Future Small Arms & Ammunition Design: Bullet Shape and Barrel Length

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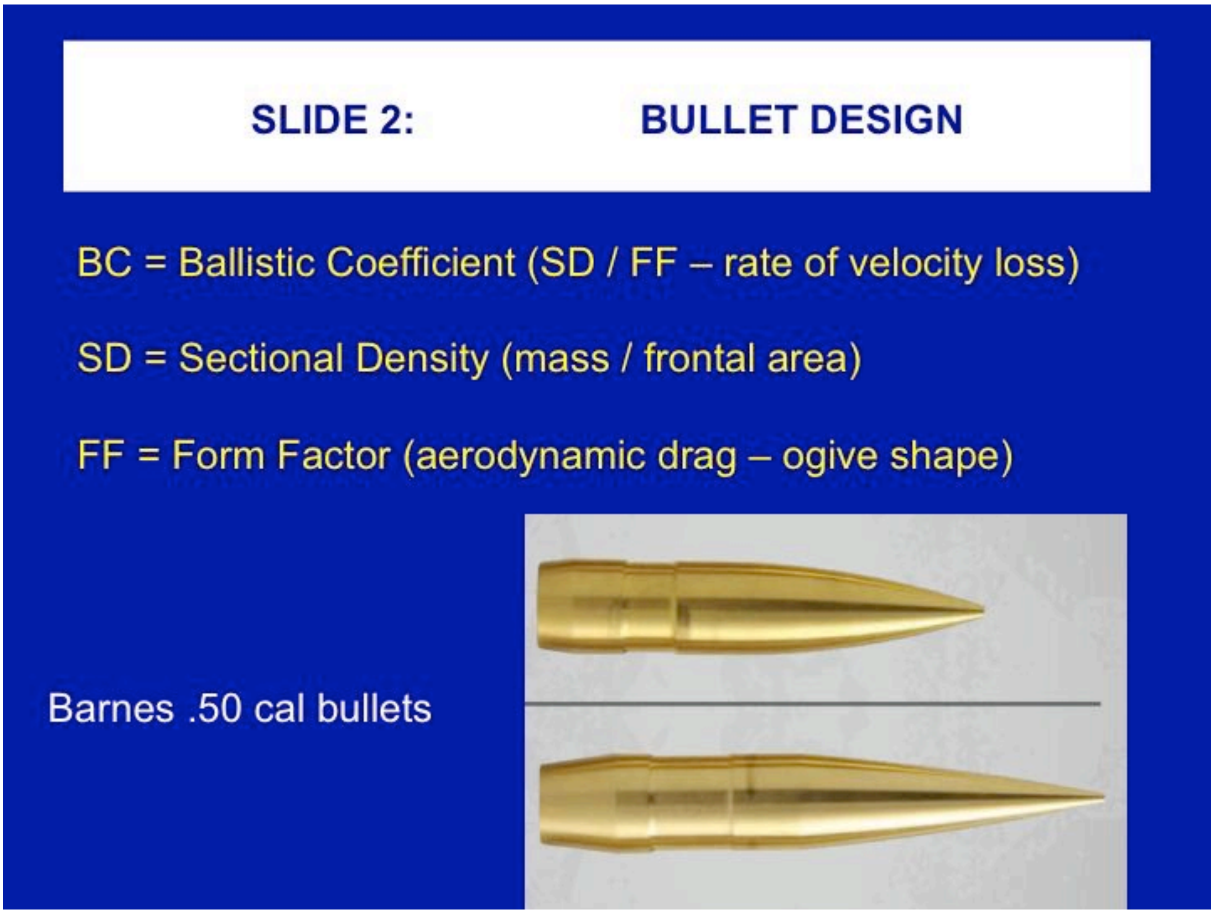
N.B. versions of this presentation were given to several meetings in 2014/15. The slides included here were those shown at the NDIA Small Arms Forum in June 2015. The text relates to these, with some additions.

In this presentation I intend to focus on just two aspects of small arms ammunition design: bullet shape and barrel length. These are both very basic issues, so I apologise to those of you who are familiar with ballistics, but they often seem to be given an undeservedly low priority in the cartridge design process. Since there is currently a lot of discussion about the possibility of new ammunition for the next generation of small arms, I want to take this opportunity to highlight these issues.

One point I want to make at the start is this: the arguments I will be presenting are independent of calibre, muzzle energy or even case type: whether conventional or cased telescoped or caseless makes no difference.

A very basic refresher: the rate at which a bullet slows down in the air is determined by the ballistic coefficient; the higher the BC, the lower the velocity loss and the further the bullet will fly. That is, "other things being equal" – always an important qualification because there are so many variables. The BC is calculated from two other numbers, the sectional density (SD) and the form factor (FF). The SD is simple to calculate as it measures the bullet weight compared with the calibre; a 100 grain 30 cal bullet will have half the SD of a 200 grain 30 cal. The higher the SD, the better for long-range performance. The FF measures the shape of the bullet; it is not simple to calculate and its effect varies with velocity, but at a basic level it's really common sense - a bullet with a long pointed nose, or ogive, is likely to have a better FF than one with a blunt ogive, especially at supersonic velocities. It's the FF that I want to talk about.

I looked around for examples of bullets which are as alike as possible except in their shape in order to illustrate the importance of the FF, and found the two .50 cal bullets from Barnes Bullets shown on the screen. They are both made from solid brass to the same standards and both weigh the same – 750 grains. Barnes helpfully provides the BCs for this pair, so it's a simple matter to feed the data into a standard ballistic calculator in order to work out the effect of the different shape. The results of this are interesting.

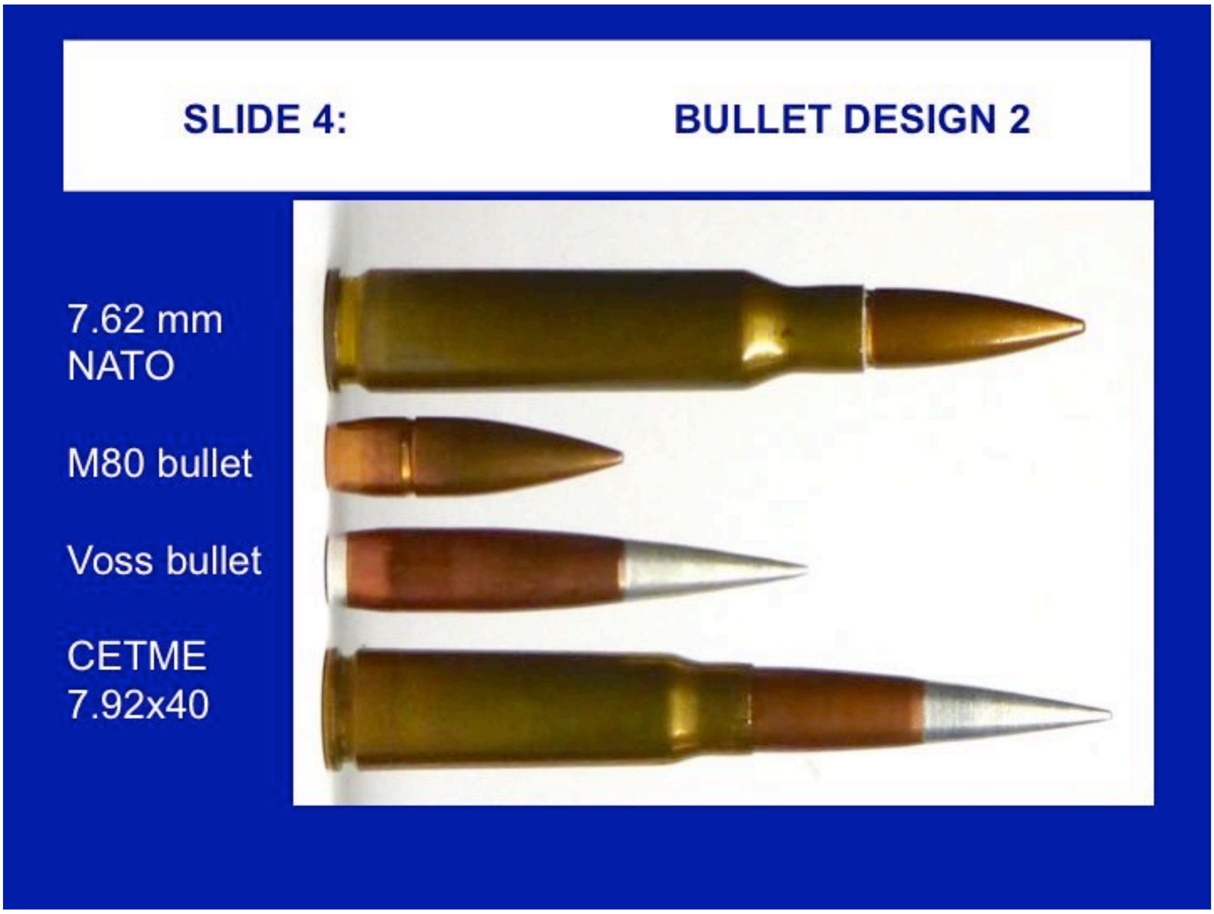


There are various ways of assessing the effective range of ammunition, one of them being the impact energy of the bullet on the target. The long bullet shown here has the same impact energy at 2,000 metres as the shorter bullet has at just over 1,400 metres. By this measure, that amounts to a 40% increase in effective range from using the long bullet rather than the shorter one – and it's free! No extra ammunition weight, no extra recoil. The catch is, of course that the shorter bullet has been designed to keep within the official maximum overall length of the .50 Browning cartridge, so that the ammunition can be loaded into magazines and will function in gun actions; loaded with the long bullet, the cartridge can only be used in specialised single-shot rifles.

This problem of a short cartridge overall length, which prevents the most efficient, low-drag bullets being used, applies to at least some degree to all NATO rifle and machine gun ammunition. The long-range performance of all of these rounds is inherently limited by their inability to use such bullets. Their bullets all have quite short ogives which results in poor FFs and therefore poor BCs. The only way to improve the BC of bullets for these rounds is to use heavier bullets to increase the SD, but that puts up ammunition weight and recoil and results in a lower muzzle velocity and steeper trajectory.

The .338 Lapua Magnum has become the international standard long-range sniping round, but it was designed for bullets of up to 250 grains and doesn't allow enough space for well-shaped versions of the 300 grain bullets which are becoming increasingly popular. It is interesting that General Dynamics selected the relatively obscure .338 Norma Magnum for their Lightweight Medium Machine Gun. I have heard various reasons why they chose the Norma round but one is incontrovertible; the shorter Norma case permits the use of bullets with a longer ogive, giving it the potential for a superior long-range performance.

The next slide is where things get really interesting. The standard 7.62mm NATO cartridge and its M80 bullet are shown at the top. The other pair illustrate one of my favourite examples of the merits of unconventional thinking. The Voss bullet was designed by a German ballistician, Dr Gunther Voss, in the early 1950s, when he was working for the Spanish CETME organisation. He wanted to develop a cartridge which combined a long range with a recoil light enough to permit controllable automatic rifle fire. He reasoned that for the recoil to be kept low, the bullet would have to be as light as possible, but as that would give it a poor sectional density, to achieve a long range would require giving it the best possible form factor. So his bullet is made of solid aluminium with a copper jacket over most of its length. It actually weighs 106.5 grains, which is less than the stumpy little .30 Carbine bullet, but the shape is so good that the BC is only a little lower than the 7.62 M80 which weighs 147 grains. Because the bullet is so light, it doesn't need much propellant to drive it at a velocity comparable with the 7.62, so it uses a smaller cartridge case, saving yet more weight and further reducing recoil.



By the few accounts I've found, Voss's CETME round did what it was designed to do. In effect, it provided 7.62 NATO performance in a package that was similar in weight and recoil to the short 7.62mm Kalashnikov round. One potential drawback was lack of penetration, but it was claimed to be able to penetrate a contemporary steel helmet at 1,100 metres. I suspect that it might not have done so well against thicknesses of material, such as timber. Unfortunately for Voss, by the time it was ready to roll it was 1953 and the 7.62 NATO round had an unstoppable momentum, flattening all rivals in its path. The irony is that the US Army had wanted a long-range, .30-calibre cartridge with a recoil light enough for controllable automatic fire in a light rifle. The Voss design came very much closer to delivering that than did the 7.62 NATO, purely because of the superb shape of the bullet.

In the early 1970s something very similar was tried by the US Army with the 5.56mm FABRL, shown alongside the contemporary 5.56mm M193. FABRL originally stood for Frankford Arsenal and the Ballistic Research Laboratory, but it was later given the sexier meaning of Future Ammunition for Burst Rifle Launch. The aim was to reduce the recoil of the contemporary 5.56mm ammunition to make the rifles more controllable in burst fire. To achieve this the bullet weight was reduced from 55 to 37 grains by making it from steel with a plastic core, yet the much improved FF meant that the BC remained the same. Little more than half the propellant was needed to match the muzzle velocity of the M193 so the cartridge case could be shortened to leave room for the long bullet, and the chamber pressure was so low (39,000 psi instead of 52,000) that the use of an aluminium case became feasible, leading to an overall reduction in cartridge weight of 50%. The trajectory remained the same, but the recoil impulse was reduced by 35% (equivalent to a reduction in free recoil energy of over 60%).

The lesson to draw from this is not that all bullets should be made of aluminium or plastic – the two I've shown are clearly extreme examples – but that a well-shaped bullet gives you options you don't have with a typical NATO bullet shape. You can keep the bullet weight the same, and enjoy an improved long-range performance; or if you don't need to extend the range, you can reduce the bullet weight while still keeping the same BC as the NATO bullet, thereby reducing cartridge weight. If you reduce the bullet weight, you have another choice: you can leave the propellant load and cartridge case the same, and enjoy a higher muzzle velocity and flatter trajectory; or you can keep the MV the same and reduce the propellant load and size of the cartridge case, as in both examples I've described, gaining further reductions in recoil and ammunition weight. These are all great choices to have, but you only get them if you adopt a very well-shaped bullet, which means that the cartridge specification has to provide room for using bullets with a long ogive.

The second subject I want to talk about is barrel length and its implications for cartridge design.

Last year, an American shooter with lots of time and enthusiasm acquired a rifle in .300 Winchester Magnum, which had a barrel of just over 24 inches. He acquired a large batch of ammo, fired some of it and measured the muzzle velocity. Then he sawed an inch off the barrel and repeated the exercise. Then another inch and so on, until he got down to just over 16 inches. At that point he calculated that the muzzle velocity was pretty much the same as he would get if firing the same bullet from a .308 Winchester cartridge (effectively 7.62 NATO) from a barrel of around 24 inches. This illustrates the fact that, for any given calibre and muzzle energy, there is an inverse relationship between barrel length and the size of the cartridge.

Think about that: to match the muzzle energy of a 7.62mm NATO from a 24 inch barrel in a carbine with a 16 inch barrel, you need a much bigger and heavier cartridge with far more recoil and a horrendous firing signature in terms of muzzle flash and blast. That's a high price to pay for an 8 inch shorter barrel, and it gets worse: the gas pressure at the muzzle is likely to be around 50% higher from the shorter barrel, which in conjunction with the greater volume of propellant means that a bigger and heavier sound suppressor would be needed to achieve the same results.

The same relationship applies lower down the power scale; if you are satisfied with the performance of the 7.62 NATO from a short carbine barrel, you can match it with something not much bigger than the .302 Whisper fired from a long barrel. Incidentally, note the bullet loaded into the Whisper case; this is almost as long as the Voss bullet, but has a much worse form factor because the ogive is kept short for use in cartridges like the two shown above it.

But of course, no-one wants a long-barrelled rifle, they are too much of a nuisance in urban fighting, climbing in an out of armoured vehicles and helicopters, and so on. Well, they are if you stick to a traditional rifle configuration, but not if you use a bullpup. Eight inches is the typical benefit you get in terms of overall length saved by adopting the bullpup layout.

The slide above shows a practical example of what I mean. I'm not arguing in favour of intermediate calibres today, but if I were I might be mentioning something like a 6.5 mm cartridge developing around 1,850 ft lbs of muzzle energy. I asked an American friend of mine, Joe Smith, who's much handier with cartridge design software than I am, how big a cartridge delivering this performance would need to be from 16 inch and 24 inch barrels, and this is the result. The smaller cartridge is effectively the 6.5mm Grendel, which will deliver this sort of performance from a long barrel. The bigger cartridge is around 9mm longer to hold the extra propellant needed to achieve the same velocity from a short barrel, and is similar to the US AMU's .264 USA. To put the choice simply: you can have a traditional short-barrelled carbine using the bigger cartridge or, for the same overall gun length, a bullpup using the smaller cartridge. The bullpup choice provides the same ballistic performance with the benefits of lighter ammunition, less recoil and a smaller firing signature, making it easier to suppress.

Not everyone likes bullpups – with good reason in the case of some of the first-generation models – but they are currently developing fast. There is only time to mention one new model here; the Polish Radon or MSBS (which stands for the Polish for Modular Firearm System), of which an initial trial batch has been ordered by the Polish Army. This is basically a kit of parts which can be assembled into various different weapons from carbines to squad automatic weapons but, uniquely, also includes provision for assembling both bullpups and traditional rifles from the same kit. The two guns shown here have 80 percent commonality, sharing the same barrel, action assembly and control layout, with the main difference being the onepiece bullpup stock compared with the two-piece traditional stock, so you don't have to choose between bullpup or traditional, you get both for the price of one.

To summarise the points I have been making:

First, a well-shaped bullet gives you significant ballistic advantages, providing options which you can't otherwise get, so any new military rifle or machine gun cartridge should be designed to accommodate low-drag bullets with long ogives.

Second, designing a cartridge for use in a long barrel rather than a short one allows the ammunition to be smaller and lighter, with less recoil and a smaller firing signature, while delivering the same ballistics.

Third, if you combine a well-shaped bullet with a long barrel, the above advantages are multiplied.

Fourth, you can have a long barrel in a short rifle by choosing the bullpup configuration.

One additional point: if I were to ask infantrymen what was the most effective firearm in their section, especially at long range, I would expect most of them to answer "the machine gun"; which is typically belt-fed and has a longer barrel than the individual weapon (rifle or carbine). Yet with the exception of LSAT, most small-arms ammunition programmes focus on optimising the cartridge for the individual weapon. Would it not be better to determine the ballistic requirements of the MG and design the ammunition to meet those, rather than concentrating on squeezing as much performance as possible out of a short-barrelled carbine?

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