# UNDERSTANDING THE FEASIBILITY AND LIMITATIONS OF THE 3Pod2.0 FIRING METHOD IN BALLISTIC ARMOUR EVALUATION

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Advanced statistical tools and complex firing procedures are increasingly used in ballistic armour evaluation to leverage available data and maximize testing efficiency. 3Pod2.0 has been proposed as a next-generation firing procedure with tunable parameters for estimating the V50 and Vx of an armor system in a more efficient and accurate manner. Originally, simulation studies supported its use in terminal ballistics, and while it is not yet adopted in ballistic standards, recent studies have shown there is an interest by the ballistics community to apply the novel procedure. The present study explores the application of 3Pod2.0 in an experimental comparison to traditional up/down procedures for soft and hard armour. Key factors that must be considered when using 3Pod2.0 are discussed and compared to the requirements of up/down methods. The study uses V50 Assist™, a commercially available ballistics software, to perform analyses and walk users through the selected firing procedure.

## INTRODUCTION

Many common ballistics standards provide a standard methodology for the evaluation of perforation resistance of soft and hard armor systems, including two primary components: a firing procedure (e.g., test velocities) and the statistical assessment of ballistic limit (V50) and the perforation probability at other quantiles than 50% (i.e., Vx). V50 represents the velocity at which a specific threat has a 50% probability of defeating an armour system. The benefits of using this metric to assess the armour performance include the ability to compute a preliminary estimate with relatively few shots and characterize the consistency between test series for an armour type. V50 studies can also quantify the safety margin of the armor vs a reference proof velocity and are often used in quality control to ensure that the armor ballistic resistance remains the same from batch to batch. For these reasons, and the simplicity of the concept, V50 tests became prevalent in ballistic standards and purchase specifications. In real-world applications, the maximum velocity for which a projectile will not perforate (i.e., Vproof) is an equally important metric. Unfortunately, it is impractical to quantify this value directly as statistical significance could only be achieved with many shots performed at the Vproof velocity. Therefore, the approach prescribed in common standards such as NIJ 0101.06 and CAST 012/17 relies on V50 testing to build the perforation probability as a function of velocity to establish the V01 or V05 (velocities at which there is a small perforation risk), which must be greater than a threat-specific threshold [1], [2]. The difference between V01 or V05 and the acceptable limit specified in test standards is commonly referred to as the armour safety margin. Current methodologies specified in ballistic standards cannot reliably ascertain the tail ends of logistic regressions for many reasons, including the limitations of the firing procedure and the statistical assumptions required for extrapolating results to these lower velocities.

A test series consists of multiple shots of the same threat at different velocities to query the failure point of an armour system. The outcome of each shot is qualified as either a non-perforation (partial penetrations, PPs) or perforation (complete penetrations, CPs). For vehicle armor, a thin aluminum witness sheet is positioned a fixed distance behind the armour sample, where a hole in the witness material is interpreted as a perforation. For body armor, the sample is fixed onto a clay block to simulate the as-worn condition. The selection of the witness/backing material has been shown to influence the V50 value [3]. Although many other parameters can be measured for every shot (yaw, residual velocity, backface deformation, depth of penetration, etc.), the present study will focus exclusively on strike velocities and the associated binary outcomes.

Statistical methods are required to compute the V50 ballistic limit from a velocity-outcome dataset. The arithmetic V50 (MIL-STD-662F and AEP 2920§H1) is a trivial approach corresponding to the average of the highest *n* non-penetration velocities, and the *n* lowest perforation velocities [4], [5]. Standards may provide additional criteria, such as the *n* velocities must fall within a specified range or must be non-perforations, or that the first set of shots that satisfy the criteria are used with subsequent shots not affecting the V50. Alternatively, a logistic regression built on strike velocity and the binary outcome data can be used to predict the perforation probability for any velocity. Two-parameter link functions, such as Probit (AEP 2920§H3) or Logit (NIJ 0101.06), are used, as part of the logistic regression process to describe the resulting sigmoid curve often referred to as the Probabilistic Velocity Response (PVR) curve. The characteristics of these curves are proxies for traditional ballistic metrics [5] [1]. The slope is representative of the Zone of Mixed Results (ZMR), with a steeper slope indicating a greater overlap between the highest PP and lowest CP velocities. Importantly, not all link functions will converge if there is no ZMR. The selection of a link function will fundamentally alter the interpretation of the results. For example, the use of a Probit inherently assumes that the perforation probability follows a normal distribution. Both Logit and Probit are symmetrical distributions meaning the V05 will be the same distance from V50 as V95. Although their behavior is generally comparable near the V50 value, the two distributions vary more noticeably at the extremes. It may be difficult to justify the use of a symmetrical distribution when the underlying process may not be fully understood. Alternate link functions, including Gompit (complementary- or c-log-log), Scobit, and Weibull have all been proposed as multiparameter models that allow for a limited or unconstrained skew in the regression but have yet to be included in ballistic standards [6]. Certain link functions may have a non-zero perforation probability at the null velocity mark, which again may be difficult to justify physically. Logistic regressions are seldom used to their full mathematical potential in ballistic testing due to insufficient discussion regarding the tail ends of the curves and the importance of confidence intervals. The quality of the link functions and validity of the underlying assumptions may be assessed *a posteriori* using the Akaike information criterion, which quantifies the goodness of fit relative to the number of parameters in the regression model. More recently, an equivalent to a link function was proposed aiming to emulate the complex physics of ballistics, thereby not relying on assumptions regarding the probability distribution [7]. The collection of velocity-outcome data is as important as the analysis method.

Many firing procedures have been proposed to efficiently ascertain key ballistic resistance properties of an armour system. In many cases, the statistical tool used to compute the ballistic limit (V50) complements the firing method, often due to historical considerations when the methods or metrics were initially developed. Ballistic limit evaluations also require initial estimates for one or more parameters, such as the anticipated V50 value or velocity limits. The most trivial firing procedures may perform a fixed number of shots at equally spaced increments (delta/ladder) between the velocity limits or may require a specific number of shots to fall within equally sized velocity bins [8]. These methods produce outcome information over a range of velocities but may not provide sufficient data near the V50 value due to inefficient testing. The velocities of subsequent shots are based on velocity-outcome information of previous shot(s). For example, the up/down (Bruceton) firing procedure and its variants seen in NIJ 0101.06, MIL-STD-662F, and AEP 2920, increase the velocity for shots following a PP and decrease the velocity for shots following a CP (i.e., first reversal) [1], [4], [5]. Most standards specify starting the test series with the initial estimate of the V50 value but some studies have shown that starting with the lower estimate of the V50 can lead to a more conservative estimate [9]. The increment can be fixed or might decrease as the test velocities converge towards V50. Although up/down methods converge efficiently, minimal information is gained at the tail ends (i.e., V05 and V95), which has important repercussions when assessing the armour safety margin. The firing methods described above have histories in ballistics testing and predate the widespread availability of computers during testing.

The Modified Langlie procedure is a more involved method for which computer assistance may be required to repeatedly probe the midpoints between specified velocity limits or shots (e.g., lowest CP velocity and highest PP velocity) [10]. Again, this method focuses on velocities near V50 but does tend to query a wider range of velocities. Many other methods reviewed in [11], will not be discussed here except for the Neyer D-optimal procedure [12]. The method was novel in that it consisted of three phases: converging on the range of interest, enforcing a zone of mixed results, and D-optimal, which maximizes the information gained during every shot. More recently, Three Phase Optimal Design (3Pod) and its successor 3Pod2.0 also sequentially modify the testing objectives by establishing the zone of mixed results, refining estimates using the D-optimal method, then implementing a modified skewed Robbins-Monro-Joseph procedure to query a specific point such as the V05 [13], [14], [11], [12], [15].

The 3Pod2.0 procedure has been the subject of multiple simulation studies that compare the expected performance of various firing methods and is starting to be used for real-world testing but remains absent from ballistic test standards [11], [16], [17], [18]. It has been found to be more robust than either 3Pod or a variant of D-optimal (Sen-Test) [11]. A practical review of the method with considerations for the realities of ballistic testing and the impact on key properties such as the armour safety margin has not been performed so far. The present work addresses this knowledge gap and introduces a commercially available software package to walk users through all aspects of ballistic testing, including firing procedures, charge calibration, data analysis, and report generation.

## METHODOLOGY

A real-world assessment of protection metrics was performed using velocity-outcome data acquired using the up/down firing procedure from AEP 2920 and the

3Pod2.0 firing method [5], [11]. Two separate comparisons were performed to encompass most ballistic projectile types, i.e., 9 mm FMJ bullets fired at a multi-layered soft armour supported by a clay backing, and a small caliber round (5.56 mm C77) fired against steel armor plates. For this study, the number of layers, material, and areal density are not reported since the focus was on the methodology and comparison between the two firing methods for each material type.

## Firing Procedure

A single 3Pod2.0 test series with 32 shots (PI/PII: 24, PIII 8) was compared against two sequential up/down V50 studies (16 shots each) for the metal plates. Three 16-shot sequential up/down V50 studies and a 48-shot 3Pod2.0 series (PI/PII: 32, PIII 16) were similarly performed for the soft armors. The initial parameters for each study are provided in TABLE *I*. For the soft armor case, the quantile of interest was 5% as per the NIJ standard for assessing the armor safety margin. For the steel target, 98% was selected since the test was intended to evaluate the perforation/overmatch capability of the projectile (lethality test).

The 3Pod2.0 firing procedure implemented for this study is shown in [11], with a single modification to correct a possible error in the flow chart describing PI by changing one arrow to match the original formulation. The flow chart describing PI in the 3Pod2.0 definition ( [11]) has a line drawn from [$\sigma_g=2/3\cdot\sigma_g$] to [$x_{i+2}=m_1+0.3\cdot\sigma_g$] to [Update $m_1$, $M_0$, $k_0$, $k_1$]. This step was modified to match the original formulation [13] and at least two other sources [19], [14], by correcting the arrow to directly connect [$\sigma_g=2/3\cdot\sigma_g$] to [Update $m_1$, $M_0$, $k_0$, $k_1$].

## Measurement Devices

Velocity measurement was performed using a SpeedTube™ (Biokinetics and Associates Ltd., Ottawa, Canada), which contains two pairs of light gates and redundantly measured the projectile velocity approximately 2.5 m prior to impact. The drag method, described in AEP 2920, was used to compute the strike velocity in the SpeedTube™ software. Projectile total yaw was measured approximately 250 mm prior to impact using the YawBox™ (Biokinetics and Associates Ltd., Ottawa, Canada) to ensure the 3°/5° requirements specified in AEP 2920 were met.

A thorough measurement uncertainty analysis was conducted on the SpeedTube™ and YawBox™ using a procedure consistent with GUM (the guide to the expression of uncertainty in measurement) and ISO 17025. The expanded uncertainties (95% coverage level, normally distributed with a coverage factor of approximately 2) are ±0.12% for the SpeedTube™ and ±0.46° for FSPs with the YawBox™ [20], [21].

TABLE I. INITIAL FIRING PROCEDURE PARAMETERS.

| | Soft Armour | Metal Plate |
|---|---|---|
| **AEP 2920** | | |
| $V_0$ set 1 | 450 m/s | 980 m/s |
| $V_0$ set 2 | Probit V50 of 16 preceding shots in set 1. | |
| $V_0$ set 3 | Probit V50 of 32 preceding shots in sets 1 and 2. | |
| **3Pod2.0** | | |
| $\mu_{min}$ | 375 m/s | 950 m/s |
| $\mu_{max}$ | 475 m/s | 1080 m/s |
| $\sigma$ | 25 m/s | 25 m/s |
| $n_{i/ii}$ | 40 | 22 |
| $n_{iii}$ | 8 | 10 |
| $\lambda_{iii}$ | 1 | 1 |
| $\alpha_{iii}$ | 5 % | 98 % |

## Data Collection

Data collection for the present study was guided by V50 Assist™ 1.01 (Biokinetics and Associates Ltd., Ottawa, Canada), a commercial-off-the-shelf (COTS) software package that walks users through common ballistics testing from data entry to analyses and reporting. The software promotes traceability by providing a standardized analysis framework, including walking a technician through the selected firing procedure (e.g., up-down or 3Pod2.0), facilitating data collection, and performing advanced statistical analyses. Test series parameters, including details on the armour system and projectiles being used, can be saved for each test file. The minimal data entry required for every shot is the strike velocity and the armor penetration outcome (PP/CP). Many other fields are also included allowing to conduct a more complete analysis, i.e.: intended velocity, shot number, firing procedure step, yaw angle, validity (fair/unfair), use (include/exclude), number of layers perforated, backface deformation and volume, residual velocity, timestamp, and operator comments. The program assists the user in determining the next shot velocity based on previous shot velocities and outcomes according to several firing procedures, including up-down methods (STANAG 2920 and NIJ 0101.06), modified Langlie (MILSTD 662F), ladder/delta method, and 3Pod2.0. Key analyses, including lethality/survivability probability curves, undermatched and overmatched testing, and many other ballistic parameters, are automatically recomputed and displayed after every shot [22]. Additional parameters, not explicitly mentioned in ballistic standards that complement the analyses, are also computed. For example, two different types of confidence bands over the full range of test velocities are provided. Extensive validation and verification have been performed for many of the analysis methods implemented in the V50 Assist™ software. Many validation datasets are also integrated into the software and can be easily loaded to verify the various computing algorithms using test datasets from AEP 2920, NIST, and other published references, including [5], [22], and [23].

## Firing Method Phases Analysis Methodology

The main potential advantage of 3Pod2.0 over traditional firing methods comes from the specific construction of each of the three firing phases. The shot count required to produce a ZMR can be used to assess phase I. The efficiency of the D-optimal approach (Phase II) can be assessed by examining the convergence of the V50 confidence intervals and the resulting slope of the link function curves. Phase III, which targets a specific velocity (here, V05 for the soft armors or V98 for metal plates tested) and confidence interval, can be assessed by comparing the change in the estimates obtained after every shot.

## RESULTS AND DISCUSSION

Any differences in results produced by conducting ballistic testing using two firing methods may be directly attributed to the distribution of strike velocities and how they query an armour system. Figure 1 illustrates the key differences in shot velocities and outcomes for the up/down and 3Pod2.0 firing procedures for the soft armor and metal plate cases. The shots occurring in the first, second, and, if applicable, third up/down series (referred to as S1, S2, and S3) or Phases I, II, or III (referred to as PI, PII, and PIII) of the 3Pod2.0 procedure illustrate the progression of testing.

The distribution of shots in PI/PII/PIII were 14/26/8 and 14/8/10 for the soft armour and metal plates, respectively, while all up/down sets contained 16 shots (i.e., 16/16/16 and 16/16). The results presented in Figure 1 provide key insights into the two different firing procedures.

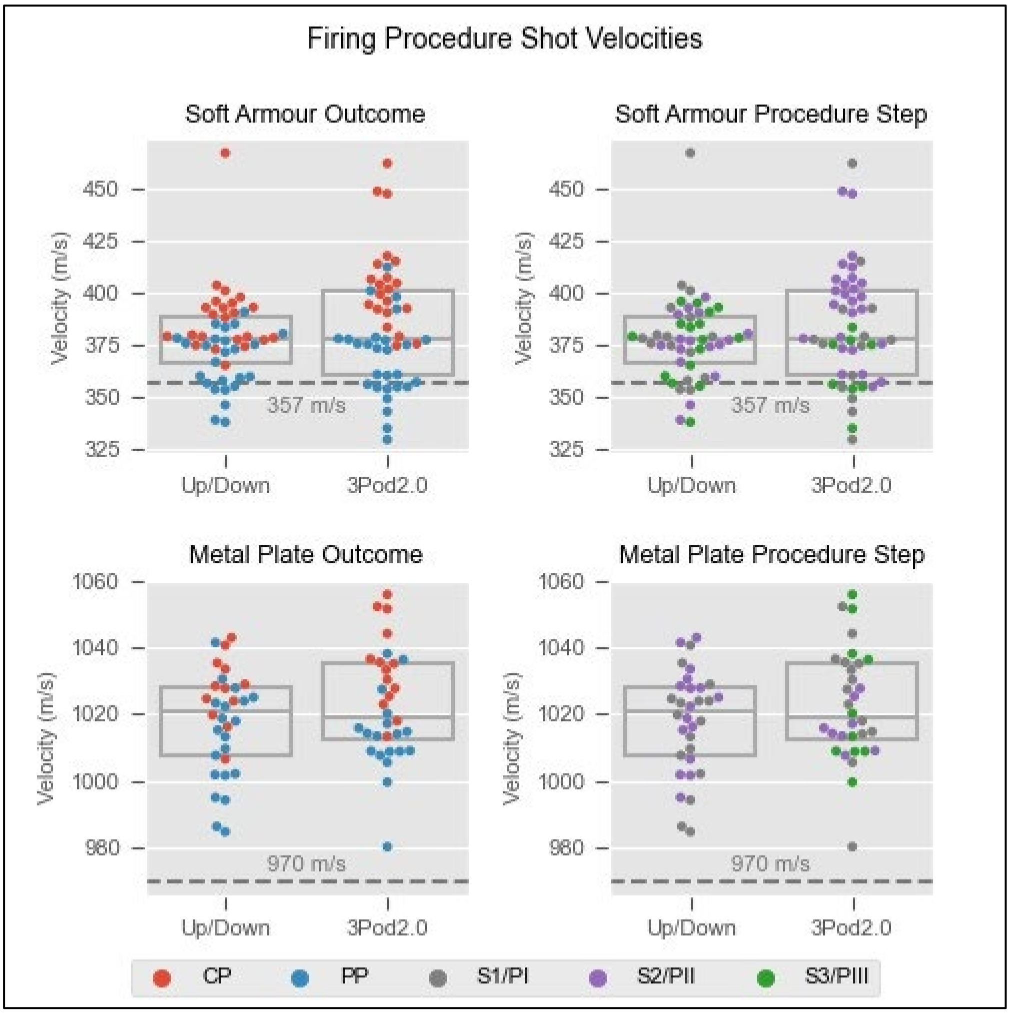


Figure 1. Shot distribution, outcomes, and series/phases in the firing procedures.

For the soft armour, the interquartile range (grey box) was much wider, and there are more distinct clusters at approximately 400 m/s, 365 m/s and 360 m/s. The groupings are also visible for up/down but are less spread out. As expected, approximately the same range of velocities was queried during each of the up/down firing series. 3Pod2.0 generated during Phase I more shots across the full range of velocities, Phase II mainly focused on increasing the reliability of the sigmoid curve slope, particularly at about 400 m/s with relatively fewer shots near the V50, and Phase III mostly queried lower velocities close to the targeted value of V05. Testing on the metal plate provided further insights; for example, the up/down procedure appears to follow more closely a normal distribution with few shots performed near the V50 value; on the other hand, 3Pod2.0 generated a multimodal distribution with fewer shots used to query at the V50 directly. This is contrary to typical strategies that are designed to make the tests converge on the V50 value with data points as close as possible to the final V50.

The results of Phase III in this study identified a possible limitation of the 3Pod2.0 method as implemented in [11]. For example, the PIII procedure describes increasing or decreasing the test velocities by a variable amount based on the outcome of the previous shot. Here, the first shot in PIII was much lower than expected (approximately 1000 m/s); therefore, rather than probing in the range of V98, many of the following shots did not directly probe the proposed intended velocity. There are consequently two choices when computing subsequent velocities in PII and PIII: either use the intended velocity and outcome for the shot (even if the intended and actual velocities are quite different) or use the strike velocity and outcome (even if the strike velocity is far from the intended velocity). The former approach was previously recommended for shatter-gap testing [24].

The original 3Pod and 3Pod2.0 papers do not differentiate between intended and actual velocity or propose limits on the acceptable discrepancies between these two values. This observation led to a discovery of equivalent behavior in Phase II, where the velocity that maximized the information gained according to the D-optimal procedure was, for example, 400 m/s. If the strike velocity on the next shot was not sufficiently close to the intended velocity (e.g., 380 m/s), the next velocity proposed by PII may have been very close to the original (e.g., 401 m/s). In theory, this error could lead to many superfluous shots that do not adequately follow the test protocol and could lead to several shots before 400 m/s is reached, at which time 3Pod2.0 may suggest a new velocity. In this case, it is prudent to repeat testing until a strike velocity is within an acceptable tolerance (e.g., 10 m/s) of the intended velocity.

If the intended velocity is not reached in PII, then maximum information gain was not achieved with the shots done. However, non-optimal information gain is nonetheless information gain, and the results should not be thrown away. Therefore, there are two possible approaches to handle these situations: continue as is, or bank the data temporarily. The first approach, which was followed in the present study, is to continue attempting to reach the suggested next velocities using the previous strike velocity data as inputs to the model (or in some instances, such as PIII, it makes more sense to use the intended velocity). Otherwise, if the strike velocity is far from the objective, keep the data in a separate databank and repeatedly attempt to reach an intended velocity until a strike occurs within a given threshold. Whenever a subsequent intended velocity is within an acceptable threshold of a previously banked test, use the banked data without repeating the test. At the end of testing or the end of PII, all banked shots should be appended to the dataset. The differences between these two approaches were not directly quantified in this study and could form the basis for future work on 3Pod2.0 (experimental or simulation).

Quantifying the differences and qualifying the effects of different firing procedures should not be limited to examining the shot velocity distributions; instead, variations in key injury-linked outcomes, such as perforation risk, should be considered by comparing the shape of the PVR sigmoid curves obtained from the logistic regression analysis. A key characteristic of these logistic regressions is the confidence interval describing the curve. Without adequately defined confidence intervals, it is impossible to perform reliable comparisons of the ballistic performance of different armour systems (i.e., assess statistical significance). Logistic confidence intervals, constructed from Wald's test for the present study, often require many shots before fully converging. With insufficient information, an upper probability confidence interval at low velocities and a lower probability confidence interval at high velocities may diverge, yielding invalid bounds on estimated metrics. Logistic regression coefficients and confidence intervals were automatically generated after every shot in each test series using V50 Assist™. The Probit V50 and confidence intervals are shown in Figure 2, along with the V05 for the soft armour and V98 for the metal plates. The blue confidence intervals (3Pod2.0) were computed successfully with significantly fewer shots than the up/down method shown in red. The confidence interval width and convergence characteristics showed significant differences between the two firing methods.

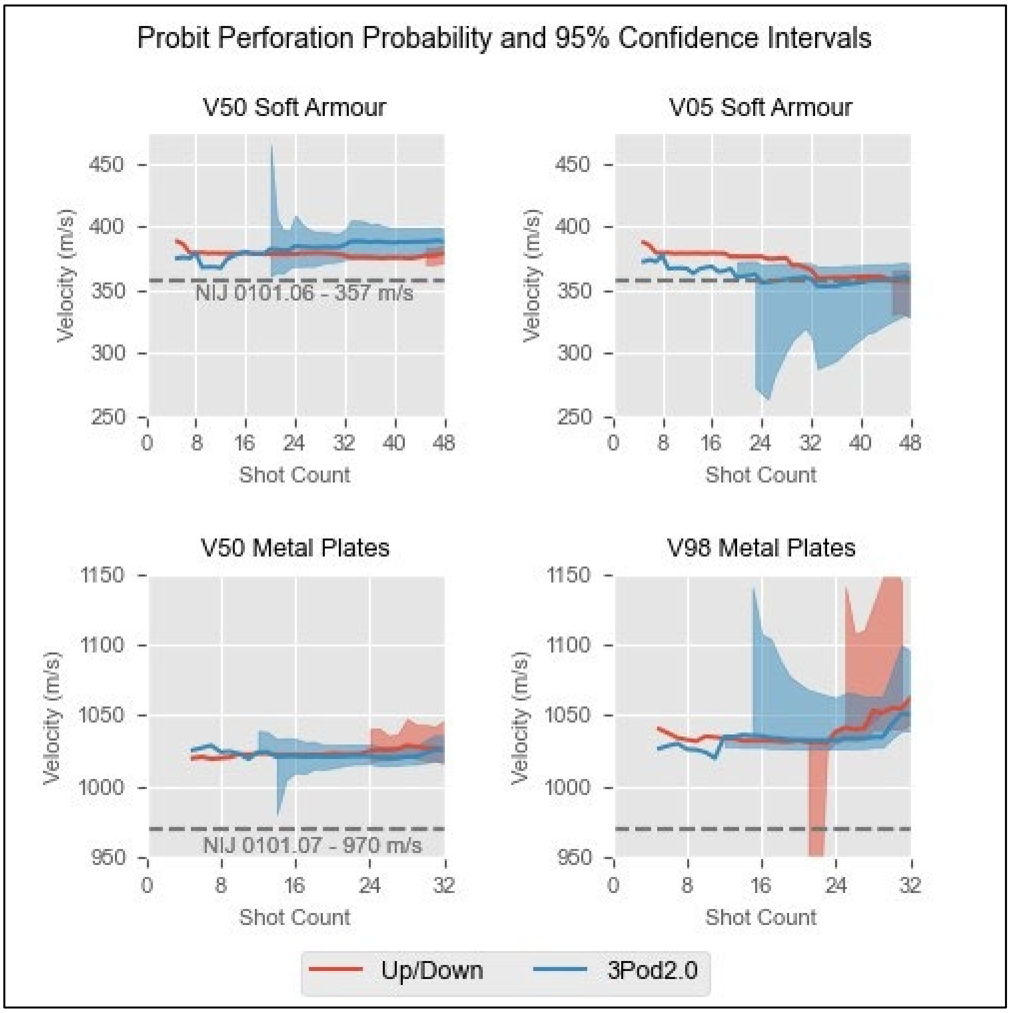


Figure 2. V50 and confidence intervals for soft armour and metal plates after every shot during tested according to up/down and 3Pod2.0 firing procedures. Only converged confidence intervals are shown.

The final confidence interval width was also generally tighter for 3Pod2.0 at the end of the test series. This indicates that despite the challenges in reaching the proposed intended velocities and different possible interpretations of the velocities (intended versus strike) to use to compute the next shot velocity (note the strike velocity should always be used in logistic V50 analyses), the results obtained with 3Pod2.0 are deemed much more reliable than up/down. In the cases shown here, there were small differences between the V50, V05, or V98 for the two firing methods. However, based on the confidence intervals obtained, any differences at the end of testing were not statistically significant.

Up/down firing procedures are generally predictable and, as the velocities generally converge towards the V50, producing a generally symmetrical velocity distribution around the V50. 3Pod2.0, however, inherently generates a skewed distribution of shot velocities, particularly if many shots are performed in PIII. It is therefore important to carefully consider the link function used in the logistic regression. With a generally predictable up/down procedure where an equal number of PPs and CPs is expected, and the spacing between shots is predictable, the use of a symmetrical link function such as Probit or Logit may be justified. With 3Pod2.0, it is difficult to justify a symmetrical link function because exploring the 5% perforation probability does not necessarily explain the complementary 9% protection probability due to the large difference in velocities and the potential effects of shatter gap or blunting gap. The larger the velocity difference, the less reasonable the symmetry assumption becomes. For instance, in one case, assuming symmetry between V40 and V60 may be valid, while in another this range may extend to V20-V80. A comparison of several link functions identified key small variations between Logit, Probit, and Gompit [22]. The greatest differences were observed at the upper and lower tails of the probability curves. Here, Gompit was proposed as a skewed link function that may be better suited to handle asymmetrical shot velocities. Figure 3 shows a few differences between Probit and Gompit for the two firing methods. First, 3Pod2.0 logistic regressions had a shallower curve, probably indicative of a wider ZMR and more overlap as expected when testing a wider range of velocities. The differences between the two link functions are most apparent at the left or right tails, particularly with 3Pod2.0, where more shots queried this range of velocities. Therefore, when assessing the armour safety margin, the user should also specify the firing procedure and link function. The difference between the V05 values from applying the Gompit and Probit functions was almost 20 m/s for the 3Pod2.0 procedure. While Gompit, which is the complimentary-log-log (or c-log-log), allows skewness at the lower end of the velocity range, the Gompit variant shown for the metal plates (Figure 3) is a log-log formulation. The log-log formulation allows for skewness toward higher velocities and is more representative of the case where PIII queries a velocity greater than V50. The difference between Probit and Gompit at the upper range of velocities is most obvious for the up/down method. The lack of difference for the 3Pod2.0 method may be due to the previously identified problems with interpreting intended vs strike velocity that led to multiple PIII shots far from V98.

The differences between the two firing methods may directly affect the armour safety margin (difference between Vproof and V05 perforation/V95 protection, for example). The armour safety margin is negative for the soft armour series when using the Gompit link function but is positive when using Probit. This indicates that the results and interpretations are highly sensitive to link functions. The projectile relative overmatch margin for the metal plate series, which for this study was calculated as the difference between V98 protection/V02 perforation and a specified reference velocity (970 m/s), is larger for the metal plates when using Gompit.

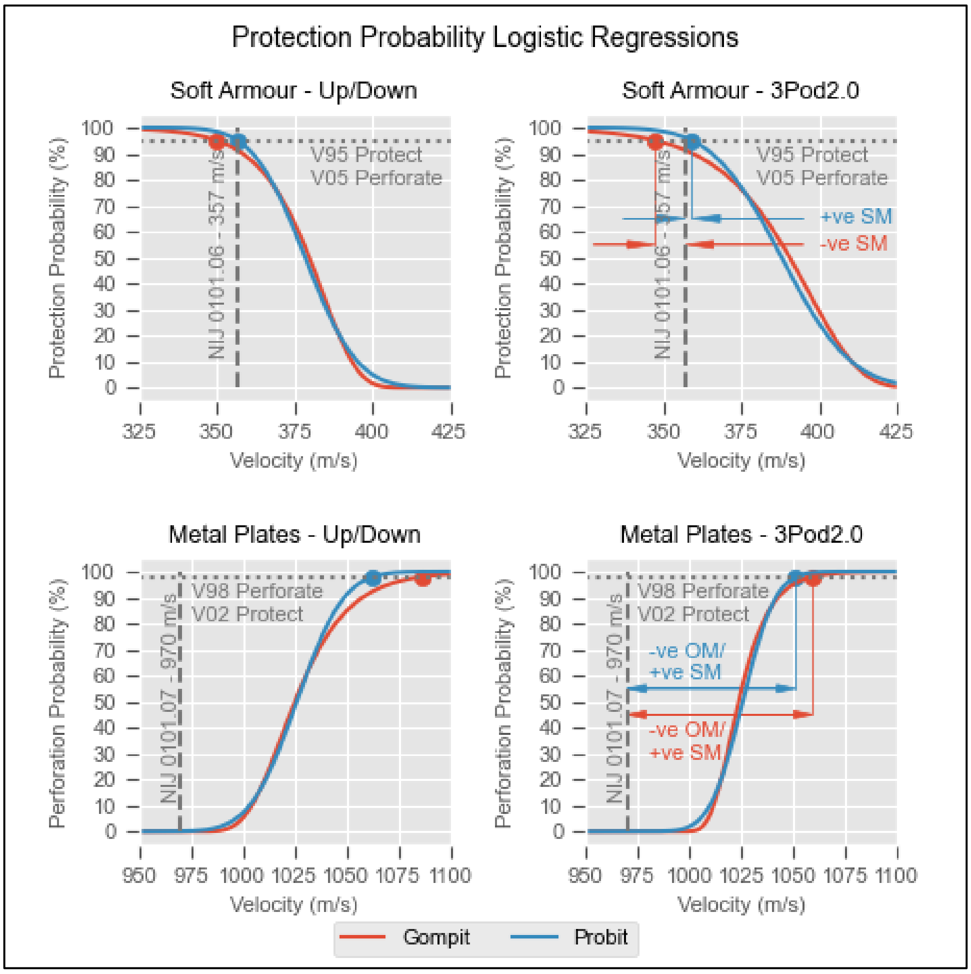


Figure 3. Logistic regressions with two different link functions for the soft armour system tested according to the up/down and 3Pod2.0 firing procedures showing the Armour Safety Margin (SM) and Projectile Overmatch Margin (OM).

Regardless of the link function, assumptions are being made regarding the perforation probability and the physical processes at play. Generally, making fewer assumptions is better. For this reason, perhaps a new link function based on physical ballistic properties (such as the Brownian approach in [7]) should be integrated into a new formulation of 3Pod for ballistic testing to provide the best possible results. Alternatively, a quality of fit metric such as the Akaike Information Criterion (AIC) can be used to justify the selection of a link function over another. Link function selection cannot be performed retroactively and must be set before PII and PIII.

## CONCLUSION AND RECOMMENDATIONS

The present study was one of the first experimental assessments of the 3Pod2.0 method focusing on providing insight into its implementation during ballistic testing with a focus on its practical limitations and considerations. This study identified potential improvements and important aspects that must be considered before routine use in body armor testing. First, PII and PIII are optional since an estimate of the V50 is guaranteed by the end of PI [14]. However, in a single 3Pod2.0 test series, multiple PIII sets could be performed, each querying a different perforation probability. For example, after performing PI and PII, a 10-shot PIII could be performed at V05; then, another 10-shot PIII could query V95. A method such as this could help determine the ideal link function for a given material by providing significantly more information at both tails. The D-optimal procedure maximizes the potential information gained from every shot. The procedure uses the Fischer information matrix, which is constructed from the partial derivatives of the likelihood with respect to regression parameters for the logistic link function. Therefore, the procedure will be different if using Logit or Probit. The final consideration presented herein concerns how discrepancies between intended and strike velocity should be treated. For example, in PII, if it takes multiple attempts to reach an acceptable velocity (± X m/s from the intended velocity), there are two options: add the non-optimal shot immediately or add the shot to a bank of shots that can be used in place of future tests. If implementing the latter method to reduce bias, a first-in-first-out approach should be used. For each new intended velocity, iterate through all banked shots, taking the first shot on the list that is within the acceptable tolerance of the intended velocity, add this shot to the main dataset and remove it from the bank. At the end of PII (or PIII), all remaining bank shots should be added to the dataset. PIII must also be treated carefully because there is more susceptibility to incorrect shot velocities biasing subsequent shots. For this reason, it is recommended that the intended velocity when determining the next shot velocity as suggested by [24] for shatter gap testing.

The most significant advantage of the 3Pod2.0 method was the faster computational convergence of the confidence intervals. Bounds on the logistic regression curves (at V50 and V05/V98) could be computed with many fewer shots than for the traditional up/down firing procedure. The increased confidence in results is key when determining when to stop testing; for example, AEP 2920 specifies a stop criterion when the width of the 95% V50 confidence interval is less than 4% of V50. Here, 3Pod2.0 would have required fewer shots and reduced testing costs.

As data processing (i.e., perforation metrics) and firing procedures become more complex and cannot be implemented in simple spreadsheets, test facilities can significantly improve their workflow by combining data collection and firing procedures with real-time results computation as performed with V50Assist™.

## DISCLOSURE STATEMENT

The primary author is a paid employee of Biokinetics and Associates Ltd., which developed V50 Assist™, the commercially available software package used herein. The methodology presented in this study could be performed with other software or analysis packages and are not exclusive to V50 Assist™.

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