform the calibration measurements, quantification of the calibration requirements and an example of the calibration measurements. Finally, Annex C advises that a pre-test validation of the test apparatus should be conducted prior to each planned test series or, at a minimum, on an annual basis.

Annex D provides an historical overview which did not exist in STANAG 4240.

Figure 2. Photograph of the US NSWCDD 3.7 m square propane burner (left). Note that only one of the side shields is installed to allow the inside of the burner to be viewed. Photograph of the burner in operation (right).

Review Process and Rational for changes to the Fast Heating Test

Significant changes to the fast heating test were developed by an international working group over the course of several meetings [1]. Besides the periodically required review of a STANAG, it was recognized that a more environmentally friendly method which allows for the use of less polluting fuels was needed. This remained the main focus during the drafting of this new STANAG edition and its accompanying AOP.

During the review process, it was clear that the test parameters of the existing Large Pool Fire Test and the Mini Fuel Fire Test required only minor updates to capture relevant test data. The most significant change made to these test methods was that the minimum number of thermocouples was increased from 4 to 6. This was to better measure the item flame engulfment in the Large Pool Fire test allowing the influence of factors such as wind to be recorded.

A new Annex C was developed to introduce the possibility to use other fuel sources, typically propane. Wherever possible, test parameters and requirements of Annex A, which details the large pool fire requirements, should be applied when using the procedure at Annex C to ensure consistency in testing. In particular, both test methods must be considered to produce a comparable thermal environment, where only the source to achieve the test parameters for the thermal environment is different. There is also a spatial uniformity requirement for these fires. This must be specified to avoid local heating due to hot spots that are more likely to occur with forced-flow heating compared to the buoyant flame produced in a liquid pool fire. Tests performed on both liquid fuel (kerosene) and gas-burning (propane) fires showed that hot spots were sufficiently avoided when the standard deviation of the average temperatures at all the locations within the hearth was less than 10% of the average temperature within the hearth.

The Working Group recognized that temperature alone, regardless of test method, is not sufficient to assure the same heat load (thermal environment) for the test item. The addition of heat flux was recognized as the most suitable test parameter to characterize an acceptable fire that produces the necessary heat load and thermal environment. Since heat flux measuring devices may shield the heat when placed between the heat source and the test item, the test method in Annex C includes a calibration section. This describes how a test facility can demonstrate that a test setup can produce the required heat load, and thermal environment, when the test item is fully exposed to the hearth.

Measurements of Heat flux values were taken from large pool fires and were found to be between 80 and 150 kW/m^2. This resulted in the group agreed to set a 80 kW/m^2 heat flux threshold as the minimum satisfactory level for the optional test method. In general, heat flux varies in time and depends on the temperature difference between two bodies. In a fuel fire test, the heat flux will increase rapidly as the hearth becomes fully developed. For that reason, the heat flux shall be measured from the moment the 800°C is reached and then averaged over the next 30 seconds. This 30 second averaging was chosen to level out sudden fluctuations and is considered long enough to give enough data points to be statistically significant.

This and other reasoning for changes are now included in a new ‘historical’ overview provided in Annex D of the new AOP. It is meant to help answer why the working group made the decisions and assist future revisions.

AOP-4241 – Bullet Impact Changes

The updated AOP-4241 includes a number of changes the most significant of which is the addition of a primary alternative test procedure (Method 2) for determining the reaction of an impact of one 12.7 mm Armor Piercing (AP) projectile. Another significant change is that different 12.7 mm AP projectiles, that meet a defined specification may be used, rather than the previously prescribed M2 cal 0.50 AP round.

Test Method 1 is the standard test procedure for determining the reaction, if any, of a munition to an impact of three 12.7 mm AP projectiles. It remains relatively unchanged. The impact velocity remains at 850 ± 20 m/s.

Test Method 2 is a primary alternative test procedure for determining the reaction, if any, of a munition to an impact of one 12.7 mm AP projectile. It is defined similarly to Test Method 1, except that only a single projectile is fired at the test item. The impact velocity remains at 850 ± 20 m/s.

Test Method 3 is an alternative, tailorable test procedure. It is equal to procedure 2 of STANAG 4241 Ed. 2. The parameters of the test are determined by the results of the Threat Hazard Assessment (THA).

The new Annex A provides recommendations for aiming point and target area. It recommends firing pre-shots at a dummy target until the required test parameters have been demonstrated to have been met (accuracy, velocity, rate of fire), at which point the actual test item can be substituted.

The new Annex B provides specification for acceptable 12.7 mm AP projectiles. This specification includes projectile size, weight, core hardness and core material. The projectile should not contain any tracer, incendiary composition, pyrotechnic or high explosives. The DM51, M2 AP and AP-M8 are listed as fulfilling the specification requirements. Figure 3 presents a photo of the 12.7x99mm NATO (.50 cal) AP-M8 cartridge. Not listed in the Annex is the 12.7 mm PF1 used in France, which is another acceptable projectile.

Figure 3. 12.7x99mm NATO (.50 cal) AP-M8 cartridge (FN Herstal, Belgium).

Annex C provides an historical overview. This overview did not exist in STANAG 4241.

Review Process and Rational for changes to the Bullet Impact Test

These BI testing changes in AOP-4241 were worked out by an international working group over several meetings. To assist the process, MSIAC gathered feedback on issues and needs using a questionnaire approach, which was written up and provided a starting point for discussions [2]. The Method 2 (primary alternative) allows one to perform the test with a single shot on the target. This method was not specifically identified in the previous STANAG but was commonly adopted by many nations. The rational adopted by nations in using this procedure is that the impact of three bullets in the small target area is considered unlikely. From a reaction mechanisms point of view, it is not a clear, or straight forward to decide, which test is most appropriate for a particular system due to differences in the relative importance of venting and material damage levels in determining reaction violence. For example, the triple bullet impact is expected to increase venting compared to a single bullet, potentially providing a reduced response reaction. Conversely, multiple bullet impacts would provide additional damage to the energetic material possibly giving rise to increased response levels.

Guidance on aim point and target area were provided to help improve accuracy and to help demonstrate compliance against the test parameters. The addition of a specification of acceptable 12.7 mm AP projectiles was added, introducing the possibility to use a range of AP projectiles.

The historical overview provided in Annex C was added in order to document the working group decisions and reasoning. It is meant to help answer why the working group made the decisions.

AOP-4382 – Slow Heating Changes

Of all the test STANAGs reviewed as part of this effort, AOP-4382 is the one which includes the most changes, the most significant being the selection of a new Heating Rate of 15°C/hour for Test Method 1 (Standard Test). The new AOP also modifies Test Method 2, and added a new Test Method 3 for the purpose of harmonization with the Hazard Classification. The means to precondition the test item before starting the temperature ramp has also changed.

Test Method 1 is the Standard Test that requires the item to be heated at a now revised rate of 15°C/hour until a reaction occurs. Before starting the ramp, the test item shall be preconditioned in the oven at 50°C (± 3°C) until it has reached thermal equilibrium. Annex A provides three methods to determine when a test item is considered to have reached equilibrium: direct measurement, modelling, or calculation based on the munition's diameter. The preconditioning period is not required to exceed 24 hours but can be extended if desired.

More guidance is now provided on recording the reaction as a function of time and temperature. Temperature reporting shall be the average of the functioning thermocouples at the times of recorded reaction events. The AOP now requires 6 thermocouples to measure the air temperature in the oven, rather than 4. The two additional thermocouples are placed above and below the test item. Furthermore, the 6 thermocouples shall be mounted 40-60 mm from the surface of the test item. Two more thermocouples are recommended to be mounted for monitoring purposes on opposite surfaces of the test item. It has been added that where it is possible to get access to the interior of the test item without altering it, interior temperatures should also be measured with additional thermocouples. A note has been included at the end of Test Method 1, allowing some gradient in oven air temperature measurements around the test item, which should not be greater than 15°C (instead of 5°C in the current STANAG). Also, at no point throughout the test should any of the surrounding oven air temperature measurements deviate from the prescribed constantly-increasing oven set point temperature by more than 15°C.

Test Method 2 is the Alternative Test for which the heating rate is identified in a Threat Hazard Analysis. The 25°C/hr HR has been deleted. Hence, a heating rate determined by national authorities should be used if a THA approach is used. Temperature preconditioning may be used but is not required with this test method.. It should be noted that real slow heating scenarios can lead to many and varying heating rates, so justifying any particular rate can be a challenge. Details of the relevant THA should be provided with the test data in the test report. The requirements and recommendations on thermocouples are the same as Test Method 1.

Test Method 3 is included to meet the Hazard Classification Test UN 7(h) test requirement for assignment to HD 1.6 assignment. The method is different from Test Methods 1 and 2 requiring the test item to be subject to a gradually increasing temperature, at a rate of 3.3°C/hour, until a reaction occurs. A record of the reaction as a function of time and temperature is required. Temperature preconditioning may be used but is not required with this method. If used, preconditioning of the item up to 55°C below the predicted reaction temperature is possible. The item is required to reach thermal equilibrium prior to starting the temperature ramp at 3.3°C/hour. The requirements and recommendations with respect to thermocouples are the same as for Test Methods 1 and 2.

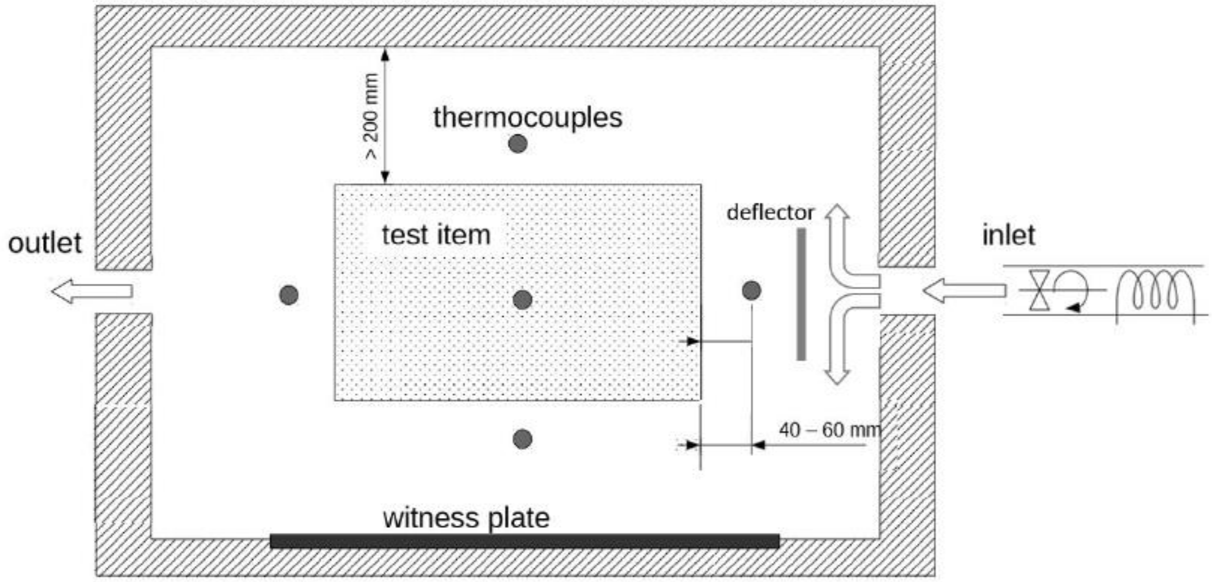

Figure 4. Side view of a “typical” slow heating test setup with a generic test item in a forced air flow oven.

Annex B provides an historical overview. This overview did not exist in STANAG 4382.

Review Process and Rational for changes to the Slow Heating Test

These Slow Heating testing changes in AOP-4382 were worked out by an international working group at several meetings. To assist the process, MSIAC again gathered feedback on issues and needs using a questionnaire approach, which was written up and provided a starting point for discussions [3].

For about two decades, the 3.3°C/hr heating rate has been discussed and the community generally agreed that this was not a credible threat. However, no study was able to propose a better Heating Rate (HR) as clearly there is no such thing as a typical slow heating accident (as opposed to fast heating fuel fire). Based on historical data, modelling and probabilities, the Working Group (especially the study led by D. Hubble) succeeded in proposing a minimal credible HR for Slow Heating events: 10°C/hr. Considering, among others, the probability of events at this HR, a consensus between nations was agreed setting the new HR at 15°C/hr.

The preconditioning was debated for a long time. Was it necessary to keep it or not? In terms of standardization, it was decided to keep the preconditioning at 50°C, in order for each test centre to start the ramp at the same temperature. Depending on the location of the test centre, and the time of the year, large temperature differences are expected, which can affect the temperature gradient in the test item during the ramp, and also the reaction of the test item.

The preconditioning duration was discussed. The 8 hours requirement in the current STANAG is not appropriate; small test item will reach their thermal equilibrium before 8 hours of preconditioning, whereas large test items will need more than 8 hours. As a compromise, the Working Group decided that the centre of the test item shall be at least 45°C before starting the thermal ramp. Annex A provides 3 methods to determine the temperature preconditioning time. Where it is not possible to get access to the interior temperature of the test item during the test (Method 1), a second method suggests to use modelling by using, for example a 1-D transient finite difference solver in cylindrical coordinates for simple geometries. This requires knowing the density, thermal conductivity, and specific heat of each major component of the test item. It will also require knowledge of the boundary conditions between the oven air and the test item. While the convective heat transfer coefficients for the oven and test item are location-specific, values will likely fall in the range of 10-25 W/m^2K for most oven configurations. Method 3 proposes that the duration of the temperature preconditioning period, measured in hours, can be determined by inserting the dimension S (mm) of the test item in the following formula:

$$\text{Preconditioning period (hrs.)} = 0.000148.S^2+0.0785.S$$

For cylindrical test items, the dimension S (mm) is the diameter. For rectangular prism-shaped test items, e.g., a typical munition or multiple munitions packaged in a typical cuboid-shaped container, the dimension S (mm) is the length of the diagonal between the two shortest sides. This method is the easiest one to use when the thermal parameters are unknown for the test item.

In the same way as for the Bullet Impact and Fragment Impact Tests, France proposed to add a tolerance on the HR. Indeed, the AOP mentions no requirement of the tolerance of the ramp. The only recommendation is the 15°C maximal homogeneity between oven air temperatures. No consensus has been reached on this point and France suggests nations add a reasonable tolerance on the average ramp between 50°C and the reaction temperature. As a basis for discussion, France has proposed a requirement of 5% tolerance on the ramp, i.e. (15 ± 0.75) °C/hr.

The historical overview provided in Annex B was added in order document the working group decisions and reasoning. It is meant to help answer why the working group made the decisions.

AOP-4396 – Sympathetic Reaction Changes

The update of the AOP is currently on-going and hence this section provides an update on discussions to date. The aim of this Standard will remain the same, i.e. to specify the test requirements and procedures to assess the response of one or more acceptor munitions and weapon systems to the effects of the reaction of an identical donor munition and weapon system.

The current STANAG requires 2 tests: one confined and one unconfined. The terms “confined” and “unconfined” are not explained. This being said, the confined configuration implies the storage configuration, while the unconfined configuration implies the logistical one. In both cases, the minimal volume required of the stack is 0.15 m^3. This volume is obtained with one donor, and at least two acceptors. For the confined test, confinement may be simulated with containers stacked around the test stack at least 1 m deep in all directions. The volume requirements are primarily required for HC but are also apply for IM purposes, and should be kept in the next AOP. The new AOP will also require two tests but there remains the possibility to perform only one test if this can be justified and approved by the National Authority.

The number of munitions required for a test is generally determined by the 0.15 m^3 requirement. The new AOP should clarify the number of test items to use and the layout of donor and acceptors munitions. Some examples should be included in Annex in order to help testers make decisions. Thus use of inert munitions will be still possible but their layout around the live acceptor munition needs further clarification.

The update of the mode of initiation will be considered as part of the review. For munitions which are designed to detonate, the guidance remains unchanged to detonate the donor in the design mode. For all others, it has been proposed to initiate the donor with a credible threat (for example Shaped Charge Jet as defined in AOP-4526(A)(1) or another normalized threat). The threat stimulus used should be approved by National Authorities.

Other guidance proposed concerns the need to perform a sympathetic reaction test for IM assessment purposes even if it is clear that the item cannot detonate. This may be the case if information on reaction violence is required (even though the IM type III requirement is met). Such a decision would need to be taken in conjunction with the National Authority.

To help determine the response of acceptor items, a calibration shot in order to characterize the contribution from the donor munition in terms of blast pressure and fragmentation (donor and inert acceptor munitions around) was discussed. It was agreed to add a new paragraph providing guidance on how to achieve this; the set-up of the calibration test should be the same as the real test.

Annex A will provide an historical overview. This overview did not exist in STANAG 4396.

Review Process and Rational for changes to the Sympathetic Reaction Test

SR testing changes to AOP-4396 were worked out by an international working group at several meetings. To assist the process, MSIAC gathered feedback on issues and needs using a questionnaire approach, which was written up and provided a starting point for discussions [4]. It is now planned that a final meeting be held in September 2019 in order to fully update the AOP.

According to the CWG, the terms used in the current STANAG are not always well understood by the community. Clarifications of several terms are needed. The most significant one is the definition of the “test item” which currently refers to the “munition”. Often for smaller munitions the test item may be the ammunition box containing multiple rounds. The question then becomes, are we assessing the reaction of the acceptor munitions within the box or are we assessing propagation between boxes? The current STANAG is not clear, which has led to differences in how the national authority interprets response levels. It was agreed that we should be looking at the reaction of the acceptor boxes and it would be a mistake to assess the reaction of each munition. Hence the test item becomes the ammunition box and the munitions within it. It was agreed that the term “test item” is preferred in the AOP over “munition”. Depending on the munition lifecycle configurations, the test item can be the bare munition; the munition and its container; or the container/ammunition box and the munitions within it.

The historical overview provided in Annex A was added in order document the working group decisions and reasoning. It is meant to help answer why the working group made the decisions.

AOP-4496 – Fragment Impact Changes

The updated AOP-4496 includes a number of changes, the most significant of which is the addition of requirements and recommendations related to the fragment orientation at impact and the aiming point [5].

Test Method 1 is the standard test procedure for assessing the reaction, if any, of a munition to the high-velocity impact of a calibrated fragment representative of a threat fragment. This remains relatively unchanged; the impact velocity remains 2530 ± 90 m/s.

Test Method 2 is the alternative test procedure for determining the reaction, if any, of a munition to the impact of a calibrated fragment representative of a threat fragment at a lower velocity. This also remains relatively unchanged with the impact velocity of the alternative test remaining at 1830 ± 60 m/s.

Mass and shape of the fragment have been extensively studied in the past [6] and the decision was made to keep these as they currently are. However, so as to better standardize the fragment, a lower limit for the Brinell hardness of the fragment has been added. The current STANAG requires that the fragment is a mild carbon steel with a Brinell Hardness (HB) less than 270. Based on the French standard (NF T70-545), the lower value of the Brinell hardness has been agreed to be specified as 190 HB. In the future, the Brinell hardess of the fragment used for the test shall be measured and included in the test report.

The number of tests remains the same as in edition 1 of the STANAG. It has been clarified that "the test shall be carried out twice per sub-component of the munition; once against the most sensitive component/energetic material (e.g. motor igniter, warhead booster) and once against the main charge filling". A definition of the "most sensitive component" was also added: the "'Most sensitive component means the component which, if exposed to the threat, is likely to lead to the most violent response of the munition".

The current STANAG does not require any accuracy measurement of the fragment at impact and during the review it was agreed to add this as a new requirement. It was recognized that because impact accuracy is very system dependent "the accuracy requirement 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. For large items, an accuracy diameter around the aim point shall be defined. For small ones (small munitions, boosters …), the requirement will be to hit the energetic material targeted. This shall be defined and recorded prior testing and should be agreed by the National Authority."

For similar reasons, the current STANAG does not require any orientation of the fragment at impact. In the new AOP, "the angular deviation (e.g. vector sum of yaw and pitch) of the fragment at impact shall be measured and recorded and should be limited to ± 10 °".

Annex B provides an historical overview. This overview did not exist in STANAG 4496.

Review Process and Rational for changes to the Fragment Impact Test

These FI testing changes in AOP-4496 were worked out by an international working group at several meetings. To assist the process, MSIAC gathered feedback on issues and needs using a questionnaire approach, which was written up and provided a starting point for discussions [7].

Already well defined, mass, shape and velocity (Methods 1 and 2) of the fragment remain unchanged. There was discussion on the Brinell hardness of the fragment, the current STANAG allows test centres to use all Brinell hardness below 270. Knowing that the behaviour of the fragment when impacting the munition can change significantly depending on its hardness, a range of acceptable hardnesses had to be defined. The lower value of the Brinell hardness in the French standard (NF T70-545) – 190 HB – was deemed acceptable by the Working Group.

Existing guidance regarding the aim point at the test item was deemed not clear enough. Rather than choosing the point of impact in order to generate the worst reaction, it has been decided that the “aim points shall be selected to create the most stressing condition on the target energetic”. It has been decided that “the aim point shall also represent a credible exposure condition, based on the Threat Hazard Assessment (THA). The shotline should avoid impact locations of low probability that may lead to irreproducible reactions. This includes, but is not limited to, welds seams or joints”. Concerning the order of tests to conduct, the first test should aim at “the center of the largest presented area of energetic material or component” has been replaced by “the centre of the energetic component”. For the second test, the “most sensitive area” has been replaced by the “most vulnerable area”. Some guidance can be found in SRD AOP-39.1 to assist with the selection of aim point. It was also agreed that the aim point and shotline for each test should be approved by the appropriate national authority prior testing. Positions of each nation were presented.

A French proposal was made to specify a 5-cm diameter circle accuracy as per the requirement for the Bullet Impact test (AOP-4241). This was ultimately rejected because it was realized that impact accuracy requirements are system specific.. For large items, it is easy to specify, but difficult for small items or specific aim points. For example, if the test item diameter is below 50 mm, then an accuracy requirement is not appropriate Therefore, it was not possible to define a specific value of accuracy. .

Studies indicate the reaction of the test item can change depending on the orientation of the fragment at impact. That is why it was decided to add a paragraph of guidance on impact orientation. France proposed an acceptable orientation of the fragment at impact of ± 10°, which was based on an assessment of fragment impact tests carried out. It was recognized that test centers can find it difficult to measure precisely the angle of impact, but at the same time it was agreed that measurements and recording of the fragment orientation are important. In conclusions, it was agreed to require the measurement and reporting of fragment orientation. It was also agreed to make a recommendation on accuracy of ± 10° , which will be introduced at this point. Once more data is available in the future this position could well change.

The issue of the sabot design was also discussed. As each test center has its own gun and hence sabot design, a standardized sabot design was thus not deemed necessary. The test centers will be responsible for determining the appropriate configuration and design for the sabots used at their facilities. The same applies to launcher system design.

Participants agreed not to add a requirement for a standoff distance between the launching system and the test item. The test centers will be responsible for determining the appropriate distance for their facilities.

There was also consensus that additional guidance on how to measure the fragment velocity was not required. However, it was deemed necessary to update the text to advise test centers to report how this measurement was made, describe their measurements in detail, and report measurement error. It is now specified in the guidance on observations and records to assess the measurement uncertainties of the impact velocity, the impact location, and the angular deviation.

All members agreed that the design of a test set-up should be left to the individual test centers. No example of a “typical” Fragment Impact test set-up has been added in the AOP.

The historical overview provided in Annex B was added in order to document the working group decisions and reasoning. It is meant to help answer why the working group made the decisions. It also captures how the shape, mass and velocities of the fragment were chosen.

AOP-4526 – Shaped Charge Jet Changes

The updated AOP-4526 includes a large number of changes, the most significant being the replacement of the standard test shaped charge threat. STANAG 4526 Ed. 2 had the aim of providing a standard test procedure for a typical top attack bomblet shaped charge jet, specifying the use of the 50 mm Rockeye, or equivalent. The new AOP-4526 EDA V1 has the aim of providing a standard test procedure (Method 1) using a Rocket Propelled Grenade (RPG) shaped charge jet threat.

The AOP provides a set of requirements for the attacking shaped charge and its jet properties. It specifies that the shaped charge shall be well documented and characterized, and is of high precision with an explosive charge diameter between 61 mm and 95 mm. The explosive is required to have a detonation velocity and Gurney energy between COMP B and pure HMX at maximum density. The test is required to strictly meet defined jet characteristics: jet diameter at the target of 2.5 - 3.5 mm, and Held's criteria (V^2d) at the target between 120 – 140 $mm^3/\mu s^2$. Two examples, along with their associated documentation and jet characterization data are provided in Annex A: USA Shaped Charge 81 mm LX-14 and Annex B: France Shaped Charge CCEB 62. These are the two shaped charges standardized by the USA and France for IM signature assessment. Figure 5 presents photographs of these shaped charges.

Method 2 (Alternative Threat Test) is an alternative test procedure for determining the degree of reaction, if any, of a munition when hit by a specific threat shaped charge jet with characteristics justified by means of a THA. It subjects a test item to a shaped charge jet which must have been fully characterized (required data very similar to Method 1) and demonstrated to match the threat documented in a THA.

The following test methods and sections that were contained in STANAG 4526 Ed. 2 were not incorporated into the updated AOP, 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.

Additionally STANAG 4526 Ed. 2 contained an inaccurate table of Held's Criteria for various shaped charges that is no longer applicable and could not be verified. Likewise, this was not retained in the updated AOP.

Annex C provides an historical overview. This overview did not exist in STANAG 4526.

Figure 5. USA Shaped Charge 81 mm LX-14 (left) and France Shaped Charge CCEB 62 (right).

Review Process and Rational for changes to the Shaped Charge Jet Test

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. Input received in meetings and during the MSIAC workshop confirmed that most member nations agree that some form of the RPG-7 is the predominant threat; these grenades are the dominant threat produced, sold and used by many countries. French and USA test standards had already been developed and used and replicate this threat. As other countries may want to use alternate shaped charges for their testing, the new AOP document defines the jet characterization and test configurations so that other test arrangements and hardware can be developed that meet the standard. As is typical of all the IM threat testing standards, an alternative threat variation is allowed, based upon a THA approach.

The working group utilized the current understanding of shaped charges and shaped charge initiation. Criteria, known as the Held criteria has been developed to evaluate the initiability of an explosive impacted by a shaped charge jet. 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 different conditions when the jet reaches the energetic material. Consequently, full characterization of the jet used is required in the updated standard. In order 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 (see figure 6 below).

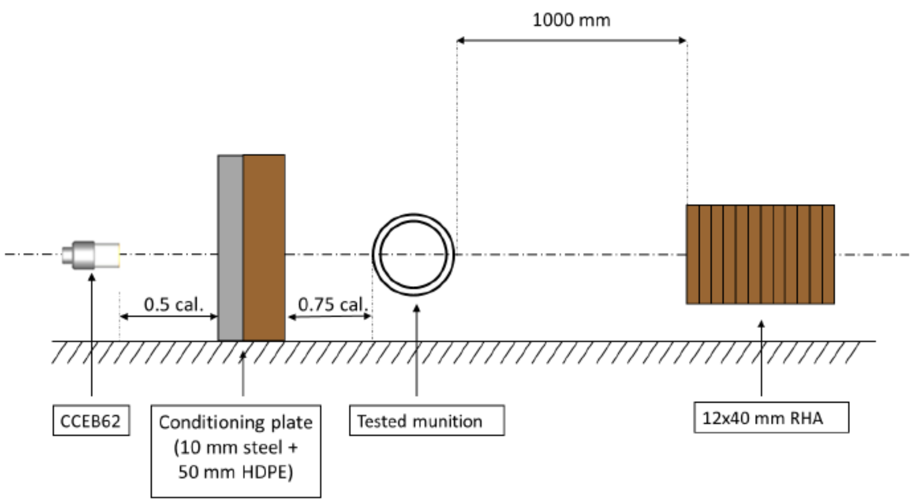

Figure 6. Recommended Set-up for IM Shaped Charge Jet Test with the CCEB62

The historical overview provided in Annex C was added in order document the working group decisions and reasoning. It is meant to help answer why the working group made the decisions.

SUMMARY

Significant progress has been made to ensure that the IM and HC tests standards have been updated and that there is now a good degree of consistency in their structure and level of guidance. The completion of the update process represents a significant effort by the community to ensure that the tests standards remain credible and implement best practice as defined by the international community.

A summary of the key changes is given in the table below:

Test	Summary of Major Changes
All standards	Standards have been structured and formatted to meet the new NATO standards requirements
AOP-4240 – Fast Heating	Introduction of new test method to allow other fuels to be used. Introduction of Heat Flux Measurement: a requirement to reach 80 kW/m^2, and the need to characterise alternative heat sources Improvements in instrumentation
AOP-4241 – Bullet Impact	Introduction of Test Method 2 recognising that many nations conduct a single bullet impact test. Introduction of alternative 12.7 mm AP projectiles which meet a defined specification
AOP-4382 – Slow Heating	Selection of a new heating rate of 15°C/hour Improvements in instrumentation Improved guidance and requirements on preconditioning (included how to calculate soak times)
AOP-4396 – Sympathetic Reaction **(on-going discussion)**	Improved definitions to remove differences in interpretations: Confined vs unconfined Definition of the test item (box vs munition) Mode of initiation Recognition of the importance of a calibration shot
AOP-4496 – Fragment Impact	Improved guidance on fragment orientation at impact and the aiming point Additional requirements for a minimum Brinell hardness of the fragment of 190 HB
AOP-4526 – Shaped Charge Jet	Agreement on the threat characteristics for the standard test RPG 61 mm and 95 mm. Agreement on threat specification range: required jet diameter at the target of 2.5 - 3.5 mm, and Held's criteria (V^2d) at the target between 120 – 140 $mm^3/\mu s^2$ Identification of new test SCs Agreement on use of jet conditioning plates

Other work is on-going under NATO aimed at harmonizing the approach to IM and HC and will likely result in some consequential changes for tests standards in the coming years.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Advancing the Propane Fast Cookoff Burner and Testing, WASHBURN, IMEMTS (2018)

[2] O-152 – An International Review of the Bullet Impact Test, MSIAC (2013)

[3] O-177 – International Review of the Slow Heating Test, MSIAC (2017)

[4] O-203 – An International Review of the Sympathetic Reaction Test, MSIAC (2018)

[5] Review and Update of STANAG 4496 Fragment Impact, JACQ, IMEMTS (2018)

[6] Historical Review of Fragment Impact Standardization, HUNTS, IMEMTS (2018)

[7] O-159 – Review of the Fragment Impact Test ed.2, MSIAC (2017)