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## 14. ABSTRACT

The relative armor penetration ability of different kinds of projectiles is of general interest from both offensive and defensive viewpoints in law enforcement and military applications. This paper presents data on armor penetration of four different projectile types (all in 5.56mm NATO) on both 6.35mm thick steel plate (A36) and proprietary glass/aramid composite armor. The bullet penetrating steel plate most readily was the M855 bullet which has a steel penetrator core. This bullet had a V50 of 1992 ft/s. The second best penetrating bullet in steel plate was the jacketed lead core M193 bullet with a V50 of 2240 ft/s. The solid copper bullet had a much higher V50 in the steel plate at 2514 ft/s. The solid brass bullet was the worst penetrator in the group with a V50 of 2612 ft/s in the steel plate. The relative penetration ability was different in the composite armor. The best penetrator was once again the M855 bullet with a V50 of 1945 ft/s. However, the second best penetrator was the solid brass bullet with a V50 of 2868 ft/s. The third best penetrator was the solid copper bullet with a V50 of 2960 ft/s. The worst penetrating bullet in the composite armor was the jacketed lead core M193 bullet with a V50 of 3049 ft/s.

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# Relative armor penetration of jacketed lead, solid copper, solid brass, and steel core bullets

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**Abstract**
The relative armor penetration ability of different kinds of projectiles is of general interest from both offensive and defensive viewpoints in law enforcement and military applications. This paper presents data on armor penetration of four different projectile types (all in 5.56mm NATO) on both 6.35mm thick steel plate (A36) and proprietary glass/aramid composite armor. The bullet penetrating steel plate most readily was the M855 bullet which has a steel penetrator core. This bullet had a V50 of 1992 ft/s. The second best penetrating bullet in steel plate was the jacketed lead core M193 bullet with a V50 of 2240 ft/s. The solid copper bullet had a much higher V50 in the steel plate at 2514 ft/s. The solid brass bullet was the worst penetrator in the group with a V50 of 2612 ft/s in the steel plate. The relative penetration ability was different in the composite armor. The best penetrator was once again the M855 bullet with a V50 of 1945 ft/s. However, the second best penetrator was the solid brass bullet with a V50 of 2868 ft/s. The third best penetrator was the solid copper bullet with a V50 of 2960 ft/s. The worst penetrating bullet in the composite armor was the jacketed lead core M193 bullet with a V50 of 3049 ft/s.

Key words: armor penetration, brass, copper, full metal jacket, steel penetrator

**Introduction**
V50, a standard metric for quantifying armor performance, is the velocity at which a specific projectile penetrates a given armor 50% of the time. There is very little data available regarding the armor penetration ability of bullets made of different materials, especially copper and brass bullets. The purpose of this experiment is to test the relative armor penetration ability of bullets of four different materials in two different types of armor, plate steel and fiber composite. A lower V50 means that a bullet has better penetrating ability in a given armor, because it will penetrate the armor at a lower impact velocity. A higher V50 means that a bullet has a worse penetrating ability, because more velocity is required to penetrate a given armor. Heye et al. (1995) reviews the law in the United States, describes a number of bullets of varying caliber and construction which might be considered armor piercing, and describes common methods for the identification of armor piercing bullets. Steel is a common armor material in vehicle and building materials; composite armor is commonly used in body armor applications because it tends to be lighter for a given protection level (Übeyli et al., 2007).

**Method**
Steel plate armor (A36 steel 6.35mm thick and 150mm square) and a proprietary fiber composite armor (glass backed with aramid fabric) were tested against four different types of bullets in 5.56mm NATO. The M193 bullet is of conventional construction with full metal jacket with a lead core and weighs 55 grains. The M855 bullet weights 62 grains and may be considered armor piercing due to a steel penetrator in the front. The 53 XFB is a 53 grain solid

copper bullet manufactured by Barnes Bullets, LLC of Mona, Utah. The bullet has a small hollow point and is scored inside the tip to expand in tissue or tissue simulant. The 55 DGBR is a solid brass bullet manufactured by Cutting Edge Machining Solutions of Drifting, Pennsylvania. The bullet has a broader hollow point and is also scored inside the tip to facilitate expansion. Each armor plate or panel was held flush against 10% ballistic gelatin prepared per the FBI protocol (MacPherson, 1994). A Remington 700 rifle in 5.56x45 mm was fired through an optical chronograph which provided velocity measurements with an uncertainty of 0.3%. The armor samples were placed 1.3 m downrange from the chronograph, so that the chronograph reading is an accurate representation of impact velocity. Velocity in feet per second was recorded along with penetration which is shown by a 0 (no penetration) or 1 (penetration). Penetration is identified as the bullet or any fragments entering the ballistic gelatin. The absence of any bullet or fragment in the ballistic gelatin is regarded as a failure to penetrate. Ten shots were taken for each combination of bullet and armor type, as impact velocity was varied to achieve a sufficient number of shots both stopped and penetrating.

For each bullet and armor type, penetration probability was graphed vs. impact velocity. V50 was then determined by least-squares logistic regression to the model for the penetration probability as a function of velocity, $f(v) = 1 - 1/(1 + (v/V50)^b)$. As described previously (Haight et al., 2012) the analysis method employed here differs from MIL-STD-662F, which is designed only for acceptance testing, does not provide an uncertainty estimate for V50, and only uses a subset of the available data points. In contrast, this analytical regression-based approach uses all the data points, provides an estimate of the uncertainty in V50, and is appropriate for comparing V50 under differing test conditions rather than merely determining acceptance or rejection relative to a lot acceptance threshold.

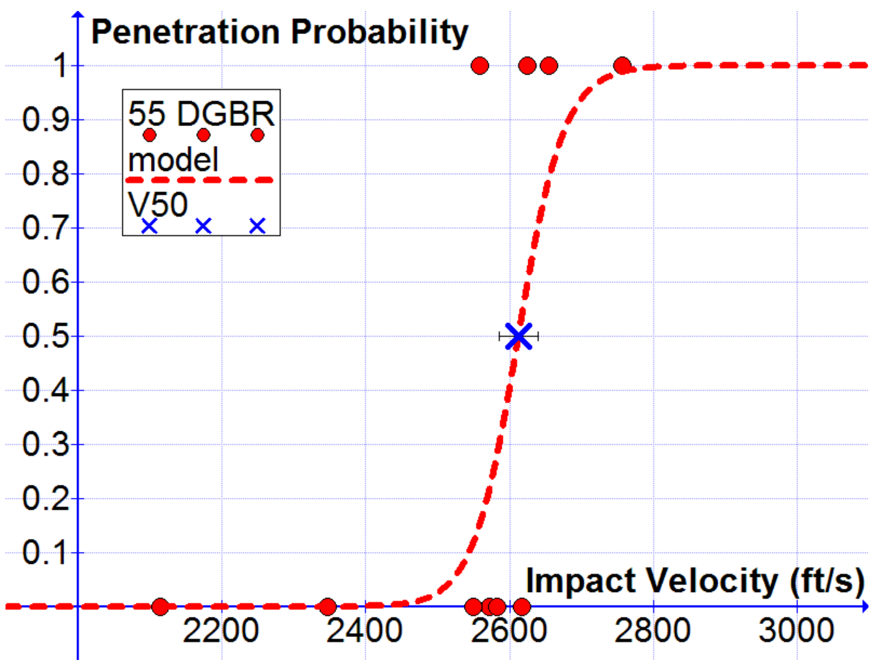


*Figure 1: Data and best-fit curve showing V50 of 55 DGBR solid brass bullet in A36 steel.*

Figure 1 illustrates the analytical method showing the best fit logistic curve for the 55 DGBR bullet in the A36 steel plate. The V50 parameter in the model is the velocity at which the model predicts 50% penetration probability. An analagous regression process is employed to determine the V50 in each combination of projectile and armor, and the regression process also returns the uncertainty in the V50.

| | Steel Plate | | Composite | |
|---|---|---|---|---|
| Bullet | V50 (ft/s) | Uncertainty | V50 (ft/s) | Uncertainty |
| M193 | 2240 | 10 | 3049 | 10 |
| 53 XFB | 2514 | 10 | 2960 | 104 |
| 55DGHP | 2611.8 | 27 | 2868.2 | 19 |
| M855 | 1992.1 | 19 | 1945 | 115 |

*Table 1: V50 and estimated uncertainty for four bullets and two armor materials.*

**Results**

Table 1 shows the resulting V50s for each of the four bullets and two armor materials. The M855 bullet with the steel penetrator tip has the lowest V50 by a considerable margin in both the steel plate and the composite armor. In contrast, the M193 bullet, a conventional jacketed lead core bullet, has the highest V50 in the composite (though not significantly different from the solid copper bullet), yet has the second to lowest V50 in the steel plate, indicating that it is a much better penetrator of the A36 steel than of the fiber composite. The solid copper 53 XFB has a higher V50 in the steel than the M193, indicating that the solid copper bullet is actually a worse penetrator of steel than the conventional jacketed lead core M193. The solid copper 53 XFB has about the same V50 as the M193 and the solid brass 55 DGHP in the composite, although the solid brass 55 DGHP does have a significantly lower V50 than the M193 in the composite. On the other hand the solid brass 55 DGHP has a higher V50 than the M193 and the 53 XFB in the A36 steel plate.

**Discussion**

It is notable that the rank ordering of penetrating ability is different between the steel plate and the composite armor. The harder bullet material does not always translate into better penetrating ability, except in the case of the steel penetrator.

The mechanics of penetration has been studied more fully for cases of tungsten and steel penetrators on thicker metal armors, and there are a number of analytical techniques available (Jonas and Zukas 1978). However, the penetrating abilities of brass and copper bullets have not been studied extensively, and we are unaware of previous reports comparing the penetrating abilities of brass and copper bullets with conventional jacketed lead core bullets and with steel core penetrators.

The present study was something of a compromise. An alternate design might have used bullets of identical mass and construction and focused only on differing material properties. Instead, the experimental design focused on commercially available designs, and bullets were not commercially available to keep the mass and construction identical and only vary the bullet material. Consequently, the data suggests that armor penetration does not depend on bullet material alone but might also depend on the detailed construction of the bullet. It is however notable that conventional jacketed lead core bullets can be much better penetrators of steel plate than hollow point bullets constructed from much harder materials. It is also notable that the bullet design with the steel penetrator core is a much better penetrator of fiber composite armor than bullets made of copper, brass, or conventional jacketed lead. Compared with a steel core, bullets made from copper, brass, or conventional jacketed lead are relatively poor penetrators of composite armor in this study.

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