TEAM WENDY®

MEASURING BALLISTIC PERFORMANCE

HOW TO ASSESS MAXIMUM BALLISTIC PROTECTION

SUMMARY

The most protective ballistic helmets are vetted by test methodologies with greater consideration for resistance to penetration than clay (or other soft material based) backface deformation measurements. This is supported by findings from the U.S. Department of Defense (DoD); this research has led the department away from including backface deformation requirements in its procurement and evaluation process and in updated test protocols. Ballistic helmets engineered with modern polyethylene materials and comprehensive penetration testing will increase survivability against projectiles, fragmentation and other ballistic threats.

BACKFACE DEFORMATION

Backface deformation (BFD), also referred to as backface signature or ballistic transient deformation (BTD), is the greatest extent of indentation in the backing material caused by a non-perforating impact on the armor. When testing helmets per Director of Operational Test and Evaluation (DOT&E) methodology, the helmet is mounted on a clay headform. The BFD is the maximum depth of the indentation left in the clay as a result of the test shot.

Backface deformation on its own is not an accurate measurement of energy transfer to the skull, nor does it predict potential for brain injury. The medical research community that develops injury thresholds for designing PPE widely acknowledges that there simply is no biomechanical link between the BFD assessment and head or neck injury, and the ways in which clay-based testing can incorrectly predict injury risk continues to be an active area of research. At the 2022 Military Health System Research Symposium (MHSRS), researchers from Duke University presented on "The Severe Limitations of Clay for Assessing Human Response for Behind Armor Blunt Trauma."

First, clay is an imperfect recording medium for helmet testing. There is no scientific study that links clay deformation to head injury. Clay was first used as the backing material for ballistic vest and body armor testing to assess abdominal injury under NIJ Standard 0101.06, but it is not a faithful representation of the human body, nor has it been shown as a reasonable medium for assessing cranial damage.[1] Other standards, such as VPAM, test using ballistic soap, though little is known about the accuracy of its biomimicry of the head.

> *"Neither the clay backing material nor the backface signature depth measurement reflects characteristics of the human torso or its response to ballistic impact. The clay backing material provides a medium for making BFS measurements."*
>
> NIJ Standard-0101.06

The NIJ body armor standard does not allow for BFD to exceed 44 mm; in its most recent body armor product descriptions, the U.S. Army has raised the maximum allowable BFD based on operational assessments, further indicating the lack of real injury correlation between historical BFD values and critical injury.

NIJ dictates the only nationally accepted standard for the ballistic gear worn by law enforcement and corrections officers in the U.S.[2] For DoD helmets tested through DOT&E methodology, the U.S. Army and U.S. Marine Corps place thresholds at 25.4 mm for test shots at the front and back of the helmet and 16 mm at the side and crown. These values do not have a scientific basis and are based on testing precedent rather than TBI potential.[1]

The Committee on Review of Test Protocols Used by the DoD to Test Combat Helmets and the Board on Army Science and Technology, in conjunction with the National Research Council, concluded after conducting an independent review of DOT&E's evaluation protocols that it is unclear whether the current definition of BFD is the most appropriate for assessing the protection level of a helmet: rather than maximum depth, deformation area, volume or some other measure may be better suited. They also included the following in their published findings:

> *"The usefulness of the helmet FAT and LAT test data on BFD is limited. The data can be used for assessing helmet performance against the requirements in the purchase description and the DOT&E helmet testing protocol; the results can also be used to compare helmet performance within and between manufacturers and over time. But the data cannot be used to determine the level of protection provided by a new helmet that is designed and manufactured according to a different set of specifications. This becomes critical when assessing the protection offered by new helmets because there are trade-offs between penetration, BFD, and other helmet characteristics, such as weight, form, and fit."*

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RESISTANCE TO PENETRATION

Resistance to penetration (RTP) is measured by shooting a ballistic projectile at a set of helmets and counting the number of complete penetrations. A complete penetration, also called perforation, is evidenced by the presence of the projectile or a projectile fragment in the clay backing material and/or by passing through the shell and headform. Any fair impact that is not a complete penetration is referred to as a partial penetration – the subject of BFD measurement.

> *"According to personnel from the Army Test Center, there is currently no practical way to determine or measure the degree or depth of penetration, and thus helmet penetration testing is currently attribute-based … The intuitive notion is that a projectile that penetrates the shell is apt to cause more serious head injuries than a projectile that does not … It is not known whether partial penetrations might be reasonably and usefully measured in order to assess the degree to which a non-perforated helmet is penetrated."*
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> Review of Department of Defense Protocols for Combat Helmets

A related, internationally recognized measure of ballistic performance is the **V50 ballistic resistance** against the 17-grain fragment-simulating projectile. A V50 measurement helps gauge the limits of a product's protection: it is the projectile velocity at which there is a 50% chance of penetration. Evaluation of the V50 ballistic resistance of different helmets is only valid when testing against the same threat; the 17-grain, .22 caliber FSP is the most used projectile for this specification worldwide.

V50 testing uses a witness plate mounted inside the helmet with a clamping fixture to assess penetration. A perforation of the witness plate resulting in a crack or hole that permits light to pass through is counted as a complete penetration. NIJ Standard-0106.01 for ballistic helmets dictates a witness plate test procedure in which penetration at any of the four test locations on the helmet shell results in failure.[3]

Given that bomb fragments do not have a known or specified velocity, protection from fragmentation is best determined using V50. Further, the variation in bullet velocities leads us to recognize that a helmet with a higher V50 provides inherently more protection against a range of threats, including handgun and rifle rounds. Therefore, a helmet's V50 rating provides a comparative ballistic performance specification.

POLYETHYLENE VS. ARAMID POLYMERS

Para-aramid polymer technology (e.g., Kevlar®) was first used by the U.S. Army in the mid-1980s in the PASGT helmet. It was eventually replaced with the development of high-molecular weight polyethylene ballistic fibers in the late 2000s. The reduced equipment weight and increased ballistic capability has made high-density polyethylene the basis of future Army helmet technology.[3]

FIGURE 1

A helmet constructed from aramid polymer (left) weighs more than a helmet made with high-molecular weight polyethylene (right) while offering less RTP. The aramid helmet on the left has a 17gr V50 = 630 m/s (2,066 ft/s) and a complete system weight of 2.37 kg (5.21 lbs). The Team Wendy EXFIL® Ballistic SL on the right has a 17gr V50 ≥ 731 m/s (2,400 ft/s) and a size M/L complete system weight of 1.01 kg (2.22 lbs).

The materials used to construct a ballistic helmet must be flexible enough to support sufficient backface deformation to prevent complete penetration. Tightly layered and stitched materials, such as aramid, cannot easily flex to catch a projectile and disperse the impact energy, leading to increased chances of penetration at higher velocities. Imagine hitting a tennis ball into the net on the court versus serving it into a window screen: the flexibility of the net allows it to catch the projectile rather than letting it tear through.

When it comes to assessing BFD performance between aramid and polyethylene helmets, evaluations based on material as the sole variable aren't straightforward. As mentioned in the committee findings on page 3, the trade-offs between other characteristics, such as weight, form and fit – all of which are influenced by material – negate analysis based on one test measurement.

PROTECTION IN THE FIELD

The Army gathered 77 helmets hit by small arms bullets during combat operations in Iraq and Afghanistan. Nearly three out of every four soldiers with a perforated helmet died. Every soldier with a partially penetrated helmet survived with relatively minor head/neck injuries. They all eventually returned to duty as well.

FIGURE 2

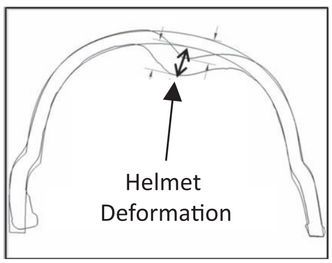
Recovered Battle Damaged Helmet Data

- **77 Helmets collected:**
  - All resulting from Small Arms Fire
  - 31 engagements resulted in wounded-in-action soldiers
  - 45 engagements resulted in killed-in-action soldiers

Ballistic Results	Total #	Wounded-in-Action	Killed-in-Action	Fatality %
Partial Penetration	16	16	0	0%
Complete Penetration	61	15	45	73.7%

- Analysis:
  - **If a helmet stopped the bullets, the soldier had a very high probability for survival**
  - 0% fatality rate for partial penetrations
  - For partial penetrations, no serious behind helmet blunt trauma reported and no serious neck injuries reported
  - 73.7% fatality rate for complete penetrations

Helmet Deformation (mm)	Ballistic Result	Injury Summary
4.29	Partial Penetration	Ranged from no injuries to minor injuries and eventual returned-to-duty
1.52	Partial Penetration	
15.61	Partial Penetration	
15.25	Complete Penetration	
2.07	Partial Penetration	
0.48	Partial Penetration	
10.34	Complete Penetration	
1.42	Partial Penetration	
23.98	Complete Penetration	
5.32	Partial Penetration	
14.99	Complete Penetration	
13.68	Complete Penetration	
7.41	Complete Penetration	
9.66	Complete Penetration	
3.02	Partial Penetration	
15.99	Complete Penetration	
2.41	Partial Penetration	
3.53	Partial Penetration	
9.53	Partial Penetration	
15.78	Complete Penetration	
6.49	Partial Penetration	
11.04	Complete Penetration	
9.22	Partial Penetration	
10.12	Partial Penetration	
6.64	Partial Penetration	
17.22	Complete Penetration	
9.79	Complete Penetration	
13.93	Complete Penetration	
0.88	Partial Penetration	



Average helmet deformation depth = 9.02 mm

Note: This data is not representative of actual deformation experienced by operators in action but comes from deformations reviewed after action. Source: "Protecting American Soldiers: The Development, Testing, and Fielding of the Enhanced Combat Helmet (ECH)"

It's important to note VPAM protocols and test requirements currently set by some DoD branches require test shots strike at 0% obliquity (in other words, straight-on) and at a specified distance. A perpendicular headshot in close combat is the worst-case scenario. In combat, shots are normally fired at considerable distances and varying angles.

Meeting basic BFD requirements still ensures the structural integrity of the helmet shell; however, unjustified focus on exceeding BFD standards is prompting some manufacturers to design unnecessarily heavy helmets that ultimately provide less penetration protection. After reviewing operational field data and independent studies, the U.S. Army is moving to drop BFD requirements from its procurement and evaluation process.

> *"There is no biomechanical link between the BFD assessment in the current test methodology and head injuries from behind helmet deformation."*

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CONCLUSION

Much of the way backface deformation is measured and evaluated is not based in scientific comparisons to the human head and potential for traumatic brain injury. Helmets that can offer increased protection from penetration without sacrificing a comfortable fit for the operator are the head protection of the future.

REFERENCES

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