

Improved Test Methods for Better Protection, a BABT Protocol Proposal for STANAG 2920

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Abstract. The group of ballistics experts working on the NATO Standard for Ballistic Test Method for Personal Armour Materials and Combat Clothing (STANAG 2920) has already reached an agreement on several aspects of the Standard. For example, shot patterns and impact locations for helmet, soft body armour and hard plates (single shot and multi-hit) have been defined but other important aspects are still under investigation. One major issue is the relevance of Plastilina to evaluate injury potential from behind armor blunt trauma. Even though this technique has provided safety benefits over the years, it has limited relationships with what is really happening on the human body during ballistic impact. As an alternative, more biofidelic tools developed to evaluate the performance of body armours and helmets against non penetrating ballistics impacts are considered by the group of experts. Publications on the use of these tools support these alternatives. However, much effort is required to include these new tools in a test performance standard. This paper summarizes the consensus reached so far by the group of experts and presents a proposal to include new procedures in STANAG 2920 for the Blunt Trauma Torso and the Ballistic Load Sensing Headform. At this stage of development, the new test devices are proposed to complement the current Plastilina method, not as a replacement.

1. INTRODUCTION

Since the group of experts began the review of STANAG 2920 (Edition 3) in 2007, several aspects were questioned. For example: the influence of the barrel twist [1] to determine ballistic limit, the accuracy of the V_{50} calculation methods [2], which (if any) environmental target conditioning approach should be included, which threats and what reference protection levels should be considered. The group of participants also conducted round robin test series to better identify the weaknesses of the protocols and proposed appropriate corrections. To optimize effort, experts were divided in smaller group to work on specific aspects that needed further discussions, testing, and more precise definitions. The conclusions reached by the subgroup focusing on shot pattern / impact location are presented in this paper.

Another important aspect of the evaluation of protection performance is the capability to attenuate behind armour blunt trauma (BABT) caused by non-penetrating ballistic impacts. The majority of past and current test standards are using the indentation created by the deformation of the armour into Plastilina to estimate impact severity. A major issue is the relevance of Plastilina to evaluate injury potential from behind armor blunt trauma. Even though this technique has provided safety benefits over the years, it has limited relationships with what is really happening on the human body during ballistic impact. Alternative tools identified as the Blunt Trauma Torso Rig and the Ballistic Load Sensing Headform were developed to provide a more biofidelic assessment of the risk of BABT. These new approaches, documented in several publications [3-7], are considered by the STANAG 2920 group of experts to complement the current Plastilina method until further validation has been conducted.

2. SHOT PATTERNS/IMPACT LOCATION

2.1 STANAG 2920 Ed. 4: Consensus from the group of experts

2.1.1 Textile Material and Soft Armour

In the following text, the terms V_{50} (ballistic limit) and V_{proof} refer to the corresponding definitions provided in STANAG 2920, Ed. 3 [8].

2.1.3 Hard Plates

V_{proof} (Single Shot) and V_{50} Tests

The proposed impact zone corresponds to the entire strike face area of the plate minus an edge zone to be defined by each end-user. A valid V_{50} or V_{proof} test can only include a single shot per plate sample. Several plate samples will therefore be required to complete a test. This is due to the inability to assure that the second shot is not affected by the damage caused by the first impact. It is however valid to produce a V_{50} or V_{proof} of first shots, followed by a V_{50} of the second shots and so on.

Multi – Hit V_{proof} Tests

Multi-hit (V_{50} or V_{proof}) shot-to-shot spacing should be defined as required by each country. A shot pattern can be suggested if a national authority does not have a specification defined. A typical pattern would be a three-shot displaced triangle with 12 cm shot-to-shot distance. Another option could include a similar triangular shot pattern, but with a shot-to-to-shot spacing corresponding to 10 times the caliber of the impacting projectile.

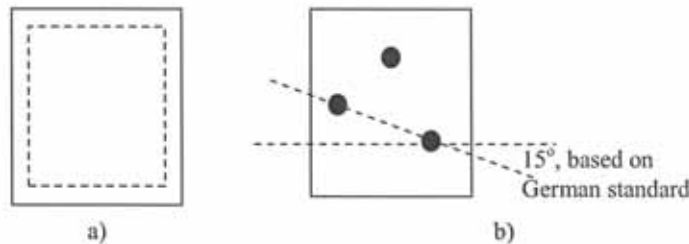


Figure 3. a) Impact zone, b) Typical multi-hit pattern

2.1.4 Transparent Armour

This category includes goggles, partial or full visors. The items may be made of polycarbonate, acrylic, glass, glass-ceramic, or a combination of these materials. The spacing between shots should not be less than 10 times the caliber of the projectile. A 2.5 cm shot-to-edge distance should be used if the target is large enough to accept it. For smaller items, the preferred approach is still under review by the NATO group.

2.2 STANAG 2920 Ed. 4: Under revision/discussion by the group of experts

2.2.1 Small Fabric Pieces

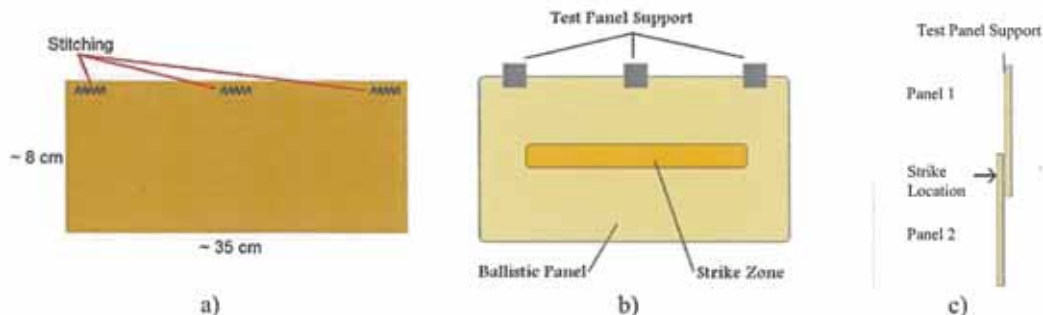


Figure 4. Small fabric pieces a) recommended dimensions, b) shot placement zone, c) Strike locations for multiple small fabrics with overlapping zone

The behaviour of small pieces of textile against ballistic threats is often discussed. In an attempt to answer this issue, a test approach is proposed by the STANAG 2920 group of experts.

The recommended dimensions are 35 cm (length) by 8.0 cm (height). The textile pieces should be sewn at three locations along the top supporting edge. Because of the small dimensions, the shot placement is limited to the central region. The edge zone (no impact) should not be smaller than 2.0 cm. With these dimensions and the 6.5 cm recommended shot-to-shot distances for textile materials, a maximum of 4 ballistic strikes can be obtained per panel. A V_{50} evaluation will therefore require multiple test samples.

For multiple overlapping small pieces of fabric, experiments have shown the necessity to have a minimum of 2.0 cm overlapping [9-10] to avoid threat slippage from the side panels. The impact zone must be at center of the overlapping section.

3. ALTERNATIVE BABT TEST PROTOCOLS

As the authors were involved in the development of the Blunt Trauma Torso Rig and the Ballistic Load Sensing Headform, these devices were selected initially as potential candidate to improve BABT assessment of helmets and body armours. But like any other test device, the proposed alternatives have their limitations and it is recognized that technical issues would have to be addressed in the future. The intent here is to show that there are potential improvements to current methods that are considered for future revisions of STANAG 2920. The group of ballistics experts is however not limited to these alternatives and other approaches will be considered as they become available. The following sections present an overview of the proposed test devices and the experimental trials conducted to demonstrate their capabilities to quantify behind armour impact severity.

3.1 Proposed Torso BABT Test Method

Once the V_{50} or V_{proof} velocities for a particular projectile and armour combination have been determined, backface deformation testing can proceed on the Blunt Trauma Torso Rig (BTTR) shown in Figure 5 using the V_{proof} velocity. The cylindrical shape of the membrane provides a useable area of 360°, as one area becomes worn the membrane can be rotated to expose a new test area. The instrumentation used to measure velocity and displacement is located in the center of the trauma rig at the same elevation as the weapon's muzzle.

After marking the shot locations on the armour test sample (as per Section 2.1.1), it is installed in the center (elevation) of the torso membrane. The BTTR is then adjusted to align the shot location perpendicular with the line of fire as shown in Figure 5. A test shot of the appropriate threat is fired at the predefined non-perforation velocity within the required impact location on the test sample. After recording the displacement transducer signal and the actual projectile's impact velocity, testing is repeated for all shot locations indicated on the armour sample.

3.1.1 Signal Processing

The membrane deflection's rate (Equation (1)) and acceleration are calculated using a moving-average function developed to determine chest velocities of crash test dummies. The viscous criterion (VC), also developed for automotive safety research, is then calculated using Equation (2). Typical BTTR test results are shown in Figure 6.

$$V(t) = \frac{8 [C(t + \delta t) - C(t - \delta t)] - [C(t + 2\delta t) - C(t - 2\delta t)]}{12\delta t} \quad (1)$$

where C is the filtered membrane's deflection signal and δt is the time interval between measurements.

$$VC(t) = 1.3 \left[V(t) \left(\frac{C(t)}{\text{chest depth}} \right) \right] \quad (2)$$

where the trauma rig's chest depth = 255.5 mm which corresponds to the 50% adult male [11].

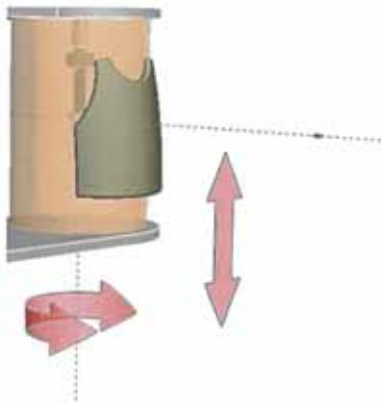


Figure 5. Blunt Trauma Torso Rig Setup

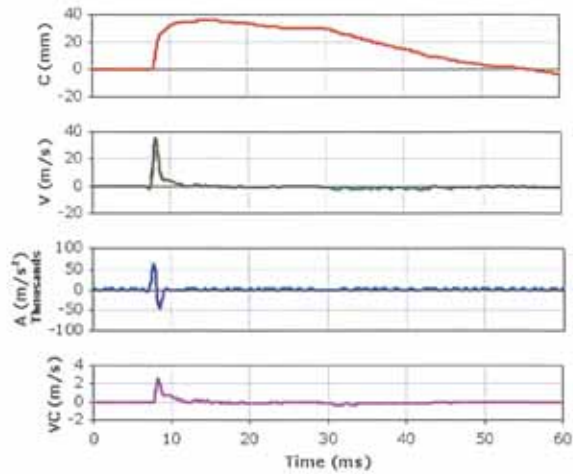


Figure 6. Typical Blunt Trauma Torso Rig Test Result

3.1.2 Experimental Validation

Testing was conducted using 12 different projectiles (5-378 g, 18-97 mm dia., Fig. 8) directly impacting the torso rig at various velocities (10-154 m/s). Approximately 150 tests were performed and a portion of these trials consisted of blunt impact conditions reported in the literature [12-14]. With the physical characteristics of these projectiles and the impact velocity, it was possible to estimate the probability of blunt trauma lethality for each test using the parametric model (Equation (3)) developed by Sturdivan [15] with animal test data impacted by plastic cylinders or related non-penetrating projectiles that reproduced impact conditions of bullets defeated by body armour.

$$P(L) = \frac{1}{1 + e^{34.13 - 3.597 \ln \left(\frac{MV^2}{W^{1/2}TD} \right)}} \quad (3)$$

where M is the projectile mass in g, V is the projectile velocity in m/s, D is the projectile diameter in cm, W is the mass of the victim in kg (78 kg), and T is the thickness body wall at impact point in cm (2 cm).



Figure 7. Test Projectiles

A series of parameters (peak and average deflection, peak velocity, peak acceleration, VC_{max}) derived from the membrane deflection measurement were plotted against the probability of lethality to identify a suitable injury predictor. Figure 8 clearly shows that the peak membrane deflection is not a good

measure of injury severity as distinct trends are observed for each projectile. For example, in Figure 8 a 44 mm limit corresponds to approximately 40% probability of injury for a 64 g projectile (37 mm dia.) while the probability drops to 20% for a 130 g projectile of similar diameter. None of the parameters evaluated was found to provide a single injury function that encompasses all test projectiles. However, an interesting trend was observed with the peak viscous criterion (VC_{max}) where good correlation was noticed for similar impact diameter, regardless of the weight (Figure 9).

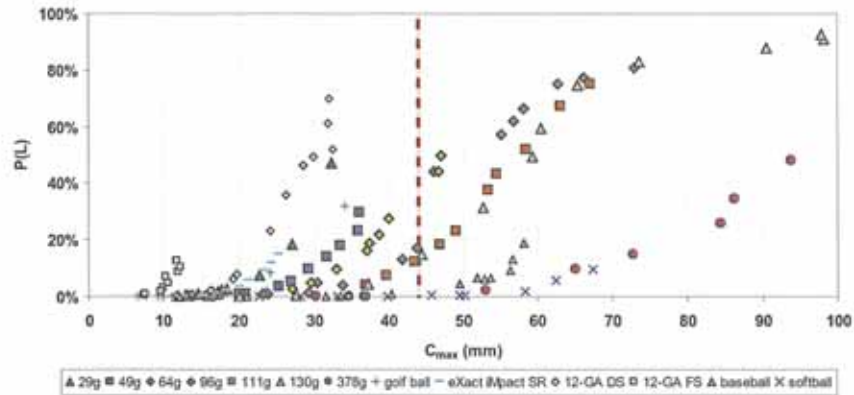


Figure 8. Probability of lethality as a function of the membrane's peak deflection

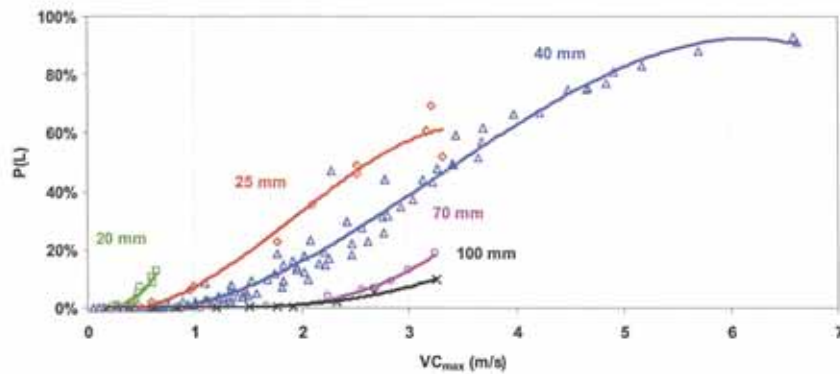


Figure 9. Probability of lethality as a function of VC_{max}

In the light of these findings, re-enactments of non-penetrating ballistic impact experiments on biological models [6, 16] were conducted to verify if the BTTR measurements can be used to predict the level of protection offered by body armour. Soft and rigid personal protection systems were tested at velocities below perforation limits. The behind armour loaded area was estimated using pressure sensitive paint (DIP[®] - Damage Indicating Paint, Sensor Products Inc., Madison, NJ USA). The use of pressure sensitive paint in this application was not to quantify the severity of impact but rather to get a crude evaluation of the contact area that can be used for comparison between loading conditions. On average, the loaded area for soft and rigid armours corresponded to approximately 60 mm and 100 mm, respectively (Figure 10). The most appropriate lethality functions defined for these loaded areas (established from Figure 9) were selected to predict impact severity of the re-enacted cases using the VC_{max} data derived from recorded with the BTTR measurements. The results are plotted against the 70 mm and 100 mm lethality curves in Figure 11. For the soft armour impacts, the BTTR predicts a relatively low risk of lethality (green line, $P(L)=2 - 15\%$). These results agree in some way with the outcomes observed on Post-Mortem Human Subjects (PMHS) [16] for similar impact conditions (AIS 1-2, i.e. minor to moderate injuries) keeping in mind that it is not possible to predict the risk of lethality using dead subjects! For the tests conducted with rigid plates, the BTTR predicts much higher risk of lethality (blue line, $P(L)=4 - 100\%$) which also matches the PMHS trials (AIS 1-4, i.e. minor to severe injuries) [6].

A conservative approach to propose an injury threshold with the current state of knowledge is to use the 40 mm lethality curve since it is based on more experimental data points (Figure 9) and it will provide a higher probability value than the 70 mm or 100 mm curves (Figure 11). As a result, a $VC_{max} = 2.4$ m/s is considered a severe injury threshold for loaded areas equal or greater than 40 mm. Ultimately, future validation and re-enactment trials will complement this initial attempt to use VC_{max} as an injury prediction parameter for the Blunt Trauma Torso Rig.

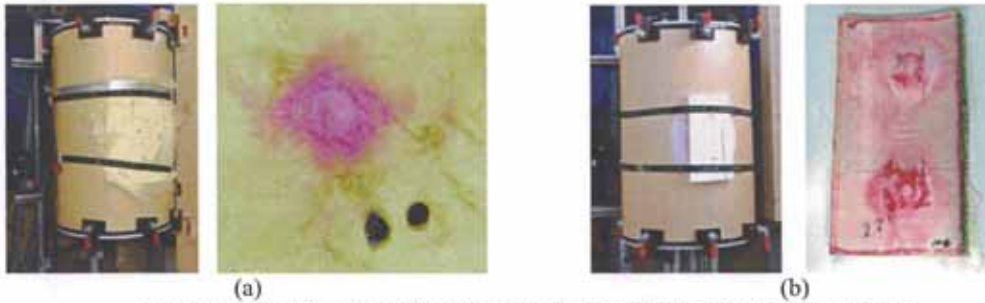


Figure 10. Test Setup and Backface Imprint for a) Soft and b) Rigid Armours

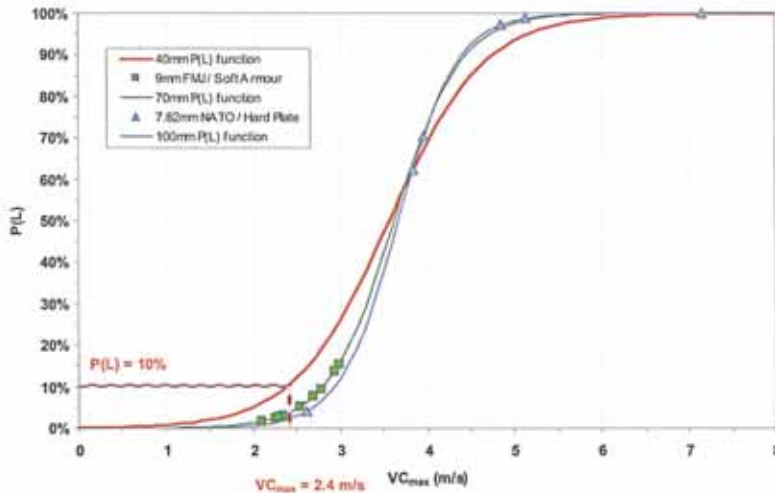


Figure 11. Lethality Prediction vs. BTTR Experimental Results

3.2 Proposed Head BABT Test Method

After establishing V_{50} or V_{proof} velocities for a particular projectile and helmet combination, the Ballistic Load Sensing Headform (BLSH) can be used for BABT assessment using the velocity that has a minimum probability of perforation.

The headform is positioned to align the target impact point with the centre load cell while maintaining perpendicularity with the line of fire as shown in Figure 12. A shot of the appropriate threat is then fired at the predefined non-perforation velocity. These steps are repeated for all impact locations (as per Section 2.1.2) and for the number of helmet samples required by the national authority. A typical test result is shown in Figure 13. The proposed parameter to quantify the associated risk of BABT is based on the total peak force.



Figure 12. Ballistic Load Sensing Headform Setup

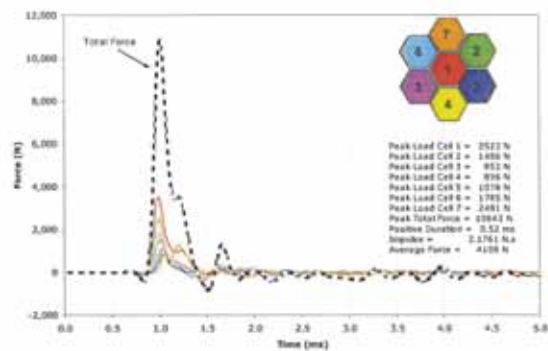


Figure 13. Typical Ballistic Load Sensing Headform Test Result (9mm FMJ defeated by combat helmet)

3.2.1 Signal Processing

The force signals are filtered with a low-pass zero-phase forward and reverse digital filter at a cutoff frequency of 4,500 Hz to keep only the components of the signals that are below the system resonant frequency. The sum of the force signals is calculated using Equation (4) to evaluate the total dynamic force applied on the load cell array. A series of parameters are derived from these signals to further characterize the impact response: positive duration, impulse, average total force (Figure 13).

$$Total\ Force(t) = \sum_{k=1}^7 F(t, k) \quad (4)$$

where k corresponds to the load cell identification.

3.2.2 Experimental Validation

The repeatability of the load sensing headform shown in Figure 14 was evaluated with eight different systems using the conditions established previously [17] that replicates helmet backface loading using a rigid plastic projectile (37 mm dia., 93 g).

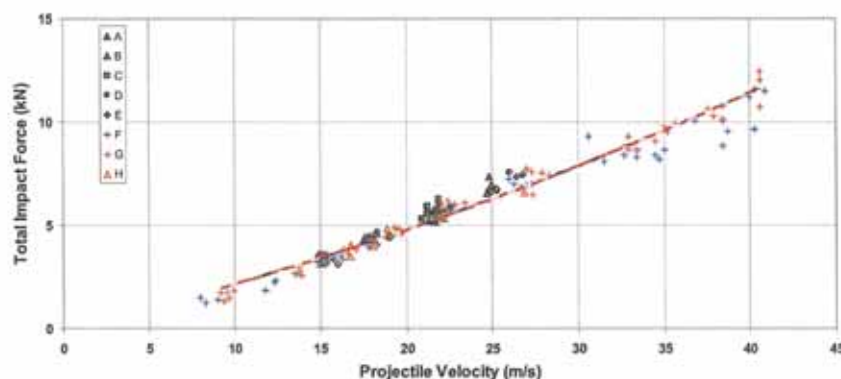


Figure 14. Total Force vs. Projectile Impact Velocity.

Using a similar approach as the proposed torso BAPT test method, the risk of skull fracture can be predicted with the Blunt Criterion (5) using the physical characteristics of the impact. The resulting blunt impact injury function was developed by Raymond [7] (Figure 15) using data from cadaver heads impacted

with a 38 mm dia., 100 g projectile at velocities ranging from 18 to 37 m/s. By combining the trend identified in Figure 14 to derive impact velocity and the Blunt Criterion (BC) skull fracture injury function, it is possible to establish the relationship between the BC and the total force measured by the load sensing headform, Figure 16. A peak total force of 6.0 kN (25% risk of skull fracture) is proposed initially as a threshold for head blunt trauma associated with ballistic impact. Here also, further validation will confirm the accuracy of the proposed threshold as it is based solely on data from direct impacts with a 38 mm dia. projectile. Future trials should include the helmet non-penetrating test conditions used by Bass et al. [5] to develop a skull fracture injury function for ballistic impact.

$$BC = \ln\left(\frac{mV^2}{2M^{1/3}TD}\right) \quad (5)$$

where m is the projectile mass in g, V is the projectile velocity in m/s, D is the projectile diameter in cm, M is the mass of the victim's head in kg (3.4 kg), and T is the combined thickness of soft tissue and skull at impact point in cm (1.3 cm).

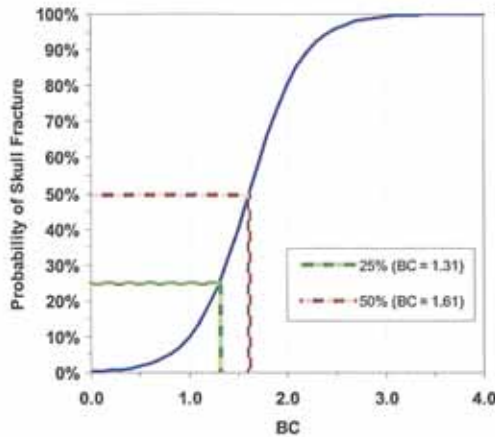


Figure 15. Probability of Skull Fracture based BC.

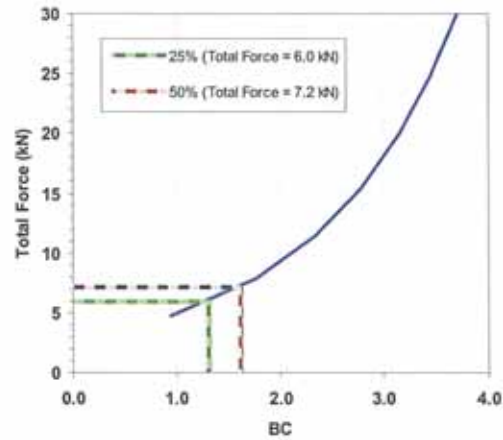


Figure 16. Total Force vs. BC for the 37 mm, 93 g projectile.

4. CONCLUSION

The group of experts working on the Edition 4 of STANAG 2920 has reached agreement on several aspects of the Standard. The main findings on shot pattern / impact location are given in this paper.

An important subject of discussion within the group of expert is the relevance of the Plastilina used for years to evaluate from the severity of behind armour blunt trauma. In an attempt to provide a more biofidelic assessment of the risk of BABT, alternative tools and criteria are proposed. For the torso, a test protocol and associated injury threshold is proposed for a cylindrical blunt trauma rig that uses the viscous criterion and the probability of lethality function developed by Sturdivan [15]. For the head, a ballistic load sensing headform is considered to assess the risk of skull fracture for non perforating impacts. The associated threshold is based on the blunt impact injury function developed by Raymond [7].

At this stage of development and considering the limited validation of the rigs, the new test devices are proposed to complement the current Plastilina method, not as a replacement. Improvement to the test devices are expected to address any technical issues identified by the users while the suggested criteria will need to be refined with further validations.

Acknowledgments

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