PROJECTING HANDGUN EFFECTIVENESS FROM ACTUAL ENGAGEMENT RESULTS

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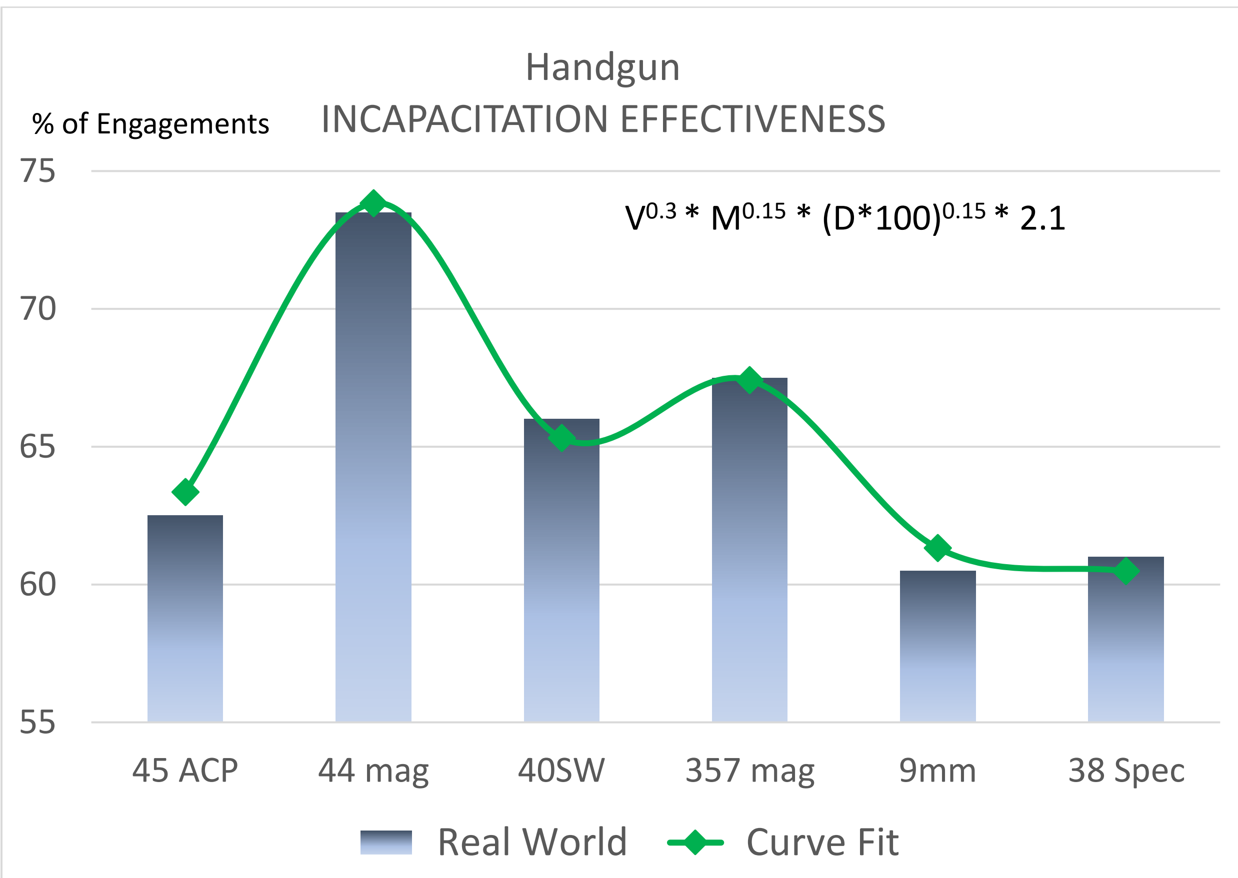
MARRYING THEORY TO THE REAL WORLD: There's nothing like real-world data to refine (or debunk) theories — and handgun-effectiveness theories are no different. Over a decade ago, Greg Ellifritz published a small treasure trove of real-world data, but I came upon it just recently. I was intrigued by the information and felt it could be useful for projecting the effectiveness of many calibers not specifically covered in his data cache. I'm a recently retired combat effectiveness analyst and engineer. (I'm also a one-time police officer (long ago) and former U.S. Navy Commander (Reserve) who earned the Navy's Expert Pistol medal.) A significant part of my defense-industry job was to assess the impact of not-yet-fielded technologies (such as hypersonic missiles and over-the-horizon sensors) on the battlespace. One of the more powerful low-cost techniques we used to help the U.S. government and defense companies decide what upcoming technologies held the most promise was *curve fitting*. Curve fitting takes field data from mature, real-world systems and applies statistical methods to develop a mathematical "curve." A curve is simply a formulaic set of datapoints that essentially matches the empirical data.

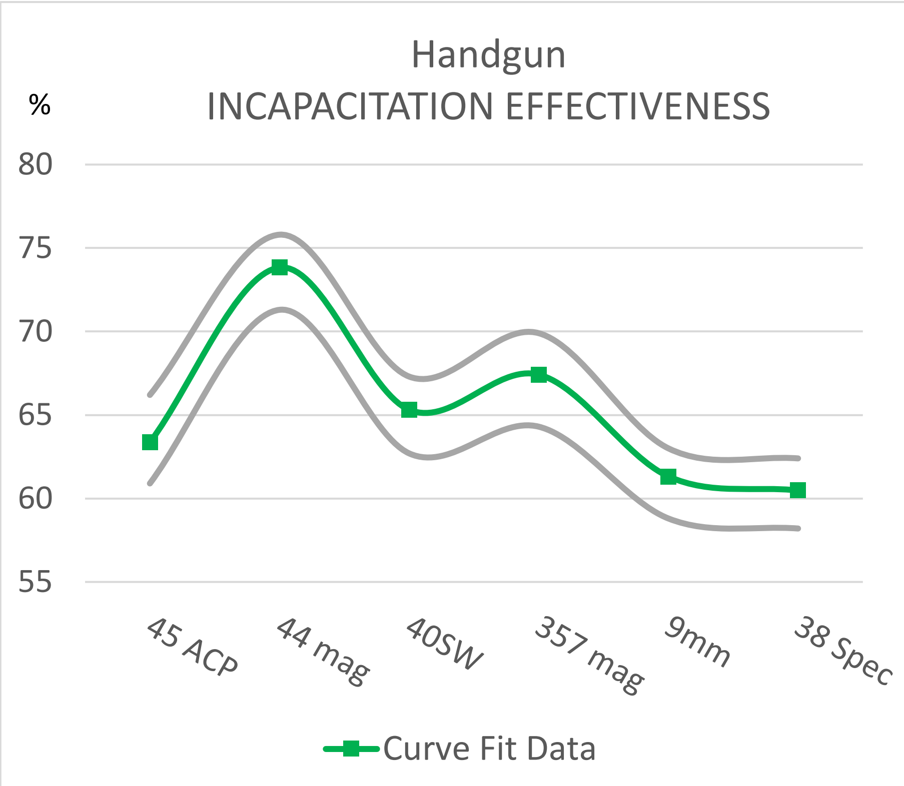
I used curve fitting to establish a formula that mirrored Greg's real-world data. It turned out to be one the tightest curves I've ever generated (and that typically means the key variables influencing outcomes have been correctly identified). Here are the results of the curve fit, overlaid on Greg's real-world data:



These are the specs for each caliber used to generate the curve:

Caliber:		45 ACP	44 mag	40SW	357 mag	9mm	38 Spec (+P)
Diam (in)		0.451	0.429	0.401	0.357	0.355	0.357
Mass (g)		200	210	155	158	115	158
Vel (f/s)		900	1500	1200	1400	1200	975

In the worst case (which was 45 ACP), the curve missed the real data by about 1%. In the combat-assessment world, that's pretty darn close.[1]



This specific curve fit is, by design, sensitive to the values selected for mass and velocity for each caliber, so it was important to choose reasonable ones (that is, values thought to be representative of an average of the captured real-world encounters. Greg did not have these numbers for many of the engagements, so estimations were necessary). The chart to the left shows the range of results from a large assortment of "common" cartridges available for each caliber.[2] The green center line is the curve-fit from the first chart. The gray lines are the projected effectiveness levels of the hottest and lightest common loads. The difference in outcomes from lightest to hottest spanned an average 4.8 percentage points across all calibers.[3] The loads used for the actual curve-fit are provided just below the first chart, so you can judge for yourself how representative you feel they are. (And, if any seem non-representative to you, the power of a curve fit lies in eventually being able to check the predicted effectiveness of your own selected loads.)

You'll notice that all the incapacitation-effectiveness values in both the real data and the curve fit fall between 60% and 74%. You may ask yourself: "If the maximum difference is 14%, why does any of this matter?" Ultimately, you will have to answer that question for yourself. I personally want every potential advantage when it comes to protecting myself and others from someone intent on criminal harm. Of course, other factors may loom larger, such as my ability to make well-placed shots with each caliber. But I'll certainly take the 14% improvement, if it's available to me without other consequences.

THE REAL-WORLD STATISTIC: Now let's get into the details of the actual statistic I developed from Greg's data … it's the statistic which formed the comparison foundation for the curve fit. (Greg's summary data is available at: *activeresponsetraining.net/an-alternate-look-at-handgun-stopping-power*
or https://www.buckeyefirearms.org/node/7866 .) The particular statistic I employed is actually a simple average of two others, namely:

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[1] I also calculated statistical confidence intervals for much of Greg's real-world data. Confidence intervals (CIs) are akin to margins of error in polling. The CIs for Greg's real-world data were +/-0.8% on average, so any tighter curve fit would quickly have wandered into statistically meaningless territory. For the statistically minded, much of Greg's data was *binary*, which means CIs are a different beast — not requiring data from all the individual cases and using different calculation techniques.

[2] Most of my load information came from caliber-comparison articles at ammo.com.

[3] You can undoubtedly find some specialized load that falls outside the gray lines for any of the calibers in the chart, but I fell it was unlikely that somewhat novel loads were used in the vast majority of real-world encounters. For the magnums, I excluded "soft' loads, essentially 44 mag loads that were no better than a high-performance 44 Special and 357 loads that weren't much better than a good 38 +P.

1) effectiveness in incapacitating *quickly* (i.e., incapacitating with the first head or torso shot). Greg's exact metric was: incapacitations divided by vital hits (where "vital" means head or torso hit).[4]

> Hypothetical Example: For caliber X, there were 30 incapacitations, with 50 vital shots into those 30 targets. The ratio would be 30/50 or 0.6 (in other words, 60% were incapacitated with one shot; this percent was Greg's reported data.)

2) effectiveness in incapacitating *at all* (with any number of shots). This was simply the inverse of Greg's reported percent of targets hit *but never incapacitated* during an engagement.

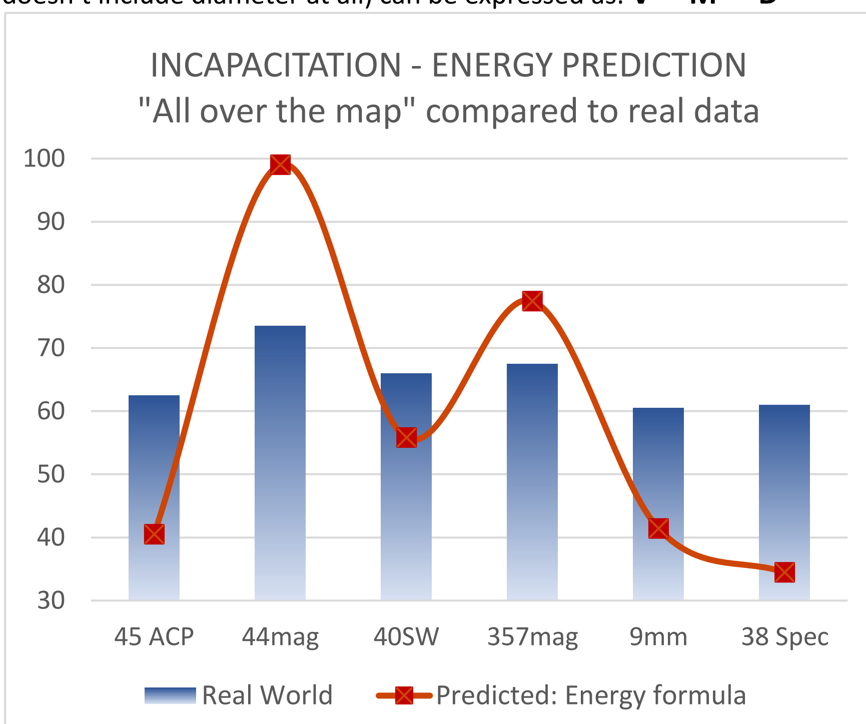
I think most would agree that *quick* incapacitation and *eventual* incapacitation are both worthy goals in any skirmish. Additionally, combining them pulled in roughly twice as much empirical data, which tends to greatly improve statistical results. The Real-World bars in the first chart are the results of averaging these two measures of effectiveness (taken from Greg's data). Statistically, this combined measure roughly approximates a 2-shot incapacitation rate — but it's derived from actual data, rather than probabistic math and statistical assumptions. I have titled this combined metric "Percent of Engagements with Medial Incapacitation" — I don't particularly like it, but it's descriptive. (I'm open to alternate titles. 😊)

FITTING THE CURVE: Next came the task of establishing a curve fit. I'm indebted to a user calling himself *DroneDamageAmplifier* in the *r/guns* forum on Reddit for pointing out that nearly all formulas proposed over the years for projecting handgun effectiveness can be reduced to:

$$\mathbf{Velocity^X * Mass^Y * Diameter^Z}$$

Even an Energy-only approach (which doesn't include diameter at all) can be expressed as: $\mathbf{V^2 * M^1 * D^0}$

This gave me a great starting point. I tried some of the more popular already-existing formulas, and got some pretty unsatisfactory results. The Energy-only approach (which I personally had been inclined to use in the past) produced a rather wild outcome. (See adjacent chart.)



The single most persistent issue with all the existing formulae was they did not account for the *slow growth* of the real-world function. By that I mean they all seriously over-estimated the improvement (or degradation) in effectiveness caused by changes in any input variable.

Now for the actual results of the curve-fit effort; like any curve-fit, the formula was derived by guided trial and error. In this case, the formula was:

[4] For this metric to be meaningful, we must assume that once a subject was incapacitated, the shooter stopped shooting. It appears Greg made this assumption, and it may have been based on narrative information not shared in his summary data. In any case, it seems like a fairly reasonable assumption, given that the shooters were police or military, as I understand it.

***Incap. Effectiveness* =** $\text{Velocity}^{0.3} * \text{Mass}^{0.15} * (\text{Diameter}*100)^{0.15} * 2.1$

This formula is visualized as the green line in the first chart in this article.

WOUND PATTERN: Many readers will immediately notice that the curve-fit formula does not directly account for wound pattern (i.e., wound penetration and wound circumference). However, we know wound pattern is certainly related to bullet diameter, weight, and speed; these values set outside bounds for what can be achieved, no matter how optimal the shape and composition are — in other words, wound size is at least partially accounted for in the data, *but imperfectly so*. We just don't know *how* imperfectly, since bullet configuration must surely factor into wound severity as well. The importance of bullet configuration cannot be determined with high confidence from this study. If we assume that the distribution of well-configured bullets was roughly the same across all calibers, then we haven't learned much about it … as configuration may loom large but have affected all calibers about equally. On the other hand, if there was significant disparity among calibers, then we can probably say configuration is a rather modest factor.

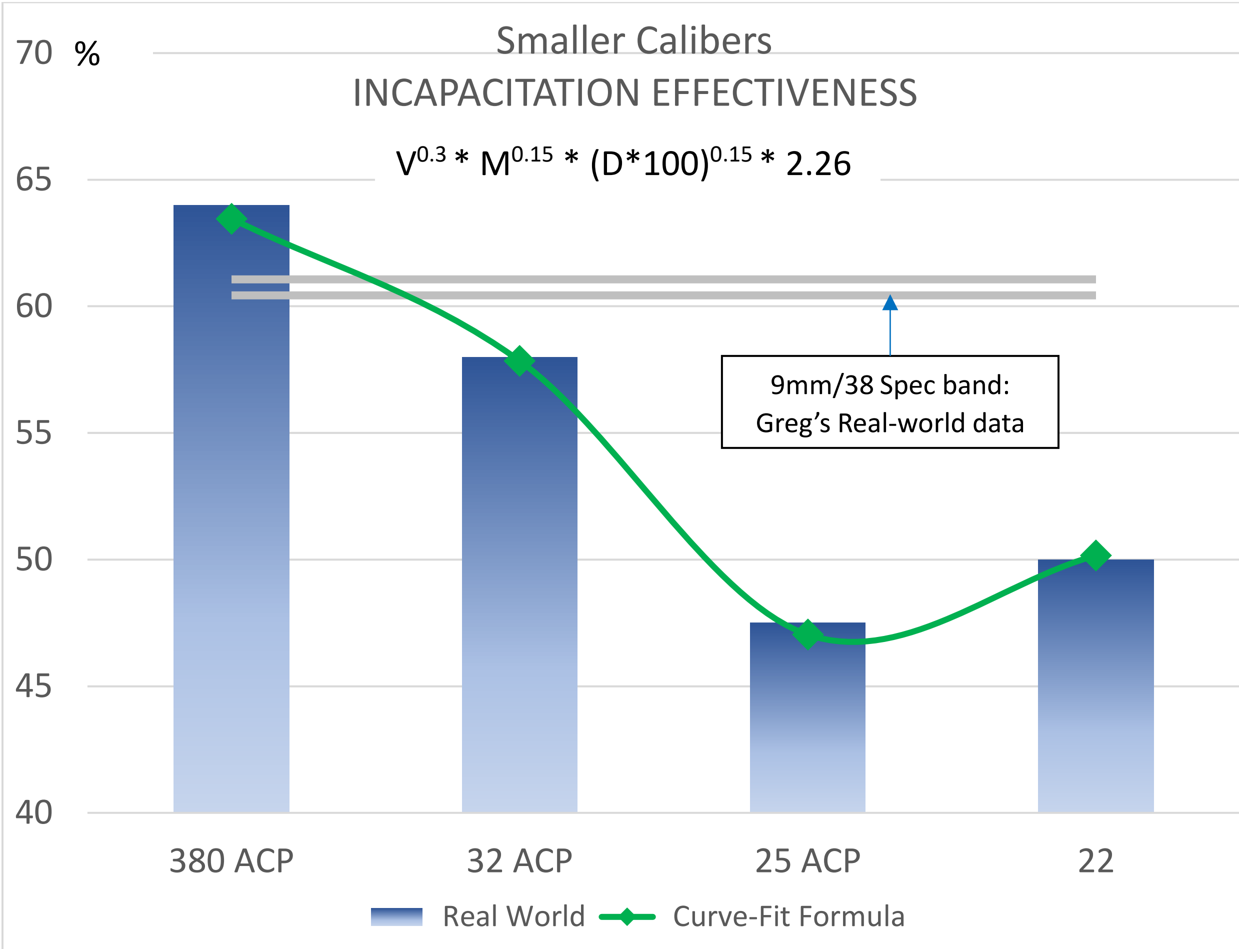
Greg reports that he had some real-world data on bullet configuration, but only in subsets of cases. He specifically noted that, for 9mm *only*, over 50% of the reported cases used ball ammo. ***If*** the other calibers had significantly less than 50% ball ammo and ***if*** configuration is a dominant factor, we would expect this to skew the results. You'll observe that the 9mm empirical data doesn't match the curve fit quite as well most of the other calibers. However, it is close enough that, in my previous line of work, we'd have considered the 9mm data a *confirmation* of the formula, not an anomaly from it. The basic result here is pretty solid, a curve-fit dream really. The probable 9mm configuration disparity leads me to believe that if we had enough data to examine the effects of bullet configuration, we would find the impact to be mild. The likely configuration disparity among calibers (in the real-world data) implies that the constraints of bullet diameter, weight, and speed dominate over configuration. This isn't to say we should ignore configuration; once again, I'll take any advantage I can get.

SMALL WEAPONS: Greg's real-world data included some smaller weapons (from 380 down to 22). I've plotted the curve-fit formula against the real-world data for these lighter calibers. These "pocket guns" are typically off-duty or back-up weapons. As a result, the engagement dynamics may have been quite different: skirmishes were probably at closer ranges (which is not to say that targeting was any easier), and encounter environments were perhaps more constrained. These scenario features (which are external to the weapons themselves) may well have played a role in a subject ceasing to fight/run/act-out/etc. In short, there may be a bit of an apples-to-oranges comparison when these light guns are analyzed alongside the duty guns.

I made a modest adjustment to the multiplier for these pocket guns. The multiplier is now 2.26; this was the only change to the formula. The new curve below actually looks extremely good. In fact, I was quite surprised by the tightness of the match; I wasn't expecting it with these small guns. All variances were below 1%, which is as good as the original "duty-gun" curve match. (It's worth pointing out that my load selection was not as rigorous in creating this "mouse-gun" curve. I looked at a several commonly available loads and picked one in the middle to upper middle. That said, I don't believe a more robust selection would have affected the curve plot much. And, of course, you can plug your own preferred loads into the formula. Also, I made the ammo selections *before* assessing whether the formula need to change — so that the formula itself could not influence my choices. Note that the input values used for 22 were reached by averaging 22 Short and 22 LR; Greg's 22 data was a roll-up of all 22 types.)

The high quality of this new curve fit implies two things: 1) all the mouse guns were affected equally by whatever was at play that mandated the multiplier change; 2) the key inputs (speed, mass, and caliber) and the relationships between them have been accurately captured in the basic curve formula. The pocket gun formula is:

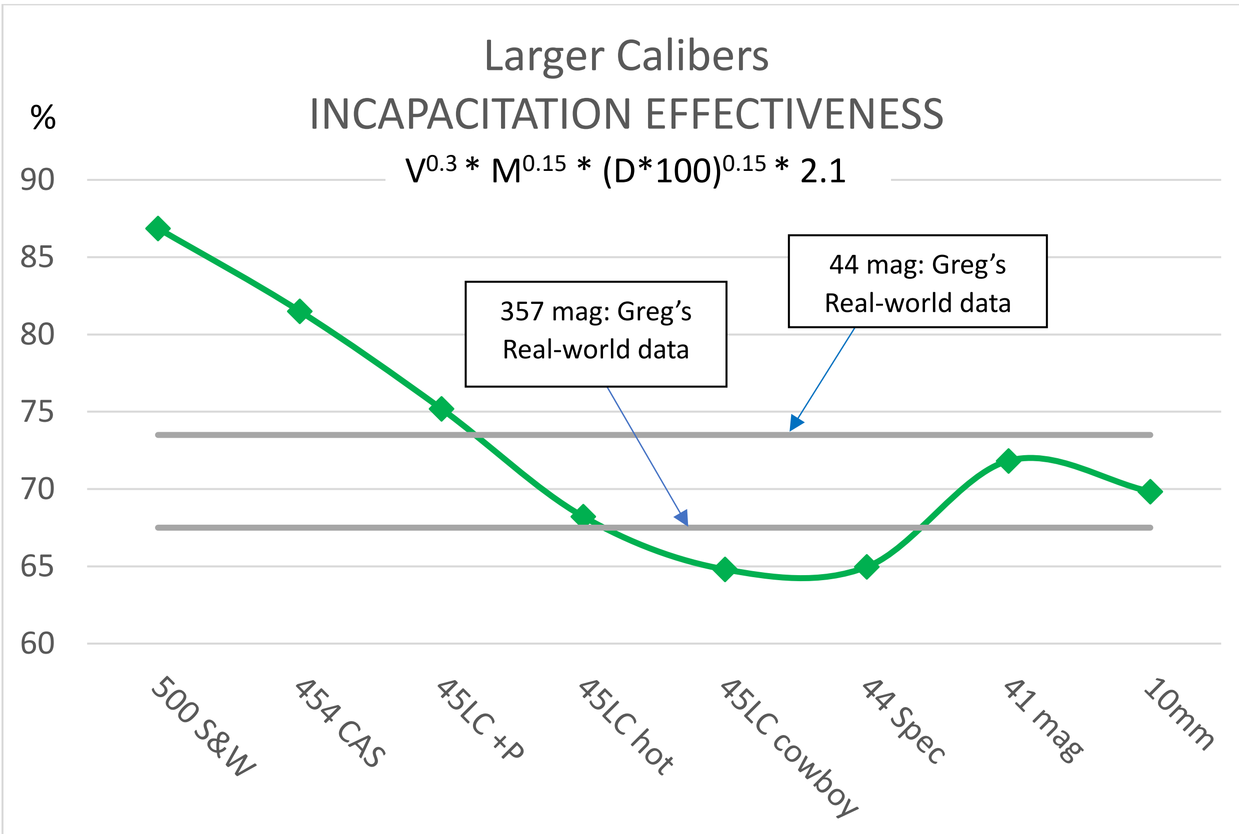
***Incap. Effectiveness* =** $\text{Velocity}^{0.3} * \text{Mass}^{0.15} * (\text{Diameter}*100)^{0.15} * 2.26$



As you will note, there is an unmistakable inversion in the *real-world data*: 380 ACP performed somewhat better than 9mm and 38 Special. (See the two gray lines labeled "9mm/38 Spec band.") Greg was very concerned, and rightly so, that this was an unlikely "reality." He wrote an article to explain what he felt may have been happening. (It's titled: "Questioning the Effectiveness of the .380 Auto Cartridge;" and it is available at: https://www.buckeyefirearms.org/questioning-effectiveness-380-auto-cartridge) Whatever is going on, the bump-up did not affect the 380 alone. If just the 380 data had been affected, it's extremely improbable the curve would match so tightly across all calibers. Those viewing Greg's data have focused on 380 because the bump phenomenon is painfully obvious there: the 380 overtakes two rounds we are all pretty confident are superior to it. I strongly suspect the thing that creates the mild shift in effectiveness for these little weapons is some *commonality in the engagement scenario that is fairly unique to these guns*; it is unlikely to be something inherent in the guns themselves.

APPLYING THE RESULTS TO A RANCH PROBLEM: I was confident enough in the results of the curve fit that I used it to make a recent purchase decision. We have a small ranch, and I wanted a long-barreled handgun to carry in case we ran across coyotes or feral hogs while milling about the ranch. (I'm well aware that stopping pigs and stopping bad guys aren't the same thing, but I felt the *trends* from this study would still hold. I also know a rifle would be better, but as an older codger I can't easily carry one and get it in shooting position rapidly.) I wanted a handgun that could convincingly reach out to 75 or 100 yards against hogs; my 45 ACP and 9mm didn't fit the bill. I eventually settled into a choice between 45 Long Colt (45LC) (with hot, but not +P, loads) and 357 mag. Hunters felt either would be up to the task. The standard Energy formula ($M*V^2$) told me the 357 mag (with 1400 f/s, 158grain ammo) was about *20% better* than the 45LC (with 1025 f/s, 250grain ammo). But the 357 load also had a recoil impulse of about 1.5 lbs-sec (which is at the edge of my comfort zone), while the 45LC load had an impulse of 1.2 lbs-sec (well within my comfort zone). When I checked the two rounds with the *Incapacitation Effectiveness Formula* created in this study, the two were almost identical. And that was enough to sell me on the 45LC.

The chart below is a comparison of several larger bore handguns (some of which are used more for hunting than defense). These are all calibers for which Greg had no real-world data. The assessment is based entirely on the curve-fit formula developed for this study. Keep in mind, of course, that the curve projects effectiveness in incapacitating *human* targets, not mid-size game.



If we include the real-world data for the mouse guns and the projections above for the big bore guns in our list of weapons choices, we are now looking at a very significant range in incapacitation effectiveness (from 47% for the 25 ACP to 87% for the 500 S&W); that's a swing of 40%, instead of our original 14%.

SOME CONCLUSIONS & WRAP-UP: You can use the *Incapacitation Effectiveness Formula* developed in this study to project the performance of many, many handguns and rounds not specifically covered in the study. (I recommend adding a grain of salt if you're looking to assess handguns chambered for rifle rounds. I've actually tried several rifle-round handguns with the formula, and the results fall easily in line with Greg's general "rifle" numbers in his empirical data, but I don't have any caliber-specific real-world data to check against.)

I believe the traditional wisdom still applies: you should generally use the largest, hottest weapon you can *easily* command. Other factors besides caliber, such as shot placement, are almost certainly more important, but the *potential incapacitation effectiveness* of each caliber still has a significant role to play. In my previous life, the U.S. military would certainly have taken notice of a weapon system that held promise for a 14% improvement in neutralizing threats. And they absolutely would have investigated a potential swing of 40%.

Turning now to the world of large-varmint control, I would apply the same conventional wisdom: the largest, hottest handgun you can easily handle is best — though what you can comfortably manage in a varmint scenario (which is usually far less "puckering") may vary considerably from what you can handle in a defense scenario.

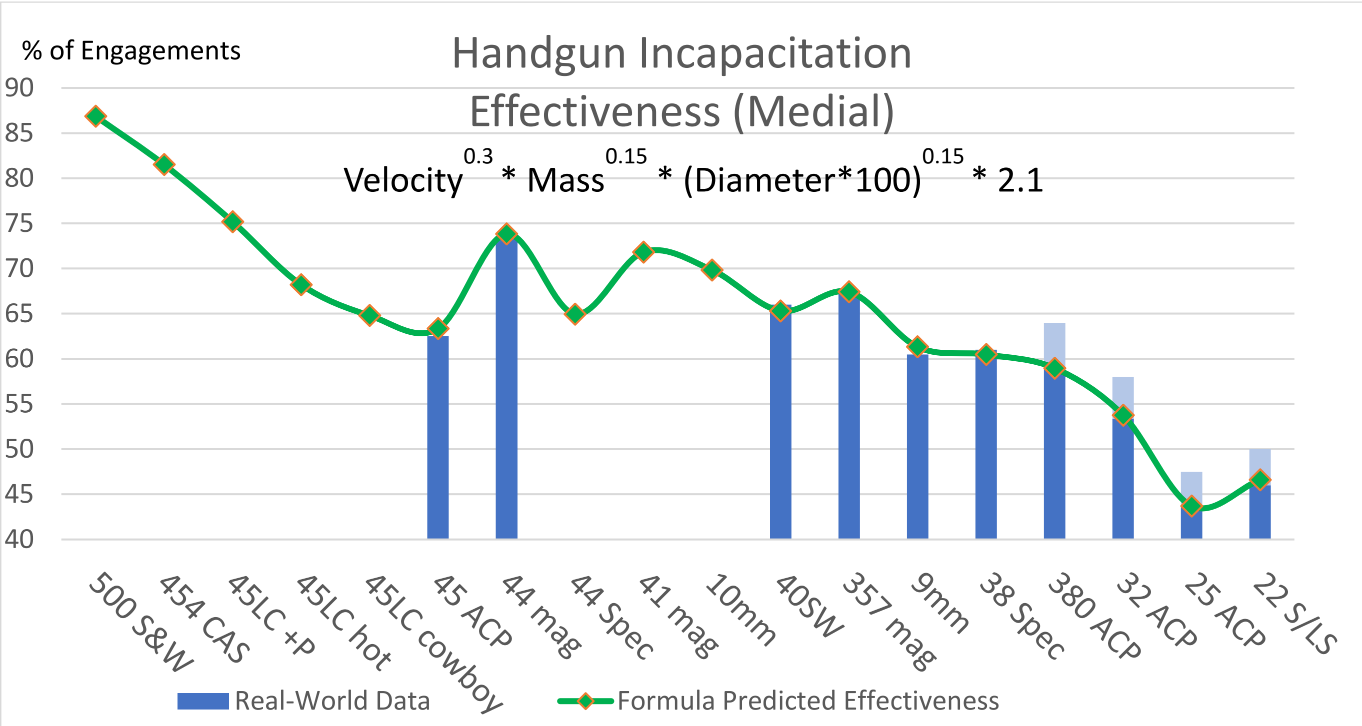
Here is a recap of the formula:

$$\textit{Incap. Effectiveness} = \text{Velocity}^{0.3} * \text{Mass}^{0.15} * (\text{Diameter}*100)^{0.15} * \text{multiplier}$$

multiplier = 2.1 for most handguns

multiplier = 2.26 for pocket gun (380 and smaller)

For what is probably a truer comparison of the small guns to the larger ones, simply leave the multiplier unchanged (at 2.1). The graph below shows the results of doing this. (Remember the lengthy discussion on these guns and the concerns Greg, I, and others have raised about the data.) I'm convinced an unchanged multiplier will best reveal the *inherent performance of the guns themselves*, minimizing any scenario-driven mutations in outcomes.



In this graph, the original real-world data for the four pocket guns is in light blue. Note that those data follow the *shape* of unaltered formula extremely well, but are all bumped up by the same percent: each by a factor of roughly 1.085 to be precise. The dark blue, *for these guns only*, is a "normalized" result — obtained by multiplying each of the original data points by 0.92.

<u>How to write the formula in Excel:</u>

=V^0.3*M^0.15*(D*100)^0.15*2.1 [substitute 2.26 in place of 2.1 for pocket guns]

For the truly ambitious Excel user, you can create a separate column with a "Y" (or a 1) for Pocket Guns and then write an IF() statement that switches the multiplier when the Pocket-Gun cell is positive. I haven't taken the time to write and test it myself.

You may contact me by email: *dan@drdanlee.com*