Different ballistic performances for reference ammunitions of varied origins

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Abstract. As part of an evaluation of a ballistic protection, it is essential to control the parameters influencing the test in order to respect the conditions of a successful test: reproducibility, representability and reliability. We have initiated a certification process for our ballistic evaluation laboratory according to the ISO 17025 standard. This requires prove the laboratory's skills and its ability to produce valid results. One of the influencing parameters on the test results is the ammunition used. Ballistic assessment standards, such as STANG2920, is based on reference assessment ammunition. Those ammunitions are recommended by name, and sometimes with a hardness for the core. For the same designation, we can find different suppliers and different batches of manufacture. In order to better know the ammunitions used in our laboratory, we have carried out protective limit speed determination tests on BLD (NF A36-800) and BLAL aluminum (NF A50-800) reference targets for different ammunition. These tests made it possible to determine a V_{50} and a V_{90} according to a PROBIT method. In parallel, we carried out tests of metallurgical characterization of these ammunitions in order to compare their composition and their hardness. The ammunition concerned are 5.56mm×45 SS109 (5 references), 7.62mm×51 NATO Ball (4 references), and 5.56mm×45 M193 (3 references). Some significant differences in ballistic performance for the same type of ammunition are observed. Those findings lead us to adopt a method of validation of ammunition batch chosen for our assessments. This paper presents the results, ballistic and metallurgical, and the methodology adopted in our laboratory to validate an ammunition.

1. INTRODUCTION

For the evaluation of dismounted soldier protective equipment, DGA Land Systems must master all aspects of its tests. To guaranty its activities, DGA Land Systems have been certifying ISO 9001 [2] already. To go further and be able to guaranty its assessments, the centre is get involved in the creation of a laboratory that, based on ISO 17025:2015 [3], aims to implement tests relating to the evaluation and classification of bulletproof equipment. In addition to a permanent search for progress, this approach makes it possible to give an additional guarantee and greater confidence in the quality of the evaluations conducted by the centre, in particular those contributing to the qualification of the definition of protection for dismounted soldiers. These ballistic protection assessments are mainly carried out using the STANAG2920 [1] standard. The evaluation threats implemented correspond to Annex B proposing four categories of ammunitions: lead core, Mild Steel Core, Hard steel core, and Tungsten Cobalt (WC) Core projectiles. Each threat is defined by the mass of the projectile, the mass of the core and the minimum hardness of the core, excepted for the lead core.

The accreditation process imposed by ISO17025 [3] requires mastering all the parameters of a test. For a test referring to STANAG 2920 [1], one can cite among the parameters most influencing the results of the test: temperature of the samples, the speed of the projectiles, the implementation of the simulant, or the batch of ammunition. Among these parameters, the ammunition used represents one of these influencing parameters and can lead to a significant bias in the evaluation of protection.

Therefore, we decided to qualify the batches of ammunition that we use in our assessments. The interest is to guarantee a continuity of results for evaluations conducted with different batches, and a continuity in the severity of the tests. This article presents the results of comparison obtained between different batches of ammunition, which we have in our laboratory. We compared two category A munitions and one category B ammunition from STANAG2920 [1]. More specifically, class A3 5.56mm×45 M193, and class A5 7.62mm×51 ammunition, as well as class B3 5.56mmx45 SS109. Two comparisons were made: one from the mechanical hardness characteristics, and one from the ballistic characteristics. All the ballistic results are presented and discussed below for 11 batches from various sources. These results should allow us to validate a method of selecting our batches of ammunition in order to have proof of the mastery of our tests to obtain ISO17025 [3] accreditation for tests according to STANAG2920 [1].

2. ISO 17025:2015 AND APPROACH TO QUALIFY AMMUNITION

ISO17025 [3] has been developed with the objective of promoting confidence in the operation of laboratories. It contains requirements for laboratories to enable them to demonstrate they operate

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competently, and are able to generate valid results. This norm specifies the general requirements for the competence, impartiality and consistent operation of laboratories. This norm contains objectives for impartiality, confidentiality, and requirements for structure, resource, process and management. It is applicable to all kind of industrials sectors or activities practicing test, and so for ballistic laboratory.

One of the requirement is that the laboratory shall ensure that only suitable externally provided products that affect laboratory activities are used. The ammunitions used in a ballistic laboratory are concerned by this requirement. Also we have to master this element having a first order impact on the performance of the protection solutions evaluated. The approach chosen in our laboratory for controlled the influence of ammunition batch is to have a procedure to justify the change of a batch of ammunition. This procedure should allow us to have continuity in the assessments. Therefore, we have chosen to define a receipt for our batches of ammunition from V_α tests (see paragraph 5) to ensure that these munitions have characteristics similar to the previous batches. In order to have a conservative approach to the validation of our protections, we choose to verify that the batches of ammunition that we use have a V_{50} and V_{90} , respectively 50% and 90% of probability of protection, within an acceptable range. The tests described below allow us to define these acceptance ranges for a batch of ammunition specifically for an ammunition type.

3. AMMUNITIONS ASSESSED

The different ammunition compared are listed in the Table 1 and were only drawn from lots of different suppliers, we were looking to draw up a large inventory. In a second step, we plan to refine our results with different batches from same manufacturers with high reproducibility behaviour.

Table 1. Ammunition tested

Munition	Designation	Batch
5.56 mm × 45 M193	M193	LC 10H105 013
		4 ALM 79
5.56 mm × 45 NATO – SS109	DM11	MEN 97
	M855	HK 89
	SS109	FNB 83
		2 MI 01
		20 RG 10
7.62 mm × 51 NATO ball	DM41	2 MEN 03
	C21	-
	M80	9 SFM 86
		LC YZ 65 505

The DGA-Land Systems laboratory also evaluates ballistic protection for vehicles in accordance with STANAG 4569 [4] Vol. 1. The ammunition chosen is also common for KE1 level of this standard to have a common acceptation procedure for our management quality system.

4. AMMUNITIONS CARACTERISTICS

STANAG2920 [1] specifies a minimum hardness for ammunition with a steel core, but nothing for lead cores. In addition, although not specified by STANAG2920 [1], the chemical composition or the mass of the constituent elements of the ammunition can explain differences in mechanical or ballistic characteristics. Therefore, we carried out metallurgical analyses and hardness analyses for all the ammunition.

4.1 Core analysis

Inductively Coupled Plasma Mass spectrometry (ICP) and elemental analysis for the elements Carbon and Sulfur determined the chemical composition of the steel core. We analysed with Energy Dispersive X-ray Spectroscopy (EDS) and Scanning Electron Microscopy (SEM) the soft core. Figure 1 gives details of analysis for one batch. Table 2 gives the results for the soft core of the 7.62 Ball in mass percentage, with the associated calculated error. Table 3 gives the same kind of results for the steel core of SS109 ammunition.

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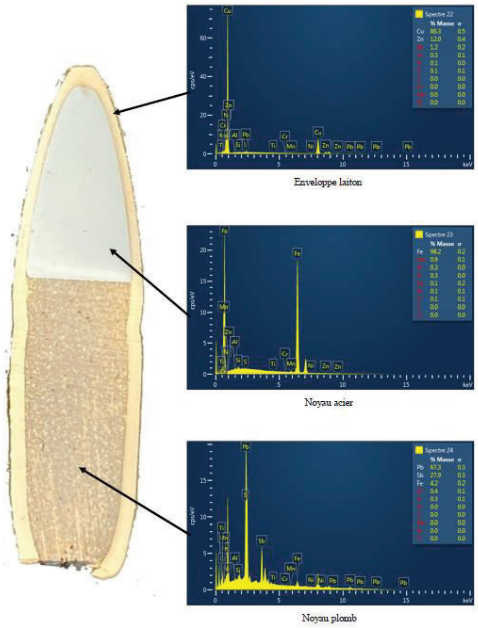

Figure 1. Chemical composition of 5.56mm×45 SS109 – 2 MI 01

For these SS109 batches, it is interesting to note that the steels are different. FNB83's steel core is compatible with C35E steel according NF EN 10083-2 norm. 02IMI01's steel core is compatible with C45E steel according NF EN 10083-2 norm. 20RG10's steel core is compatible with A508 Grade 1 steel according ASTM A 508/A508M-04a norm. The same kind of heterogeneity is observable between the several components (jacket or core) of the several batches for each kind of ammunition.

Table 2. Mass percentage and associated measurement error - Soft core - 7.62mm×51 – M80

	Sb	Pb	Cu	Fe	Al	P	Si
9 SFM 86	**3,55**	**87,45**	**0,23**	**0,43**	**3,48**	**1,13**	**3,28**
	0,14	*1,08*	*0,04*	*0,10*	*0,91*	*0,09*	*0,22*
LC YZ 65 505	**9,37**	**78,20**	**0,24**	**0,94**	**6,58**	**1,02**	**3,00**
	0,22	*1,01*	*0,04*	*0,12*	*0,91*	*0,08*	*0,20*

Table 3. Mass percentage and associated measurement error - Steel core – 5.56mm×45 SS109

	Fe	Mn	Cr	Si	Al	Ti	Zn	Ni
FNB 83	**98,9**	**0,5**			**0,4**	**0,1**		
	0,2	*0,1*			*0,1*	*0,1*		
2 MI 01	**98,2**	**0,9**		**0,3**	**0,3**	**0,1**	**0,1**	**0,1**
	0,2	*0,1*		*0,0*	*0,0*	*0,1*	*0,2*	*0,1*
20 RG 10	**98,3**	**0,9**	**0,2**	**0,2**	**0,3**			
	0,2	*0,1*	*0,1*	*0,1*	*0,1*			

4.2 Ammunition hardness

Hardness measurements, Vickers (HV2, 2kg load) for steel core, or Brinell (HB1 / 2.5, 1 mm diameter ball and 2.5 kg load) for soft core, were made at different points on the jacket and on the projectile core. As example, Figure 2 presents the measurements for the SS109 ammunitions. At last five measurements were made to get the hardness at different points for each core.

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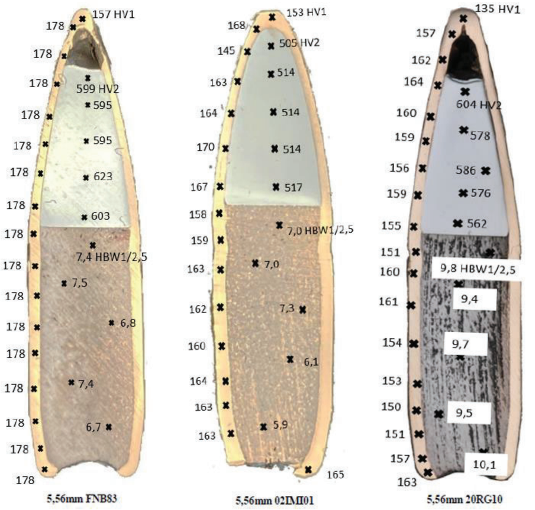

Figure 2. Hardness of core and jackets for 5.56mm×45 SS109

Table 4 summarizes the hardness average for all the batches. Between two batches of the same kind of ammunition, we can observe until 15% of difference for the hardness of the steel core, or between 26% and 40% for hardness of the soft core.

For the SS109 with a mild steel core, STANAG 2920 [1] recommends a hardness greater than 40HRC, all our batches respect this prescription.

Table 4. Hardness measurement for all ammunitions

			Hardness	
Ammunition	**Designation**	**Batch**	**HB1/2.5**	**HV2**
			Soft core	**steel core**
5.56 mm x 45 M193	**M193**	*LC 10H105 013*	8,84	
		4 ALM 79	6,52	
5.56 mm x 45 NATO – SS109	**DM11**	*MEN 97*		
	M855	*HK 89*		
	SS109	*FNB 83*	7,16	603
		2 MI 01	6,66	512,8
		20 RG 10	9,7	581,2
7.62 mm x 51 NATO ball	**DM41**	*2 MEN 03*	5,84	
	C21	-		
	M80	*9 SFM 86*	6,4	
		LC YZ 65 505	9,8	

5. AMMUNITION BALLISTIC CARACTERITICS

The ballistic performances of an ammunition can be evaluated from different tests: Depth Of Penetration, Vi/Vr tests, VLP tests, V_α , … [8]. In order to have a relevant comparison, the targets used must be composed of a reference target: armoured steel, reference targets, etc. We have chosen to determine the characteristics of our ammunition by a V_α test on a metal target. This test gives a protection velocity for a probability of protection α. DGA Land Systems implemented two test campaigns with the means and teams of the unit. The processing of shooting data was carried out by the PROBIT method and an evolution of this method. These two treatments are presented below.

The 5.56mm×45 M193 ammunition was evaluated only against 6mm of BLD armour steel. The other munitions, 5.56mm×45 SS109 and 7.62mm×51 O, were evaluated on both 8 mm BLD armour steel and 25 mm BLAL1 armour aluminium.

5.1 Test apparatus

Ammunitions were fired from a pyrotechnical launch system. The firing distance was about 10m. All the munitions were charged specifically to get the attempted velocity on target. The ammunition speeds

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were determined by a set of 6 optical screen. The attitude (yaw) of the projectile was measured for each shot by the Projectile Obliquity Measurement system (POM), an orthogonal photographic system. The position of the target was perpendicular to the line of fire and was controlled for each set up. The target was moved horizontally or vertically at each shot to get a new point impact to keep an orthogonality between the target and the line of fire.

5.2 Targets

We have chosen metallic targets. Two types of alloy were chosen: a BLD type armour steel complying with the NFA36-800 standard [5], it is equivalent to an Rolled Homogeneous Armour, .and a BLAL1 type armour aluminium (7020) according to the NFA50-800 standard [6]. They have a minimum ballistic limit imposed by these standards against a 7.62mm×51AP for the thicknesses that we have used, those limits are validated by specific ballistic tests after casting. We used thicknesses of 6 mm and 8 mm for BLD armour steel and 25 mm for BLAL1 armour aluminium.

5.3 Test protocol

The ammunition was fired to frame the expected V_{50} velocity. We carried out series of 15 to 20 shots for each batch of ammunition. In order to distinguish a protection from a perforation, we used a witness control system corresponding to STANAG2920 [1]. This witness consisted of a sheet of aluminium alloy 0.5 mm thick (AlCuMg compliant with ISO / R209 standard and having at least a tensile strength limit of 440 N/mm²). The shots selected complied with the recommendations of the STANAG2920 [1] on influencing parameters: distances from the edge, speed range, yaw, temperature, etc....

5.4 Balistic limit determination

The definition of a ballistic limit for ammunition differs depending on the standard used. This ballistic limit designates a threshold to simplify the transition phenomenon between “protection” and “non-protection”. Indeed, the perforation of a protection by an ammunition is a physical phenomenon comprising a random nature that can be quantified by a dispersion. Several statistical methods exist to determine this mixed zone. We determined this transition zone by a series of shots framing the average value. Different statistical methods make it possible to process this sampling of shots to determine the protection limit speeds. We chose to determine this transition zone by two methods: the PROBIT method of the STANAG 2920 [1], and a modified PROBIT method evaluating an uncertainty for each speed of the transition zone.

5.4.1 PROBIT approach

The PROBIT approach [7], described in STANAG 2920 [1], proposes to model this phenomenon by a normal probability density *f* in order to estimate the mean, denoted V_{50}, and the dispersion, noted σ :

$$f(v) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(v-v_{50})^2}{2\sigma^2}} \tag{1}$$

The probability obtained with regard to this law corresponds to the probability of perforation of the ammunition according to the velocity of impact *v* of the ammunition on the protection. The mean V_{50} therefore represents the speed at which the probability of perforation, $P_{perforation}$, (or respectively of protection, $P_{protection}$) is equal to 0.5. As a reminder, the probabilities of perforation and protection are dual, formally:

$$P_{perforation} = 1 - P_{protection} \tag{2}$$

The unknown parameters V_{50} and σ are estimated on the basis of N perforation results at different speeds of impact of the munition on the protection studied. The PROBIT method proposes the maximization of a likelihood law. By generalizing the concept of V_{50}, the values V_α, representing the velocity at which a perforation is caused with a probability α, can be deduced from the previous estimates (V_{50}*, σ*) and normal law fractiles, formally:

$$v_\alpha = V_{50}^* - u_\alpha \cdot \sigma^* \qquad \text{for} \qquad \alpha = [0,1] \tag{3}$$

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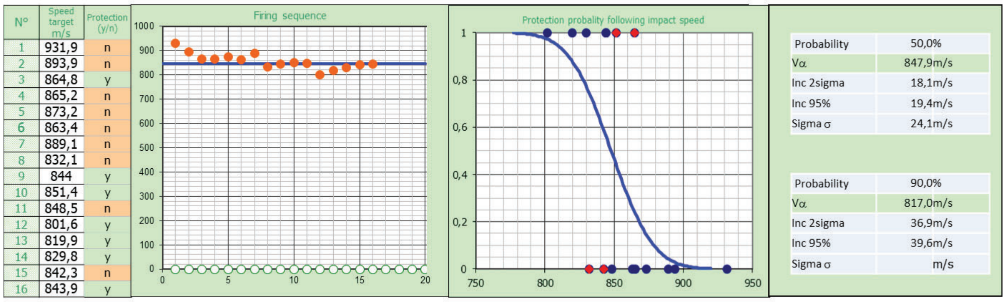
In this equation, u_α represents the normal law fractile associated with the probability α. An example of the result of implementation of the PROBIT method with deduction of the risk curve V_α is represented Figure 3 with the probability of protection for a 5.56mm×45 SS109.



N°	Speed target m/s	Protection (y/n)
1	931,9	n
2	893,9	n
3	864,8	y
4	865,2	n
5	873,2	n
6	863,4	n
7	889,1	n
8	832,1	n
9	844	y
10	851,4	y
11	848,5	n
12	801,6	y
13	819,9	y
14	829,8	y
15	842,3	n
16	843,9	y

Probability	50,0%
Vα	847,9m/s
Inc 2sigma	18,1m/s
Inc 95%	19,4m/s
Sigma σ	24,1m/s

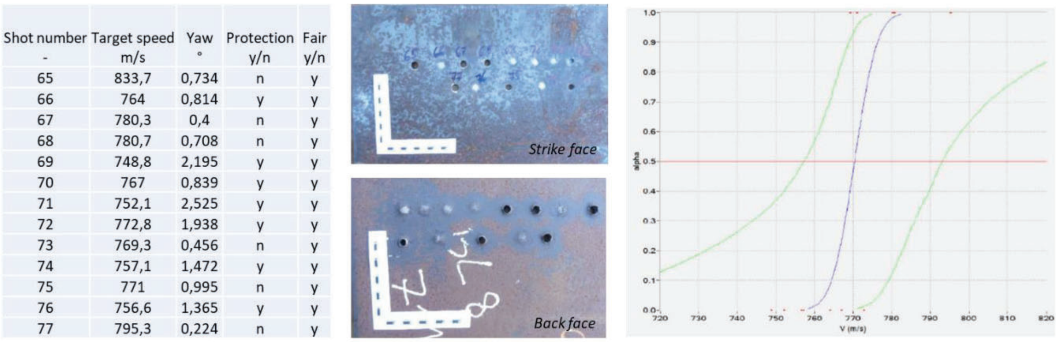
Probability	90,0%
Vα	817,0m/s
Inc 2sigma	36,9m/s
Inc 95%	39,6m/s
Sigma σ	m/s

Figure 3. Test round for 5.56mm×45 SS109 - 02IMI01 / BLD 6 mm – Protection probability

5.4.2 PROBIT modified approach

The STANAG2920 [1] proposes the calculation of confidence intervals for the parameters V_{50} and σ. However, nothing about the V_α confidence interval calculation is discussed, while uncertainty on the risk curve is an important element when assessing protection. This uncertainty is a function of the number of shots fired and the intrinsic dispersion of the physical phenomenon of perforation. The proposed approach is to use the two-dimensional likelihood law L (V_{50}, σ) determined using the test data as the Monte-Carlo generation law of the parameters V_{50} and σ. Thanks to the use of normal law fractiles, an empirical distribution of V_α is thus obtained on the basis of the two empirical distributions of V_{50} and σ from Monte-Carlo simulations. The lower and upper bounds of the bilateral confidence intervals on V_α are deduced by identifying the 2.5th and 97.5th percentile of the empirical distribution obtained. This process must be reproduced for any α varying from 0 to 1 with a sufficient resolution step in order to obtain good resolution of the confidence envelope associated with the risk curve. The number n of Monte-Carlo simulations must be reasonably high in order to ensure the convergence of the approach (for example n = 105). An example of the result of calculating the risk curve and the associated 95% confidence envelope is shown Figure 4 for the perforation probability for the 7.62mm×51.

We therefore systematically determined the V_{50} , 50% of protection probability, and the V_{90} , 90% of protection probability, for each munition from a series of shots composed of 15 to 20 shots at different speeds.



Shot number -	Target speed m/s	Yaw °	Protection y/n	Fair y/n
65	833,7	0,734	n	y
66	764	0,814	y	y
67	780,3	0,4	n	y
68	780,7	0,708	n	y
69	748,8	2,195	y	y
70	767	0,839	y	y
71	752,1	2,525	y	y
72	772,8	1,938	y	y
73	769,3	0,456	n	y
74	757,1	1,472	y	y
75	771	0,995	n	y
76	756,6	1,365	y	y
77	795,3	0,224	n	y

Figure 4. Test round for 7.62mm×51 C21 / 6 mm BLD – Perforation probability

5.4.3 Comparison for the two approaches

These two methods gave us the same V_{50} and V_{90} for draws with shots giving a mixed zone of results around the average value. The differences noted between these two methods during this test campaign are less than 10m/s on few shooting sequences having little shooting with speeds giving both protection

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and non-protection. We present Table 5 here the results of the two methods for the 7.62mm×51 ammunitions face to BLD.

Table 5. Comparison of both approaches for 7.62mm×51 bullet on 8 mm BLD

	7.62 x 51 NATO Ball											
	DM41			C21			M80			M80		
	7.62 DM41 - 02MEN03			7.62 C21			7.62 M80 - 9SFM86			7.62 M80 - LCY762505		
	Campaign 1			Campaign 2			Campaign 1			Campaign 1		
	BLD 8mm			BLD 8mm			BLD 8mm			BLD 8mm		
VLP PROBIT 2920	V50	774,74	m/s	V50	770,37	m/s	V50	781,41	m/s	V50	795,41	m/s
	Inc 2sigma	6,32	m/s	Inc 2sigma	5,49	m/s	Inc 2sigma	9,65	m/s	Inc 2sigma	-	m/s
	Inc 95%	6,78	m/s	Inc 95%	6,05	m/s	Inc 95%	10,14	m/s	Inc 95%	-	m/s
	Sigma	6,42	m/s	Sigma	4,66	m/s	Sigma	9,25	m/s	Sigma	11,18	m/s
	V90	766,51	m/s	V90	764,40	m/s	V90	769,56	m/s	V90	781,08	m/s
	Inc 2sigma	10,90	m/s	Inc 2sigma	9,16	m/s	Inc 2sigma	12,81	m/s	Inc 2sigma	-	m/s
	Inc 95%	11,69	m/s	Inc 95%	10,08	m/s	Inc 95%	13,46	m/s	Inc 95%	-	m/s
VLP PROBIT modified	V50min (95%)	750,51	m/s	V50min (95%)	757,08	m/s	V50min (95%)	767,00	m/s	V50min (95%)	770,52	m/s
	V50	774,73	m/s	V50	770,37	m/s	V50	781,39	m/s	V50	791,97	m/s
	V50max (95%)	792,01	m/s	V50max (95%)	793,08	m/s	V50max (95%)	805,00	m/s	V50max (95%)	808,02	m/s
	V90min	695,92	m/s	V90min	714,37	m/s	V90min	695,45	m/s	V90min	698,85	m/s
	V90	766,54	m/s	V90	764,41	m/s	V90	769,61	m/s	V90	779,34	m/s
	V90max	777,42	m/s	V90max	779,57	m/s	V90max	787,91	m/s	V90max	792,09	m/s

5.5 Ballistic results

The results obtained for 5,56mm ammunition are presented in the Figure 5 to 7 below.

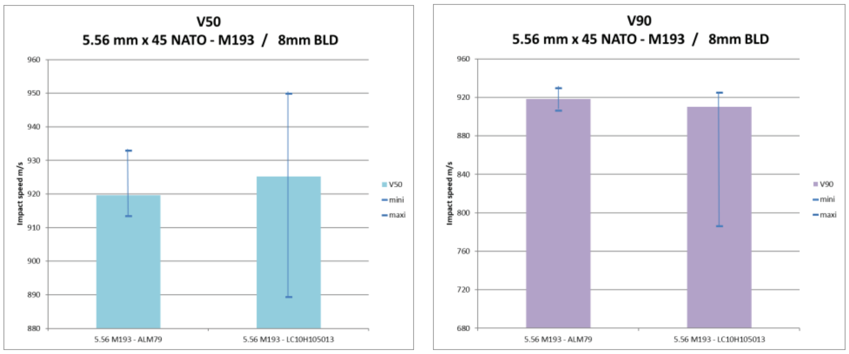

Figure 5. Results for 5.56mm×45 M193 on 8 mm BLD with uncertainties.

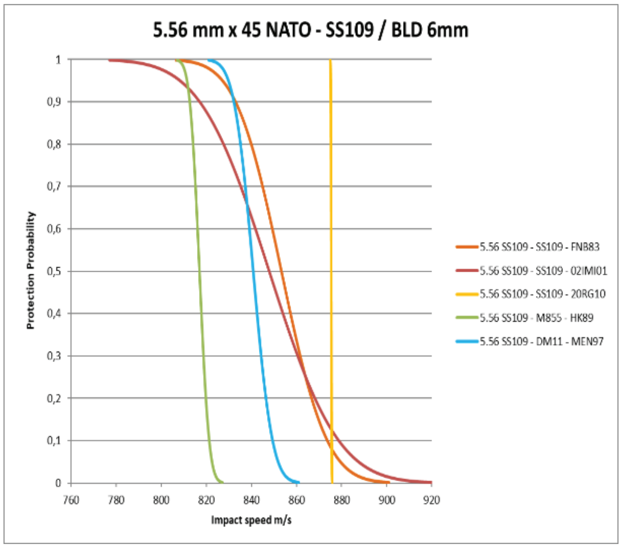

Figure 6. Results for 5.56mm×45 SS109 on 6 mm BLD

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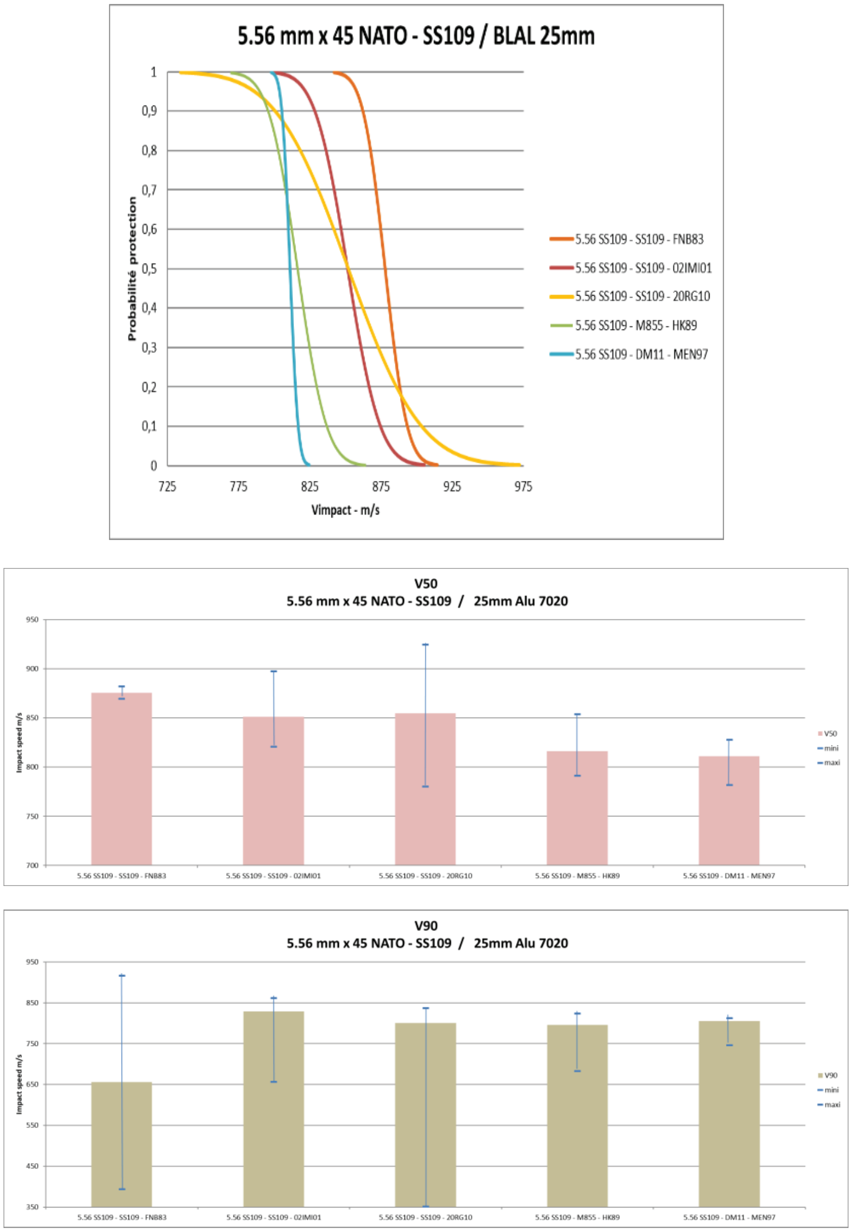

Figure 7. Results for 5.56mm×45 SS109 ,on 25 mm BLAL

5.6 Discussion of ballistic results

The first observation is the "crossing" of the different transition curves. The order of the V_{50} for the different munitions is not the same as the order of the V_{90}. Thus, performance approaches based on the V_{50} or V_{90} separately would not define the same ammunition as the best performing or the least vulnerable. Locally, for the 5.56mm×45 SS109 for example, differences depending on the batches appear:

- Faced with aluminium, batch FNB83 has a higher V_{50} (> 50 m/s compared to the "weak" batches), however, this result is mitigated by a V_{90} at lower than all the other batches.
- Facing steel, the batch HK89 has the weakest V_{50}. However, for the V_{90}, this batch is as efficient as the others are.

These results come from only one series of batch shots. It is a very small sample. A second sequence of shots would probably give different results under the same conditions.

However, by trying to compare the uncertainties for the ballistic limits obtained from our unique draw, we can get an idea of the high and low limits for each munition: they all seem in the same interval. The uncertainty intervals for our V_{50} and V_{90} values overlap respectively. We can deduce that, without additional firing campaigns to refine our results, macroscopically the batches of ammunition have substantially the same performance in V_{50} and V_{90} on steel armour and aluminium armour.

Depending on the types of targets (steel or aluminium), the bullets do not have the same order of severity. The nature of the target influences the "severity order" of our batches. We believe that the order would be different for another target technology: ceramic materials, composite materials, multi-layers … In addition, protection assessments are carried out on new concepts that by nature have never been assessed; and so we cannot preselect the most sever ammunition for this kind of material. Also, it seems to us more important to have continuity of evaluations than to isolate the most conservative ammunition for metallic targets, this ammunition could become a weak selection ammunition for a target made of another material.

6. VALIDATION OF A BATCH OF AN AMMUNITION

The metallurgic analysis gave us different steel for the same kind of ammunition, and the hardness can be very scattered between two batches ; also those two methods don't seem us adapted to validate a batch in continuity with our reference batch. In addition, those analysis are not easy to realize in our ballistic laboratory, and need to be externalise to a competent and accredited supplier.

The hardness analyses can only be indicative between two batches from different suppliers. The core hardness is nevertheless important because of the STANAG2920 [1] recommendation for the bullet from category B, C, and D giving a minimum. We have to respect this minimum hardness core specified for the ISO17025 [3] accreditation. It is necessary to get those results, but of the ballistic point of view, it is just an indication.

With those different considerations, we plan to validate a change of batch of ammunition with a ballistic assessment.

This validation will consist of a series of 20 shots on a BLD steel plate 6 mm or 8 mm thick. This series will allow us to determine a V_{50} and a V_{90}. We wish to validate the batches for V_{50} and V_{90} intervals listed in the Table 6 below. The tolerances envisaged are ± 20m / s. The batch will have to respect these intervals for both the V_{50} and V_{90}.

More tests are planned to confirm those values, particularly the number of time necessary to repeat the protocol of 20 shots. For example, the standards NFA36-800 [5] and NFA50-800 [6] recommend 7 repetitions of their VLP protocol for validate a new batch of ammunition.

Table 6. Required V_{50} and V_{90}

Munition	**Target**	**V_{90}**	**V_{50}**
5.56 mm × 45 M193	BLD 8 mm	910 m/s	930 m/s
5.56 mm × 45 NATO – SS109	BLD 6 mm	830 m/s	850 m/s
7.62 mm × 51 NATO ball	BLD 8 mm	750 m/s	780 m/s

7. CONCLUSION

The results presented above allow us to propose a ballistic limit, V_{50} and V_{90} values for batches of ammunition used for the ballistic protection assessment in accordance with STANAG2920 [1]. The proposed values will be validated by new tests: same batches on different sheets (other casting), and different batches on the same sheets (same casting).

This method has the advantage of giving access to a ballistic laboratory the possibility of validating a batch using shots, and not from a hardness measurement often outsourced and very scattered between different ammunition suppliers. In addition, the validation of the final performance of an ammunition by the characteristics of the target is a practice already recommended in the STANAG 2310 [9] on the validation of small calibre ammunition.

Nota:
The results presented here are not representative of the terminal ballistics performance of batches of ammunition in operational situations. These batches have their own characteristics depending on the operational conditions of implementation: type of weapon, engagement distances, environmental conditions, storage conditions, nature of the target, etc. These results therefore do not allow ammunition

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from different suppliers to be compared for a supply assessment; they are only laboratory results with a test mount and specific pyrotechnic charges on a series of restricted shots.

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