Development of a drop-mass test method for assessing the back face signature reduction potential of trauma attenuation backings

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Abstract. Larger-calibre sniper rifles have become a threat on the battlefield for hard armour designed to protect against less severe threats. Trauma Attenuating Backings (TABs) have been developed to reduce the Back Face Signature (BFS) generated by higher Kinetic Energies (KE) rifle threats; however, these TABs may not be used with the same armour for which they were designed. It is difficult to compare the relative BFS reduction potential of TAB systems, as there is no dedicated test method or associated performance levels. To partially address this gap, a guided-fall drop-mass test method was developed, in which a heavy steel impactor is dropped onto a TAB sample in the standalone condition, supported on a conditioned clay block to record the BFS. The striking KE and impactor diameter were adjusted to match the transmitted KE encountered during ballistics tests of hard armour inserts. The clay deformations observed from the drop impacts on a new rigid TAB model closely resembled the damage profile obtained from ballistics tests on a reference armour plate with the same TAB placed behind. The resulting BFS were characterized by measuring Back Face Deformation (BFD) and clay cavity volumes during the ballistics tests with the four TAB models. The novel TAB model was also tested with a second reference hard armour plate against a larger-calibre soft-core round, and the BFD obtained was substantially less than the threshold of 44 mm. However, the resulting clay cavity volumes were very large, likely leading to an underestimation of the actual injury severity. The relative performance ranking of the TAB models vs. the no-TAB case was then calculated using cavity volume reduction normalized by the TAB thickness. DRDC's VD^2 injury risk function was used to estimate the probability of AIS-3 injury, taking into account volume and BFD. Although the loading mechanisms involved differ between the drop-mass and ballistics tests, the same overall performance ranking was obtained for the four TAB models tested, with the two rigid models outperforming the flexible and semi-rigid models. The larger striking impulse during drop testing resulted in significantly larger cavities in the clay backing, highlighting one limitation of this method, which was primarily designed for quality control. The need remains for ballistic testing of TABs in conjunction with body armour, for which a reduction of BFS may be necessary for emerging higher-energy threats.

1. BACKGROUND: BFD OVERMATCHING FROM LARGER-CALIBER THREATS

The protection levels of soft and hard body armour are classified based on reference handgun and rifle threats, classified into protection levels. For each level, the armour must successfully withstand the specified projectiles at muzzle velocity (point-blank) while being supported on a clay backing to evaluate resistance to perforation (RTP) and back face deformation (BFD). The clay backing serves as a medium for recording BFD and representing the as-worn condition of the armour. Each protection level encompasses multiple projectiles, with one often chosen for its greater perforation ability and another selected for its greater capacity to deform the armour. RTP is typically assessed at a constant velocity (Vproof) using a series of non-perforating shots, with the BFD pass/fail criterion in clay set at 44 mm, as per the National Institute of Justice (NIJ) standard [1], which corresponds to an acceptable risk of injury [2]. The UK Home Office standard [3] is more stringent, with the BFD limit set to 30 mm. The VPAM German standard [4] also incorporates a performance criterion based on the maximum cavity volume in clay. In Canada, DRDC has investigated the use of an injury predictor that combines BFD and cavity volume (the VD2 model) [5], from which injury risk functions were developed. To address the limited medical foundation and correlation between clay-based BFD measurements and Behind Armour Blunt Trauma (BABT), numerous studies [6-8] have been initiated in recent years to enhance the understanding of the injury mechanisms involved and establish relevant injury metrics and tolerance limits. Improved laboratory methods, including physical models [9] and injury functions (e.g., viscous criterion and peak pressures), are also being considered and may eventually replace clay-based testing for body armour certification once performance thresholds are established. For soft armour, there are many cases of serious to severe BABT documented by the law enforcement community. On the military side, there are fewer cases, but BABT is still a concern, as reported during the conflict in Ukraine [10].

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The highest threat levels included in most test standards for hard armour are the 7.62x51mm and 7.62x54mm calibres associated with machine guns and sniper rifles. Larger-calibre threats, such as the 12.7mm and 14.5mm calibres, which are primarily used for anti-material defeat, are included in the VPAM standard. However, the newly introduced calibres (see Table 1), which bridge the gap between 7.62 mm and 12.7 mm, are not yet included in any body armour standard. Since the war in Iraq, there has also been a marked increase in the deployment of sniper rifles [11], with the newer, larger calibre rifles being able to kill unprotected soldiers at distances of up to 2 km. Projectiles for sniper rifles are typically designed with higher masses to lower velocity retardation and make them more incapacitating and lethal than lighter bullets which are designed to be more effective at shorter ranges. Even though armour-piercing (AP) bullets have been developed for larger-calibre sniper rifles, soft-core ball match rounds are more frequently used over the AP variants due to their greater accuracy and lower cost. Commonly used NIJ Level RF2/3 [12] hard armour inserts are capable of stopping these heavier and faster soft-core projectiles even at close range; however, the resulting backface deformation (BFD) will likely exceed the 44 mm BFD threshold, leading to potentially more serious injury. Figure 1 compares the Kinetic Energy (KE) of the projectiles of Table 1 as a function of range, where KE serves as a proxy for estimating the likelihood of BFS. For NIJ RF2/3 hard armour inserts, BFS overmatch could occur at distances up to 300 m when impacted by a 178-grain bullet fired from a .300 Win Mag rifle. For the .375 calibre projectiles, which possess nearly three times the kinetic energy of the 7.62mm M80 bullet at point-blank range, BFD overmatch could occur up to 800 meters.

Table 1. Comparison of larger calibre sniper rifles.

Calibre	Cartridge case capacity (mL)	Bullet weight g (gr)	Nominal diameter (mm)	Muzzle velocity (m/s)	Muzzle kinetic energy (J)	Muzzle kinetic energy density (J/mm^2)
0.223 NATO (5.56x45mm)	1.85	4.0 (62)	5.6 (4.6 core)	930	1730	71 (105 core)
0.308 NATO (7.62x51mm)	3.60	9.7 (150)	7.82	850	3504	73
0.300 Win Mag (7.62x67 mm)	6.10	11.5 (178)	7.82	945	5135	107
0.300 Norma Mag (7.62x63 mm)	6.75	14.9 (230)	7.82	915	6237	130
0.338 Norma Mag (8.59x63.3 mm)	6.95	19.4 (300)	8.6	830	6696	116
0.338 Lapua Mag (8.58x70 mm)	7.53	18.5 (285)	8.6	837	6372	111
0.375 Swiss P (9.5x70 mm)	NA	22.7 (350)	9.55	865	8492	119
0.375 Chey Tac (9.5x77 mm)	10.71	20.7 (320)	9.53	930	8952	126

The Kinetic Energy Density (KED) vs. range curves (Figure 1) follow the same trends as the KE curves but with a tighter grouping between the various calibres, still exhibiting a significant offset relative to the baseline 7.62 mm M80 round. KED is used as a proxy to assess the relative perforation capability of the projectiles. However, the diameter of the soft-core rounds expands significantly upon impact, making them much less penetrative (i.e., lower effective KED) than non-deforming hard-core bullets. At ranges below 800 meters, the potential for the BFD overmatch is likely much more substantial than the potential for the hard armour to be perforated by the heavier soft-core projectiles, since current RF2/3 hard armours are only constructed to comply with the 44 mm BFD limit from the projectiles' KE they are rated for. The resulting cavity volume in clay, which is related to the transmitted energy, typically increases more than the cavity depth when firing larger-calibre soft-core bullets on hard armour, which produce wider cavities. For spherical-cap-shaped cavities, the volume increases with depth raised to the third power and cavity diameter squared. There is then a risk of underestimating the resulting injury severity when using only BFD compared to measuring both cavity volume and depth. For coping with more severe injury risks from larger-calibre sniper rifles, one option would be to use current RF2/3-rated armour inserts with Trauma Attenuating Backings (TAB) engineered to prevent BFD overmatch.

Sondén [13] demonstrated that TABs can significantly reduce the size of lung contusions and peak thoracic pressures during tests conducted on live animals protected with hard armour impacted by 7.62 mm rifle projectiles. Additionally, the mean BFD in clay was decreased from 28 mm to 19 mm.

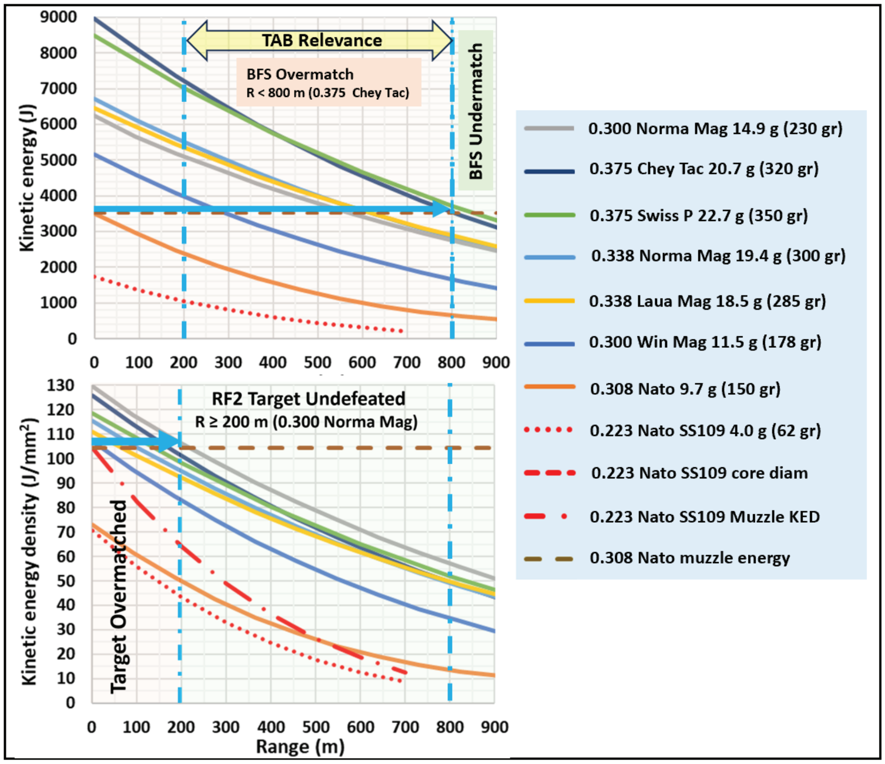

Figure 1: KE (upper graph) and KED (lower graph) of Table 1 projectiles vs range.

2. TAB SYSTEM REVIEW, SELECTION AND BFS MITIGATION ASSESSMENT

A detailed market survey of Commercial Off-the-Shelf (COTS) TAB systems was conducted to identify promising systems in the flexible, semi-rigid and rigid categories. TABs, often called anti-trauma liners, pads, or plates, utilize a combination of materials to absorb, dissipate, and redistribute the energy transferred from the armour. This process effectively reduces the deflection and velocity of the thoracic wall, thereby minimizing the risk of injury. Over twenty COTS models of non-ballistic TABs have been identified as being available online. Attractive marketing strategies are used to promote TAB products, such as claiming they would eliminate thoracic blunt trauma. Innovative materials for TAB, such as auxetic foams with negative Poisson's ratios and non-Newtonian materials (e.g., shear-thickening fluids and viscoelastic compounds), have been explored [14-16] to enhance impact energy absorption. The absence of a standardized BFS mitigation testing method for TABs, coupled with the lack of operationally relevant higher-calibre protection levels in current body armour standards, enables the promotion of TAB products with uncertain and potentially overstated performance claims, which may mislead end-users and explain their limited use. Also, since TABs are typically designed for a specific armour configuration and a designated threat level, there is no guarantee that an adequate level of BFS mitigation will be achieved for other body armour constructions and threat levels, leading to a risk of overestimating the actual protection provided. To address these deficiencies, it was decided to develop a repeatable laboratory test method that simulates the loading from ballistics tests and assesses the TAB relative BFS mitigation performance in the standalone condition, i.e., not in conjunction with a plate.
A test method that does not involve ballistics tests on hard armour plates would facilitate quality controls during the production of TABS and help end-users identify more promising TAB technologies.

Based on the survey results, the three most promising TAB systems available (models A, B, and C) were selected, and their properties (mass and areal density) are presented in Table 2. The desired performance criteria included a thickness of ≤ 6.5 mm, a weight of ≤ 250 g, full coverage, and curvature matching of the primary reference hard armour plate (RP1). The maximum TAB thickness and the plate curvature requirements for the TAB rigid models are essential to ensure that the plate inserts and the TAB fit well within the existing plate carrier while minimizing bulk. Although the flexibility feature of TAB Model A was appealing for conforming to the plate inner shape, it only covered 80% of the surface area of the RP1 plates, which were of medium size (25 x 30 cm) with a shooter cut profile. Since none of the COTS systems reviewed met the end-user requirements, DRDC initiated the development of a custom TAB model. After many concept and material iterations, the design successfully converged to TAB Model D, which met all the requirements while providing a high level of BFS mitigation for the principal reference hard armour plate insert (RP1) rated RF2+ [12]. The four TAB models were tested in conjunction with the RP1 armour insert (RP1) supported on a calibrated clay block as per ASTM standard E3004 [17]. The performance of TAB model D was also tested in conjunction with a secondary reference hard armour plate (RP2), also rated RF2+, using a single shot of a 0.338 Lapua Mag calibre ball bullet.

Table 2. TAB models, properties, and test results (AD: areal density, CV: cavity volume, n: repeats).

Target	TAB type	Thickness t (mm)	TAB AD (kg/m²)	Mean CV (ml)	Mean BFD (cm)	ΔCV/t (%/mm)	Prob AIS3 (%)
Ref. plate RP1 (n=10)	None	----	----	313.4	5.2	----	99.9
TAB A + RP1 (n=3)	Flexible	9.7	3.1	198.3	4.0	3.8	46.0
TAB B + RP1 (n=3)	Semi-rigid	6.8	2.6	178.6	4.1	6.3	39.8
TAB C + RP1 (n=3)	Rigid	18	5.0	127.6	3.3	3.3	5.5
TAB D + RP1 (n=8)	Rigid	6.5	3.7	146.1	3.6	8.2	11.1
Ref. plate RP2 (n=2)	None	----	----	240.5	3.5	----	37.8
TAB D + RP2 (n=2)	Rigid	6.5	3.7	156.4	3.0	5.4	5.7

Each plate and plate/TAB combination was impacted three times by the 7.62 mm rifle projectile, with a first left corner shot at 42 mm from the bottom left and the left edge, a second shot at 42 mm from the right edge and 75 mm from the plate bottom, and with the third shot near the crown area. The velocity of the 7.62 mm projectile was adjusted to ensure the BFD exceeded the 44 mm limit (i.e., 52 mm without TAB) for generating BFD overmatch conditions, thereby enabling the assessment of the relative BFS mitigation capability of the TAB models. The measurement of the three BFD depths in the clay backing was performed according to the procedures outlined in ASTM Standard E3068 [18], using a precision digital caliper, after completing the three shots on each plate. The cavity volumes were measured only for the crown shot using the water-filling method (Figure 2). Once the cavity was filled with the clay block levelled, the water was extracted with a syringe and transferred to a beaker, which was weighed using a precision scale to determine the water mass. The cavity volume was then computed by assuming a specific gravity of one for water. The test results are provided in Table 2 and Figure 3.

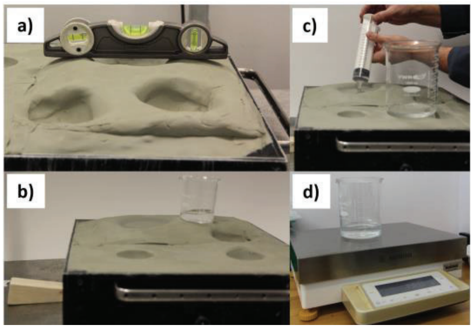

Figure 2: Water method for cavity volume measurement (right).

The BFD values reported in Table 2 are the mean values for the crown shots. The probability of AIS-3 injuries is calculated using the Injury Risk Function (IRF) given by Equation 1. This IRF [5] is referred to as the VD^2 model since it uses cavity volume (V) times BFD squared as the injury predictor. The IRF was obtained from the logistic regression of the Cooper test results [19] on live anaesthetized animals impacted at the anterior mid-sternum with rigid projectiles (ϕ37 mm, masses:140-380 g, velocities: up to 72 m/s) for cases leading to AIS-3 injuries. The risk of 50% AIS-3 injuries is estimated to occur for a $\boldsymbol{Vol{\cdot}BFD^2}$ value of 3280 cm^5, as shown by the solid purple line in Figure 3, where the red lines correspond to the VPAM criteria (harder and softer clays).

$$\boldsymbol{Prob(AIS3) = 1/(1+e^{(4.919-0.0015*Vol\cdot BFD^2)})} \qquad \textbf{Eq. (1)}$$

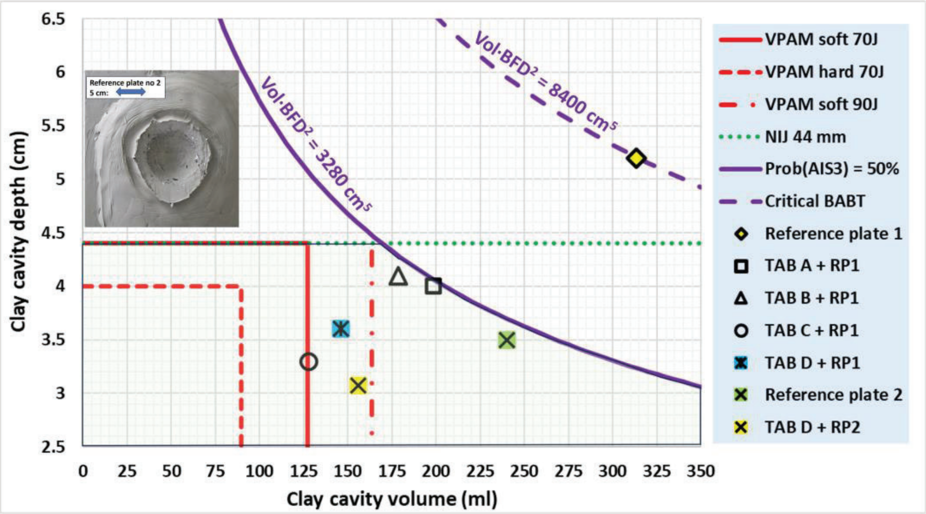

Figure 3: Clay cavity depths and volumes results compared to VPAM and NIJ requirements.

The Table 2 results indicate that all the TABs tested succeeded in significantly reducing BFD and cavity volume. However, TAB models A and B, flexible and semi-rigid types, respectively, were not as efficient for the corner shots. TAB model C was the one that provided the smallest cavity volume and the most severe VPAM requirement, but it exceeded the weight and thickness requirements. When normalizing the reduction in cavity volume over the TAB thickness, TAB model D performed the best with a cavity volume reduction of 8.5% per millimetre of plate thickness. As shown in the picture included in Figure 3, the post-impact clay cavity for the RP2 insert impacted by the 0.338 ball round is enormous, with a volume of 240 ml, despite having a BFD value of 35 mm, which is well below the 44 mm threshold. Such a cavity would likely lead to serious thoracic injuries and would be underestimated by the NIJ criteria. In comparison, the VD2 model predicts a notable risk of AIS-3 injury at 37.8%, which is reduced to 5.7% when wearing TAB model D. This highlights the benefits of being able to scale up the BFS mitigation level of in-service armour when high-intensity threat environments are anticipated.

3. DROP-MASS TEST METHOD DEVELOPMENT

A literature review was conducted on test methods and standards [20-26] for assessing the impact performance of chest protectors, which may also mitigate thoracic injuries and blunt trauma, as with the TAB. The relevant standards are summarized in Table 3. The review included older research work and more recent studies [6-8] where large-mass (100 to 200 grams) rigid impactors are launched with gas guns at low velocities (≈55 m/s) to reproduce the deformation profile of body armour impacted at high velocity (≈850 m/s) by low-mass (≈ 8 grams) small-calibre bullets. Gas-gun testing with rigid impactors is primarily used for performing tests with Post Mortem Human Subjects (PMHS) and Live Animal Subjects (LAS), as it does not require shooting bullets on actual armour, thus providing better repeatability. In a recent study, McMahon [7] observed that rib fractures occurred for impact energies exceeding 60 Joules with a 50% risk for impulses as low as 2.54 Newton-seconds (Ns).

Table 3. Laboratory methods for BFS studies and PPE tests (*maximum energies and impulses).

Study/standard	Launch method	Impactor shape	Mass (kg)	*Impact energy (J)	*Impulse (N·s)
Op't Eynde-Yogonandan: BFS	Gas gun	Spherical cap	0.214	306	11.4
Prather: BFS soft armour	Gas gun	Hemispherical	0.200	303	11.1
Arborelius: BFS hard armour	Gas/powder gun	Spherical cap	0.058	317	6.1
Bowen: Non-Lethal Weapons	Gas gun	Flat	0.196	350	11.7
Bir-Cooper-Whilhem-NATO AEP-99	Gas gun	Flat	0.140	112	5.6
CSA Z617-06 Torso PPE	Linear impactor	Hemispherical	1.460	75	14.8
HOSDB 20/07 2007 BT PPE	Guided drop	Bar & wedge	1.60	40	11.3
VPAM KDIW 2004 Stab/impact PPE	Free fall drop	Pyramidal	5.00	100	31.6
NOCSAE ND200-22 Chest protector	Gas gun	Lacrosse ball	0.15	36.4	3.2
EN 356 Security glazing	Free fall drop	Steel ball	4.10	370.0	55.0
EN 1621 Motorcycle armour	Free fall drop	Hemispherical	5.00	50.0	22.4

The gas-gun option was considered, but since it is more difficult to achieve reproducible impact conditions with no yaw and since not as widely available in independent test laboratories, it was decided to explore the drop-mass testing methodology currently used for assessing the performance of thoracic Personal Protective Equipment (PPE) and chest protectors. The approach consisted of adjusting the impactor's shape, mass, and energy levels to replicate loading conditions similar to those observed during the ballistics tests [6-8], but with the TAB tested standalone rather than in conjunction with a hard armour insert. Although numerous physical surrogates have been developed specifically for testing non-penetrating blunt ballistic impacts [27], it was decided to support the TAB samples on back-filled clay backings, as this approach was more straightforward and allowed for direct comparison with the ballistic results obtained. Due to limitations in drop height, the impact velocities achievable through drop testing are significantly lower (≈ 8 m/s) compared to those obtained with gas guns. Consequently, increasing the impactor's mass was necessary to achieve the required impact energy levels (≈300 J) that produce injuries comparable to those observed in gas gun studies using rigid indenters. Matching the impact energy with a higher mass and lower velocity results in more significant impact momentum, as illustrated in Table 3, which usually leads to much larger target deformation. The first drop-mass configuration implemented was a free-fall drop test (i.e. no guide tube or rail) inspired by the EN-356 standard, where a 4.1 kg (100 mm diameter) steel ball generates impact energies of up to 370 Joules. Due to ceiling height limitations, a larger and heavier steel ball (127 mm, 8.37 kg) was used instead, as shown in Figure 4.

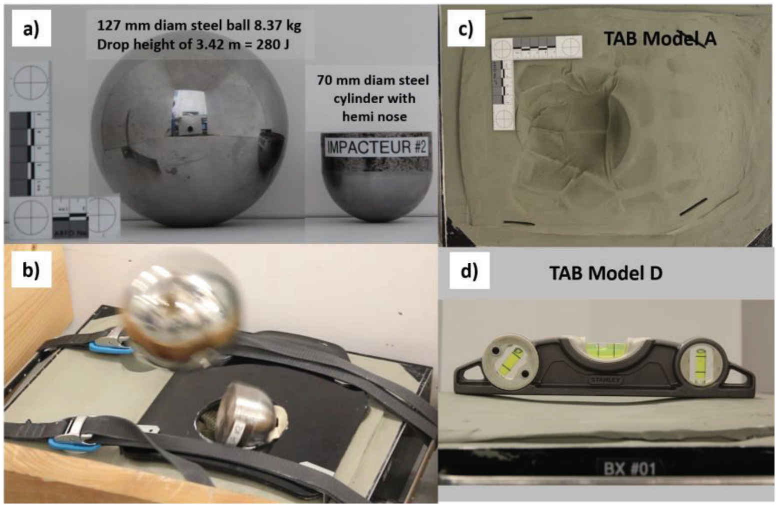

Figure 4: Drop tests with large steel ball and resulting clay cavities for TAB models A and D.

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The tests were performed on TAB Model D samples with a drop height of 3.42 m, resulting in an impact energy of 280 joules. TAB Model D was selected as the reference for comparing the post-impact residual TAB damage between the drop and ballistic test conditions. The BFDs in clay obtained with the TAB Model D samples were much smaller than those with the ballistics tests, and they did not sustain any permanent damage or residual deformation. The test configuration was then changed to make a ball-on-anvil drop where the 8.37 kg ball hit a hemi-nose cylinder of 70 mm diameter fixed at the impact point on the TAB sample, as shown in Figure 4b. This configuration succeeded in generating more localized deformations than the direct ball impact method, especially for the flexible and semi-rigid TAB Models (A and B), as illustrated in Figure 4c. However, it was quite challenging to make the large steel ball consistently hit the centre of the fixed anvil cylinder, leading to poor repeatability and unreliable outcomes. To ensure repeatable results, it was decided to adopt a guided free fall configuration (Figure 5) using the drop apparatus specified in the VPAM stab/impact [23] and NIJ stab standards [28]. The guiding assembly offers the benefit of maintaining vertical free-fall conditions with minimal friction, providing effective control over the impact point and angle, as well as excellent velocity reproducibility. Instead of using the large steel ball, the drop impactor was replaced with a hemisphere steel cylinder (30HRC) of 9 kg mass, enclosed within a plastic sabot, as in stab testing, to minimize friction. The impactor was also designed to allow the nose piece to be interchanged with different diameters (i.e., 50.8 mm and 63.5 mm) while keeping the same total mass (i.e., 9 kg). The drop tests were performed at energy levels ranging from 280 to 330 Joules. It was observed that the impactor with a 50.8 mm diameter nose, dropped from a height of 3.8 m, resulting in an impact energy of 330 Joules, produced sufficient localized blunt impact loading for the residual shape of the TAB Model D to closely match the post-impact denting profiles obtained during the ballistics tests as shown in Figure 6. For the 330 J drop impacts, the striking impulses are about 6.4 times larger than those achieved with gas gun tests (≈12 N-s). A much lighter impactor (i.e., 1.4 kg) would be used to match this impulse level with the same drop height, but with generating impact energies 6.4 times lower than those with ballistic impacts using a rigid indenter.

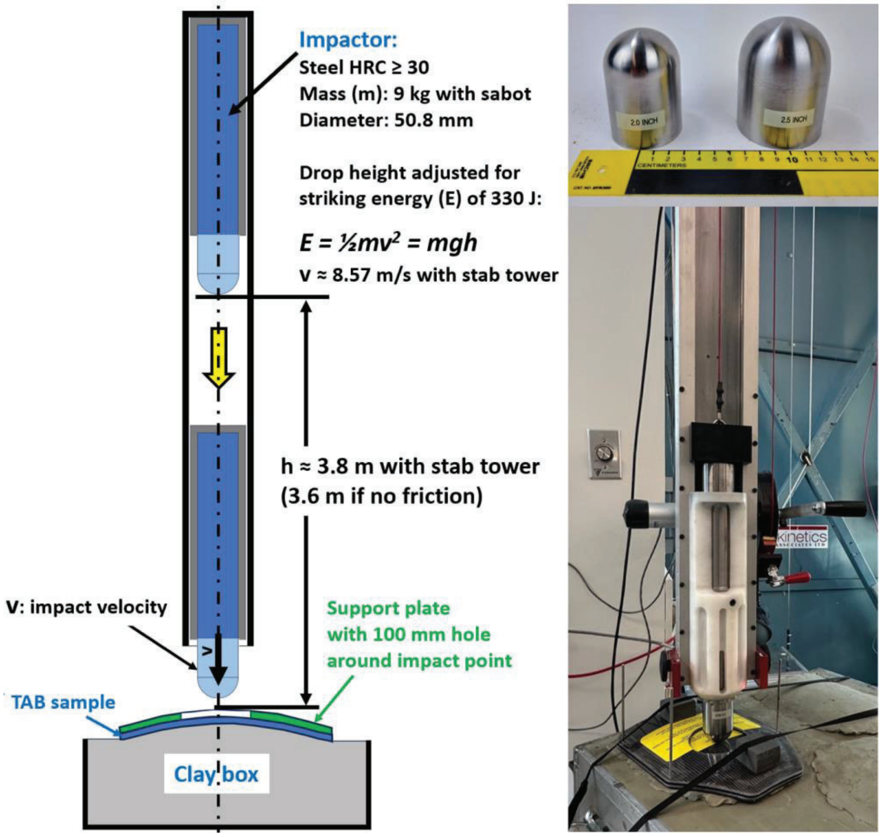

Figure 5: Final drop test setup with hemi-cylinder impactor striking TAB sample with support plate.

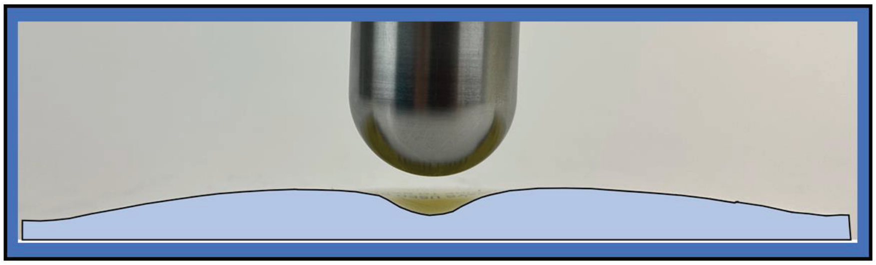

Figure 6: Denting profile of TAB Model D from 330 J impacts with the 50.8 mm diameter impactor.

For drop tests, the energy (E) to impulse (I) ratio (E/I) is independent of the mass, i.e., $E/I = 2.2 \cdot h^{1/2}$, while for gas-gun tests, the ratio is proportional only to impact velocity, i.e., $E/I = v/2$. Therefore, to achieve a match for 330 J impacts, a drop height of 160 meters would be required using the same impactor. Since the drop test method was intended for quality control of rigid TABs, such as Models C and D, replicating the post-test residual profile was used as the deciding factor for adopting a relevant impact energy level rather than matching the impulse level, given the limitations on drop height.

As shown in Figure 5, the TAB samples were supported by calibrated clay blocks shaped to follow the inner curvature of the reference plates used (RP1 and RP2), thereby reproducing the ballistic test conditions. Each TAB sample was impacted only once at the crown location. To more accurately replicate the TAB boundary conditions during ballistics tests, which are restricted by a hard armour plate, a support plate that corresponds to the shape of the hard armour plate was positioned over the TAB samples during the drop tests. A 100 mm diameter hole was incorporated into the support plate at the designated impact point (i.e., the crown location) to permit the impactor to pass through without obstruction. The support plate and the TAB samples were firmly secured to the backing material using two 25 mm wide webbing straps, one positioned near the top of the support plate and the other at the bottom. This configuration effectively prevented the edges and corners of the TAB sample from bending upwards during impact, particularly for the flexible and semi-rigid variants (TAB models A and B), while ensuring more realistic loading conditions. The support plate also incorporated four holes in each corner, allowing for the insertion of spike blades to mitigate any potential slippage of the support plate and TAB sample during impact by the heavy drop mass. After each impact, the TAB sample was removed from the backing material fixture and checked for penetration by the impactor. The resulting BFD in the clay backing was then measured relative to the original surface of the clay backing using a precision digital depth caliper, as illustrated in Figure 7. After each impact, the clay backing was smoothed out and reshaped to the original reference plate (RP1) curvature. The drop tests were repeated only once for COTS TAB Models A, B and C, with 5 repeats for TAB Model D.

4. DROP-MASS TEST RESULTS AND DISCUSSION

For TAB Model D, an average BFD in clay of 33 mm was obtained with the final drop test configuration described in the previous section, with the damage and residual denting profile (Figure 6) of the TAB samples being quite similar for both the drop impacts and ballistics tests since the drop test was designed this way. However, the resulting clay cavity shapes obtained for the four TABS tests were quite different between the drop and ballistics tests. When the TAB models were ballistically tested in conjunction with the hard armour plates, the profiles of the cavities formed in the clay backings followed a spherical cap shape, with the cavity diameters typically twice the cavity depths. In contrast, the resulting cavities were significantly larger for the drop tests on the four TAB models, especially for the flexible and semi-rigid TAB models A and B ($n = 2$), with mean cavity depths exceeding 100 mm, as shown in Figure 7. For the TAB Model D, although the cavity depths were similar to those of the ballistics tests (≈33 mm), the cavity shapes obtained were different, being larger and non-axisymmetric. TAB D is a rigid model, and the increased impact momentum from the drop tests may have caused the observed cross-folding, making the cavity volume measurement with the water method impossible. The maximum clay cavity depth for TAB Model C ($n = 2$) was larger (≈ 50 mm) and more localized than for TAB D but much smaller than those obtained with TAB Models A and B. TAB Model C sustained extensive damage, including a through-hole at the impact point.

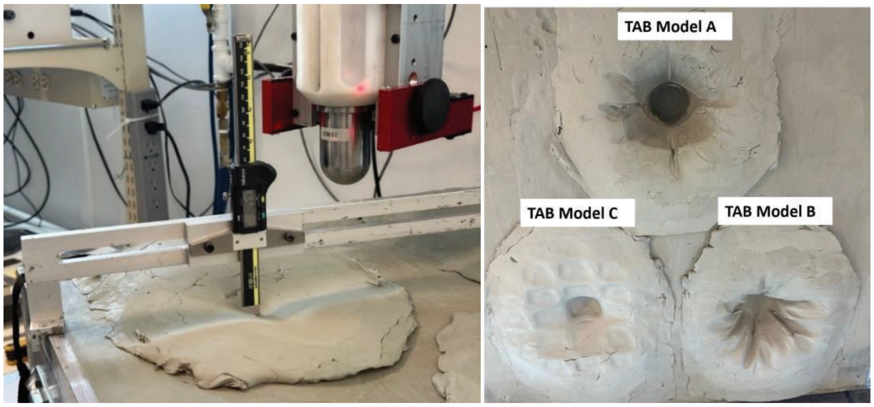

Figure 7: Cavity depth measurement of TAB D (left); clay deformations for TABs A, B and C (right).

Although the post-impact shapes and damages obtained differed, a similar overall qualitative performance ranking was observed between the drop-mass and ballistics tests. The results indicate that the rigid TAB models (C and D) provide increased BFS mitigation compared to the flexible and semi-rigid models tested (A and B) for both the ballistic (in-conjunction) and the drop test cases (standalone). The drop test method was shown to produce repeatable results with the TAB model D samples.

5. SUMMARY AND CONCLUSIONS

Larger-calibre sniper rifles (e.g., 338 Lapua Mag) are becoming more prevalent in military operations capable of producing BFD overmatch conditions at typical engagement ranges for hard armour plates engineered to provide ballistic protection against standard 7.62 mm NATO small arms. BFS mitigation can be achieved by using COTS TABs; however, the lack of standardized testing protocols and performance metrics limits progress in developing TABs optimized for BFS mitigation with reduced weight and bulk. The ballistics tests conducted with the four TAB models underscored the limitations of relying solely on BFD reduction in clay backings as the exclusive metric for BFS mitigation. Applying the VD2 injury risk function, which accounts for both clay cavity volume and depth, enabled more effective discrimination of the relative performance of the tested TABs. The drop-mass test method implemented as a complementary approach to ballistics tests, involving a 9 kg impactor striking with 330 J of energy, succeeded in replicating the localized deformation obtained with the TAB model D, used as a reference. For the three commercial TAB models tested (A, B, C), the damage incurred was more significant. The post-impact clay cavities were also notably larger, especially for the flexible and semi-rigid TAB models (A, B), which may be attributed to the greater impulse experienced during drop impacts and the extended duration of momentum transfer relative to ballistics tests. The challenges of simultaneously achieving both impact energy and impulse while under similar boundary conditions represent limitations of the drop-mass test method. Nonetheless, the proposed method can be used for initial performance assessments and primarily for quality control during production. There will always be a need to conduct ballistic testing with hard armour and the larger-calibre rifle threats expected on the battlefield, highlighting the need to update body armour standards to include larger-calibre sniper threats. One of the industry's challenges in assessing the performance of TAB systems through ballistic testing is the high cost of obtaining multiple hard armour samples, particularly when various models, sizes, and threat projectiles are required. Therefore, the capability to conduct some performance screening without the need for armour would be advantageous. Future research may investigate the application of novel physical torso surrogates recently developed [9] in conjunction with more relevant performance metrics for evaluating the effectiveness of TABs. Rigid impactors launched by gas guns could be explored in future studies; however, this approach also has its limitations, as it does not necessarily replicate the complex BABT loading mechanisms involved.

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