

# The Case for a General-Purpose Rifle and Machine Gun Cartridge (GPC)

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*Selected slides from the PowerPoint presentations are included: the full set of slides for the NDIA presentation is available on their website<sup>1</sup>*

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## THE AFGHAN EXPERIENCE

The conflict in Afghanistan, with its emphasis on targeting specific enemy individuals while avoiding collateral damage, demanded the use of weapons of high precision and limited destructive effect. As a result, infantry small arms acquired a much more prominent role than that expected in conventional high-intensity warfare and this highlighted the performance of their ammunition to a greater extent than ever before. While no-one can be certain what form future warfare might take, it is generally assumed that this kind of limited conflict is at least as likely as anything else.

Over the next decade several NATO nations, including the USA and the UK which are currently planning to replace their existing rifles and LMGs from 2025, will be defining their requirements for the next generation of small arms. This is therefore a rare opportunity to ask the question: is the present combination of 5.56 and 7.62 mm rifle and machine gun cartridges optimal, or could we do better in the next generation?

The British Army analysed several hundred small-arms engagements in Afghanistan during the late 2000s. The results are thought-provoking. Ever since World War 2 around 300 metres has been regarded as the normal maximum range for small-arms engagements, but this was not the case in Afghanistan where ranges have been much longer. Apart from the ubiquitous and rather short-ranged AKM carbines, the Taliban are equipped with PKM light machine guns and SVD sniper rifles chambered in the old but powerful 7.62 x 54R Russian cartridge, and more than half of their attacks were launched from ranges of between 300 and 900 metres. As the fighting progressed there were indications that the engagement ranges in Afghanistan if anything became longer: an article in the *American Rifleman* of February 2011<sup>2</sup> states that: "U.S. Army data....reveals that more than half of the war's small arms engagements are now beyond 500 meters, with the enemy employing heavier weapons and then withdrawing before air support or artillery fire can arrive". The reason for this seems to have been connected with the limited range of the 5.56 mm weapons being carried by most ISAF forces.



### PROBLEMS WITH 5.56mm AMMUNITION

British foot patrols were initially equipped only with 5.56 guns; the L85A2 rifle, L86A2 Light Support Weapon, and L110A1 Minimi Para light machine gun. Similarly, US troops were primarily armed with the M4 Carbine (Army) or M16A4 rifle (USMC) plus the M249 LMG (Minimi). These all fired the standard NATO ball ammunition, designated SS109 (M855 in US service). However, this ammunition proved inadequate at long range. Whatever performance they may demonstrate on a firing range, a combination of battle experience and the testing of ammunition terminal effectiveness led to a judgment at that time that weapons with the 500 mm (c.20 inch) barrels which the ammunition was designed for, were effective only up to about 300 metres. Weapons with shorter barrels, such as the M4 and the Minimi Para LMG, have reduced ballistics resulting in an even shorter effective range. What this means is that more than half the small-arms engagements took place beyond the effective range of the standard British infantry rifle, and about 70% of the engagements were beyond the effective range of short-barrelled carbines like the M4. **More recently, the British Army has claimed longer effective ranges for their 5.56 mm weapons (especially the long-barrelled L86A2), although it has to be observed that estimates of effective range tend to go up in peacetime and down in wartime.**

**The key question is of course what is meant by "effective". There are various definitions but no clear answer. Given that the overwhelming majority of small-arms ammunition fired in battle fails to cause any casualties (as explained in the article *"Towards a '600 m' lightweight General Purpose Cartridge"*<sup>3</sup>), the main practical purpose is suppression: pinning down the enemy so that they are unable to return accurate fire, or prevent your fire team from manoeuvring into a better position to press home their attack, or escape from supporting fire from mortars, artillery or aircraft.**

How is suppression by small arms fire achieved? There are three elements: accuracy of fire; volume of fire; and weight of fire. The first two are self-explanatory. Weight of fire refers to the bullet signature at the receiving end, in terms of the impact with the ground or nearby objects, or the sound made by a bullet passing overhead, especially if it is supersonic. Suppression is a subjective effect and there is no agreed formula for calculating it, but in broad terms both battlefield reports and the limited tests which have been carried out indicate that the bigger and more energetic the bullet, the greater its signature and suppressive effect. In consequence, fire from 7.62 mm MGs was, unsurprisingly, reported to be considerably more effective than from 5.56 mm MGs; the bigger bullet retains more of its velocity and energy, and is less affected by wind drift, increasing its advantage as the range extends.

## BRITISH 5.56mm GUNS AND EFFECTIVE RANGES



**L86A2 LSW**  
25in / 65cm barrel  
300-400 metres

**L85A2 rifle**  
20in / 52cm barrel  
c.300 metres

**L110A1 LMG**  
14in / 35cm barrel  
c.200 metres

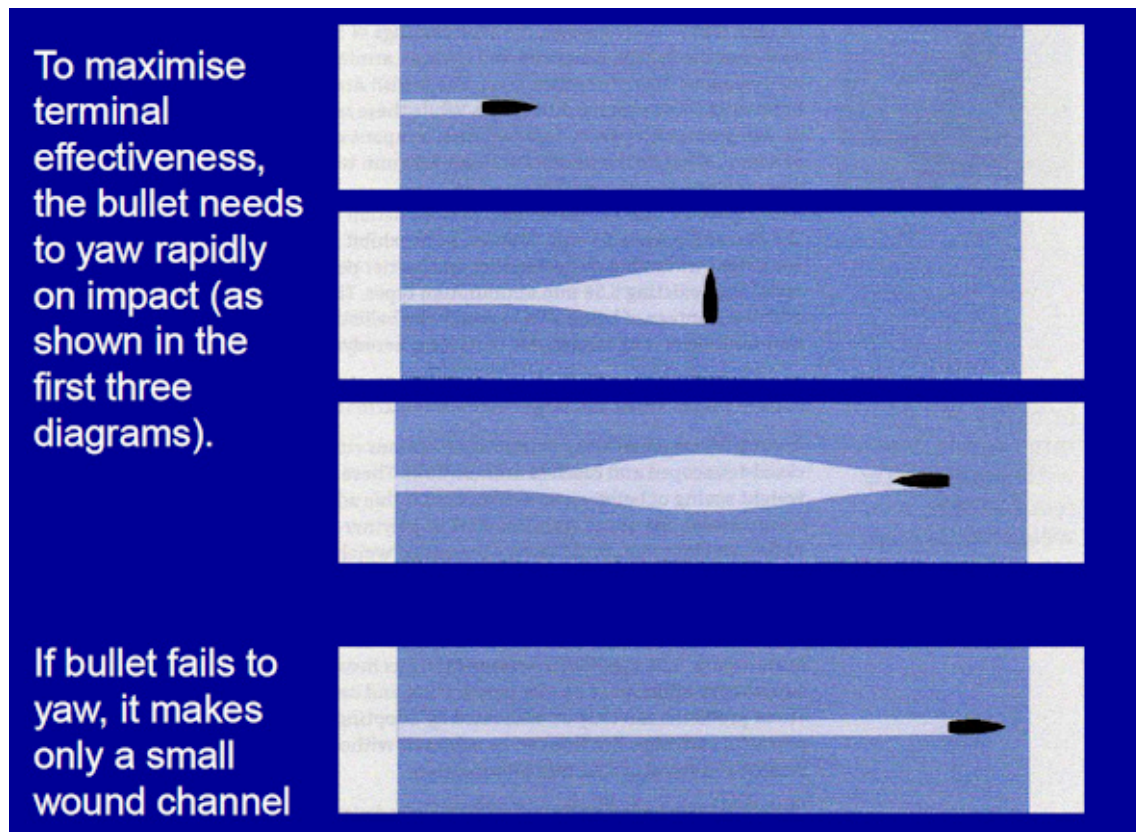


This lack of effective range and suppressive effect were the two major concerns with 5.56 mm ammunition which were reported by the British Army, but there were also complaints about two other issues which have long been highlighted in the USA and widely reported: erratic terminal effectiveness, even within its effective range, and poor barrier penetration.

Erratic terminal effectiveness is mainly due to the fact that, while the SS109/M855 bullet is capable of inflicting incapacitating injuries at shorter ranges, it frequently does not yaw rapidly on impact but may instead pass through most of the body point-first. When this happens, it will inflict a relatively minor injury unless it hits a vital organ. There is anecdotal evidence aplenty of erratic effectiveness in combat (for example in an article in early 2011 in the Royal Marines' magazine, *Globe and*

**Laurel**, which commented that it could take up to 15 hits to stop an attacker at close range), and this has been confirmed by laboratory testing, which reveals that 85% of the bullets do not start to yaw until they have penetrated at least 120 mm - which could take them most of the way through a body. While no small-arms cartridge is effective 100% of the time, the general consensus of those with combat experience with both 5.56 mm and 7.62 mm rifles seems to be that on average about twice as many 5.56 mm hits are required to cause rapid incapacitation.

Problems with penetrating intermediate barriers such as walls or car doors and even windscreens have also been confirmed in laboratory testing. A 2008 presentation<sup>4</sup> by Dr Roberts detailed these problems and illustrated the results of laboratory testing. The commander of the German troops in Afghanistan made similar complaints in 2009 about the poor effectiveness and barrier penetration of 5.56 mm ammunition. Interestingly, the British Army adopted a semi-automatic shotgun to provide more reliable close-range effectiveness than 5.56 mm weapons.



A 2009 analysis<sup>5</sup> by Major Thomas P. Ehrhart, United States Army, of the performance of US Army small arms in Afghanistan (*Increasing Small Arms Lethality in Afghanistan: Taking Back the Infantry Half-Kilometre*) makes similar points to the British studies concerning typical engagement ranges and the limited effective range of 5.56 mm weapons, and also stresses the importance of marksmanship training.

In 2010 the US Army's Soldier Weapons Assessment Team carried out interviews with soldiers in theatre to discover any issues. The need for their carbines to be effective beyond 500 metres was one of the key requests from troops. The 7.62 M14 EBR (Enhanced Battle Rifle), an updated version of the old M14 which was rushed into service when the 5.56 mm range problem became apparent, proved so popular



that the troops wanted it to be an organic part of squad equipment. And the 7.62 mm MK48 light machine gun was increasingly being carried instead of the 5.56 mm M249: as the Team put it; *"lethality trumps weight reduction when extended ranges are required"*.

Not everyone agrees that 5.56 mm weapons have such a short effective range. Some proponents argue that in good conditions they can be effective to 500 m in the hands of well-trained soldiers - although the ballistic graphs later in this article demonstrate that they will have a harder job hitting targets, or getting close enough for suppressive effect, than with larger-calibre weapons, as they are more prone to being blown off-course by side-winds.

These shortcomings meant that British as well as US foot patrols started carrying 7.62 mm weapons in place of some of their 5.56 mm guns; the very effective L7A2 GPMG (similar to the US Army's M240) and the new L129A1 sharpshooter rifle, of which several hundred were purchased from 2010 as an Urgent Operational Requirement specifically to overcome the lack of range of 5.56 mm weapons. The problem with the GPMG is that both the gun and its ammunition are very heavy; most unwelcome given that reducing the burden (then around 60 kg - 132 lbs) worn and borne by the infantryman in patrol order was and remains one of the top equipment priorities of the British Army. The Army at one time planned to follow the US lead in adopting lighter 7.62 mm machine guns - the 7.62 mm version of the FN MINIMI having been selected - to match the characteristics of the Russian PKM, although in the event these have only been acquired for special forces. The weight of 7.62 mm ammunition remains a problem; a key issue with belt-fed machine guns.

## INCREASED USE OF 7.62mm WEAPONS

L7A2 GPMG (right)

L129A1 (below)



## IMPROVEMENTS TO THE 5.56 MM AMMUNITION

US forces have adopted new 5.56 mm ammunition with the aim of replacing the M855. In mid-2010 the US Army started to field the M855A1 EPR (Enhanced Performance Round, previously known as the LFS - Lead Free Slug), while the USMC selected in early 2010 the MK318 Mod 0 SOST (Special Operations Science & Technology). Both rounds are claimed to offer better performance from short-barrelled carbines, improved barrier penetration and more reliable terminal effectiveness. The M855A1 also penetrates more armour and contains no lead. Initial indications are that while the USMC is happy with the more consistent effectiveness of the MK318 (and has developed but not yet fielded a lead-free Mod 1 version), they have expressed concern that the high-pressure M855A1 causes some problems concerning barrel wear and gun life<sup>6</sup>. The Individual Carbine competition held by the US Army in 2013 was abandoned when none of the competing guns was able to meet the Army's reliability requirements when using the M855A1 ammunition.

These new rounds appear to have ameliorated the M855's penetration and effectiveness issues, but their exterior ballistics are not good enough to eliminate the need for larger-calibre small arms to cover the longer ranges, and in any case they may not be acceptable to European nations, as we shall see. As of Autumn 2015, the US Congress had expressed concern that the US Army and USMC are using different 5.56 mm ball ammunition, and called for a report on the subject<sup>6</sup>.



## THE "GOLF BAG" APPROACH: A MIX OF 5.56mm AND 7.62mm WEAPONS


That brings us up to date. 7.62 mm guns are being used much more widely, although their ammunition is big and heavy and generates nearly four times as much free recoil energy as 5.56 mm (other things being equal). Heavy recoil in a rifle makes it more difficult to train recruits, reduces accuracy, slows down rapid semi-automatic fire and makes fully automatic fire virtually uncontrollable. The author has tried the 7.62 FN SCAR-H acquired by the US Special Operations Command and recoil is sharp even in semi-auto fire: a soldier with extensive small-arms experience commented that only the first round of an automatic burst was likely to hit the target. But the 7.62 gets the job done, so do we really need a new cartridge? The 7.62 weapons can deal with the long-range work, with 5.56 carbines retained for short-range fighting.

One problem with this is that it may not be possible to draw neat lines around scenarios: a patrol may be clearing houses in a village at one moment then come under long-range fire as they leave. It means that those carrying 7.62 weapons will be less well equipped for the close-quarter battle, while those with 5.56 guns will be unable to participate effectively in long-range engagements or even to pass their ammunition over to those with 7.62 guns, thereby reducing the effective firepower of the section. Finally, it still leaves us with the 7.62's weight and recoil, plus the erratic terminal effectiveness and poor barrier penetration of the 5.56 M855.

### DO WE NEED A NEW CARTRIDGE?

5.56 x 45

7.62 x 51



	Cartridge weight grains/gm	Bullet weight grains/gm	Muzzle velocity* fps/mps	Muzzle energy* ft lbs/joules
5.56mm M855	185/12	62/4.0	3,050/930	1,285/1,730
7.62mm M80	370/24	147/9.5	2,700/823	2,392/3,217

\* From 20 inch (508mm) barrels

Furthermore, the proliferation of new small arms in Afghanistan increased the total number of portable rifles and MGs in the British section to five (not including sniper and special forces rifles) – the three original 5.56 mm guns and two 7.62 mm ones: the L129A1 and L7A2. Even worse, the US Army and Marine Corps used eight between them: four in each calibre (M4, M16, M27 and M249 in 5.56 mm; M14EBR, M110, M240 and MK48 in 7.62 mm). This proliferation of weapons has obvious practical disadvantages in terms of procurement, training and maintenance. The evidence presented below suggests that it is possible to meet military requirements with a much smaller number of weapons. The key to this is the ammunition.

## MILITARY CARTRIDGE REQUIREMENTS

The performance of the ammunition determines the potential of the weapon. So the design of future rifles and machine guns should start by defining the required terminal effects of a bullet against soft and hard targets out to a specified range (bearing in mind the likely growth in the use of body armour by potential opponents), and the exterior ballistics out to the maximum range for effective suppressive fire, in terms of the bullet's trajectory, susceptibility to wind drift and remaining velocity and energy.

Add in the various barrel lengths which might be used – future small arms will almost certainly be modular, with a choice of barrel lengths, as is already the case with several recent rifle designs – and that provides most of the factors controlling the cartridge design. The guns should then be designed around the cartridge. That's the logical priority order anyway, although in practice it doesn't usually happen that way – as demonstrated by the recent US Individual Carbine competition, which was theoretically open to calibres other than 5.56 mm, but in practice was not. Gun designers tend to be stuck with existing cartridges even though *far* greater improvements in capability could be achieved by changing the ammunition than by changing the guns.

What do we want infantry small arms to achieve? The most important gun in the dismounted infantry section/squad is the machine gun, which due to its volume of fire has the greatest suppressive effect out to the longest range. It therefore follows that this should normally use the longest barrels available to maximise the effective range. Infantry rifles or carbines may be fitted with shorter barrels in the interest of handiness in confined spaces; it is up to each army to decide the appropriate balance between compactness and ballistic performance (much less of a problem for those armies using rifles of bullpup configuration).

The following appear to be the main priorities:

**First**, their bullets should be capable of reliably inflicting sufficiently serious wounds to provide a high probability of an enemy being rapidly incapacitated by a centre-mass (torso) hit, **at least at short to medium ranges**.

**Secondly**, their bullets should be capable of penetrating a wide range of intermediate barriers while still maintaining their trajectory afterwards; what's known as "barrier blind".

**Thirdly**, sharpshooter rifles and LMGs should have the effective range to at least



match an enemy using full-power 7.62 mm weapons such as the PKM LMG and SVD rifle, since these are in widespread use and likely to remain so.

**Finally**, the weapons and their ammunition should have the lightest weight and lowest recoil consistent with the first three requirements.

These requirements are all essentially dependent on the right choice of ammunition. The first three can clearly be met by the 7.62 mm cartridge but this falls down badly on the fourth. The 5.56 mm round delivers the opposite results.

## APPROACHES FOR MEETING THE REQUIREMENTS

There are several possible approaches:

1. Retain the 5.56 and 7.62, but introduce an improved 5.56 loading.
2. Return to using the 7.62 in all weapons, preferably with an improved loading.
3. Replace the 5.56 with a more effective short to medium range cartridge, retaining the 7.62 in sharpshooter rifles and MGs.
4. Replace both existing rounds in the dismounted infantry section/squad with one new general purpose cartridge (GPC) with good long-range performance.

The pros and cons of these options can be summarised as follows:

**Option 1:** Various attempts have been and continue to be made to upgrade the performance of the 5.56 mm cartridge; in US service we have seen the MK262 and now the MK318 Mod 0 and the M855A1, and these all offer some improvements in performance. These new rounds may mitigate to some degree the M855's penetration and effectiveness problems, but their exterior ballistics (in particular the wind drift) are not good enough to eliminate the need for larger-calibre small arms to cover the longer ranges. **Anyway, the degree of improvement is fundamentally limited by the small size and modest power of the cartridge, and in particular the limited space between the case length and the overall length, which precludes the use of well-shaped bullets with long ogives (noses).** It's worth remembering that in many US states and in the UK, the 5.56 cartridge is considered insufficiently powerful to hunt anything other than small game, even when loaded with the more effective expanding bullets which are banned for military use by international agreement.

Furthermore, the MK262 and MK318 have open-point bullets, which are regarded as unacceptable by the British and other European countries, for reasons which are worth a short digression. Declaration III of the 1899 Hague Convention, states that: *"The Contracting Parties agree to abstain from the use of bullets which expand or flatten easily in the human body, such as bullets with a hard envelope which does not entirely cover the core, or is pierced with incisions"*. **Strictly speaking this carries little legal weight, as it only applied to warfare between the signatory nations (of which the USA was not one) and also does not apply to irregular forces, but the general principle has been subsumed within the Geneva Conventions which prohibit the use of "weapons, projectiles and material and methods of war of a nature to cause**

*superfluous injury or unnecessary suffering".*

The precise implications for bullet design of this vague wording are wide open to debate. US lawyers argue that their bullets are not designed to expand, so the clause does not apply; European lawyers still tend to adhere to the specific wording in the Hague Convention. For example, the UK Manual of the Law of Armed Conflict (LOAC, Ministry of Defence, 2004) states in its chapter on weapons: *It is prohibited to use in international armed conflicts "bullets which expand or flatten easily in the human body, such as bullets with a hard envelope which does not entirely cover the core or is pierced with incisions. This prohibition is aimed at soft-nosed bullets that mushroom on impact or bullets whose casing is designed to fragment on impact causing, in either case, unnecessarily serious injuries".*

It is worth noting that all of these references to bullet jackets which do not "entirely cover the core" ignore the fact that the base of nearly all military rifle bullets is not covered by the jacket anyway. There are also bullet designs which do not use jackets: the French Army use the PPI bullet (now made by RUAG as their HC line) in both 7.62 mm and 12.7 mm calibres: this consists of a steel bullet with a brass "shoe" enclosing the rear part, and will neither expand nor fragment in soft tissues.

The US Army's EPR bullet (M855A1 and M80A1) does have a jacket which does not cover the exposed steel tip, but like the PPI bullet it clearly cannot expand. However, as with the M855 the EPR appears to rely on bullet fragmentation to maximise its soft-target effectiveness (it is said to fragment to lower impact velocities, i.e. at longer ranges) which is also regarded as unacceptable by UK lawyers because of the wording of the LOAC given above. The original British L2A1 5.56 mm ball bullet did fragment in a similar way to the M855, but this was made less likely in the L2A2 and subsequent patterns by using a thicker jacket.

As a result of all this, the US rounds are very unlikely to be approved as NATO standards, although they may of course be adopted by individual NATO nations depending on the particular interpretation of international law which they accept. It also seems unlikely that the British lead-free EP (Enhanced Performance) 5.56 round currently being developed by BAE, which has a steel core, will offer the terminal effectiveness improvements claimed for the M855A1, since it is intended only to match the effectiveness of the SS109/M855.

**Option 2:** The 7.62 M80 (the standard NATO ball round) is an old design which is effective but not very efficient. It is not efficient for two reasons. First, because the bullet does not usually yaw very rapidly on impact. Second, it has an unimpressive long-range performance for its calibre due to the mediocre aerodynamics of the bullet which sheds velocity quite quickly. It is effective simply through the size and power of the bullet which delivers considerable terminal effectiveness and barrier penetration, but that power has a serious cost in weight and recoil. *Some improvements could be made by introducing a more modern and efficient loading, but the only ones to emerge recently rely either on an open-point bullet (MK319) or an unjacketed steel tip (M80A1, which is basically a scaled-up version of the M855A1).* The M80A1 bullet is significantly lighter than the M80 at 8.4 g (right on the minimum of NATO's STANAG 2310, which requires standard 7.62 mm ball bullets to weigh between 130 and 155 grains (8.4 to 10.0 g), but it is fired at a higher velocity – it is presumably

optimised for short-to-medium range use. This will do little to mitigate the weight and recoil issues.

In the longer term there may be the possibility of using a combination of a lighter but better-shaped lead-free bullet which matches the ballistics of the existing M80, in combination with a mostly polymer case, as proposed in the article already referred to<sup>3</sup>. Such a case would not only reduce weight considerably, but could be moulded around the bullet, enabling the use of a more tapered, long-nosed shape in the interests of aerodynamics. Such a reduction in weight (and to a lesser extent recoil) would be very attractive and could be usable in existing weapons. However, such technologies have yet to be proved, and these weight saving methods could of course be applied to any calibre.

Despite all of the issues with 7.62 mm, it should be noted that the Turkish army (the second largest in NATO) recently cancelled plans to adopt a new 5.56 mm infantry rifle in favour of a new standard rifle in 7.62 x 51 calibre. The New Zealand Army, which recently adopted a 7.62 mm Designated Marksman Weapon, is also phasing out their 5.56 mm C9 LMG (FN Minimi) in favour of the 7.62 mm version.

**Option 3:** To achieve a worthwhile performance increase over the 5.56 mm it is necessary to move to a larger calibre with increased case capacity. There will be some penalties in the form of increased weight and recoil, but these can be considerably less than the figures for the 7.62 mm. The most thorough recent attempt emerged a few years ago as a joint effort between Remington and some soldiers within SOCOM; the 6.8 x 43 Remington Special Purpose Cartridge, or SPC. Muzzle energy and ammunition weight are half-way between the 5.56 and 7.62. Tests indicate that its terminal effectiveness and barrier penetration are very impressive, albeit achieved with an open-point bullet. In comparative shooting tests (courtesy of Heckler & Koch) the author found that the additional recoil appears to be quite modest, feeling much closer to the 5.56 than it does to the 7.62, despite the fact that the HK416/6.8 rifle is lighter than the big HK417. However, the long-range performance, while better than the 5.56, is not good enough to replace the 7.62 as it is limited by the relatively short and light bullet needed to keep the overall length the same as the 5.56mm. The 6.8 mm Rem has achieved service status, being adopted for certain guard units first by Jordan and then (much more significantly in terms of numbers) by Saudi Arabia. However, the special loading developed for Saudi Arabia uses an even lighter bullet optimised for use in short-barrelled carbines and is only intended to be effective within about 300 m.

Another option for improving on the performance of the 5.56 mm are the virtually identical .300 Whisper/Blackout rounds based on the 5.56 mm case, but in their supersonic loadings these do little more than replicate the ballistic performance of the Russian 7.62 x 39 M1943 cartridge in a smaller package, so are only effective at short to medium range.

**Option 4:** This option is based on the fact that once you are in the size and performance class of the 6.8 Remington, the right choice of calibre and - especially - bullet can in theory match the long-range performance of the 7.62 mm M80 with a significantly lower ammunition weight and recoil. This therefore opens the possibility of one common general-purpose cartridge (GPC) used by the weapons carried by

the dismounted infantry section. While the extra range would initially benefit LMGs and sharpshooters, and may not be needed in assault rifles, it does give them the potential for delivering long-range suppressive fire given the increasing use of telescopic sights and bipods; provided of course that appropriate training is given. Furthermore, advanced sights already on the market (incorporating laser rangefinders and ballistic computers) could enable all riflemen to fire more effectively at long range. If a single GPC could be achieved, the benefits resulting from all of the weapons within the squad/section being suited to use at all combat ranges and being able to share ammunition, plus the simplification of weapon and ammunition acquisition, logistics and training would make this an attractive option.

### **AMMUNITION HISTORY - WE NEARLY MADE IT BEFORE!**

It is worth taking a brief look at what we can learn from cartridges developed in the past, before considering the specifications which could deliver Option 4.

One of the early small-calibre cartridges was the Japanese 6.5 mm Arisaka. When introduced in the late 19th century it had a round-nosed bullet but from 1905 the pointed-bullet Type 38 loading was introduced, and this remained in service until 1945. It was recognised to be an impressive performer, with terminal effectiveness comparable with the later 7.7 mm MG round. It developed a muzzle energy of 2,590 Joules (1,920 ft lbs), a figure worth remembering.

The US Army came close to adopting a reduced power, general-purpose cartridge eight decades ago. Following exhaustive testing by the Army's Caliber Board, the .30'06 round was very nearly replaced in the 1930s by the .276 Pedersen, which developed 2,390 J of muzzle energy. The British were very interested in this cartridge and even established an ammunition production line but it was rejected by the US Army mainly on cost grounds, because of the large stocks of .30'06 ammunition.

The next attempt took place in the years following World War 2 during the trials to select NATO's first standard rifle and machine gun cartridge. As a result of WW2 experience there was a strong wish in both the US and British armies to adopt one general-purpose selective-fire rifle to replace the proliferation of weapons in service. The British wanted a rifle compact and controllable enough in automatic fire to replace sub-machine guns as well as the .303 rifle, the Americans wanted one which would replace their M1 Garand rifle, M2 Carbine, Browning Automatic Rifle and M3 sub-machine gun.

For the NATO tests Britain submitted a new reduced-power 7 mm round co-developed with Belgium and supported by Canada. Various designations were used as it developed, starting with the .276, then the .280, the .280/30 and finally the 7 mm Mk 1Z, although it is now often referred to as the 7 x 43. This used a long, heavy bullet which lost velocity more slowly than the 7.62's, enabling it to deliver more energy at long range despite a lower muzzle energy (initially c.2,450 J) with less weight and recoil.

The British designed the EM-2 bullpup rifle around this cartridge in order to achieve the short gun needed for urban fighting combined with the long barrel needed for long-range fire. This combination was compact and controllable enough to replace sub-machine guns as well as the old .303 rifles. It was, for a time, officially adopted

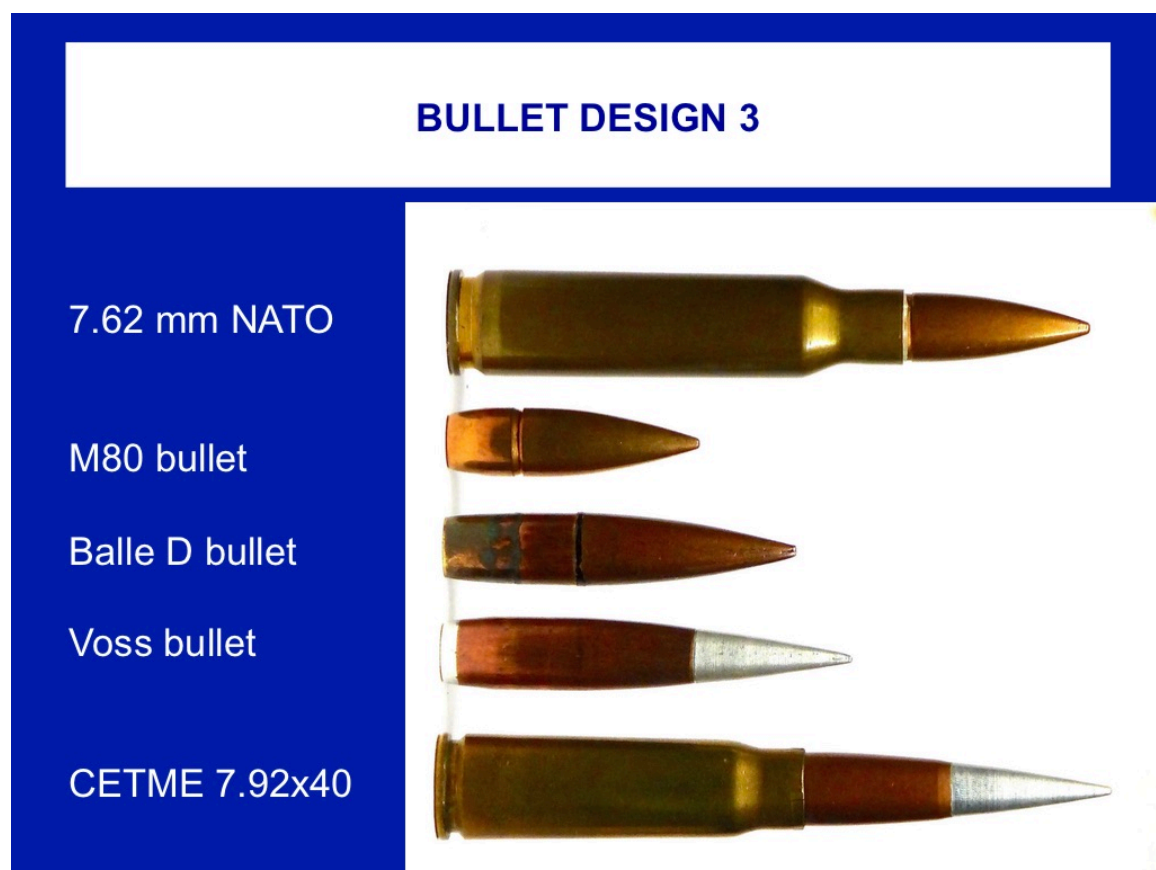


by the British Army. However, this had to be cancelled when the US Army insisted on their new .30 calibre cartridge which was duly adopted as the 7.62 NATO. Unfortunately, at 3,200-3,400 J this is just as powerful as the old full-power rifle/MG rounds which had seen service in both World Wars and, as we have seen, generates so much recoil that effective automatic rifle fire proved impossible. The M14 rifle in this calibre was therefore only able to replace one of the four weapons it was intended to: the M1 Garand rifle, over which it was only a modest improvement.



Also in the early 1950s, a remarkable example of the virtues of "thinking outside the box" came from Spain in the form of the CETME carbine in 7.92 x 41 calibre. This round was developed by a German ballistician, Dr Gunther Voss, when working at CETME (*Centro de Estudios Técnicos de Materiales Especiales* = Center for Technical Studies of Special Materials), a Spanish government design and development organisation. He wanted to develop a carbine which would combine a long range with a low enough recoil for automatic fire to be controllable. To achieve a major reduction in recoil compared with a conventional round like the 7.62 NATO required a much lighter bullet - which he chose to make from solid aluminium, with a copper sleeve over most of its length. **This would normally lose velocity very quickly, so to avoid this Voss developed one of the finest aerodynamic forms ever used in a rifle bullet (it has since been matched by some bullets for a few specialised very long-range rifles such as the .408 Chey-Tac).** The ballistic coefficient of the resulting 6.9 g bullet was close to that of the 9.7 g 7.62 mm M80, as was the muzzle velocity (800 m/s from a 435mm/17 inch barrel), so the trajectory and effective range were very similar, but the ammunition weight and especially recoil were significantly reduced, aided by the fact that the lightweight bullet required less propellant and therefore a smaller cartridge case. This ammunition did what it was designed to by all accounts,

but by the time it emerged in 1953 the 7.62 NATO was unstoppable. The slide below compares the CETME round and bullet with the 7.62 M80, next to an early champion of a good ballistic shape, the 8mm Balle D which entered French Army service in 1898.



There have also been more conventional attempts at a new cartridge, intermediate in power between the 5.56 mm and the 7.62 mm. The British developed an interesting 6.25 mm cartridge around 1970, but this was not designed for very long range and used a relatively light bullet. At much the same time the US Army was developing the 6 x 45, for use in a squad automatic weapon; this was similar in performance to the 6.25 mm, but biased a little more in favour of long-range performance. This was abandoned when improved 5.56 ammunition with a longer effective range was promised – which eventually arrived as the M855.

A more promising approach is the 6.5 x 40, a recent private venture by Mitch Shoffner, which is basically a 6.8 mm Rem necked-down to the smaller calibre and shortened to allow the use of long, aerodynamic bullets while still being compatible with 5.56 mm actions. While this is not powerful enough to replace the 7.62 x 51, its long-range performance would probably be good enough to make the carrying of 7.62 mm weapons by dismounted troops normally unnecessary. Another recent private-venture experimental round is the 7 x 46 UIAC by Cris Murray, which is in effect a lengthened and necked-out 6.5 mm Grendel. This has plenty of performance, but may be too close to the 7.62 mm in weight and recoil to stand much chance of adoption.

The other two shown in the slide below are particularly relevant because they achieved a good long-range performance from a small cartridge by using a heavy bullet at a medium velocity. The most recent production round to deliver high energy to long range by firing a heavy, reduced calibre bullet at a moderate muzzle velocity is the 6.5mm Grendel from Alexander Arms (6.5 x 38).

### AMMUNITION OPTIONS HISTORY

<p><b>.30'06 (1906+)</b> 150gr / 9.7gm @ 2,700 fps / 823 mps</p>	
<p><b>.276 Pedersen (c.1930)</b> 125gr / 8.1gm @ 2,520 fps / 768 mps</p>	
<p><b>7 x 43 British (c.1950)</b> 140gr / 9.0gm @ 2,415 fps / 736 mps</p>	
<p><b>6.25 x 43 British (c.1970)</b> 100gr / 6.5gm @ 2,680 fps / 817 mps</p>	
<p><b>6 x 45 SAW (c.1970)</b> 105gr / 6.8gm @ 2,520 fps / 768 mps</p>	
<p><b>6.5mm Grendel (2000s)</b> 123gr / 8.0gm @ 2,600 fps / 790 mps</p>	

Shown below are the NATO 7.62 and 5.56, the 6.8 Remington and the 6.5 Grendel. Both the Remington and the Grendel rounds can develop up to 2,500 J muzzle energy when fired from a long barrel - very similar to the 6.5mm Arisaka, the .276 Pedersen and the 7 x 43.

### CURRENT RIFLE ROUNDS & BULLETS



Left to right:

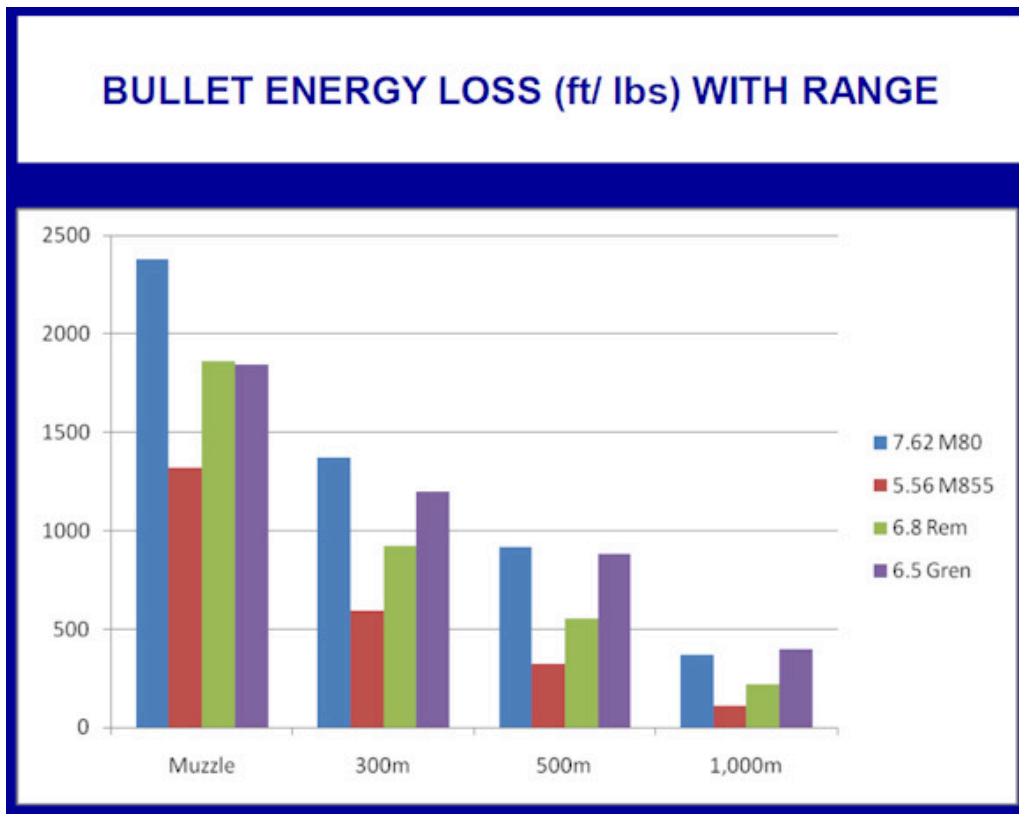
7.62x51 M80

5.56x45 SS109

6.8x43 Rem SPC 115 gr

6.5x38 Grendel 123 gr





The chart above compares how the energy of the four bullets changes at different ranges. Two things are obvious: first, that the initial performance gaps between the 5.56 and the 6.8, and between the 6.8 and the 7.62, become steadily wider with increasing range. The second point is that the 6.5 mm performs differently; while starting with a muzzle energy similar to the 6.8, its longer, thinner and more aerodynamic bullet allows it to match the 7.62 at long range. It also offers a flatter trajectory and much less wind drift despite its lower muzzle velocity, as demonstrated in the graphs below. The four rounds are shown together above, with their bullets. Note that the design of both the 6.8 and the 6.5 was constrained by having to fit within a converted AR-15, so the total length had to be the same as the 5.56. This prevents the 6.8 from using long bullets with good long-range performance. With a new calibre and family of weapons, this need not be a constraint.

### THE PROBLEM OF BULLET MATERIALS

One important reservation concerning the impressive performance of the Grendel is that these results were obtained with the use of a low-drag, lead-cored target bullet. The US Army has since chosen to develop lead-free small-arms bullets to minimise the risk of environmental pollution on practice ranges; the M855A1 EPR is the first, since joined by the 7.62 mm equivalent; the M80A1. Other nations generally accept, however reluctantly, that they will eventually have to follow suit as far as ball ammunition is concerned, although lead-cored bullets may well be retained for special purposes like sniping, for which ammunition expenditure is extremely low. Therefore a GPC must be able to deliver results with lead-free bullets; but it is difficult to match the performance of a lead-cored target bullet with a mass-produced lead-



free military ball round unless a very refined bullet shape is adopted, as with the Voss bullet already described. Such bullets have a very long ogive projecting a considerable distance from the case mouth, which is unlikely to be feasible with conventional cartridge designs. The alternative is a bullet which extends deeper into the cartridge case, reducing the space for propellant, and this indicates that the Grendel is probably too small to do the job required unless a long barrel is selected, or perhaps a lighter but better-shaped bullet.

There are three alternative metals to lead commonly found in bullet cores: steel, copper and tungsten. Of these, tungsten is the only one which is more dense than lead (170% of the density) but is reserved for armour-piercing ammunition because of its high cost (20 times as much as lead). In any case, all heavy metals tend to be toxic to some degree, so there would be little environmental improvement from using it. So in effect mass-produced lead-free bullets capable of being used in conventional cartridges (unlike the Voss bullet) are limited to copper (or copper alloy, such as brass) and steel. Copper has 80% of the density of lead but is about four times the price; steel has 70% of the density but is only a quarter of the price (although specially hardened alloys to improve penetration will be costlier). Machine-turned solid brass bullets are often used in very low-drag designs for long-range target shooting as they can be made with great precision, but they are costly to manufacture and do not penetrate armour as well as hardened steel.

The lower density of copper and steel means that to achieve a given weight, they need to be longer than FMJ bullets with lead cores of the same calibre. Assuming that a bullet is 50/50 copper/steel by volume, then its overall density will be in the region of  $8.1 \text{ g/cm}^3$  compared with about  $9.9 \text{ g/cm}^3$  for a typical FMJ bullet. This means that to bring the mass up to the same as the lead-cored version the bullet must increase in volume by something like 22%; which in any given calibre, means it must increase in length by about that much. This potentially causes two problems: packaging the ammunition, and stabilising the bullet.

For an existing cartridge there is usually no room to have the bullet protruding further from the case without exceeding the limits on overall cartridge length (above which the ammunition may not fit into the gun actions or magazines). It is therefore necessary for the lead-free bullet to extend more deeply into the case as mentioned above, reducing the space for propellant. Unless a more volume-efficient propellant with the right pressure characteristics can be found, this means that the muzzle velocity and energy achieved at any given chamber pressure will be reduced.

Bullet stabilisation depends on the relationship between its length/diameter ratio (L/D) and the barrel rifling twist. In any given calibre, the longer the bullet, the tighter the rifling twist needs to be. In practice, there is a limit in the L/D of about 6:1, beyond which stabilisation by rifling is no longer feasible (e.g. a calibre 6 mm bullet cannot exceed 36 mm in length); in fact, standard military bullets typically have L/Ds of around 4:1. Which is why long, thin, discarding-sabot projectiles are stabilised by fins at the end and are preferably fired from smooth-bored guns.

Of the bullets shown above, the performance champion is the 6.5mm Grendel's 123 grain (8 g) Lapua Scenar, which has a lead core. It is good because of its long thin shape, but this means it already has an L/D of about 4.9:1 (partly because the tip is

hollow). Adding 22% to its 33 mm length would bring this up to about 40 mm, with an L/D of close to 6:1 – right on the absolute limit and requiring the tightest possible rifling twist. Bearing in mind that any military machine gun ammunition must include tracer bullets and these are almost invariably longer than the ball bullets (as their chemical contents are much less dense than core metals), this is simply too long. The extra 7 mm of length would also have to be packaged somehow.

The maximum feasible weight for a 6.5 mm brass/steel military bullet was determined by the French over a century ago in their search for a new long-range military cartridge to replace the 8 mm Lebel. The result of their investigations, reported in 1911, was the "bi-metallic Balle E.N.T. No. 123" which weighed 7.5 grams (116 grains) and was 36 mm long, giving an L/D ratio of 5.35:1.

The reduced mass of lead-free bullets means that they cannot match the ballistic performance of lead-cored bullets of equally good shape, as will be illustrated later.

Incidentally, the smaller the calibre, the harder it becomes to achieve a low-drag bullet in lead-free materials. The best ballistic performer of the 5.56 mm loadings to have seen military service, the MK262, uses a lead-cored target bullet weighing 77 grains (5 grams). This is 25 mm long, giving an L/D ratio of 4.4:1. An EPR bullet of the same weight would be around 32.5 mm long, giving an L/D of 5.7:1 - too long, once tracer bullets are added. Yet the MK262, although a very good performer by 5.56mm standards, doesn't even match the 7.62 mm M80 in its ballistic performance (it has a slightly worse G7 ballistic coefficient of .190 - see below) and, as we have seen, the M80 is a very mediocre performer compared with the Grendel.

## CHARACTERISTICS OF GENERAL PURPOSE CARTRIDGES

Taking all of these issues into account, it is possible to draw up the characteristics of cartridges to meet the requirements previously listed. The calibre could be anywhere between 6 mm and 7 mm, although at the smaller end of the scale designers may struggle to provide a worthwhile improvement over the 5.56 mm (especially with lead-free bullets), while at the larger end the problem will be a weight and recoil which may be too close to the 7.62 mm to be worth the cost of changing. **As a result, 6.35 to 6.8 mm appears to be the optimum calibre range.**

Some useful pointers emerged from practical tests carried out by the US Army's ARDEC (Armament Research, Development and Engineering Center) Small Caliber Munitions Technology Branch to determine the optimum calibre for a military rifle, with the results emerging in March 2011. A wide range of criteria were examined including: penetration; terminal effectiveness; accuracy; initial, retained and striking energy; wind drift; stowed kills; and recoil. 5.56 mm and 7.62 mm rounds were compared with 6 mm, 6.35 mm and 6.8 mm, all loaded with lead-free copper+steel bullets to represent the EPR. The outcome was that both 6.35 mm and 6.8 mm comprehensively outperformed the others in their overall balance of characteristics.

In 2012 AMU - the US Army Marksmanship Unit - carried out another study into the optimum cartridge for a future infantry carbine, and this concluded that the if the constraint of staying within the 5.56 mm overall length could be removed, the

cartridge length and diameter should be greater than 5.56 x 45, the calibre should be 6.5 mm and the muzzle energy around 2,500 J, with low-drag bullets (G7 BC =.250+; see below) being used to provide good long-range performance, bettering that of the 7.62 mm M80. The resulting cartridge was designated the .264 USA, effectively a necked-down version of Cris Murray's 7 x 46 UIAC. A variation on this was the .277 USA (a 6.8 mm version) thought to have advantages with lead-free bullets. A third alternative, which AMU produced in case a new cartridge had to be usable in adapted 5.56 mm weapons, was the 6.5 mm SPC Short, which is basically the same as Mitch Shoffner's 6.5 x 40 referred to earlier.

In 2014/5 Textron Systems, the lead contractor for the US Army's Lightweight Small Arms Technologies (LSAT) programme which has already resulted in 5.56 mm and 7.62 mm polymer-cased telescoped (CT) rounds, carried out a "Caliber/Configuration Tradeoff Study" which involved examining ten calibres each with three different projectile shapes. The result was the identification of the 6.5 mm calibre with a relatively long, low-drag bullet design as offering the best balance of characteristics, the principal variables being system weight, recoil impulse, lethality at short and long ranges and time of flight.

Article<sup>3</sup> includes a comprehensive analysis of potential new rifle/MG rounds from various perspectives, including their heat flux – the limitations on sustained rates of fire caused by barrel heating. Retained energy, recoil impulse, and likely effectiveness in suppression are also taken into account, with three different bullet shapes in five calibres (5.56, 6, 6.5, 7, 7.62 mm) being assessed. The best results are obtained for 6.5 mm and 7 mm calibres, generating 2,500-2,700 J from a 500 mm barrel. Compared with the 7.62 mm M80, the 6.5 mm solution delivers the same impact energy from 600 m onwards, a longer supersonic range, reduced bullet drop and 25% less wind drift, as well as reductions in recoil and cartridge weight.

The outcome of all of these studies should hardly be a surprise, since as Major Ehrhart observed in his study mentioned above: *"The 2006 study by the Joint Service Wound Ballistics – Integrated Product Team discovered that the ideal caliber seems to be between 6.5 and 7-mm. This was also the general conclusion of all military ballistics studies since the end of World War I."*

The common conclusions of all of these studies are supported by a growing view that the next US rifle should be effective at ranges of up to at least 600 m and that the 5.56 x 45 could not deliver this, no matter what bullets were loaded.

In the light of these studies, it seems reasonable to select the 6.5 mm calibre in order to work up some examples of how a purpose-designed GPC might perform. The examples which follow are therefore merely to illustrate the potential; the optimum characteristics including the calibre would only be determined after extensive practical testing of various options.

The impressive ballistic performance of the Grendel (albeit from a long barrel – the bigger .264 USA delivers similar performance from a much shorter barrel) gives some clear goals at which to aim for our concept demonstration cartridges. This indicates that the muzzle energy, weight and calculated recoil of the GPC from a 20 inch (508 mm) barrel should be approximately midway between the 5.56 and 7.62 –

close to that of the 6.8 Remington and 6.5 Grendel. The bullet's performance at 1,000 metres should be comparable with the 7.62 M80 ball, as measured by hit probability (a function of trajectory, flight time and susceptibility to wind drift) and damage potential (bullet energy and penetration).

In order to achieve this the GPC needs to use a low-drag bullet (more technically, one with a high ballistic coefficient, or BC) to minimise the velocity loss with range. This is important because a low-drag bullet brings substantial benefits. As it loses velocity more slowly, achieving a given performance at maximum range means that it can start off at a lower velocity than a higher-drag bullet; which means that less propellant will be needed, the cartridge can be smaller and lighter and will generate less recoil. The current 7.62 NATO bullet has a very mediocre ballistic coefficient, or BC; the 5.56 is worse still.

It should be noted that there are two different methods of calculating the BC of rifle bullets: the standard commercial one is designated G1, and applies to pointed bullets with flat bases; the more appropriate one for low-drag boat-tailed bullets (i.e. tapering towards the base, as with all the examples shown here) is designated G7. The difference matters, because G1 figures come out at around twice as high as G7 (which is probably why commercial manufacturers like using them - they look better!). All of the BCs quoted in this article are G7.


There are two factors which determine the BC of a bullet in any given calibre: the mass (heavier is better) and the shape, or form factor (FF). The problem with adding mass is that it increases both ammunition weight and recoil; so the FF needs to be as good as possible. That means the bullet needs a long, gently tapering nose. We have seen what can be achieved if the FF is taken to an extreme in the 7.9 mm Voss bullet shown previously, but are there any current military rifle/MG bullets with a good FF which can be taken as a more conventional model? Yes, there is one - the standard Russian 5.45 mm 7N6 ball bullet as used in the ammunition for the AK-74 assault rifle and RPK-74 squad automatic weapon.

The slide below shows the standard Russian 5.45 mm ball bullet in comparison with the NATO 5.56 and 7.62, with their form factors and ballistic coefficients as measured by the US Army's Ballistic Research Laboratory. These figures show that the FF of the 5.45 is better than that of the other two bullets (a lower FF is better, in contrast with the BC in the final column in which a higher figure is better). The figures in the yellow box are for a couple of theoretical 6.5 mm bullets, an 8 gram lead-cored one and a 7 gram one which, as discussed above, is probably around the maximum practical length for a lead-free bullet in this calibre.

Simply matching the 5.45's FF in such bullets would provide the potential for a good long-range performance, even in a lead-free version, as can be seen by the BCs in the bottom right of the chart. These bullets would lose velocity more slowly than the 7.62 ball, let alone the 5.56.



### BULLET DATA (US ARMY BRL)



Cartridge	Wt gm	G7 FF	G7 BC
5.45x39	3.47	.929	.168
5.56mm M855	4.0	1.172	.151
7.62mm M80	9.5	1.105	.200
6.5mm 1 (lead)	8.0	.929	.271
6.5mm 2 (lead free)	7.0	.929	.237

5.45mm; 5.56mm; 7.62mm

The slide below involves a bit of photoshopping to illustrate these issues. The first two pairs of cartridges show the current 5.56 and 7.62 next to what they would look like with scaled-up 5.45 bullets.

### PHOTO MOCKUPS (showing 5.45mm bullets)



5.56mm (1,730J)

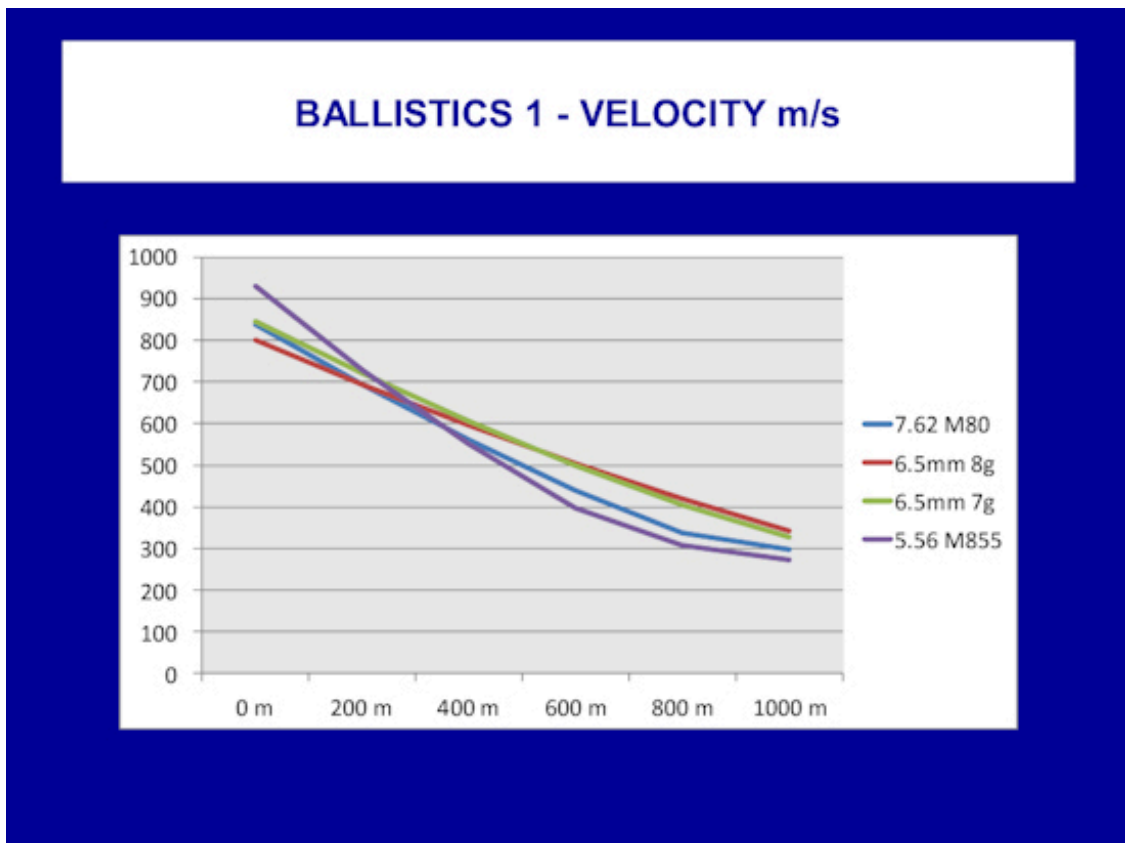
7.62mm (3,400 J)

6.5mm x2 (c.2,500J)

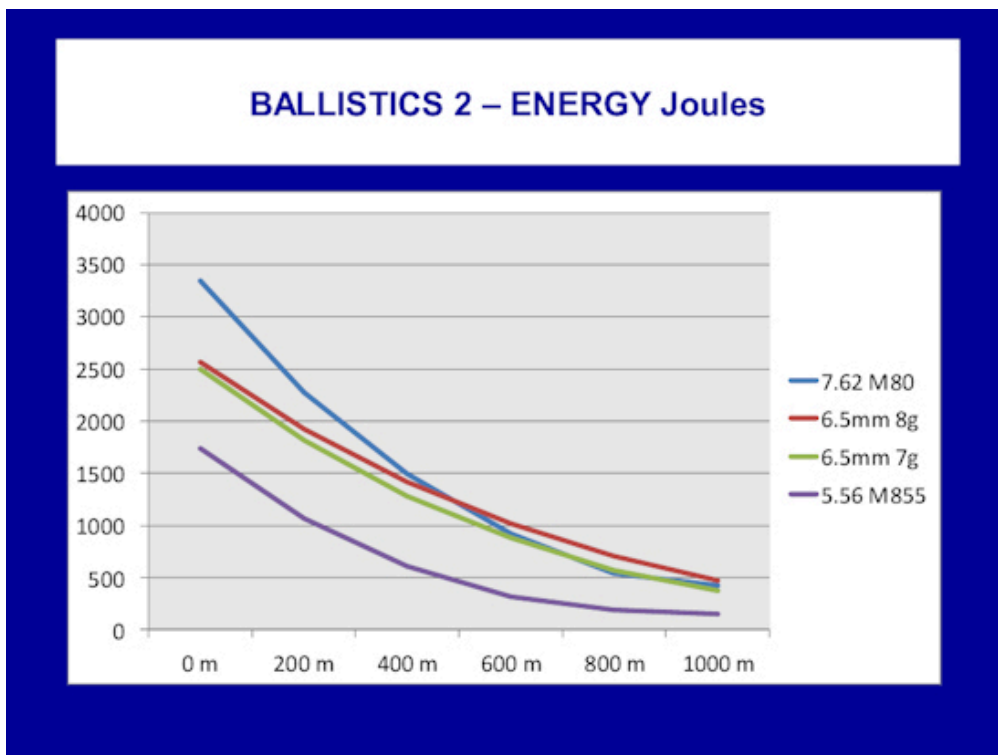
As can be seen, the existing cartridges cannot accommodate such finely-tapered low-drag bullets because that would make them too long to fit into rifle magazines and gun actions. They are therefore fundamentally restricted in the ballistic improvements which are possible. The last two photo mock-ups show two different 6.5mm cartridges with similar bullets (these are not meant to represent the ideal, they are just to illustrate what might be possible). The cases have different lengths and diameters but are both approximately the right size to provide a muzzle energy of around 2,500 J from a 508 mm barrel, midway between the 5.56 and 7.62. The first one is based on the 6.8 mm Rem case (10.7 mm diameter) slightly lengthened and, more important, with a much longer overall length to allow the low-drag bullet to be used. The second is based on the Grendel (11.3 mm diameter), lengthened by a few mm to provide a greater case capacity and of course also with a greater overall length. How might these perform?

The next few charts, compiled using the JBM ballistic calculator, compare the performance of the 5.56 mm and 7.62 mm NATO rounds with these two 6.5 mm cartridges. 20 inch (508mm) barrels are assumed in all cases for comparison purposes (armies may choose shorter barrels for their rifles, but the resulting reduction in performance is likely to apply more or less equally to all calibres).

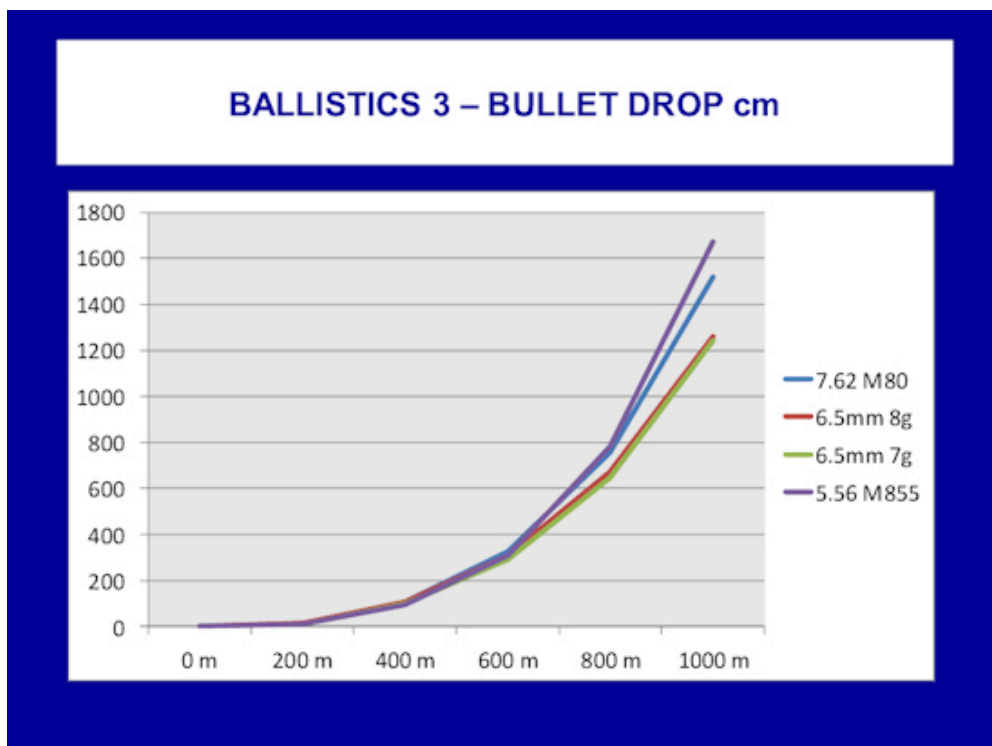
The first chart (below) shows the velocities with range; the 8 gram 6.5 mm bullet starts off the slowest but overtakes the 7.62 by 200 metres, while the 7 gram bullet remains faster throughout its flight; the 5.56 starts the fastest but after 400 m becomes the slowest.



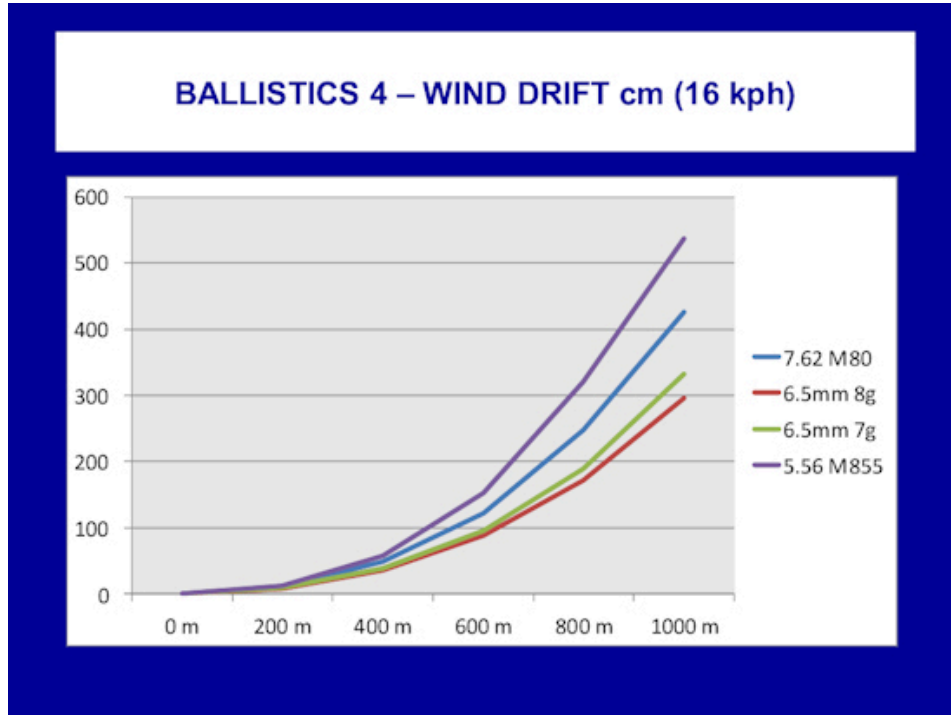
The second chart below shows the retained energies at different ranges; the heavy 6.5 catches up with the 7.62 by 500 metres, the light one by about 700 metres; the 5.56mm is increasingly outclassed at every range.



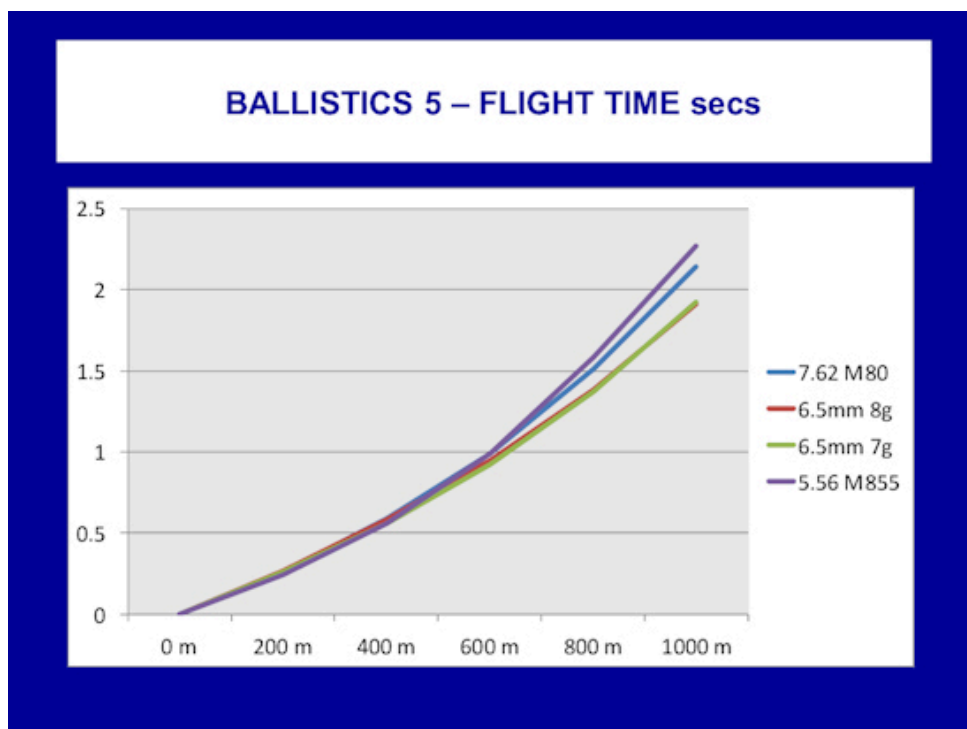
The third chart below shows the bullet drop in centimetres from rifles zeroed at 100 metres; at 1000 metres both 6.5s will have dropped about 12.5 metres below the line of sight, the 7.62 more than 15 metres, the 5.56 nearly 17.



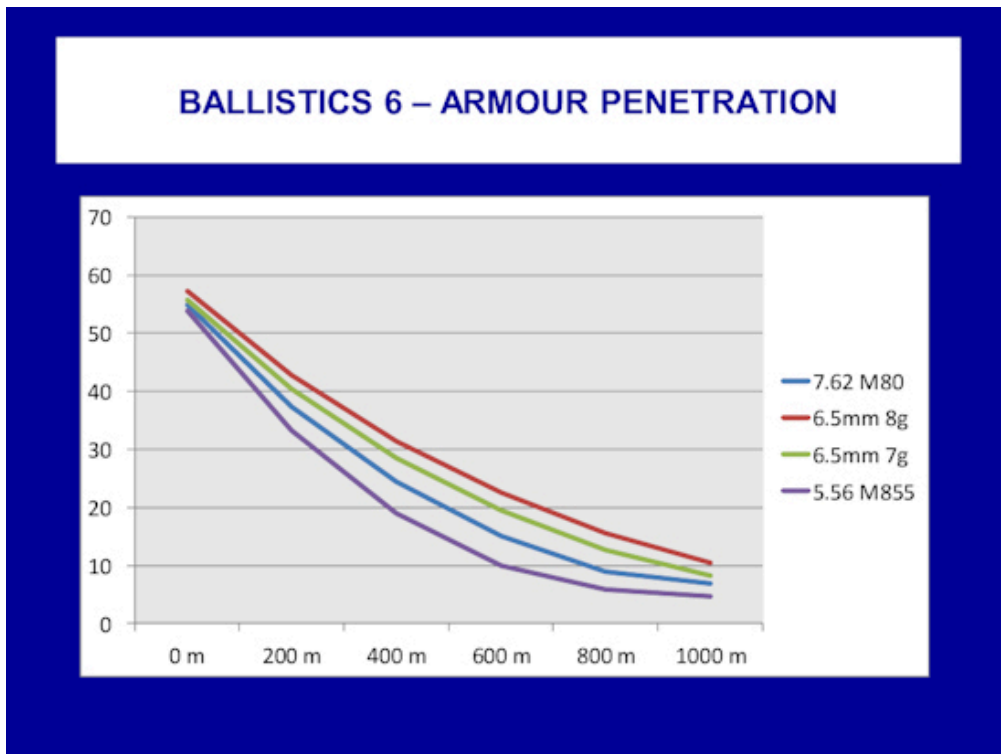
The fourth chart below shows the wind drift in a 10 mph cross-wind, an important element in long-range hit probability; at 1000 metres the heavy 6.5 will be blown sideways about 3 metres, the light lead-free 6.5 about 3.3 metres, the 7.62 about 4.25 m and the 5.56 about 5.4 m. Even at shorter ranges, this can make the difference between solidly hitting a target and entirely missing.



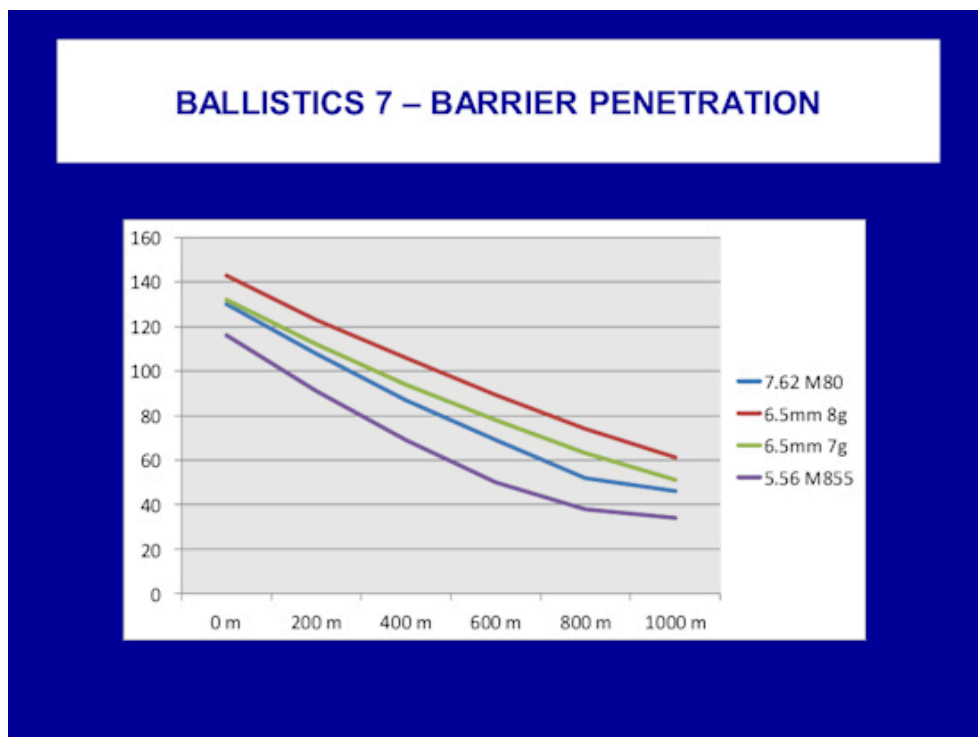
The fifth chart below shows the time of flight of the bullet in seconds; both 6.5mm bullets take about 1.9 seconds to reach 1000 metres, the 7.62mm about 2.1 seconds and the 5.56mm about 2.2.







The sixth slide above shows the potential for armour penetration (assuming similar AP bullet designs); this is calculated by dividing the impact energy by the cross-sectional area of the bullets. The numbers on the chart represent joules per mm<sup>2</sup>. There isn't much difference at close range, but the gaps widen as the range increases, the 6.5s gaining a clear advantage while the 5.56 particularly suffers.



Barrier penetration, shown in the seventh slide above, is calculated differently from armour penetration for the purposes of this exercise, as it requires momentum as

much as energy to plough through thicknesses of material. This chart is the result of multiplying the bullet weight by the muzzle velocity and then dividing the result by the cross-sectional area of the bullet. The numbers on the chart represent grams x metres/sec divided by mm<sup>2</sup>. Again, it's the 6.5s (especially the heavy lead-cored one) which lead the way with the 5.56 trailing badly.

The 6.5s have two other advantages over 7.62 mm: assuming conventional brass cases, their weights achieve an estimated reduction of around 20-25% (particularly useful in belt-fed MGs), and the free recoil energy in equivalent guns is reduced by 40-50% (important in rifles). Not surprisingly, these are the only areas where the 5.56 has a clear advantage over the other rounds, but since its poor performance at long range means that it is incapable of fulfilling the role of a GPC, that is rather academic.

To sum up, the 6.5s don't just match the 7.62's long-range performance; they are clearly superior to it despite their much lower muzzle energy, even when suffering the performance penalty of a lead-free bullet. And that's by using a bullet comparable with one the Russians have been churning out by the million for four decades, so no unrealistic assumptions have been made. Needless to say the 5.56 trails badly in most of these comparisons and becomes completely outclassed at longer ranges. Something like the lead-free 6.5 shown above would provide a significant weight saving over 7.62 without losing anything in long-range ballistics or penetration at any range. Combined with a recoil midway between 7.62 and 5.56, this would make it a viable candidate for a GPC.

## OTHER ASPECTS OF DESIGN AND PERFORMANCE

The preferred US Army "Enhanced Performance Round" bullet design features an exposed steel penetrator, and it seems likely that a similar design would be adopted in any other standard US rifle/MG calibre. However, to satisfy European requirements, the standard (ball) bullet must be compliant with their interpretation of the Hague and Geneva Conventions. Which is to say that in a jacketed bullet, the jacket must fully enclose the nose and sides of the bullet. Furthermore, the bullet must not only not expand on impact, it should be designed so that it does not readily fragment either (as mentioned, the French Army takes a slightly different view: any bullet is allowed, as long as it doesn't expand or fragment – but the latter restriction would presumably rule out the EPR anyway). It is possible for a non-jacketed bullet to meet these requirements; the solid brass target bullets already mentioned will neither expand nor fragment (amazingly, one of the early "small calibre" military bullets, the French 8 mm Balle D of 1898 previously shown on the Voss slide was made from solid brass, *and* was the first to have a finely-pointed nose, *and* was the first to have a boat-tail to minimise drag at long range; it is an impressive performer even today). Both RUAG and Nammo offer steel-cored fully-jacketed lead-free loadings in military calibres now, so such designs could easily be applied to a GPC. Another possibility is the RUAG 7.62 mm HC type already described: a 6.5 mm bullet of this type with an L/D of 5 will weigh around 7.0 g and have a G7 BC of about 0.24. In any case, armour-piercing and tracer rounds also need to be developed at the same time (although with any steel-cored types, providing an initial level of AP performance may be merely a matter of using harder steel).

One aspect of bullet performance which is difficult to quantify is the terminal effectiveness against unprotected human targets. As we have seen, with non-fragmenting, non-expanding bullets this depends on the rapidity and reliability with which the bullet yaws after impact. Rapid yaw means that the bullet is more likely to stop within the target (or at least exit at low velocity) and therefore less likely to result in collateral damage by continuing on to strike someone else. The problem is that this aspect of performance can be significantly affected by quite minor changes in bullet shape or construction so is difficult to predict with any confidence: a great deal of experimental work would be required to maximise the probability that the bullet does not over-penetrate in human targets.

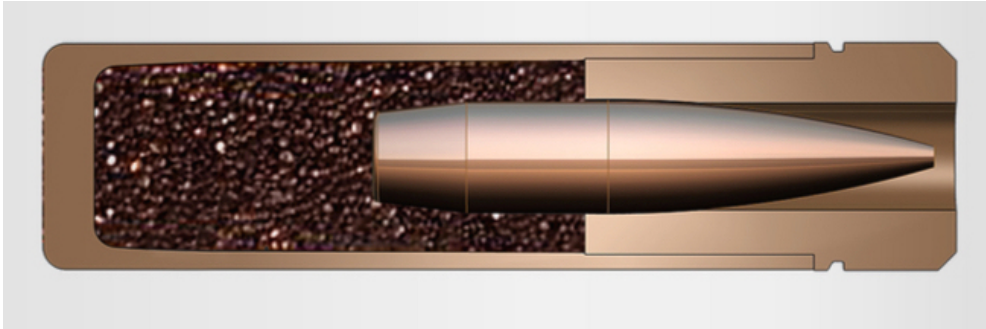
As already mentioned, the bullet also needs (as far as is feasible) to be "barrier blind" - maintaining its trajectory after passing through intermediate barriers, such as windscreen glass, on the way to the target. This again is difficult to predict in advance.

All in all, the design of a bullet to meet these varied requirements (some of which may be in conflict with each other) will be a complex exercise in juggling priorities and will involve a lot of trial and error in the development programme, but it is important to the success of the GPC concept to get it right: the bullet is the key!

A further issue which is of importance in determining the design of any new small-arms cartridge is the barrel length from which the required ballistics must be achieved. There has been a trend in recent years for barrels to become ever-shorter in the interests of handiness in moving in and out of armoured vehicles and helicopters, and for urban fighting. However, for any specified muzzle energy, the shorter the barrel, the more propellant is needed to accelerate the bullet more rapidly; and the more propellant is needed, the bigger and heavier the cartridge case will be, and the more recoil will be generated. Furthermore, firing a larger quantity of propellant from a shorter barrel will greatly increase the firing signature - muzzle flash and blast - and indicates that a larger and heavier suppressor will be needed in order to achieve the same decibel rating. Burning more propellant for each shot can also be expected to increase barrel heating, reducing the practical rate of fire. All of these points suggest that a bullpup rifle with a long barrel in a short gun, may be attractive for use with a GPC, an argument developed in more detail in another article<sup>7</sup>.

It may have been noticed that little has been said so far about advanced ammunition concepts; cases of stainless steel, light-alloy or polymer or entirely caseless, and perhaps of telescoped design. That is because this article is primarily concerned with the performance of the bullet after it has left the gun; how it gets to that point is a secondary issue. However, if an entirely new gun and ammunition system such as LSAT, using plastic-cased telescoped (CT) cartridges of cylindrical form, were to be adopted, it would be a terrible waste of an opportunity if this merely replicated a calibre we already have, simply because we already have it. A CT GPC would weigh about the same as the current 5.56mm, which would make the GPC concept even more attractive: the arguments for CT and for a GPC are mutually supportive.

Most of the CT development carried out by Textron Systems up to now has been in 5.56 mm calibre, with a 7.62 mm version also having been demonstrated and a 6.5 mm, selected as the ballistic optimum, now being developed, as already described.



*6.5 mm CT configuration (courtesy of Textron Systems Unmanned Systems)*

Even if CT rounds are not adopted, current developments in lightweight conventional cases (especially part-polymer) as briefly described under **Option 2** above, promise weight savings of 25-30% over brass-cased ammunition, which will apply whatever their calibre.

### OBJECTIONS AND RESPONSES

Finally, this article addresses some of the objections to the proposed general purpose cartridge, of which many have been put forward!

**1. "The problem is not the ammunition, it's the training: just train soldiers to shoot straight."** Of course, training is by far the most important element in soldier performance, and given the current emphasis on infantry small-arms the development and maintenance of rifle-shooting skills should be a high priority for all infantry, not just for a few marksmen. However, it is unrealistic to expect soldiers in combat to hit a small strip a few inches wide running from the forehead to the upper chest, as has been suggested as a solution to the 5.56's effectiveness problem. In any case, we go to a lot of trouble and expense to make sure that our troops are well trained and equipped; why shouldn't they also have the most effective weapons we can provide? At the very least, it can't hurt morale to have weapons which the soldier is confident can do what's needed over any likely engagement ranges.

**2. "The 5.56 mm performs well at long range; troops can hit targets out to 500-700 metres."** The 5.56 mm *can* hit targets at long range in ideal circumstances and with skilled shooters: but it is far more subject to drift in cross-winds than a GPC would be; the smaller sonic bang as it goes past has less of a suppressive effect (and the bullet becomes subsonic earlier anyway); and it has far less energy to do work when it gets there. It is significant that as soon as Taliban attacks started to be launched from long range, ISAF troops were willing to carry 7.62 mm rifles and machine guns, despite their extra weight. The 5.56 mm was thought to be perfectly satisfactory in peacetime, but the test of combat proved otherwise.

**3. "Ammunition with very long range capability is wasted in a rifle anyway, because only snipers and marksmen are trained to shoot that far."** For now, the long-range capability would primarily be of benefit in MGs and sharpshooter rifles, although it would also aid ordinary riflemen in delivering effective suppressive fire - the main purpose of long-range small-arms fire - for which a lesser standard of accuracy is required than that for scoring hits. However, advanced sights currently in

development include laser rangefinders and ballistic computers and some can also take into account crosswinds and other variables. Although initially intended for snipers, it is not difficult to predict that they will become small and inexpensive enough to be available for infantry rifles within the foreseeable future. These could do for long-range rifle shooting what precision guidance kits have done for aircraft bombs, and will enable an average soldier to deliver accurate rifle fire to long range - provided that the ammunition is effective at such a range.

**4. "The extra weight of an intermediate cartridge over the 5.56 would increase the soldier's burden."** With ammunition weight in between between 5.56 mm and 7.62 mm, the overall weight burden for a given number of rounds will depend on the mix of weapons in the squad; if more 7.62 mm than 5.56 mm ammunition is currently carried, then there will be an overall weight saving with the GPC. In any case, when engagements take place beyond the effective range of 5.56 mm weapons (as they did about half the time in Afghanistan) the 5.56 mm weapons and ammunition become useless dead weight, whereas GPC and 7.62 mm weapons will be effective at any range. Furthermore, advanced ammunition developments such as part-polymer cases or the Textron CT programme have the potential to keep the GPC weight down to levels comparable with the current 5.56 mm.

**5. "Soldiers within a section don't exchange ammunition between rifles and belt-fed machine guns anyway, so ammunition sharing isn't realistic".** That misses the point: towards the end of the fighting in Afghanistan, a British 8-man infantry section normally included one 7.62 mm belt-fed MG, one 5.56 mm belt-fed MG, one 7.62 mm rifle, and 5.56 mm rifles. The US Army used a similar mix. So the machine-gunners couldn't share MG belts, and the riflemen couldn't share magazines across the calibres. That adds a significant element of tactical inflexibility. This is even more significant if the LMG is magazine-fed, as it is in some forces, since a GPC will allow magazines to be exchanged between all members of a squad.

**6. "Fiddling with the calibres isn't worth the effort; there is no such thing as a 'golden bullet' that will put the enemy down first shot every time."** This is true, but it's a question of probability: how often will the cartridge fail to do the job? Both combat experience and lab testing indicate that, other things being equal, the smaller and less powerful the cartridge, the more likely it is to fail to incapacitate the target rapidly.

**7. "The GPC concept is untried: it's just an internet fantasy".** Every concept is untried until it's actually made and put into service. However, the calculations are firmly based in reality, not fantasy. The bullet FF used in the examples in this article is the same as the Russian standard military bullet; the cartridge sizes and muzzle energies are closely based on existing production rounds; the ballistic calculations are standard and reliable. There is no reason to doubt that it will perform as it should. What is uncertain is the terminal effectiveness, but that is true of any new bullet.

**8. "A GPC would be such a compromise that it would be bad at everything".** The ballistic calculations are based in reality (see above) and show that at long range the GPC can match or beat the 7.62 mm in virtually every performance criterion, with the exception of terminal effectiveness which is unknown (but we do know that the 7.62 mm M80 is not a stellar performer for its calibre, since it yaws only slowly on



impact). The GPC's ballistics would be superior to the 5.56's in every respect (again, the terminal performance would need to be tested).

**9. "A GPC would just add one more calibre: the 5.56 mm and 7.62 mm will remain in service."** The focus of this concept is on the needs of dismounted infantry who have to carry their weapons into battle. For them, the GPC would mean carrying one type of ammunition, one type of rifle, and one type of machine gun, rather than two of each, so keeping them supplied would be simpler. There would be no urgency about replacing vehicle-mounted 7.62 mm MGs, although the GPC could be expected to take over eventually. Similarly, 5.56 mm (especially in lightweight carbines) could be expected to remain in service with non-infantry troops as personal defence weapons for an indefinite period - although the cartridge is not optimal in short-barrelled guns, so ultimately a better solution may be found.

**10. "The GPC bullet requires such a high BC that it would never work in practice."** Not true. The BC is a function of the calibre, the weight and the form factor. The assumed FF is the same as the mass-produced Russian 5.45 mm, so we know it can be done.

**11. "Why choose 6.5 mm calibre with a muzzle energy at 2,500 Joules?"** That is chosen for illustrative purposes only. The end result of a lot of evaluation might well have a smaller or larger calibre, and be more or less powerful. However, 6.5 mm and 2,500 J represent the approximate mid-point of the likely range of values, as indicated by number of previous intermediate cartridges around this figure. **The optimum calibre of around 6.35-6.8 mm was also identified in the US Army's ARDEC trials of 2010/11, and both the calibre and muzzle energy are supported by the 2012 AMU study, the 2015 Textron CT study, and the detailed calculations in article<sup>3</sup>.**

**12. "Why not settle on one specification for the GPC, instead of leaving it open?"** Because there would need to be extensive comparative trials before the final configuration could be decided: and the NATO armies (especially the US Army) would have to lot to say about the final outcome.

**13. "The historical trend for well over a century is for ammunition to become steadily smaller: anything new would probably be smaller than the 5.56 mm".** Considering that the 5.56 mm was adopted mostly by accident (it was pushed on the US Army as a short-term expedient which they did not want) and that there has been a vocal body of opinion ever since that while something smaller than the 7.62 mm was needed the 5.56 mm was a step too far, that seems unlikely. The fundamentals of exterior ballistics remain the same, regardless of technical developments.

**14. "Small arms don't matter at long range - immediate heavy fire support will always be on call."** This may not necessarily be the case in counter-insurgency scenarios when foot patrols may be thinly spread over a wide area. And even when it is **(or if portable HE weapons are carried)**, the risk of collateral damage may restrict its use: US artillery and air support was considerably restricted in Afghanistan for this reason. As General Petraeus said: *"Every Afghan civilian death diminishes our cause."* Use of excessive force, he argued, could turn *"tactical victories" into "strategic setbacks"*.

**15. "The calibre of the small arms will have no effect on the outcome of a war."**

The same could be said about most other military equipment, and it isn't really the point: the effectiveness of their small arms makes a great deal of difference to the soldiers whose lives may depend upon them.

**16. "It would cost too much to change calibres, there are other priorities for our limited funds."** Clearly there are always likely to be budgetary problems, but guns wear out and a new generation of small arms will need to be introduced in due course, providing an opportunity to phase in a new calibre. This would especially be true if CT ammunition were to be adopted. And selecting one general-purpose cartridge would halve the number of different weapons required, saving money in the long run on acquisition, training and support.

**17. "Afghanistan is not typical in its emphasis on long-range fire; if we changed calibres we would be equipping for the last war, not the next one."**

Current thinking in both the British and US Armies is that counter-insurgency warfare will remain the most probable type of conflict. That means the infantry and their weapons will remain key elements. An examination of less stable parts of the world indicates that such conflicts are just as likely as not to take place in areas where there are opportunities for long-range fire. It is worth emphasising that full-power 7.62 mm rifles and machine guns are still in common use around the world, and facing an enemy armed with these puts troops equipped with 5.56 mm weapons at a disadvantage, increasingly so as the range lengthens. It is unlikely to be an accident that Taliban attacks were so frequently launched at long range - they would have known the limitations of the 5.56. Besides, what would be the downside of adopting an intermediate calibre even if future combat is at shorter ranges? Troops would still benefit from ammunition that is designed to be much more effective than 5.56 at any range while being lighter and more controllable than 7.62.

**18. "We would never get all of the NATO nations to agree to change to a new intermediate cartridge."**

That isn't necessary. The US Army unilaterally adopted the 5.56 mm round about fifteen years before NATO (and even then, some NATO nations didn't switch to the 5.56 mm for a long time). For pistols and SMGs the 9x19 is the only NATO-standardised cartridge, which hasn't stopped Germany and Norway from adopting the 4.6 mm or Belgium the 5.7 mm. Even the fervently law-abiding UK has adopted the .338 LM for sniper rifles - which is not NATO standardised. And does anyone seriously imagine that if the US decides to go for a CT system they would wait until all of NATO agreed before making the move? Realistically, it would be problematic for any single country to adopt a new standard rifle/MG cartridge without the USA being on board; but if they are, what the rest of NATO decides doesn't really matter.

**19. "Various effective ranges have been quoted for the GPC, from 600 m to 1,000 m – which is it? The GPC will need to match the effectiveness of 7.62 mm M80 when fired from comparable barrel lengths. The effective range of 7.62 mm weapons is generally regarded as around 1,000 m from MGs (give or take, depending on whether the MG is fired from a bipod in the light role or a tripod in the support role); about 800 m from sniper/sharpshooter rifles, and up to 600 m from infantry rifles. So a GPC should match these distances.**

**20. "Why should a GPC try to match the performance of the 7.62 mm NATO at 1,000 m – wouldn't it be easier to set 600 m as the target?"** No – quite the reverse. A GPC will have a muzzle energy about midway between the 5.56 mm and 7.62 mm. Its better-shaped bullet will lose velocity and energy more slowly than the 7.62 mm M80, meaning that the GPC's velocity and then energy will gradually catch up. To match the energy of the 7.62 at 600 m would require a more powerful round than is required to match it at 1,000 m.

**21. "The trend is for decreasing barrel lengths for carbines and LMGs, which to obtain the performance targets of the GPC would require a large and powerful cartridge."** This trend mainly applies to individual rifles and 5.56 mm LMGs. In 7.62 mm MGs in US service, the lightweight MK48 has a barrel length of 502 mm (19.75 inches); the lightened M240L 528 mm (20.8 inches) and the standard M240 630 mm (24.8 inches). The new HK MG5 has a choice of barrel lengths (as any future MG or rifle is likely to) but the standard one is 550 mm (21.6 inches). And of course, the main opposition LMG, the 7.62 mm Russian PKM, manages with a barrel of 645 mm (25.4 inches).

Since the LMG is the most effective gun in the dismounted infantry section/squad, especially at long range, it should have a barrel long enough to extract the optimum performance from the cartridge, as should sharpshooter rifles/DMRs. For individual rifles/carbines, it will be for each army to assess the optimum balance between compactness and ballistic performance (although, as mentioned, bullpup rifles simplify that choice). Since future small arms are virtually certain to be modular and feature interchangeable barrels, that does provide the option of acquiring barrels of different lengths for different purposes.

## US DEVELOPMENTS

In 2011 a report emerged from the US Army's Program Executive Office Soldier: **Soldier Battlefield Effectiveness**<sup>8</sup>. This analysis covers a lot of ground including some points concerning the ideal characteristics of infantry rifles and their ammunition:

*"A Soldier must be able to engage the threat he's faced with – whether it's at eight meters or 800."*

*"To be effective in all scenarios, a Soldier needs to have true "general purpose" rounds in his weapon magazine that are accurate and effective against a wide range of targets."*

*"Weapons....must be accurate and capable of engaging the enemy at overmatch distances."*

In 2013 the US Army announced a '**Caliber Configuration Study**' to support two new small-arms programmes, designated **CLAWS** (Combat Lightweight Automatic Weapon System) and **LDAM** (Lightweight Dismounted Automatic Machinegun). The announcement was made at an NDIA (National Defense Industries Association) conference held in mid-November at the Army's Picatinny Arsenal. Since then, CLAWS has been replaced by **NGSW** (Next Generation Squad Weapon) and the CCS by **SAAC** (the Small Arms Ammunition Configuration study).

In 2015 an Army spokesman indicated that SAAC was expected to be completed sometime in 2016. It is understood that in contrast with the other calibre studies mentioned in this article, this study will not just be looking at ballistic issues but also at industrial and financial implications.

Very little information about NGSW and LDAM has been revealed, but it appears that NGSW is intended to result in the eventual replacement of all of the existing 5.56 mm rifles, carbines and light machine guns by one modular weapon family with interchangeable barrels, stocks and accessories. LDAM appears to be seen as an eventual replacement for the 7.62 mm M240 medium machine gun (FN MAG) and possibly the .50 calibre (12.7 mm) heavy machine gun in dismounted applications. If these assumptions are correct, this indicates the replacement of the existing 5.56 mm and 7.62 mm NATO rounds that have been in US service for 50 and almost 60 years respectively.

LDAM appears to be intended to match the effective range of the .50 Browning with much less weight, so it needs to fire a considerably larger and more powerful cartridge than the 7.62 mm. The obvious existing candidates are the .338 inch (8.6 mm) Norma and Lapua Magnum rounds which differ only slightly, with weapons designed for one being readily adaptable to the other. The Lapua round is in widespread use in long-range sniper rifles (including the British Army's L115 from Accuracy International), while the Norma cartridge was selected for the General Dynamics LWMMG (Lightweight Medium Machine Gun) revealed in 2012; possibly in part because the case is shorter than the Lapua's, allowing space for bullets with longer ogives to improve the long-range performance. The LWMMG weighs little more than the M240, although the ammunition is significantly heavier. **CT cartridges in this calibre have been studied by Textron Systems.**

If the supporting fire role is to be filled by weapons in 8.6 mm or similar calibre intermediate in power between the 7.62 mm and 12.7 mm, that implies that the NGSW weapons will need to replace some of the lighter current 7.62 mm rifles like the M14EBR and M110 (the British equivalent being the L129A1 'Sharpshooter'), plus light machine guns such as the MK48 (FN 7.62 mm Minimi). A reduction in effective range will probably be unacceptable, which means that whatever cartridge is chosen for NGSW will need a longer range than 5.56 mm can provide - in other words, it would need a specification similar to that of the GPC discussed above.

## SUMMARY

1. The limited, counter-insurgency type of warfare seen in Afghanistan is likely to recur in future conflicts. Such conflicts put the emphasis on dismounted infantry operations, because of the need to provide a reassuring presence to the population. The need to minimise the risk of civilian casualties or other unintended damage also puts the emphasis on high-precision weapons of limited destructiveness, particularly small arms.
2. Small arms engagements may take place anywhere between 0 and 800+ metres. The US Army's PEO Soldier report identifies the need for general purpose rifles and ammunition effective at all ranges.

3. 5.56 mm ammunition has limited range, and effectiveness problems even at short range when using NATO-standard ammunition; 7.62 mm ammunition suffers from weight and recoil issues. Neither is capable of significant improvement which would adequately address these problems, other than lightweight cartridge cases which will also bring similar benefits to other rounds, such as a GPC.

4. It is now technically feasible to develop a combination of weapon, ammunition and sights which is effective across the entire 0-800+ m range. The enhanced firepower and flexibility this would offer over a mixed-calibre infantry section, plus the savings in procurement, logistics and training, make this a desirable aim for the next generation of small arms.

5. Recent work by Textron Systems and the US Army's ARDEC and AMU has separately identified similar characteristics for the optimum cartridge for future military rifles: around 6.5mm calibre, and around 2,500 J muzzle energy. This is reinforced by the detailed study<sup>3</sup> by Emeric Daniau of the DGA.

6. The reported aims of the NGSW element of the US Army's Small Arms Ammunition Configuration Study, alongside the results of the ARDEC and AMU studies, indicate that a calibre between the 5.56mm and 7.62mm might be favourably considered for future portable small arms, especially if CT technology is adopted.

In conclusion: the case for a General Purpose Cartridge appears to have been accepted by those organisations concerned with designing and developing the next generation of US Army small arms (those which have so far expressed a view, anyway). Whether this will lead to the adoption of such a round, and if so whether it will have a cartridge case of conventional shape or telescoped, remains very uncertain.

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## Links

<sup>1</sup> "The Next Generation: the case for a new NATO rifle and machine gun cartridge" <http://www.dtic.mil/ndia/2010armament/WednesdayLandmarkBAnthonyWilliams.pdf>

<sup>2</sup> "The M14 Enhanced Battle Rifle" in the *American Rifleman*, February 2011 <http://www.americanrifleman.org/articles/2011/2/23/the-m14-enhanced-battle-rifle/>

<sup>3</sup> "Towards a "600 m" lightweight General Purpose Cartridge, v2015" by Emeric Daniau, DGA Techniques Terrestres <http://quarryhs.co.uk/600mv2015num.pdf>

<sup>4</sup> "Time for a Change: U.S. Military Small Arms Ammunition Failures and Solutions" <http://www.dtic.mil/ndia/2008Intl/Roberts.pdf>

<sup>5</sup> "Increasing Small Arms Lethality in Afghanistan: Taking Back the Infantry Half-Kilometer" <http://www.dtic.mil/get-tr-doc/pdf?AD=ADA512331>



<sup>6</sup> "Army, Marines face new pressure to use same ammunition", Army Times 4<sup>th</sup> May 2015 <http://www.armytimes.com/story/military/tech/2015/05/04/army-marines-face-new-pressure-to-use-same-ammunition/26657177/>

<sup>7</sup> "Why Bullpups?" <http://quarryhs.co.uk/bullpups.htm>

<sup>8</sup> "Dual Path Strategy Series: Part III – Soldier Battlefield Effectiveness" <http://usarmy.vo.llnwd.net/e2/c/downloads/215919.pdf>

A follow-up article looking at the characteristics of the next generation of military small arms is at: <http://quarryhs.co.uk/future%20small%20arms.htm>

A history of the development of assault rifles and their ammunition is at: <http://quarryhs.co.uk/Assault.htm>

The home website is at: <http://quarryhs.co.uk/index.html>

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