DART Projectile – IM tests Assessment

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ABSTRACT

The new OTO MELARA DART are guided projectiles especially designed for last ship defence system against high performance manoeuvring target which succeeded in penetrating the outer ship defence layer. The primary target is an anti-ship missile (supersonic or subsonic, sea-skimming or diving, with terminal manoeuvre capability), the secondary target is an attack aircraft and small and fast naval platform with high manoeuvrability.
The DART are high velocity projectiles guided by the ship combat system on the target using an RF beam mounted on the 76 gun.

DART ammunitions are equipped with high performance WH and multifunctional fuze (in flight programmable).

The ammunition embeds live improved IM components such as an HMX-based cast PBX main charge and ECL® propellant.

IM testing was performed in different configurations, according to the STANAG 4439: thermal testing (Fast and Slow Cook-off), 12m drop tests, Bullet impact, Sympathetic Reaction.

This paper will describe the design principles and focus on results obtained against STANAG 4439 trials.

The IM signature of the complete round will be given.

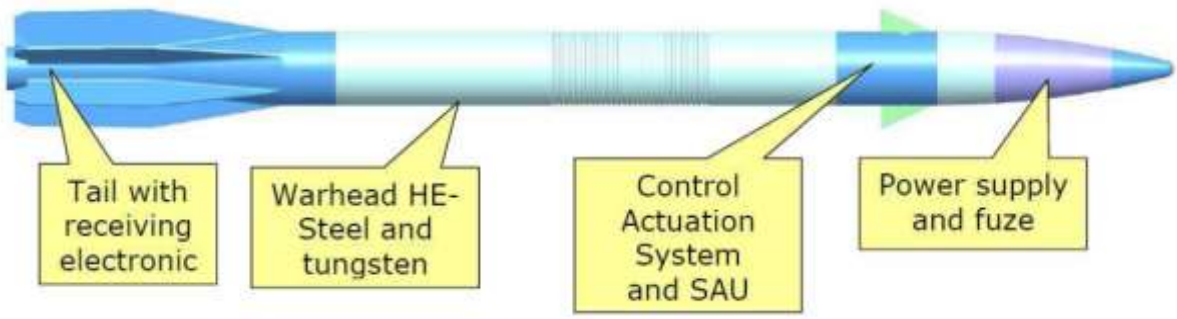
1. INTRODUCTION

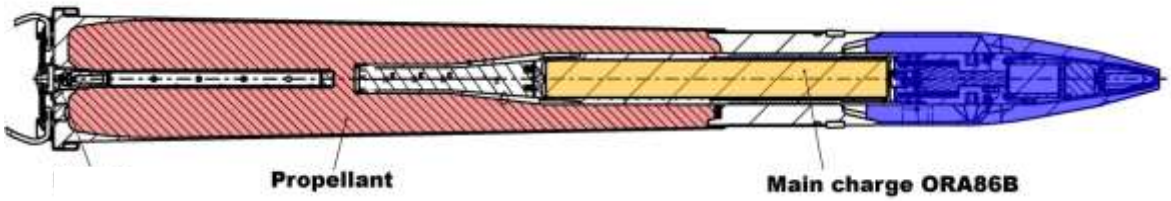
The DART (Driven Ammunition Reduced Time of flight) Ammunition is the new Oto Melara subcalibered guided ammunition. It covers the new defence needs of a modern military ship against high speed high manoeuvrability missiles.

As part of the ammunition Qualification process, IM testing were peformed on complete DART rounds. This paper describes design principles, overall architectures and focus on results obtained against Insensitive Munitions specifications.

2. DESCRIPTION OF THE AMMUNITION

DART ammunition is equipped with multifunctional fuze. The WHs are filled with modern insensitive PBX HE. DART ammunition is fixed round with the projectile rigidly secured to the brass cartridge case by crimping. The explosive charge is an HMX based cast-cured substance "ORA86B" (400 g) and ignited with a B2238A booster (1 g) and a SAU containing a detonator (100 mg). The ammunition is propelled with an ECL® propellant consisting of simple base powder (10 mm diameter and 19 holes) (2600 g in total). The propellant is initiated by an igniter filled with black powder (15 g). The DART ammunition is presented in the following figures:





DART ammunition with the front protection

DART ammunition without the front protection: SAU is visible

DART ammunition is equipped with a modern and high performance warhead that uses tungsten-alloy preformed splinters and steel guided-fragmentation splinters, a multifunctional fuze allows to engage different type of targets and to guide sea skimming thanks to the altimetry features.

DART is guided ammunition especially designed for last ship defence system against high performance manoeuvring target which succeeded in penetrating the outer ship defence layer. The primary target is an anti-ship missile (supersonic or subsonic, sea-skimming or diving, with terminal manoeuvre capability), the secondary target is an attack aircraft and small and fast naval platform with high manoeuvrability.

Guided ammunition DART needs specific modifications to the 76 gun to be guided. The 76 gun with these specific apparatus is named "Strales System". The DART ammunition guidance System is an "RF beam rider" continuous guidance. It uses a guidance antenna that is aimed to the target actual position, following the aiming of the ship tracking radar. The guidance system includes data transmission to the projectiles that allows fuze programming during flight too. The DART ammunition can be fired by the Oto Melara 76/62 naval gun in both the version Compact "C" and Super Rapid "SR" equipped with double feeding or multi feeding system.

DART ammunition is fully Qualified by the Italian Navy according to STANAG 4667.

DART ammunition is in production. In 2014 DART ammunitions have been delivered to the Italian Navy and Colombian Navy as well.

3. IM ASSESSMENT

IM assessments and experimental testing were performed on DART rounds:

- 12 m Safety drops,
- Fast cook-off,
- Slow cook-off,
- Bullet impact,
- Sympathetic reaction.

The table below summarizes the tests performed, applicable requirements, and quantities of units.

ITEM	TEST TITLE	REFERENCES	AMMO CONFIG.	SAMPLING				
				Nb of trials	DART nb	Single Box	Triple Box	Unpack.
1	SAFETY DROP - Logistic Drop 12m	STANAG 4375, ED3	Packaged (Single box + triple box)	6+1	12	3+1	3	0
2	LIQUID FUEL / EXTERNAL FIRE	STANAG 4240 Ed.2	Test 1: Packaged (triple box); Test 2: unpackaged	2	4	1	1	0
3	SLOW HEATING	Stanag 4382 Ed.2	Unpackaged	2	2	0	0	2
4	BULLET IMPACT	STANAG 4241 Ed.2, AOP 39	Unpackaged	2	2	0	0	2
5	SYMPATHETIC REACTION	STANAG 4396 Ed.2	Packaged (triple box)	2	6	0	2	0
			TOTAL Qty	**14**	**26**	**4**	**6**	**4**

12 m safety drops

Experimental configuration
The baseline of the drop test requirement is STANAG 4375 edition 3. All rounds were pre-conditioned at +40°C before testing.

Impact surface
Impact surface is composed of smooth 80 millimetres thick steel plate; its Brinnell hardness is higher than 200; it is placed on 600 millimetres thick reinforced concrete slab. Steel plate dimensions are 3015 mm x 3013 mm; it is horizontally positioned with two degrees accuracy. It is flat and not deformed from previous impacts.

Drop height
Standardised 12 m drop height is defined. The height accuracy is better than the 1% requirement (120 mm). The accuracy is 20 mm.

Orientation and number of drops
Three separate drops, at different impact orientations were required:

- major axis vertical, nose down ↓;
- major axis vertical, base down ↑;
- major axis horizontal, →;

Drop test configuration
Two test series were conducted: with the Single box and the Triple Box. Angular deviation of test item from the required position on impact is controlled through video movies to assess that it is conform to +/- 10 degrees.

Pre-conditionning
Munitions inside boxes are warmed at 40°C during more than 4 hours before tests. Munitions inside their boxes are maintained at this temperature + 0°C / - 4°C due to the short duration to prepare the drops.

Quick release mechanism
The quick-release mechanism is capable of releasing the test item without imparting any rotation. Some 0,8g PETN Detonators are used for rope cutting to achieve this requirement.

Tests results
No reaction of DART ammunition was observed, in any configuration. The results are given in the table below.

Trial #	Orientation	Packaging	Result	Comment
1	→	Single box	no reaction	Box slightly damaged
2	↓	Single box	no reaction	Box verly lightly damaged
3	↑	Single box	no reaction	Box verly lightly damaged
4	→	Single box	no reaction	Box verly lightly damaged
5	→	Triple box	no reaction	/
6	↓	Triple box	no reaction	Box verly lightly damaged
7	↑	Triple box	no reaction	Box verly lightly damaged


Fast cook-off

Experimental configuration
The baseline of the fast-cook off test requirement is STANAG 4240 edition 2. The tests were conducted on 3 & 4 September 2014 in CESPY Vonges Firing Range (France).

Test configuration
Two test series were conducted: with the Single box and the Triple Box.

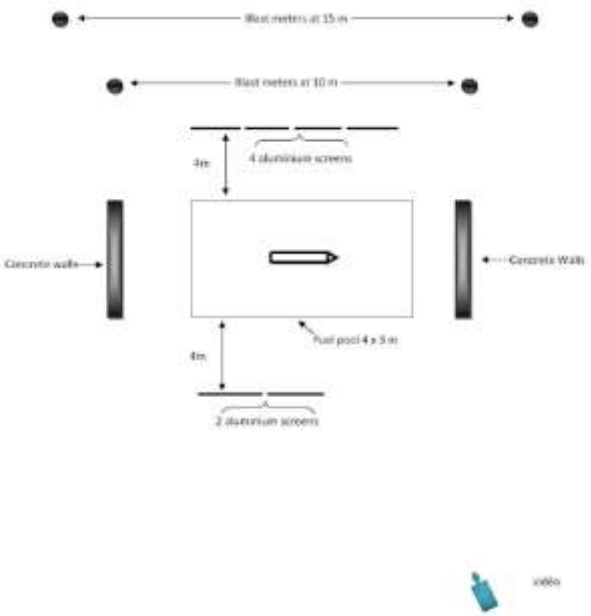
Hearth
Dimensions 4.4 m x 3.0 m are large enough to allow at least 1m clearance on each side of the test item, and designed to provide a volume of flame which completely engulfs the test item throughout the trial.

Fuel
JET A1 was used:

- 1600 liters for the triple box test (fire duration arr. 16 minutes),
- 800 liters for the single box test (fire duration arr. 8 minutes).

To provoke hearth ignition, a bundle of cotton waste completely soaked in petrol is ignited with electrical igniters and 10g of black powder.

Position and mounting of the test item
DART ammunitions boxes are horizontally hanged 40 cm above the fuel surface; these are engulfed by flames without any limitation.



Measurements

- Temperature: Six K Thermocouples mounted 40-60 mm from the surface of the test item at positions fore, aft, starboard and port along a horizontal plane through the centreline of the test-item. Data are recorded at 1 Hz frequency.
- Air pressure : Blast overpressures are recorded thought four Chalard's blast-meter positioned at 10 m & 15 m along two perpendicular axes.
- Photographs and videos were taken before, during and after the tests.

Witness screens
Four aluminium screens (1 m x 2 m) are positioned around the hearth.

Tests results

<u>Triple box configuration</u>

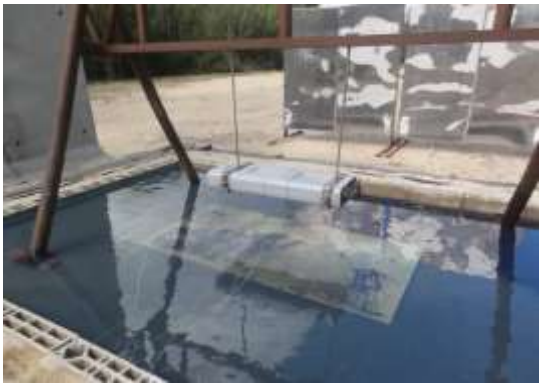
DART Munitions reactions after 550°C temperature thresholds :

- 75"
- 79"
- 84"

The 550°C temperature threshold has been reach 17" after the hearth ignition. The average flame temperature is 790°C according the STANAG rules; it is slightly lower than the mandatory level (800°C), but there isn't any influence on the test result. The triple box has blown up; fragments are recovered up to 32 meters. The three propulsion charges have burnt. Two warheads have been projected and has been recovered un-reacted at 1.5 m and 21 m.

No blast overpressure recorded.

Witness screens have been damaged by the fire, there is not any impact.



→ Level of reaction: **Type IV**.

<u>Single box configuration</u>

DART Munitions reacts 53" after 550°C temperature threshold. The 550°C temperature threshold has been reach 23" after the hearth ignition. The average flame temperature is 845°C according the STANAG rules.

The single box has blown up; fragments are recovered up to 14 meters. The propulsion charge has burnt, the warhead has been projected and has been recovered un-reacted at 6.2 m.

No blast overpressure recorded.

Witness screen have been damaged by the fire, however there is no impact.

→ Level of reaction: **Type V**.

Slow cook-off

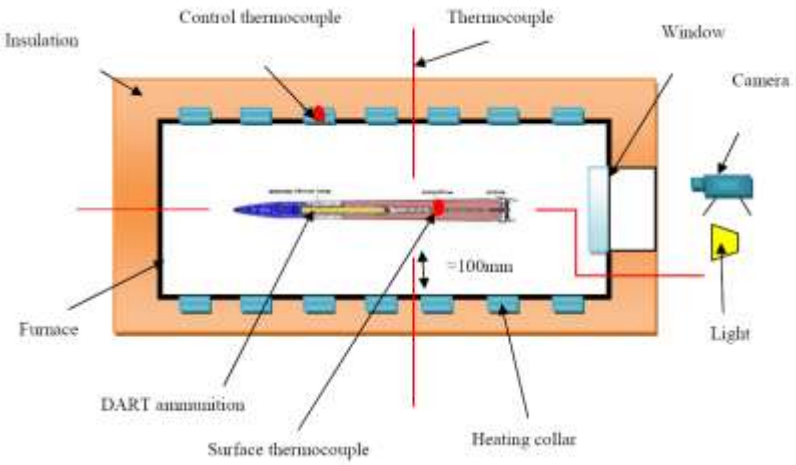
Experimental configuration
The slow heating test is defined in STANAG 4382 Edition 2 (24/03/03). The procedure applied to these tests was based on the recommendations of this STANAG. To do this, the ammunition is put in a specific furnace. The procedure consists in a first step to stabilize the furnace temperature to 50°C for at least eight hours before the second step which consists in applying a temperature ramp of 3.3°C per hour until the initiation temperature of one of the energetic materials in the ammunition is reacted. The reaction time will be considered from the beginning of the temperature ramp. The test is validated only if the specifications of temperature rise are met. For a temperature ramp of 3.3°C/h, it is considered an acceptable deviation of ± 0.5°C/h.

Instrumentation
The instrumentation set up to measure the temperature inside the furnace and to control the temperature regulation is as follows:

- Four thermocouples are set up to measure the temperature inside the furnace. They are placed in a horizontal plane through the central axis of the ammunition, 10 mm from inner walls of the furnace, at the front, rear and sides of the ammunition.
- One (for the first test) and two (for the second test) thermocouples placed on the ammunition to measure the surface temperature of the object (located in the middle of the metallic shell for the first test and 1/3, 2/3 of the metallic shell for the second test).
- One thermocouple to measure and monitor the temperature of the heating collars (thermocouple control), placed between the oven and the oven heaters.
- One power unit connected to an electronic controller to control the temperature of the oven according to the temperature read by the control thermocouple.
- For these measurements, thermocouples type J, Class 1, 1mm diameter, sheathed with Inconel, were selected.
- A witness plate has been placed in the oven to help us judge the potential violence of reaction of the ammunition.
- Photographs have been taken before and after the tests.
- A camera records the test through a window located at the rear of the ammunition.

Trials configuration
The heating device is designed so that the temperature ramp is 3.3°C per hour. The ammunition is maintained in an oven made of steel which diameter is 600 mm and length is 1600 mm. The ammunition is set vertically and clamped in the centre of the furnace. The oven is equipped with adapted heaters (seven pairs of half-band heaters, 600 W each, circling the outer wall of the oven) and thermal insulation to insulate the heating device and the oven. Pictures of the experimental setup are shown in the following figures.

Dimensions 4.4 m x 3.0 m are large enough to allow at least 1m clearance on each side of the test item, and designed to provide a volume of flame which completely engulfs the test item throughout the trial.



Ammunition in the furnace

Furnace before the test (front part)

Light and camera in front of the window

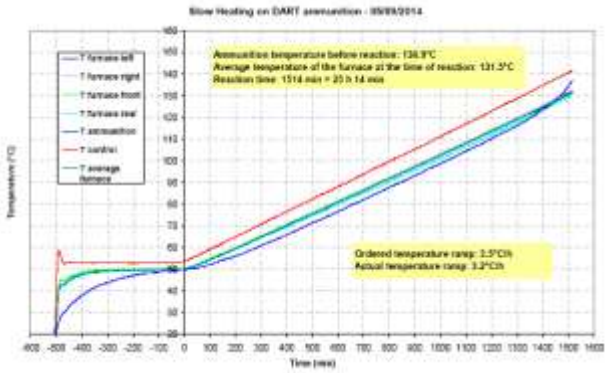
Furnace before the test (rear part)

Tests Results

Two tests performed, both on unpackaged ammunition.

<u>Test 1</u>

First, the measurements performed during the test show that the temperature reached in the furnace is homogeneous.



Usually, the temperature in the furnace is less than the regulation temperature by a few degrees because of the thermal exchanges that occur with the external environment (primarily through the window display). To compensate for these heat losses, the temperature of the heaters was set at 52°C and the temperature actually reached in the furnace is close to 50°C. For the same reason, the order for the temperature ramp programmed into the control unit has been set to 3.5°C/h. These values come from preliminary tests performed on inert objects. Finally, the actual temperature ramp is 3.2 ± 0.5°C/h.

The average temperature in the furnace before the beginning of the temperature ramp was 50°C. This temperature has been obtained after more than 8 hours. The average temperature rise in the furnace is 3.2°C/h. This temperature ramp fits perfectly within the tolerances required by the standard. Measurements recorded with the thermocouples allow us to date the thermal initiation of the DART ammunition to 25 hours 14 minutes (1514 minutes) after the beginning of the temperature ramp, with an average furnace temperature of 131.5°C. The reaction time of the ammunition is the one corresponding to the instant when the thermocouples recorded the temperature peak associated with the thermal runaway. Just prior to reaction, the temperature of the ammunition has been recorded to 136.9°C.

Ammunition after test (inside the oven)	*Furnace after test*
Recovered parts of the ammunition	*Impacts on the inner wall of the furnace*

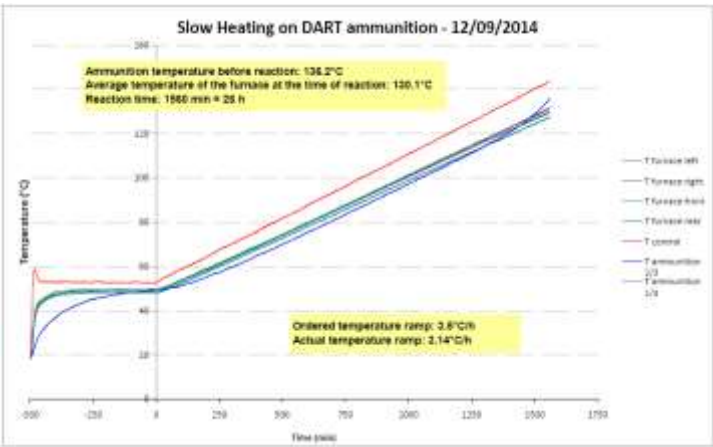
At any time, there is a uniform temperature in the oven. The temperature ramp achieved in the oven is 3.2°C/h and is perfectly correlated with the requirements of STANAG which are 3.3°C/h ± 0.5°C/h. The test is validated. The warhead is intact. The furnace has suffered damages during the reaction of the ammunition (few perforations). These impacts reflect the pneumatic explosion of the envelope containing the propellant grains, which burned. The propellant grains burned, without propulsion phenomenon.

Actual temperature ramp	Furnace temperature at the time of reaction	Time to reaction	Reaction type
3.2°C/h	**131.5°C**	**1514 min**	**IV**

Level of reaction → **type IV.**

<u>Test 2</u>

First, the measurements performed during the test (see below) show that the temperature reached in the furnace is homogeneous.



The average temperature in the furnace before the beginning of the temperature ramp was 49.2°C. This temperature has been obtained after more than 8 hours. The average temperature rise in the furnace is 3.14°C/h.

This temperature ramp fits perfectly within the tolerances required by the standard. Measurements recorded with the thermocouples allow us to date the thermal initiation of the DART ammunition to 26 hours (1560 minutes) after the beginning of the temperature ramp, with an average furnace temperature of 130.1°C. The reaction time of the ammunition is the one corresponding to the instant when the thermocouples recorded the temperature peak associated with the thermal runaway. Just prior to reaction, the temperature of the ammunition has been recorded to 136.2°C.

At any time, there is a uniform temperature in the oven. The temperature ramp achieved in the oven is 3.14°C/h and is perfectly correlated with the requirements of STANAG which are 3.3°C/h ± 0.5°C/h. The test is validated.

The warhead is intact. The furnace has suffered damages during the reaction of the ammunition (few perforations). These impacts reflect the pneumatic explosion of the envelope containing the propellant grains, which burned. The propellant grains burned, without propulsion phenomenon.

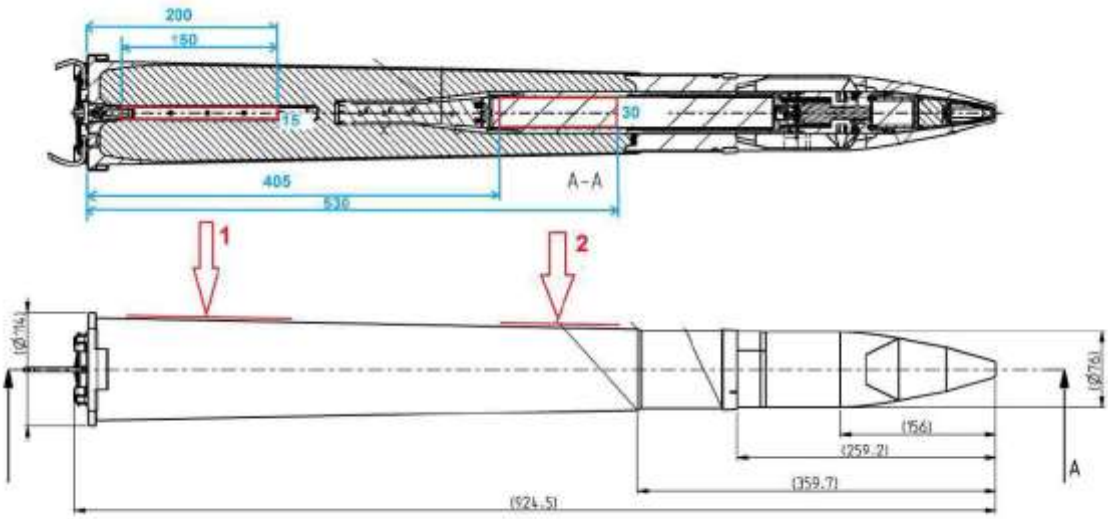
Actual temperature ramp	Furnace temperature at the time of reaction	Time to reaction	Reaction type
3.14°C/h	130.1°C	1560 min	IV

Level of reaction → **type IV.**

Bullet impact

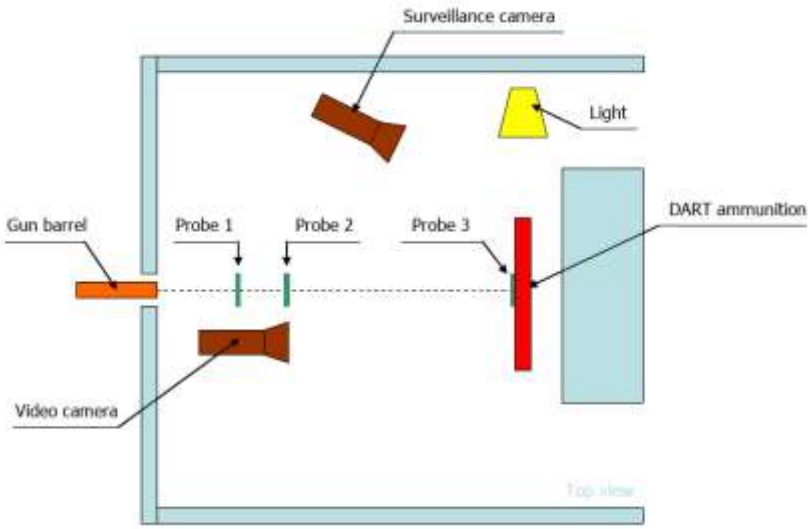
Experimental configuration
The Bullet Impact (BI) test is performed to assess the reaction type of munitions submitted to one to three impacts of M2 armor-piercing 0.5" (12.7 mm) caliber bullet, fired at 850 m/s, according to the STANAG 4241 ed. 2. In this case, a single impact test (procedure #1) was proposed and performed.

Two tests were conducted, with different target points, as shown on the following figure.



1. Case 1 : Target point on igniter.
2. Case 2 : Target point on the main explosive charge.

The experimental configuration is presented in the following figure (top view).



Instrumentation and reaction assessment
Bullet velocity is measured through a three short-cut probes system. Two probes are fixed on a specific assembly (probes 1 and 2), placed on the firing axis, and the third one is on item (as well used for video triggering). All of them are connected to chronometers for bullet velocity measurement. Bullet velocity has to be 850 m/s ± 20 m/s.

Tests results: Test 1

The reaction of DART ammunition is established from:

- The possible recovery of fragments and their examination.
- The examination of a steel witness plate placed under the ammunition (1,5 mm thickness).
- Pictures of test set up taken before and after the test.
- Movies recorded with a video camera (60 fps) and a surveillance camera (25 fps).

The following figure presents photographs of the set-up before the test. In this test, the target point is located in the propulsive part.

Target point on the probe 3

DART ammunition with short-cut probes system

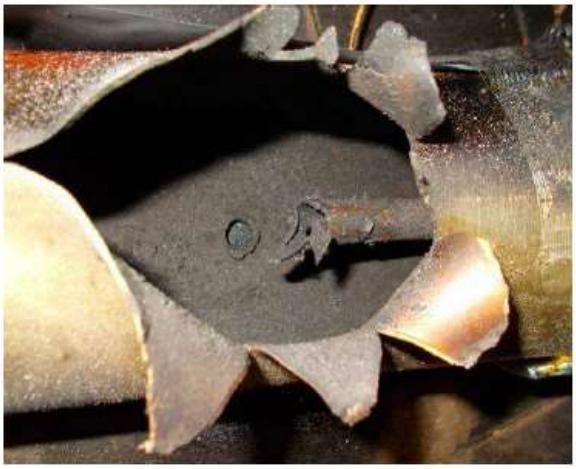
Probes 1 and 2, and the video camera

The test results are summarized:

- Measured bullet velocity: 862 m/s ± 8 m/s.
- Impact on target point.
- The ammunition was found open and the igniter was impacted (see Figure 6)
- Partial combustion of the gun propellant (426 g recovered, about 16 % of the initial gun propellant mass).
- The explosive warhead was recovered in one single piece.
- A piece from the igniter was recovered in the corridor of the detonation chamber, supposedly after several rebounds. Without a reference test, it is difficult to say whether this piece has been ejected because of the reaction of the gun propellant or because of the bullet impact. The mass of this piece is 53 g.

Impact on target point

Open ammunition



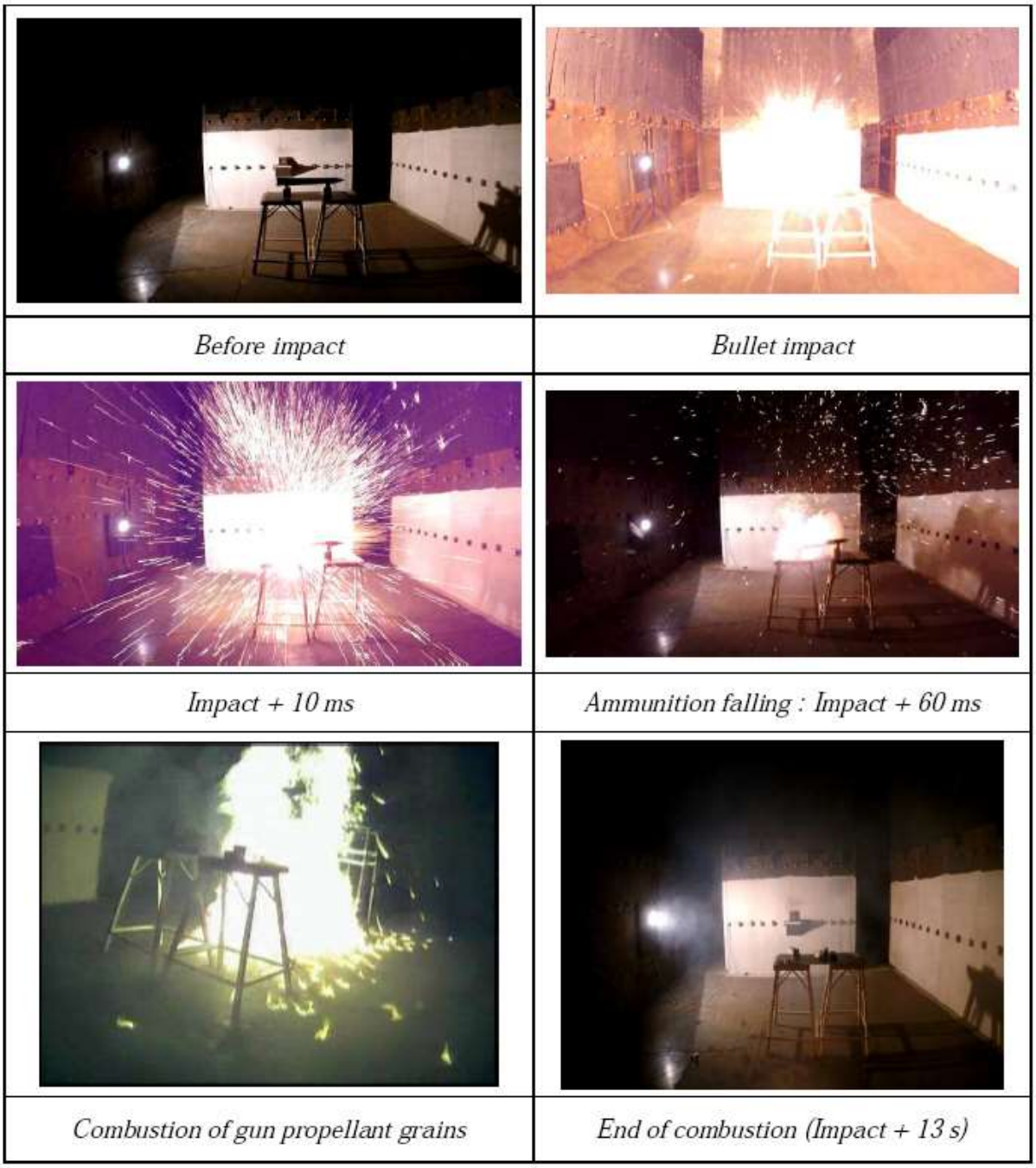
Igniter after test 1

Witness plate without any impacts

Piece from the igniter recovered in the corridor of the detonation chamber

We can see on the pictures that the bullet passed through the ammunition. We can also note that the igniter was impacted and the witness plate under the ammunition remained intact.

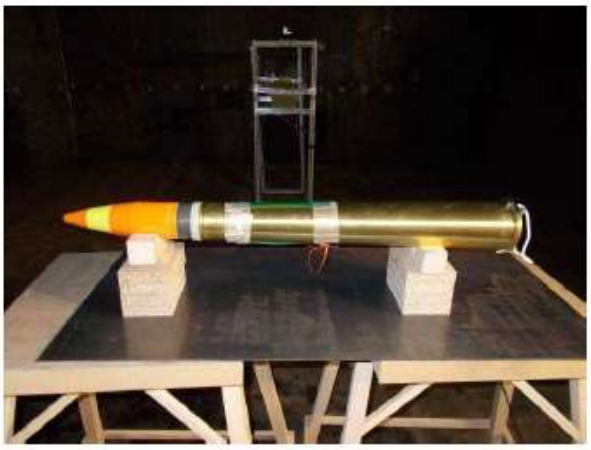
Pictures on the following figure are extracted from movies obtained with the cameras. We can see that the ammunition fell on the ground after impact and combustion of gun propellant stopped after 13 seconds.



Tests results: Test 2

The following figure presents us photographs of the set-up before the test. In this test, the target point is located in the explosive part.

Target point on the probe 3



DART ammunition with short-cut probes system

Probes 1 and 2, and the video camera

The test results are summarized:

- Measured bullet velocity: 854 m/s ± 8 m/s.
- Impact on target point.
- The ammunition was found open and the main explosive charge was impacted (see Figure here after).
- Very partial combustion of the gun propellant (2518 g recovered, about 97 % of the initial gun propellant mass).
- 20 g of ORA86B were recovered in the detonation chamber. The remaining part of the main charge was still in the warhead body.
- Two fragments were ejected at 2 and 3 m from the initial position of the ammunition.

	
Ammunition after test 2	*Open ammunition*

	
Impact point after test 2	*Witness plate without any impacts*

We can see on the pictures that the bullet passed through the ammunition. We can also note that the explosive charge was impacted and the witness plate under the ammunition remained intact.

Pictures on the following figure are extracted from movies obtained with the cameras. We can see that the ammunition fell on the ground after impact.

Before impact

Bullet impact

Ammunition falling : Impact + 20 ms

End of test

Bullet impact test Results

The results of these tests are a non-violent reaction in both cases. For the first test, the target point was on the igniter. In this case, we noticed a partial combustion of the gun propellant (16 % of gun propellant were recovered) and the main explosive charge was intact. The ammunition was found open and only a 53 g piece from the igniter was recovered in the corridor after several rebounds. We suppose that this piece has been ejected because of the bullet impact. Due to the detonation chamber walls, it is difficult to estimate the projection distance of this piece in an open-field configuration. According to the experts in Le Bouchet Research Centre, it is highly unlikely to think that this piece would have been projected over 58 m. As a consequence and according to AOP39 ed. 3, the reaction type in this case is V.

Test 1 → **Type V reaction.**

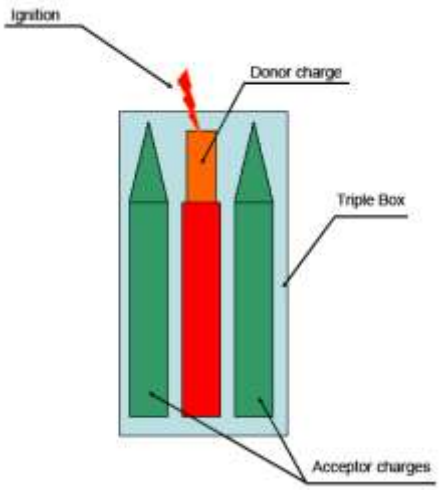
For the second test, the target point was on the main explosive charge. In this case, we noticed a very partial combustion of the gun propellant (97 % of gun propellant were recovered) and the main charge was impacted and was found in the warhead structure. The ammunition was found open and only two fragments were ejected at 2 and 3 m from their initial position. The reaction type in this case is V.

Test 2 → **Type V reaction.**

Sympathetic reaction

Experimental configuration
DART ammunitions are transported in single boxes and triple boxes. In the case of these sympathetic reaction tests, we will consider the influence of the detonation of a DART ammunition on two other ammunitions in a triple box. The objective of sympathetic reaction tests is to assess the reaction type of an object while an adjacent object is detonating. The purpose of this test is to determine the reaction violence of the aggressed objects.

Instrumentation and tests set-up
Two identical tests were conducted with one donor charge and two active acceptors stored in a triple box, as shown below.



The reaction of acceptor charges is established from:

- The examination of the steel witness plate horizontally placed under the triple box. The witness plate dimensions are adjusted to those of the triple box (approximately 1 m x 0.8 m) and the plate thickness is 20 mm.
- The possible recovery of fragments and their examination.
- Photographs taken before and after the test.
- Pressure measurements at 2.32 m and 2.42 m from the center of the Triple Box. The time of ignition is determined with a probe set on the detonator.
- Movies recorded with a video camera (120 fps), a camcorder and a surveillance camera (25 fps).

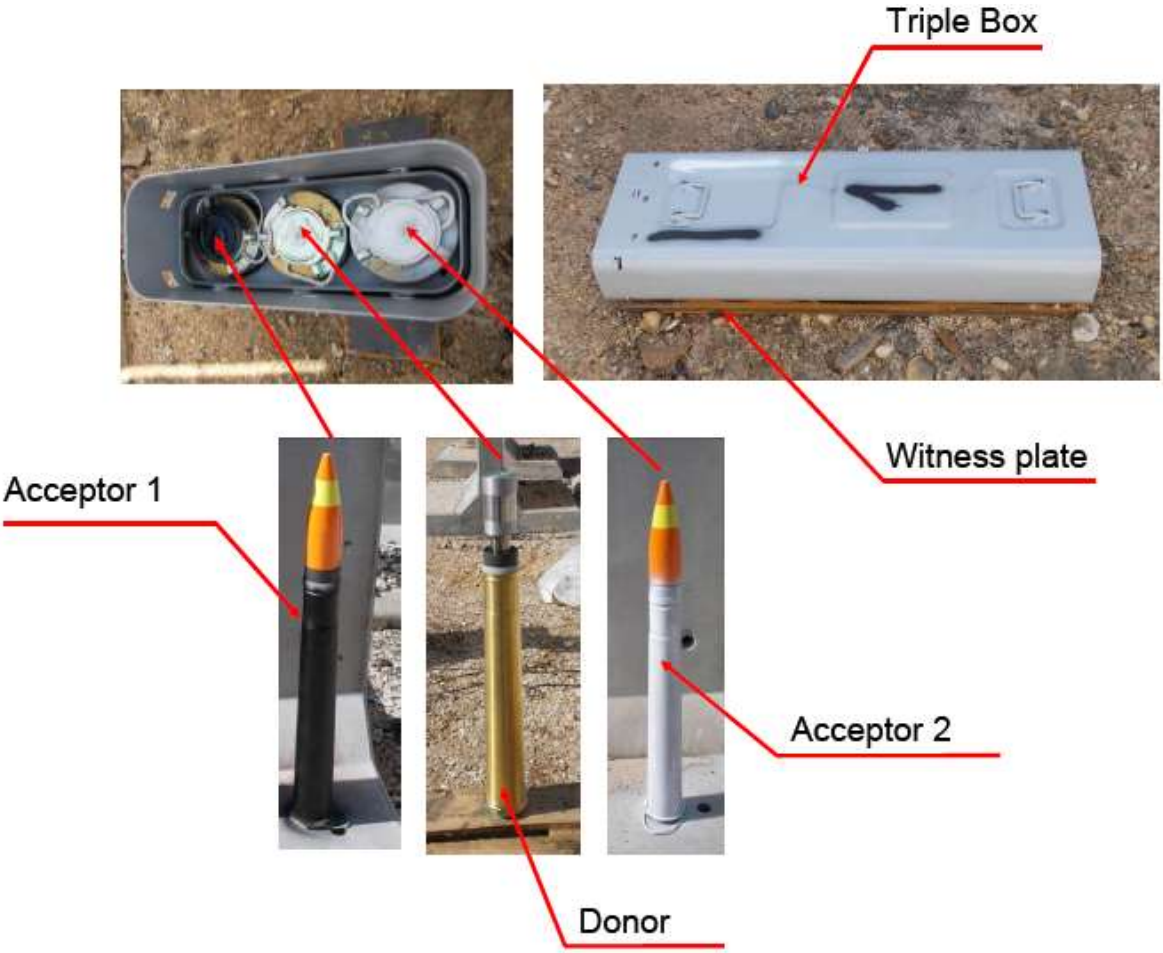
Initiation
For these tests, the explosive charge is directly initiated in the triple box. To do this, the front part of the ammunition and the SAU are removed. In this configuration, the ORA86B is visible as shown in the following figure:

For both tests, the donor is initiated with a SA4016 detonator and Hexomax® (26 g in the case of the first test and 22 g in the case of the second test) used as a booster. Initiation is performed by placing Hexomax® directly on the main charge and placing the detonator in contact with Hexomax® as shown in the following figures. Furthermore, to keep the effect of containment due to the presence of the SAU, an aluminum part with an

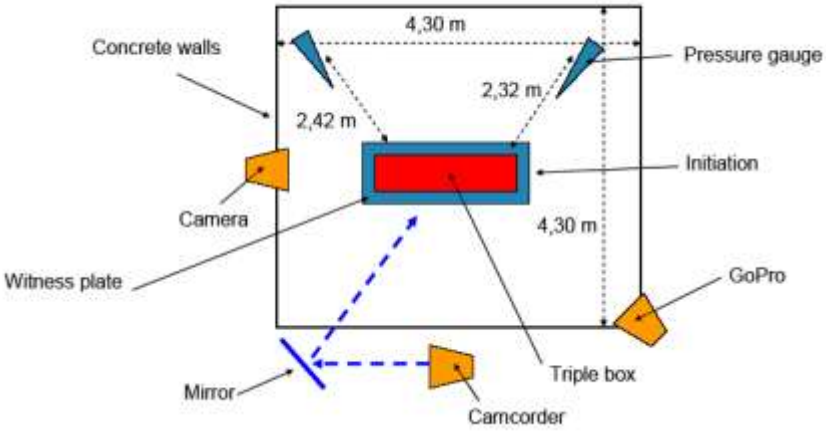
equivalent weight (about 1 kg) was designed and manufactured. Finally, to allow the initiation of the ammunition once in the box, an opening was machined in the Triple Box.

		
Hexomax® in the ammunition	*Aluminum piece in contact with Hexomax®*	*Opening in the triple box*

DART ammunitions are placed in a closed triple box. Live acceptors are placed on each side of the donor ammunition and their position is indicated by a color: the acceptor charges are painted black (left) and white (right). The donor charge placed at the center of the box and is not painted. The box is then put on a witness plate in the center of the test pad, which is surrounded by concrete walls. The following photographs show the ammunitions before and after being introduced into the triple box.



The following figure and photos present the experimental configuration and the position of pressure gauges and cameras in the test pad.



Witness plate (20 mm thick) put in the centre of the test pad | *Instrumentation*

Camcorder | *Instrumentation*

Test Results

<u>Test 1</u>
The examination of the steel witness plate has been used to validate the detonation of the donor charge thanks to visible impacts around the explosive charge. No impact has been observed under the initial position of acceptor charges, which means that both DART ammunitions on each side of the donor did not detonate. This result has been confirmed with the recovered fragments and pressure measurements.

After test, the triple box was found open. The lid located at the rear of ammunitions was recovered in one single piece as well as the rear part of the sabot from the three ammunitions.

Rear part of the three ammunitions

Lid of the triple box

Besides, we also found around the test area both warheads with ORA86B inside. This confirms the fact that only the explosive charge of the donor ammunition detonated and ORA86B in acceptor warheads has not reacted.

Warhead and ORA86B from one of the acceptors

Warhead and ORA86B from the other acceptor

Both SAU from acceptor charges have been found, as shown in the following figure.

Igniters, initially filled with black powder, were all recovered, even the one coming from the donor ammunition. This means that the powder from the donor igniter did not violently react. This is confirmed by the fact that the rear part of the three sabots was also recovered. In addition, the black powder initially located inside the acceptor igniters burnt. The following photograph shows that the black powder inside the igniter only burnt and the igniter is still in one piece. This means that the reaction was not violent. Moreover, it was not possible to determine the origin (donor or acceptor) of the recovered igniters.

Besides, fragments from ammunition sabot have been recovered as shown in the following figure.

	
Ejected gun propellant pieces on the ground	*Combustion traces*

Pressure measurements were measured during the test, as given in the following table:

Gauge	Distance from the charge	Overpressure level
1	2.42 m	1.06 bar
2	2.32 m	1.07 bar

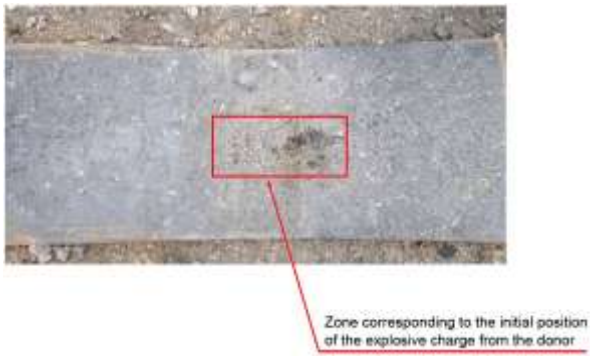
The measured overpressure levels are close to the theoretical values obtained with the detonation of the explosive charge from the donor. These values confirm the fact that only the ORA86B from the donor charge detonated. This analysis allows us to turn down the type III. However, the measured values are slightly higher than theoretical values of the detonation of 350 g on the ground. This difference can be explained by the fact that the reaction of gun propellant charges from the donor ammunition, although this is not a detonation, has released an amount of energy visible with pressure measurements. The detonation of the ORA86B from the donor charge may also have a directional effect which depends on the experimental configuration. This assumption is difficult to validate without reference test.

Test 1, conclusion
Analysis of the witness plate, analysis of the recovered fragments, pressure measurements and analysis of the movies from test 1 show that the effects of the donor ammunition detonation on the acceptor charges are very limited. Indeed, we did not observe detonation of acceptor ammunitions on the witness plate; we were able to recover in very good shape the explosive charge and the SAU from acceptor charges and the igniters from the three ammunitions. We observed the partial combustion of the gun propellant charges and the ejection of some of powder at up to 20 m away from the ignition point. Without a reference test with inert acceptor ammunitions, it is not possible to say whether the ejection of these charges is due to the reaction of the donor or the reaction of the acceptor ammunitions. Thus, we cannot conclude between type IV and type V.

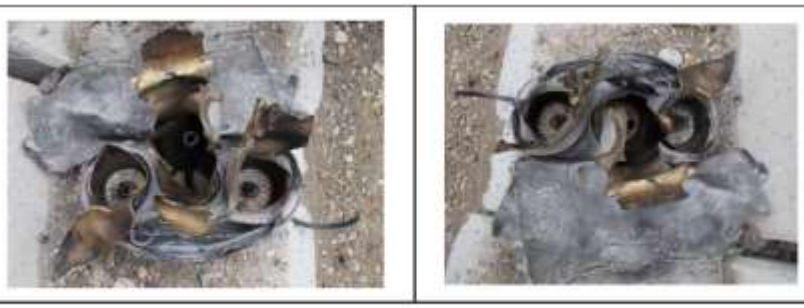
Bullet impact, **level of reaction Type IV or V**.

Test 2

Witness plate examination
The examination of the steel witness plate has been used to validate the detonation of the donor charge thanks to visible impacts around the explosive charge. No impact has been observed under the initial position of acceptor charges, which means that both DART ammunitions on each side of the donor did not detonate. This result has been confirmed with the recovered fragments and pressure measurements. This first analysis allows us to turn down the most violent types of reaction (types I and II).



Recovered fragments
After test, the triple box was found open. As for test 1, the rear part of the ammunitions was recovered in one single piece. We also notice that the donor charge igniter was still in the sabot after test.



Rear part of the ammunitions

Fragment from the triple box

Warheads with ORA86B inside were found around the test area. This confirms the fact that only the explosive charge of the donor ammunition detonated and ORA86B in acceptor warheads has not reacted.

Warhead and ORA86B from one of the acceptor charges

ORA86B out of the warhead and the warhead of the other acceptor charge

It is interesting to note that the mass of the recovered bare charge of ORA86B weighs 344 g to 350 g initially. It means that nearly 100% of the explosive charge has been recovered.

Both SAU from acceptor charges have been found, as shown in the following figure.


As for test 1, igniters, initially filled with black powder, were all recovered. This means that the powder from the donor igniter did not violently react. This is confirmed by the fact that the rear part of the sabots was recovered. In addition, the black powder initially located inside acceptor igniters burnt. The following photograph shows that the black powder inside the igniter only burnt and the
igniter is still in one piece. This means that the reaction was not violent.

Besides, fragments from ammunition sabot have been recovered as shown in the following figure.

Finally, many gun propellant charges were found on the ground around the test area. As confirmed by the video and some photographs, some of these charges have burnt and were thrown more than 20 meters away from the test area.

Gun propellant on the ground

Combustion stamps

Only from photographs and movies made during the test and without a reference test with inert acceptors, it is difficult to say whether the recovered gun propellant charges or the burnt charges are from the donor or the acceptors. In the same way, some powder was ejected more than 20 m from the firing zone, but it is impossible to say, without a reference test, whether the ejection of these charges is due to the reaction of the donor charge or to the reaction of the acceptor charges.

Pressure measurements

Measured pressures are given in the following table. Expected theoretical value at 2.42 and 2.32 m due to the detonation of one main charge is arr. 0.9 to 1 bar.

Gauge	Distance from the charge	Overpressure level
1	2.42 m	1.07 bar
2	2.32 m	*

The measured overpressure levels are close to the theoretical values obtained with the detonation of the explosive charge from the donor. These values confirm the fact that only the ORA86B from the donor charge detonated. This analysis allows us to turn down the type III.

Test 1&2, conclusion

Analysis of the witness plate, recovered fragments, pressure measurements and the movies from test 1 and 2 show that the effects of the donor ammunition detonation on the acceptor charges are very limited. We have also seen a good reproducibility between test 1 and test 2.

Sympathetic reaction → **level of reaction Type IV or V**.

4. IM SIGNATURE

Evaluation of IM Signature: complete round or warhead only
The evaluation of the level of reaction is evaluated in accordance with AOP39 Ed. 3 and STANAG 4439 Ed. 3.
The IM signature of DART ammunition was established using:

- test results analyses as described previously for the complete round,
- based on the tests results and reading across experimental results obtained in equivalent configurations, for the warhead only.

The table below summarizes the tests performed and type of reactions observed.

ITEM	TEST	AMMO CONFIG	Expected Reaction	Observed Reaction	Reached expectation
1	12m drop test	Single Box	**NR**	**NR**	**YES**
2	12m drop test	Single Box	**NR**	**NR**	**YES**
3	12m drop test	Single Box	**NR**	**NR**	**YES**
1bis*	12m drop test	Single Box	**NR**	**NR**	**YES**
4	12m drop test	Triple Box	**NR**	**NR**	**YES**
5	12m drop test	Triple Box	**NR**	**NR**	**YES**
6	12m drop test	Triple Box	**NR**	**NR**	**YES**
7	Fuel Fire	Triple Box	**IV or better**	**IV**	**YES**
8	Fuel Fire	Single Box	**IV or better**	**V**	**YES**
9	Slow Heating	Unpackaged	**IV or better**	**IV**	**YES**
10	Slow Heating	Unpackaged	**IV or better**	**IV**	**YES**
11	Bullet impact	Unpackaged	**IV or better**	**V**	**YES**
12	Bullet impact	Unpackaged	**IV or better**	**V**	**YES**
13	Sympathetic Reaction	Triple Box	**III or better**	**IV**	**YES**
14	Sympathetic Reaction	Triple Box	**III or better**	**IV**	**YES**

The table below is a theoretical analysis proposed on the basis of the results of IM tests performed on complete round, for the warhead only.

ITEM	TEST	AMMO CONFIG	Type of Reaction expected
1	12m drop test	Single or Triple Box	**NR**
2	Fuel Fire	Single Box	**V**
3	Slow Heating	Unpackaged	**TBE**[1]
4	Bullet impact	Unpackaged	**NR**
5	Sympathetic Reaction	Triple Box	**IV**

IM Signature: complete round

ITEM	TEST	STANAG 4439 Requirement	Type of Reaction	Compliance to IM STANAG 4439
1	12m drop test	N/A	**NR**	YES
2	Fuel Fire	V	**IV**	NO
3	Slow Heating	V	**IV**	NO
4	Bullet impact	V	**V**	YES
5	Sympathetic Reaction	III	**IV**	YES

The complete round does not meet the STANAG 4439 requirement.

IM Signature: warhead only

ITEM	TEST	STANAG 4439 Requirement	Type of Reaction	Compliance to IM STANAG 4439
1	12m drop test	N/A	**NR**	YES
2	Fuel Fire	V	**V**	YES
3	Slow Heating	V	**To Be Evaluated**	To Be Evaluated
4	Bullet impact	V	**NR**	YES
5	Sympathetic Reaction	III	**IV**	YES

The compliance to STANAG 4439 would depend on the result under slow heating test. The slow heating initiation temperature of bare explosive ORA86B is 195°C. Without the propellant charge, ORA86B would start reacting at 195°C. Then, the explosive will start to burn and generate combustion gas under pressure. The type of reaction will mainly depend on the venting capacity of the warhead (SAU+Explosive charge), to evacuate the gas under pressure and mitigate the level of reaction.

5. CONCLUSION

The DARTs ammunitions meet the expected reactions. When tested in complete round configuration, the thermal threats Slow Heating and Fast Cook-Off lead to reaction which is not compatible with the STANAG 4439 IM Signature Requirements. Venting solutions of the filled cartridge and/or the warhead may be designed to improve the level of reaction when exposed to such threats.

5. REFERENCES

[1] 12m Safety Drop Test on DART ammunitions, RS N° 10/14/HKS/ICS/NPL, November 07th 2014, Yves GUENGANT, Isabelle LAINE

[2] Liquid fuel / External fire test on DART ammunitions, RS N° 11/14/HKS/ICS/NP, November 07th 2014, Yves GUENGANT, Isabelle LAINE

[3] Bullet Impact Test on DART ammunitions, CR n° 45/2014/TMF, October 23, 2104, Olivier BETTALE, Karol WOIRIN, Christelle COLLET

[4] Sympathetic Reaction test on DART ammunitions, CR n° 35/2014/TMF, September 22, 2014, Yann GUGUIN, Karol WOIRIN, Christelle COLLET

[5] Slow Heating on DART ammunitions, CR n° 36/2014/TMF, September 23, 2014, Olivier BETTALE, Karol WOIRIN, Christelle COLLET

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