Reconciling Developmental Weapons Safety Tests in MIL-STD-2105

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Abstract: Since MIL-STD-2105 was revised to clarify and update the Insensitive Munitions (IM) tests as called out by the Joint Service Requirement for Insensitive Munitions (JSRIM), and by various NATO STANAGs, it is common practice within the US Navy to assess munitions with respect to hazards using IM tests in MIL-STD-2105; Hazard Classification (HC) tests in TB 700-2 (transportation and storage purposes); and safety and suitability for service (S3) assessment testing in NATO STANAGs and Allied Publications. The basic safety tests have begun the promulgation process in a series of interconnected NATO Allied Publications. This paper explores the contemporary situation of delineation of these tests in MIL-STD-2105D and an approach to improve the transparency of this seminal set of standards. This paper will recommend how the safety tests can be reconciled in MIL-STD-2105D, the roadmap for reconciling the safety tests in MIL-STD-2105D, and will reference the series of NATO standards containing the safety tests. The expected result is that an updated MIL-STD-2105 will be a less confusing and a more focused standard for IM testing and that Safety and Suitability for Service (S3) assessment testing will be accessed in a well-defined set of NATO standards.

Introduction

Three sets of tests are commonly used to assess munitions hazards. Insensitive Munitions (IM) tests are contained in MIL-STD-2105D (DoD 2011) and “provide a basis to test munitions against meaningful, credible, potential threats and evaluate munition response against criteria that reflect the services IM vulnerability and hazard reduction goals.” Hazard Classification (HC) tests in TB 700-2 (DoD 2012) provide procedures for assessing the reaction of ammunition and explosives (AE) to specified phenomena, and are used to assign the Class and Hazard Division for AE transportation and storage. Basic safety tests are used for Safety and Suitability for Service (S3) assessment as contained in STANAG 4629 (NATO 2011). Multiple standards and test procedures exist, confusing or conflicting, a serious dilemma impacting weapons safety test planning and testing. Reconciling multiple standards can be time consuming if multiple agencies are involved and expensive if multiple/redundant tests need to be conducted. A joint services’ funded study[1], was conducted in 2008 to evaluate joint safety test requirements and identify areas where economies could be achieved. This study involved collecting safety tests and identifying inconsistent and duplicate tests, to gaining Joint Service agreement on the first joint

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[1] Booz Allen Hamilton, “Joint Service Safety Testing Study,” Paper prepared for the Defense Safety Oversight Council Acquisition and Technology Programs Task Force and the Marine Corps Systems Command, April 2008.

test[2], and then transitioned to Joint Munitions Safety Testing (JMST), which entails drafting NATO test standards[3].

A framework for reconciling developmental safety tests in MIL-STD-2105 was outlined by Mirick (Mirick 2011) at the National Defense Industrial Association Systems Engineering Conference. The impetus for this was the JMST initiative sponsored by the Acquisition and Technology Programs Task Force (ATP TF) of the Defense Safety Oversight Council (DSOC) under the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (OUSD(AT&L)) in response to the Secretary of Defense's (SECDEF) memo on reducing preventable accidents (SECDEF 2003). The US Special Operations Command (USSOCOM) funded Joint Shipboard Weapons and Ordnance (JSWORD) experiments to establish, document, and publish standard joint procedures for operations involving US Army and USSOCOM helicopters on board US Navy ships. These experiments showed that this work is necessary and would produce meaningful and executable outcomes for the Services. Following these developments, the Joint Requirements Oversight Council (JROC) recognized all weapon/explosive systems as categorically joint (JROCM 2005).

These issues present DoD acquisition with challenges in safety testing of munitions including multiple duplicate or overlapping standards, and multiple applications of the same standard by different Services. To meet these challenges, three interwoven initiatives to enhance support to USSOCOM and the Joint Warfighting Environment have been established. The three initiatives involve material reviews, requirements, and testing. These initiatives enable collaboration on joint weapons safety reviews, integrating joint weapons safety requirements in Joint Capabilities Integration and Development System (JCIDS), and developing joint service weapons safety testing standards (Mirick 2011). The end result will be a more streamlined process for developmental weapons safety testing involving fewer tests using fewer and non-overlapping standards. This, in turn, will help to shorten the acquisition cycle for weapons. Under the auspices of the NATO AC/326 Subgroup 3 (now Subgroup B), the Working Group for the Development of S3 documents developed STANAG 4629 (NATO 2011) "Safety and Suitability for Service Assessment Testing of Non-Nuclear Munitions," a standardization agreement paving the way for improved munitions type-specific joint test standards. As the S3 Working Group efforts were complimentary with the Joint Service Safety Testing recommendations, the work was linked in a dual path (domestic and international) process, hereafter referred to as JMST.

The NATO S3 Working Group develops Allied Ammunition Safety and Suitability for Service Publications (AAS3Ps) for munition commodity groups. The documents refer to existing STANAGS/NATO test methods under AC/326 or AC/327, where possible, to enhance interoperability. AAS3P-01 (NATO 2011) is the principle AAS3P covered by STANAG 4629. AAS3P-01 provides overarching guidance and requirements regarding the internationally agreed-to S3 assessments, test methodologies and test procedures for all non-nuclear munitions, which will facilitate interoperability and the reciprocal procurement of munitions by NATO Nations.

The US Joint Working Group publishes a commodity-specific corresponding Joint Ordnance Test Procedure (JOTP) for each AAS3P. In most cases, these two products are developed at

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[2] The 40-ft Logistic Drop Safety Test, JOTP-001, was completed in 2010. The entire language of JOTP-001 safety drop test was incorporated into MIL-STD-2105; JOTP-001 was subsequently retired.

[3] The deliberations and product of JMST now fall under the purview of the Joint Weapon Safety Working Group (JWSWG); the JWSWG advises the JMST.

the same time, by the same group of subject matter experts, and contain identical procedures. The NATO ratification process can be lengthy, and the JOTP approval process provides a much quicker path to US DoD implementation of the requirements. A JOTP is designed to be retired when the corresponding AAS3P is ratified. If the NATO Allied Publication route encounters difficulties or is delayed, then a MIL-STD may be used as an alternative to eventually replace the JOTPs. An example of this is the 40-ft Logistic Drop Safety Test, for which JOTP-001 was developed. Those procedures were integrated into the MIL-STD-2105, and the JOTP-001 was retired.

MIL-STD-2105D Basic Safety Tests

MIL-STD-2105D provides or references tests and test procedures for the assessment of safety and IM characteristics for all non-nuclear munitions, munition subsystems, and explosive devices. Historically, this standard replaced WR-50 (DoN 1964) and was used primarily for the assessment of weapon safety, while the IM technical requirements were addressed in NAVSEAINST 8010.5 (NAVSEA 1985). The original standard was revised in 1991 to incorporate the IM requirements in a document that could be contractually referenced. Joint Service Requirements for Insensitive Munitions (JSRIM) was dictated by JROCM 235-06 (6 Nov 2006), and subsequently amplified by OSD Joint Insensitive Munitions Test Standards and Compliance Assessment, Feb 1, 2010, which detailed the number of IM tests and test configurations that were not specified in 2105 or the STANAGs. MIL-STD-2105D implemented these two documents by specifying requirements for testing in operational and logistical configurations. The testing in MIL-STD-2105D is broken into two types of testing, the basic safety tests and the IM tests. The four basic safety tests are: 28-day temperature and humidity (T&H) test; Vibration test; 4-day T&H test; 12-meter (40-foot) drop test.

The six IM tests contained in MIL-STD-2105D, fast cook-off, slow cook-off, bullet impact, fragment impact, sympathetic reaction, and shaped charge jet impact, were discussed extensively in relation to the Qualification and Final (Type) Qualification of Explosives (Tomasello, et al. 2010). Figure 1, from MIL-STD-2105D, shows a typical test sequence for the basic safety tests and the IM tests, shows the delineation between the two types of tests, and clearly shows the absence of any connection between the basic safety tests and the IM tests.

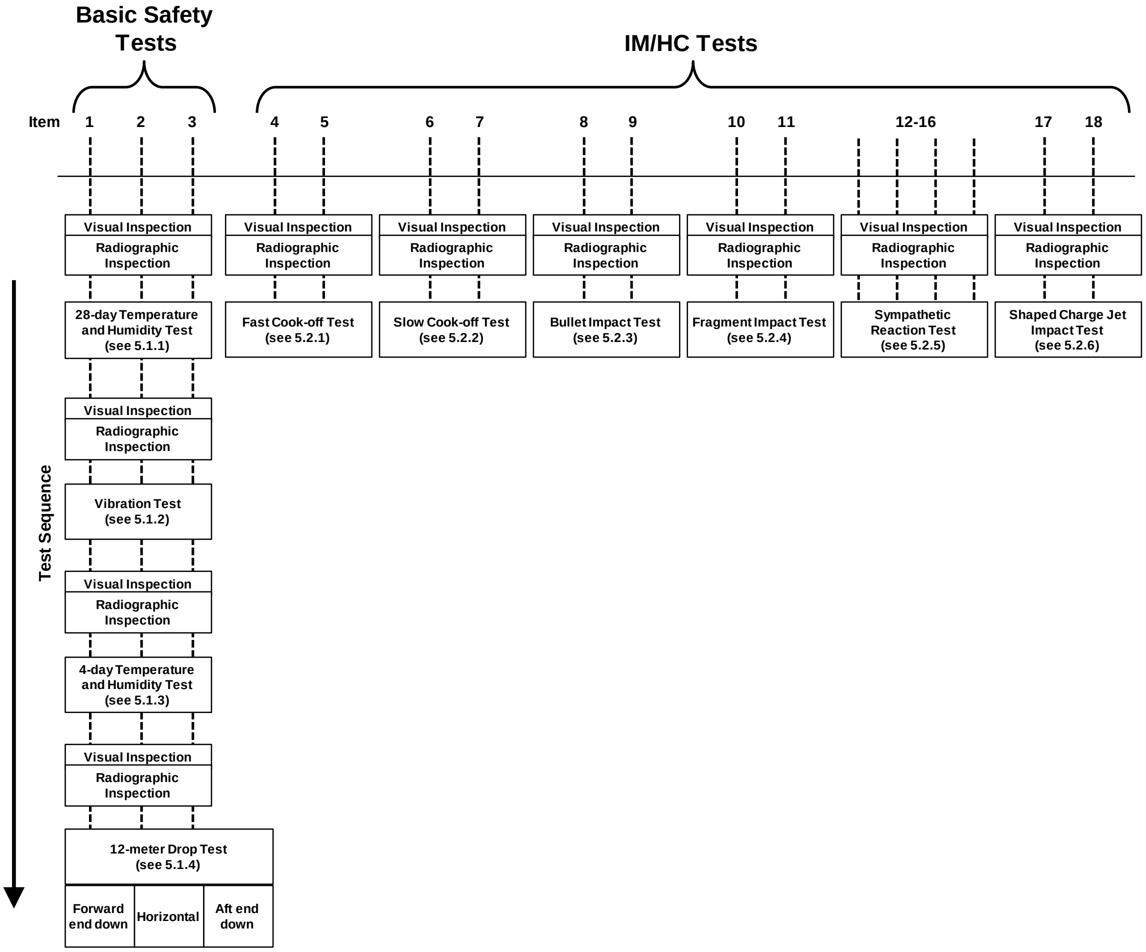

Figure 1. Typical Test Sequence – MIL-STD-2105D

<u>28-day T&H Test</u>: The 28-day T&H test consists of exposing the test item to alternating 24-hour periods of high and low temperatures for a total of 28 days. Temperature range and relative humidity are derived from a Threat Hazard Assessment (THA), which contains an analysis of the munition's life cycle. There are no comparable requirements in the NATO documents.

The Navy has been conducting essentially the same 28-day T&H test for over 50 years to determine the safety of explosives in ordnance. The origins of this test are unknown and may be, to a certain extent, arbitrary. Although the Army performs T&H testing, it does not conduct the same 28-day T&H protocol as the Navy.

The analysis in AAS3P-10 using the Arrhenius relationship to determine the activation energy for the degradation mechanism seems to be a valid methodology for determining explosive test requirements. A similar approach for analyzing Navy explosives and the 28-day T&H test protocol would aid reconciliation of the T&H safety tests in the US standards and the NATO standards. The way to do this is to first establish the rationale for T&H safety testing, and determine if the test represents a realistic environment. Would a Lifecycle Environmental Profile from a THA, or a stockpile-to-target sequence provide a more realistic sequence? Analyses such as the Arrhenius relationship could then be used to determine the activation energy for the degradation mechanism for a realistic T&H sequence.

Vibration Test: The vibration test consists of exposing the test item to the most intense vibration environment that it will encounter during its life cycle. The vibration schedule and test temperatures are dictated from the THA. Transportation vibration, aircraft vibration, and shipboard vibration are environments to be considered, as well as those in MIL-STD-167 (DoD 1992) (DoD 2005) and MIL-STD-810 (DoD 2008). A comparison of the MIL-STD-2105D requirements for this test and comparative NATO requirements shows that both MIL-STD-2105D and STANAG 4370 direct that the vibration schedules applied should be derived from the life cycle of the system. STANAG 4370 provides additional direction with respect to the specific parameters of the vibration schedules contained in the ITOPs 01-1-050 and 06-06-1997, which are derived from historical test data for each platform. The schedules can be tailored. The STANAG allows for tailoring out Aircraft vibration and/or Shipboard vibration in the case of materiel that will be transported by tactical ground vehicles due to the more severe environment that will be tested.

WR-50 referenced the shipboard and transportation vibration schedules based on the frequencies, displacements, and durations called out in MIL-STD-167 (DoN 1954) and MIL-STD-303 (DoD 1963), subsequently canceled and replaced by MIL STD 331. STANAG 4370 provides additional direction with respect to the specific parameters of the vibration schedules contained in the ITOPs 01-1-050 and 06-06-1997, which are derived from historical test data for each platform. The schedules can be tailored based on the expected exposure of the munition.

4-day T&H Test: The 4-day T&H test is a 4-day version of the 28-day T&H test, and consists of exposing the item to alternating 24-hour periods of temperature and relative humidity as derived from the THA environmental profile. The test items are subjected to two complete cycles. There are no comparable requirements found in the NATO documents.

As described for the 28-day T&H test, WR-50 did not provide any original specific rationale for the 4-day version of the T&H cycling test. The origins of this test are similarly unknown. Although they are intended to replicate chemical based degradation mechanisms, the number of cycles and temperature extremes are presumed to be somewhat arbitrary. The Army also does not conduct the same 4-day T&H protocol as the Navy. The 4-day T&H test is not required in the AAS3Ps. The Arrhenius analysis described previously could be used to establish a realistic T&H testing sequence that would replace the 4-day protocol as well as the 28-day protocol.

12-meter (40-foot) Drop Test: MIL-STD-2105D states that this test is to be performed in accordance with STANAG 4375. MIL-STD-2105D incorporates the procedures from the 40-ft logistic drop safety test of JOTP-001 (now retired). These procedures are similar to the logistic drop procedures of STANAG 4375 (NATO 2010); STANAG 4375 also includes a deployment drop (3 m height) identified by the THA, as well as a more severe drop condition. Table 1 shows the MIL-STD-2105D requirements for this test compared to the requirements found in the NATO documents.

Table 1 — 12-Meter Drop Test

MIL-STD-2105D	STANAG 4375	Differences
Conduct radiographic iaw ASTM E-1742 to record the condition of the test item prior to and after the test.	X-ray equipment: As required	No callout in STANAG 4375 for X-rays of test item before and after testing.
Configuration. Test item dropped in packaged configuration at specified orientations representing worst case	Configuration. Test item shall be in the most vulnerable drop configuration, either packaged	MIL-STD-2105 mentions munitions exposed to Naval flight deck

MIL-STD-2105D	STANAG 4375	Differences
situations derived from Life Cycle Environmental Profile as defined in MIL-STD-810G. Exception: munitions exposed to Naval flight deck environment during aircraft weapon system loading: test conducted using unpackaged configuration. The test item must be to the full production standard; non-explosive sections can be geometrically (including weight and balance) and structurally representative of the production item.	or unpacked, representing worst case situation derived from the THA. The test item must be to the full production standard, although non-explosive sections of the item can be geometrically and structurally representative. For all-up rounds (AURs) that contain more than one major energetic component (such as rocket motors and warheads), the energetic components may be tested either individually or as all-up round.	environment; STANAG 4375 makes no mention of Naval flight deck environment, but mentions “unpacked” and THA-derived worst case situation. STANAG 4375 discusses testing AURs containing more than one major energetic component. STANAG 4375 wording may be more comprehensive, with the exception of the Naval flight deck environment.
Test surface. Smooth steel plate, ≥75 mm thick; Brinell hardness ≥200; steel plate supported by ≥600 mm of reinforced concrete of ≥28 MN/m2 compressive strength; no free water is retained on plate; plate level within 2°; debris removed from impact surface prior to testing;	Test surface. Smooth steel plate, ≥75 mm thick; Brinell hardness ≥200; steel plate supported by ≥600 mm of reinforced concrete of ≥28 MN/m2 compressive strength; no free water is retained on plate; plate level within 2°; debris removed from impact surface prior to testing;	None.
Orientation and number of drops. Minimum of three separate drops, at different orientations; major axis vertical, nose down and base down; major axis horizontal. The sample size is package dependent per “configuration” block. Test item to be dropped within 2° off-axis. Tests should be carried out in order of decreasing likelihood of producing unwanted events.	Orientation and number of drops. STANAG 4375 has a deployment drop (<3 m). Sample size in MIL-STD-2105D is dependent upon THA analysis. MIL-STD-2105D specifies accuracy of test item when dropped (within 2°); STANAG calls out accuracy upon impact of ±10°.	MIL-STD-2105 has more flexibility of sample size. STANAG 4375 controls accuracy of impact; MIL-STD-2105D specifies only accuracy on drop, but has no specifics on accuracy upon impact.
Conditioning and pre-stressing. Defines conditioning as steady state temperature an item achieves and maintains as -65°F and +160°F. Pre-stressing is defined as specific environmental effects, which comprise the test item just prior to the drop. Category 1 munitions will be dropped at ambient conditions and have undergone environmental pre-stressing; the munitions may be dropped at extreme conditions.	Conditioning and pre-stressing. Pre-conditioning of the test item should simulate the likely worst cast temperature conditions at the moment of a free fall. Conditioning temperature is derived from the life cycle analysis, a temperature expected to make the test item most sensitive to impact. If no data is available, AECTP-200 is referenced. Time lapse	MIL-STD-2105D defines Category 1 and 2 munitions, references APs for environmental conditioning data, and allows Category 1 munitions to be tested at ambient conditions with pre-stressing, and Category 2 munitions conditioned for testing. STANAG 4375 call for pre-

MIL-STD-2105D	STANAG 4375	Differences
Category 2 munitions will be conditioned immediately prior to the test; environments based on life cycle environmental profile. Allied Publications can be referenced for environmental conditioning data.	between removal from conditioning chamber and drop test shall be short to avoid unacceptable temperature change or icing. Pre-stress prior to test if expected result is an increased sensitivity to impact.	conditioning, recommends a short time lapse, and references AECTP-200 for environmental conditioning data, and allows for pre-stressing if expected result is increased sensitivity.
Passing criteria. No visible or audio reaction of the propellant, pyrotechnic, or explosive in the test item. The test item remains safe for disposal.	Passing criteria. No specific passing criteria listed. As noted in the Purpose section, "the main objective of these drop tests is to determine if munitions can withstand shocks caused by drops onto a hard surface and remains safe for handling and use or safe for disposal".	In the Observations and Records section of STANAG 4375, the natures of any reactions by the test item are required to be recorded.
Test assessment and analysis report. The results of all safety drop testing and analysis conducted relevant to assessing the munitions safety for service shall be compiled into a safety data package for review	Test assessment and analysis report. Measurements and observations are to be made and records kept, including reactions of the test item.	No specific report is required for STANAG 4375
Other. Except for drop orientation of the test item, no tolerances on testing variables are noted.	Other. Tolerances (accuracy) for drop height, impact angular deviation, and test item temperature are required. The drop mechanism must not impart rotation to the test item.	MIL-STD-2105D has a tolerance on the drop orientation of the test item.

STANAG 4375 includes a 12-m logistic drop test, but provides no rationale other than what is stated in the purpose, which is to "determine if munitions can withstand shocks caused by drops onto a hard surface and remain safe for handling and use or safe for disposal" (NATO 2010). WR-50 provided no rationale for the 40-foot drop test. Prior to the release of WR-50 in 1964 however, the Naval Ordnance Laboratory (NOL) noted that the 40-foot drop test "originated during World War II to insure safety of handling aircraft bombs aboard ship" and that "ordnance is exposed to potential drops from the fork lift, cherry picker, mobile crane, ships gear, shore based gear, or floating crane" at drop heights up to 30.5 m (100 ft) (Starr, Morrison and Misener 1962). In 1963, the Navy came out with an instruction (DoN 1963) on the 40-foot drop test that provided background information and stated the policy of the Missile Development Office regarding this particular test. This instruction noted that "demonstrating the ability of certain ordnance components to withstand heavy impacts such as might occur at various stages of the logistic cycle" was of great value.

Testing Rationale

Reconciling developmental weapons safety tests is a much simpler proposition if there is justification or rationale for the specific test. MIL-STD-2105D has evolved from DoD-STD-2105

(Navy) (DoD 1982), which replaced WR-50 (DoN 1964), a Navy document that was published in 1964. WR-50 did not provide any rationale for T&H tests or the forty-foot drop test; WR-50 did reference the shipboard and transportation vibration schedules based on the frequencies, displacements, and durations called out in MIL-STD-167 (DoN 1954) and MIL-STD-303 (DoD 1963), subsequently canceled and replaced by MIL STD 331. In addition, no rationale for the specific sequence of the safety tests has been captured. The NATO documents capture an expanded series of Sequential Environmental Tests, based on a generic munition probable lifecycle, and which can be tailored to the specific lifecycle of the munition under test.

The NATO documents provide some rationale for the climatic environment tests. For example, the high temperature storage test is intended to accelerate chemical based degradation mechanisms via a period of testing using a constant elevated temperature of +71°C (+160°F). Analysis, using the Arrhenius relationship has shown that nine days of testing gives a similar degree of chemical degradation to that expected for 28 A1 'Storage and Transit' temperature cycles using an assumed activation energy of 70kJ/mol for the degradation mechanism (NATO 2011). For low temperature storage, statistics are used to show "a 1 percent probability that materiel deployed in arctic areas (Category C3, AECTP 200 (NATO 2009)) will be exposed to a temperature of -51°C". Less objective criteria are used for other tests, such as the high temperature cycling and low temperature shock tests.

During subsequent revisions to AAS3Ps and NATO test STANAGs, a conscious effort should be made to meet the identified need to document the technical purpose for conducting a test, the technical rationale for pass/fail criteria, standard instrumentation requirements, standard measurements/units, and standard reporting requirements so that data packages can withstand scrutiny and provide transparent results that are retrievable years later. The subject matter experts should evaluate the applicability of test parameters, which should continue to evolve as they are synchronized with NATO STANAGs.

Recommendations

As the AAS3P commodity-specific documents are developed, the expected result is a detailed set of S3 standards for weapons and a method to address unique national requirements. In the event of a more severe national requirement, the AAS3Ps can be tailored. Therefore, there will no longer be a need to address the basic safety tests in MIL-STD- 2105D. MIL-STD- 2105D can be revised to address IM tests only, without loss of requirements or guidance.

Observations and Conclusions

This paper is the result of a review of historical documents and interviews with members of the IM and safety community. In general, the safety tests developed over the years were in response to incidents or accidents with ordnance, and were designed to gather information that would alleviate the problem in the future. However, the specific rationale for test parameters and pass/fail criteria may go back to World War II or before, may not be documented, and may have been lost to history, for instance the T&H cycling tests, or the height of the 40' foot drop test.

The basic safety tests have recently begun the promulgation process in a series of interconnected NATO documents with the weight of STANAGs. This process is well underway, with strong leadership commitment, and will continue to review current practices with the goal to align test methodology, both within the US DoD and within the NATO community. If MIL-STD-2105D is revised to eliminate the safety series of tests, the result will be a less confusing and a more focused standard for IM testing and S3 assessment testing will be accessed in a well-defined set of NATO standards.

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