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Chambering the Next Round

Emergent Small-calibre Cartridge Technologies

By N.R. Jenzen-Jones

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List of abbreviations

AFV	Armoured fighting vehicle
AMU	Army Marksmanship Unit
BC	Ballistic coefficient
CCS	Caliber Configuration Study
CT	Cased telescoped
DMR	Designated marksman rifle
EI	Extruded Impregnated
FMJ	Full metal jacket
GPMG	General-purpose machine gun
HITP	High-ignition-temperature propellant
ISAF	International Security Assistance Force
J	Joules
LMG	Light machine gun
LSAT	Lightweight Small Arms Technologies
LWMMG	Lightweight Medium Machine Gun
MOA	Minutes of angle
NATO	North Atlantic Treaty Organization
OWL	One-way luminescence
SAW	Squad automatic weapon
SCHV	Small-calibre, high-velocity
SPC	Special Purpose Cartridge
TRL	Technology readiness level
TWSS	Thin-walled stainless steel
USSOCOM	United States Special Operations Command

About the author

N.R. Jenzen-Jones is a military arms and munitions specialist and security analyst who focuses on current and recent conflicts. He is the Small Arms Survey's technical specialist and director of Armament Research Services (ARES), a specialist technical intelligence consultancy. He has produced extensive research and analysis on a range of small arms and small arms ammunition issues, as well as technical assessments of incendiary weapons, emergent arms technology, and arms proliferation. His other research fields include the exploitation of technical intelligence to support counter-piracy, counter-narcotics, and other operations. He is a qualified armourer and ammunition collector, and a member of the European Cartridge Research Association, the International Ammunition Association, and the International Ballistics Society.

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I. Overview

Emergent ammunition technologies are likely to prove key in future firearms designs, while many also apply to legacy weapons. Emergent cartridge case technologies, the rise of the 'general-purpose' calibre, and other nascent technologies will affect the way in which firearms are designed, produced, managed in service, tactically employed, maintained, and sustained.

Many of these technologies are focused on reducing the logistics burden on armed forces and security agencies, and on reducing the carrying load of the individual combatant. While these technologies also apply to medium- and large-calibre ammunition, this Working Paper restricts its focus to small-calibre ammunition—cartridges of up to 14.5 × 114 mm in calibre—which are commonly fired from firearms referred to as small arms and light weapons.

The introduction of a ballistically superior general-purpose calibre—which is generally acknowledged to be in the range of 6.0–7.0 mm—has the potential to bridge the gap between the 5.56 × 45 mm and 7.62 × 51 mm cartridges in many modern militaries. Small-calibre ammunition in this range would be applicable to a variety of small arms. If such a calibre were to replace two or more in-service calibres, it could usher in significant financial savings, a simplification of production, procurement and sustainment, and advantages for interoperability of weapons systems and commonality of training.

Polymer cartridge cases have the potential to reduce the cost and weight of conventional ammunition significantly. Several militaries and commercial interests have begun to accept such ammunition, and the technologies are rapidly advancing. Caseless ammunition seeks to obviate the need for cartridge cases entirely, instead embedding the projectile in a 'block' of propellant. Although caseless ammunition would allow for even greater reductions in weight, it presents several technological hurdles. Telescoped ammunition is another method of minimizing weight while also reducing the overall volume of a round. This technology is being applied to both caseless and polymer-cased ammunition.

Many of these emergent technologies are, or will be, compatible with one another, offering advanced synergies for the ammunition of tomorrow. In part motivated by the experiences of recent conflicts in Afghanistan, Iraq, and elsewhere, the development of emergent ammunition technologies has typically sought to fulfil two critical end-user requirements, namely:

- to increase the range and lethality of standard-issue individual weapons; and
- to reduce the overall combat load of infantry personnel.

The call for an increase in the range and lethality of future cartridges would be at least partially satisfied by the introduction of a general-purpose calibre, but the corresponding weapons usually favour larger projectiles, and therefore larger, heavier cartridges. This trend is often at odds with the pressing need to reduce—or, at least, not to increase—the overall load burden on the modern frontline combatant, a goal enabled by various emergent cartridge case technologies.

The synergy of these technologies may lead to significant additional benefits beyond the primary objectives of the technologies as introduced. A general-purpose calibre could readily be made compatible with other emergent ammunition technologies, perhaps heralding the introduction, for example, of a polymer-cased telescoped intermediate-calibre cartridge.[1] Where these technologies meet is perhaps where the greatest potential for net gain is present. Combinations of the technologies discussed in this report, and others, may allow for:

- increased standardization of calibres within the infantry squad;
- a reduced logistics burden on the supply chain;
- reduced overall economic costs;
- reduced ammunition weight and volume;
- improved hit probability;
- improved general performance and function; and
- the development of cartridges for special applications.

Other emergent ammunition technologies—such as guided small-calibre ammunition and advanced marking practices using lasers and ballistic imprinting ('microstamping')—are not covered in this report, but they may also influence the development of ammunition in the future.

The advent of new technologies that are applicable to small-calibre ammunition presents several policy implications and may contribute to proliferation concerns. It is important to identify the likely and current customers for these technologies, and to examine how a potential surplus of current-standard ammunition created by the adoption of such technologies may contribute to proliferation concerns. Finally, an assessment of how these technologies will affect current and future marking, record-keeping, and tracing procedures, and what law enforcement challenges are posed by their adoption, will be of value to stakeholders.

In the field of small-calibre ammunition, the terms 'cartridge' and 'round' are synonymous; both refer to a complete unit of ammunition, which includes:

- the projectile,[2] which is fired from the gun;
- the propellant, which deflagrates and develops the gas pressure that propels the projectile along the barrel;
- the primer, which is initiated by the gun and ignites the propellant; and,
- with the exception of caseless ammunition, the cartridge case itself, which contains the components of a complete round of ammunition and provides the airtight seal known as obturation, which allows pressure to build up behind the projectile[3] (Goad and Halsey, 1982).

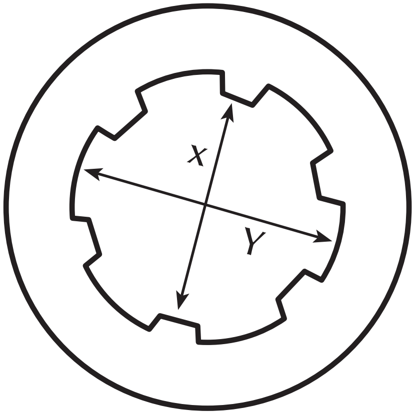
Photo 1 shows the component parts of a typical small-calibre cartridge.

This report uses standard metric designations to describe cartridges, employing millimetres for measurements. The calibre of the projectile is provided first (for example, 7.62), followed by the cartridge case length (for example, 39 mm). In this example, the cartridge description would be 7.62 × 39 mm. The calibre designation of a cartridge reflects the nominal projectile diameter,

Photo 1 **A sectioned (cutaway) 7.62 × 51 mm cartridge, showing the projectile, propellant, primer, and cartridge case**

Source: Anthony G. Williams

Figure 1 **Cross-section of a typical firearm bore, with measurements across the lands and grooves**



X: Diameter as measured between lands
Y: Diameter as measured between grooves

Source: Armament Research Services (ARES)

which is most often determined based on the bore of a weapon, as measured across the features of the weapon's rifling[4] (see Figure 1). The calibre can be determined from the diameter of the lands (X), the diameter of the grooves (Y), or the average diameter of both (X+Y divided by 2); alternatively, it can correspond with an arbitrary figure, which is provided by the cartridge or weapon designer. Some calibres (typically those using imperial measurements[5]) are commonly measured between the grooves, instead of being based on the diameter of the lands of the barrel's rifling, although this is not always the case.[6] For cartridges that are usually provided using imperial measurements, this report states the imperial measurement first, followed by the metric measurement in brackets.

Terminology has not yet been standardized for caseless or cased telescoped ammunition. The second figure in descriptions of caseless ammunition generally refers to the length of the propellant block. For conventionally configured caseless cartridges, the block is shorter than the overall length of the cartridge; for telescoped caseless cartridges, it is equal to the overall cartridge length. For cased telescoped ammunition, the second figure may describe either the overall cartridge length (including the end cap or similar) or the cartridge case length.

Some programmes refer to a calibre evaluated to replace 5.56 × 45 mm and 7.62 × 51 mm cartridges as an 'intermediate calibre' (such as the US Army's Lightweight Small Arms Technologies programme) or 'intermediate common calibre' or ICC (such as the US Army Soldier Weapons Strategy 2014). While this terminology is accurate in this limited context, intermediate-calibre cartridges are widely understood to be those developed for and adopted with early assault rifles—that is, cartridges in a calibre designed to be intermediate between pistol-calibre sub-machine gun cartridges and 'full-power' rifle cartridges.[7] Other common terms include 'universal calibre' and 'unified calibre'. This report uses the term 'general-purpose calibre' to refer to a calibre that is between 6 and 7 mm and intended to replace intermediate or small-calibre, high-velocity (SCHV) and full-power rifle cartridges in military service.

II. The introduction of a modern 'general-purpose' calibre

The development of service rifle and machine gun calibres

The first half of the 20th century saw limited developments in small arms and small-calibre ammunition. Most militaries had one 'general-purpose' cartridge in service with infantry forces;[8] it was used in both the bolt-action rifles of the time and the machine guns that had begun to enter service at the end of the 19th century. Most nations had opted for a 'full-power' round in 7.5 to 8 mm calibre; however, some adopted smaller cartridges in the 6.5 mm range. These latter nations, including Japan, Italy, and other European countries, later adopted cartridges in the range of 7.7 to 8 mm to supplement the 6.5 mm, which was primarily intended for service with tripod-mounted machine guns (Williams, 2015b).

During World War II, German designers determined that full-power rifle cartridges were too powerful for the standard infantry rifle.[9] They were large, generated excessive recoil when fired, and were heavy when carried in useful quantities. This last factor was especially problematic in the case of self-loading rifles, given their higher rates of fire and faster ammunition consumption. To facilitate the carriage of sufficient ammunition, and to allow for automatic fire from infantry rifles, the German military introduced a lighter 'intermediate-calibre' rifle cartridge, the 7.92 × 33 mm *Kurz* ('short'), with physical characteristics and recoil somewhere between traditional handgun- and rifle-calibre cartridges (Johnston and Nelson, 2010). While the German StG 44[10] was the first mass-produced rifle chambered for a cartridge of this type, its influence was limited by the comparatively small scale of production; fewer than half a million were produced.

The later *Avtomat Kalashnikova* (AK), however, was the first in an influential series of rifles designed and produced in the Soviet Union and then the Russian Federation. Originally chambered for 7.62 × 39 mm,[11] the original AK has since given rise to nearly 200 variants, derivatives, and copies (both licensed and unlicensed), which are produced throughout the world (Ferguson and Jenzen-Jones, 2014). At least 70 million AK-type rifles have been produced since 1949, making it the most common self-loading military rifle in existence (ARES, 2015a).

US designers also examined the intermediate-calibre concept but ultimately reduced the projectile diameter and increased its velocity.[12] In the 1950s, the first of these 'small-calibre, high-velocity'[13] specimens to be widely issued was the US 5.56 × 45 mm cartridge, adopted with the AR-15 (type-designated as the M16 in US military service).[14] This rifle became standard issue during the 1970s, and at least 13 million AR-15-type rifles had been produced for military purposes by late 2015 (Jenzen-Jones, 2016). In 1980, NATO accepted the 5.56 × 45 mm cartridge as a standard cartridge, alongside the 7.62 × 51 mm round; today it is in service with numerous NATO and non-NATO states (Johnston and Nelson, 2010; Rottman, 2011). Although Soviet developments subsequently gave rise to the 5.45 × 39 mm SCHV cartridge, which became standard issue for the Russian military, the 5.56 × 45 mm and 7.62 × 39 mm cartridges remain the predominant military rifle cartridges in service globally (ARES, 2015a).

Intermediate-calibre cartridges, including SCHV designs, were widely expected to replace the older, full-power designs in military usage. Contrary to these expectations, however, many full-power infantry rifle calibres have remained in service alongside both the 'original' intermediate calibres and the SCHV calibres (Ferguson et al., 2015). Some calibres that remain in military use have been in service for quite some time. The oldest of these, the 7.62 × 54R mm cartridge, was originally introduced by the Imperial Russian Army in 1891, alongside the Mosin-Nagant bolt-action rifle (Lapin, 2013). Nowadays, most of the world's armies employ a two-calibre system for primary infantry arms (predominantly rifles and machine guns).[15] Broadly speaking, a larger cartridge is used with general-purpose machine guns (GPMGs) and specialist rifles,[16] while a smaller cartridge is used with standard service rifles and light machine guns. Larger calibres still are used for heavy machine guns, but these are either crew-served or mounted on mobility platforms.

This two-calibre approach to primary infantry arms has allowed for the development and use of cartridges tailored to the differing requirements of their respective weapon systems; however, it has come at an economic and logistic cost. In most cases, units must be resupplied with at least two calibres for their primary arms. In NATO and allied nations, these two calibres are the 5.56 ×

45 mm and 7.62 × 51 mm cartridges. Former Warsaw Pact countries have a history of employing the 7.62 × 39 mm and 7.62 × 54R mm cartridges in these roles, although some of these states have since replaced or supplemented their use of 7.62 × 39 mm with the 5.45 × 39 mm SCHV cartridge, first adopted by the Soviet Union in 1974. China relied on the standard Warsaw Pact cartridges before developing the indigenous 5.8 × 42 mm cartridge to replace the 7.62 × 39 mm in general service, beginning in 1995 (Johnston and Nelson, 2010; Régenstreif, 1983; Williams, 2015b). These post-World War II cartridges adopted by large national militaries have all been employed in both self-loading rifles (including assault rifles) and light machine guns (Williams, 2014b; see Photo 2 and Table 1).[17]

Photo 2 **Dominant worldwide service rifle and machine gun calibres in modern usage. From left to right: 7.62 × 54R mm; 7.62 × 51 mm; 7.62 × 39 mm; 5.56 × 45 mm; 5.45 × 39 mm; and 5.8 × 42 mm**

Source: Anthony G. Williams

Table 1 **Dominant worldwide service rifle and machine gun calibres in modern usage**

Cartridge designation	Country of origin	Total weight (g)	Bullet weight (g)	Muzzle velocity (m/s)	Muzzle energy (joules)
7.62 × 54R mm	Russian Empire	24.0	9.5	845	3,400
7.62 × 51 mm	United States	24.0	9.5	838	3,340
7.62 × 39 mm	Soviet Union	16.5	7.9	715	2,020
5.8 × 42 mm	China	12.8	4.6	790–970	1,920
5.56 × 45 mm	United States	12.0	4.0	875–950	1,530–1,800
5.45 × 39 mm	Soviet Union	10.5	3.4	900	1,417

Note: All figures are approximations and vary according to barrel length, cartridge type, and other factors.

Source: Williams (2015b)

In Soviet service, the 7.62 × 39 mm round was initially issued in a general manner, being used in both self-loading AK and AKM rifles as well as the RPD light machine gun (LMG), issued at the squad level. The 7.62 × 54R cartridge, by contrast, was absent from the early Soviet infantry squad, being retained at higher organizational levels for use in heavier machine guns and sniper rifles. Soviet battlefield experience later led to the introduction of the PKM GPMG, chambered for 7.62 × 54R and issued at the squad level, in order to provide the infantry squad with longer-range firepower (Williams, 2015b). Subsequently, when 5.45 × 39 mm-calibre weapons replaced those chambered for 7.62 × 39 mm, the PKM was retained.

Similarly, albeit some time later, most NATO and allied states adopted the 5.56 × 45 cartridge on a general basis, issuing infantry squads[18] with rifles, carbines, and LMGs chambered for this calibre. Like the Soviet Union, NATO states typically reserved weapons chambered for full-power rifle calibres for higher organizational levels. The US military, for example, issued GPMGs chambered for 7.62 × 51 mm at the platoon level (Hughes, 1995). This decision was influenced by notable infantry arms studies such as the Hall and Hitchman reports of the early 1950s, which concluded that small arms fire was largely ineffective beyond 300 m, and that the general issue of SCHV cartridges would significantly reduce the weight combatants had to carry, while simultaneously improving hit probability within the specified engagement ranges (Hall, 1952; Hitchman, 1952; Williams, 2015b).

The current combination of 5.56 × 45 mm and 7.62 × 51 mm employed by most NATO states and many other countries has a few key limitations, as follows:

- The 5.56 × 45 mm cartridge has a relatively short effective range, which has proven insufficient in recent conflicts. Some observers also claim it has erratic terminal effectiveness.[19]
- The 7.62 × 51 mm cartridge is large and heavy, posing a challenge to portability when issued in the quantities required for a belt-fed machine gun. The recoil impulse from this cartridge is often considered too great for controllable automatic or rapid semi-automatic fire.
- Requiring two different calibres for an infantry squad's primary arms results in tactical, logistic, and economic disadvantages, limiting ammunition sharing, complicating sustainment and the associated logistics, and often resulting in the acquisition and maintenance of two different 'families' of small arms.

The maximum overall length of both existing cartridges limits the use of low-drag projectiles with long noses, such that their long-range performance cannot be significantly improved.

Whereas neither Warsaw Pact nor NATO forces saw the advent of SCHV calibres as a complete replacement for full-power weapon systems, China took a different approach. The 5.8 × 42 mm calibre was designed as a general-purpose round, one which China claimed outperformed both the NATO 5.56 × 45 mm SS109 loading and the Russian 5.45 × 39 mm 7N6 loading (Fortier, 2002). The Type 95 family of weapons, which was developed alongside the cartridge, included assault rifles, carbines, and LMGs, as well as a sniper rifle, a GPMG, and a machine gun intended for use with armoured fighting vehicles (AFV) (Andrew, 2015).

This generalist approach has been unsuccessful in several respects. Initially, two different loadings of the 5.8 × 42 mm were produced with differing projectile weights: the 'light' DBP87 and the 'heavy' DBP88. The former was intended for the assault rifles, carbines, and LMGs, while the latter was intended for the GPMG, AFV machine gun, and sniper rifle. A modified version of the DBP88, known as the DVP88, was introduced to provide better ballistics. The DBP88 loading was deliberately loaded to an overall length, which did not permit the cartridge to fit into assault rifle magazines. The DVP88 and DBP88 loadings are not optimal for weapons intended to use the DBP87; however, the former could be chambered and fired by all small arms in the Type 95 family due to its reduced overall length. This proved problematic, and in 2010 both of these loadings were replaced by the DBP10 'universal' loading, which can be chambered by all Type 95 family weapons (*Qinq BingQi*, 2011). In addition, the long-range performance of the 5.8 × 42 mm cartridge appears to have been considered unsatisfactory by Chinese forces, as evidenced by the retention of 7.62 × 54R mm GPMGs. This is perhaps unsurprising, given the cartridge's ballistic similarity with the 5.56 × 45 mm NATO round.

Towards a 'general-purpose' calibre

Despite the near-global adoption of a two-calibre system to date, recent trends in design and development have indicated an increasing level of interest in a so-called 'general-purpose' calibre. Advocates of such a calibre are largely driven by a desire for efficiency; they expect that its introduction into military service would reduce the logistic and economic burdens of small-calibre ammunition supply. They see such a cartridge as both light and controllable enough to be used with assault rifles and light machine guns, as well as powerful and ballistically efficient enough to be effective at longer combat ranges.

In NATO and allied countries, the range requirements of infantry small arms—deemed to be no more than 300 m in the Hall and Hitchman reports of the 1950s—have been reconsidered in light of recent battlefield experiences. In Afghanistan, infantry small arms played a more pivotal role than was anticipated on a 'modern' battlefield. Traditional supporting fires—delivered by heavier weapon systems such as artillery and air-delivered munitions—were often restricted under rules of engagement or operational practices. Meanwhile, opposition forces have increasingly operated from within civilian communities, and military leadership and popular opinion have exhibited a lower tolerance for civilian casualties. As a result, infantrymen were frequently required to engage enemy combatants beyond 300 m, and often beyond the listed 500 m effective range of the M4 carbine (Ehrhart, 2009).[20]

US Army data suggests that more than 50 per cent of the small arms engagements in Afghanistan in 2011 required US Army forces to engage targets beyond 500 m. For their part, opposition forces would engage International Security Assistance Force (ISAF) units from ranges of up to 900 m or farther, employing full-power-calibre GPMGs and designated marksman rifles (DMRs) (Plaster, 2011; Williams, 2015b).[21] This threat 'overmatch' has been a driving factor behind increased interest in general-purpose calibres from military sources.

Further, several observers have called into question the lethality—which is often incorporated into the concept of 'terminal effectiveness' in ballistics parlance—of the 5.56 × 45 mm cartridge. The original 5.56 × 45 mm cartridge was a modification of a commercial cartridge, the .222 Remington,[22] which was originally intended for use against small varmints within 250 m (Schatz, 2015a). It is important to note, however, that the cartridge has undergone significant improvement since its introduction, and the lethality of some modern projectile designs is significantly greater. Nonetheless, there remain issues with light projectiles that are designed around a requirement for armour penetration at long range. In 2006, the US Joint Service Wound Ballistics Integrated Product Team released a study on the wounding potential of various calibres, which finds that:

> *The best performing systems emphasizing tissue damage, on the average, in this study were of larger caliber than 5.56mm [. . .]. The 6.8mm performance observed in this test suggests that an intermediate caliber is the answer to the trade-off balance issue* (Roberts, 2008).

Some observers point out that the 5.56 × 45 mm projectile has erratic terminal effectiveness within shorter ranges, as the small bullet needs to yaw[23] rapidly and fragment for maximum effectiveness, which does not occur reliably (Williams, 2015b). Nonetheless, it should be noted that shot placement remains the most critical factor in achieving lethality with small arms.

As a result, several ISAF nations began to allocate weapons chambered for full-power calibres to dismounted infantry squads. Initially, most of these weapons were drawn from available stockpiles of 7.62 × 51 mm GPMGs. They were supplemented by both modernized variants of available weapons, such as the US development of the Mk 14 Enhanced Battle Rifle (EBR) series, and new weapon systems such as the British acquisition of the L129A1 and the Australian acquisition of the Heckler & Koch HK417, both chambered for 7.62 × 51 mm and issued in the designated marksman or sharpshooter role (Armstrong, 2007; British Army, 2015). New machine guns chambered for full-power rifle cartridges, such as the Mk 48 as adopted by the United States and the FN Herstal Minimi in 7.62 × 51 mm adopted by the New Zealand Army, were also issued (Crane, 2004; Johnson, 2013). These sought to reduce the weight of the weapon while retaining the full-power calibre (Williams, 2015b).

More recently, the Turkish armed forces opted to adopt a new self-loading rifle chambered for 7.62 × 51 mm, designated MPT-76, contrary to expectations that they would adopt a 5.56 × 45 mm rifle in line with other NATO nations (Sariibrahimoglu, 2015). The Italian military has already allocated funds for another new 7.62 × 51 mm DMR, the Beretta ARX 200, which is expected to be issued to an 'expert marksman' (*tiratore esperto*) on a one-per-section basis (ARES, 2015b).

Proponents of a general-purpose calibre suggest that it is possible to retain the range and terminal effectiveness of a full-power rifle calibre with a smaller and lighter cartridge design, suitable for issue in primary service weapons. Such a calibre would, ideally, resolve the range and lethality criticisms levelled at current SCHV and intermediate-calibre cartridges, while conferring significant tactical, logistic, and economic advantages (Schatz, 2015a; Williams, 2014a). That is, a successful general-purpose calibre should:

- have greater range than existing SCHV or intermediate-calibre cartridges, ideally similar to a full-power rifle cartridge;
- have increased terminal effectiveness over existing SCHV or intermediate-calibre cartridges;
- be lighter in weight than existing full-power rifle cartridges, ideally similar to a SCHV or intermediate-calibre cartridge;

- allow for increased standardization of calibres within an infantry squad and, in turn, provide a tactical advantage via the interoperability of ammunition;
- reduce the logistics burden along the entirety of the supply chain, from factory production, through transport and stockpiling, to sustainment; and
- reduce the economic costs associated with developing, manufacturing, purchasing, stockpiling, and sustaining multiple calibres at the infantry squad level and higher.

Technical requirements of a general-purpose calibre

To be a candidate for adoption by a major military power, a general-purpose calibre must be significantly lighter and smaller—that is, have less volume—than existing full-power rifle cartridges but retain many of its performance characteristics, especially in terms of effective range when fired from different weapon systems. Expected effective ranges may be estimated at 600 m for a rifle, 800 m for a bipod-mounted LMG or DMR, and 1,000 m for a tripod-mounted GPMG (Williams, 2015b).

To attain these ranges, a general-purpose calibre must meet key ballistic requirements. It must deliver approximately the same trajectory, velocity, time of flight, and resistance to cross winds as a full-power rifle cartridge, out to 1,000 m or more. To meet these requirements, the calibre, projectile shape, projectile construction, quantity and type of propellant, and other factors, such as the cartridge case shape, size, and construction, must be suitable. Increasing the range of a projectile depends on improving the external shape of the bullet so as to reduce its resistance to the air, enhance its stability in flight, and reduce yaw; enhancing the output of the propellant charge may also increase the range (Goad and Halsey, 1982).[24] In some cases, a well-shaped projectile can beat a poor one at long range, even with a lower propellant charge.

A reduction in calibre and cartridge size is likely to be necessary in order to achieve the desired weight and volume savings[25] of a general-purpose cartridge. If such a cartridge is to meet the ballistic requirements outlined above, it must feature a projectile with a better ballistic coefficient (BC) than its full-power predecessors. The BC of a projectile is a measure of aerodynamic drag; a higher BC generally indicates that a projectile is more ballistically efficient[26]—

Photo 3 **The three projectiles at left show the progression towards the ogives (tapered ends) common among rifle bullets today. To their right are the 7.62 × 51 mm M80 projectile, followed by projectiles from the 6.8 × 43 mm Remington SPC and 6.5 × 39 mm Grendel cartridges. The 6.5 Grendel projectile has the best BC of all pictured**

Source: Anthony G. Williams

meaning that it retains more velocity during flight. Broadly speaking, a relatively thin projectile with a long, tapered nose will have a better BC than a shorter, broader projectile of the same mass (Litz, 2011). To find the optimum balance between mass, length, and diameter, a variety of bullet designs have been developed, tested, and employed over time (see Photo 3).

Some commentators have questioned the need for a longer-range cartridge for infantry personnel. One line of argumentation suggests that engagement ranges in Afghanistan are atypical and thus not suitable as a yardstick for those of future conflicts. The counterpoint to this notes that one cannot confidently predict the exact location or nature of future conflicts, and that ISAF combatants have fought in Afghanistan for more than ten years. Some argue that the training and skill level of the infantry make accurate engagements past a certain range (usually 300 m or 500 m) unlikely with a service rifle. With the increasingly wide issue of optical sights in modern militaries, the expected engagement range has certainly increased beyond the 300 m outlined in the 1950s Hall and

Hitchman reports. Advanced sights—such as those incorporating rangefinders and ballistic computers—are increasingly becoming available and, in future, they may facilitate accurate long-range shooting for infantry personnel.

The optimum calibre for a general-purpose cartridge has been debated for decades, and exhaustively tested by ammunition developers, world militaries, and civilian target shooters. Most analysts seem to agree: it will fall between 6 and 7 mm, and probably between 6.35 and 6.8 mm[27] (Ehrhart, 2009; Williams, 2015b). While some may observe that this calibre resembles those of Japanese and Italian cartridges of World War II and earlier, the projectile design would be significantly different in order to meet the desired ballistic requirements.[28] The projectile would be lighter, more efficiently shaped, and propelled at a higher velocity. In addition, the cartridge case would be smaller in overall length and volume. The muzzle energy of a general-purpose calibre with these characteristics will probably be midway between that of the 5.56 × 45 mm and 7.62 × 51 mm cartridges, at around 2,500 joules (J) (Williams, 2014a).

Lead, typically alloyed with antimony for hardness, has long served as the standard core material for military ball (also known as full metal jacket, or FMJ) projectiles. In recent years, NATO and allied states have sought alternatives to lead, primarily in response to environmental and toxicity concerns. In conjunction with the use of non-toxic or reduced-toxicity primer and propellant compounds, so-called 'green' ammunition is designed to reduce exposure of manufacturers, users, and the environment to heavy metals such as cadmium, mercury, lead, and arsenic, as well as other toxic compounds (Antenen et al., 2013; Schatz, 2014).[29] This is especially important for protecting one's own military forces, as the great majority of ammunition fired by troops is expended during training activities, often on home soil.

Initially encouraged by the adoption of green ammunition in Finland, Norway, and Sweden, the United States and other countries have taken similar steps. In former Warsaw Pact states, 7.62 × 39 mm and 7.62 × 54R mm projectiles have long been constructed with a combination of mild steel and lead cores (primarily for cost-saving reasons), whereas green ammunition is a relatively modern concept. Alternative projectile materials—such as copper, steel, or bismuth–tin alloy—are typically less dense than lead[30] and therefore result in a lighter bullet for a given shape. Other factors being equal, this cartridge would have a worse BC, meaning that optimizing a projectile's shape will be even more critical if lead alternatives are to be used.

Once the optimum calibre, shape, and weight for the projectile have been established, the desired velocity and requisite propellant type and quantity must be determined. A key factor is the barrel length of weapons with which a general-purpose cartridge is to be employed; in longer barrels, less propellant is required to propel the projectile at a given muzzle velocity. The primary restriction is the acceptable level of chamber pressure generated by the propellant gas. Wherever higher pressures are possible, a smaller volume of propellant is required; however, too much pressure results in more rapid barrel wear and a shorter firearm lifespan. A general-purpose cartridge would need to conform to current pressure limits if it were to be used in current weapon systems or slightly modified versions of these.

The propellant type and quantity will be selected based on the abovementioned factors. The selection process must take into account propellant characteristics such as base composition, burn rate, 'all burnt' point, granule shape and size, and granule coating (Antenen et al., 2013). The cartridge case shape and size can then be optimized to contain the required amount of propellant and to operate reliably in the different firearms with which it is expected to function; to a lesser extent, these characteristics can also be designed with efficient packaging in mind. A reduction in weight and volume of a general-purpose cartridge will be aided by the optimization of these factors; ideally, the resulting cartridge will have a high propellant load density (meaning little ullage, or 'leftover' air space inside the cartridge case). By ensuring that the propellant burns more consistently, and thus preventing 'spikes' in pressure, these adjustments may enhance accuracy (Hogdon, 2008). Recent efforts have focused on minimising cartridge case size, often in conjunction with the use of advanced or emergent propellant formulations or geometries. Knox Engineering Company's alternative 5.56 mm cartridge has a form factor which is approximately half the volume and 70 per cent of the total weight of an M855 cartridge, whilst using the same projectile (see Photo 4). The Knox Engineering design uses approximately 50 per cent as much propellant, but yields equivalent or better external ballistics (Sadowski, 2005).

Photo 4 **A comparison of the Knox Engineering Company 5.56 mm alternative cartridge geometry (top) and a standard 5.56 × 45 mm M855 cartridge (bottom)**

Source: Knox Engineering Company

The recoil impulse of a general-purpose cartridge that fulfils the above criteria would most probably be between that of the 5.56 × 45 mm and 7.62 × 51 mm cartridges; it would sit somewhere slightly above that of the 7.62 × 39 mm round (see Table 2). This latter cartridge is generally considered suitable for controlled semi-automatic fire, and for controlled automatic fire at short ranges. The design of an optimum general-purpose calibre cartridge would seek to limit recoil impulse as much as practicable.

Ideally, a general-purpose cartridge for military service would be capable of being chambered by modified weapons that are already commonly in service. In most NATO states and other Western nations, this would mean weapons chambered for 5.56 × 45 mm. The round would also need to remain within the overall dimensions of the 7.62 × 51 mm cartridge so that existing weapon designs chambering full-power rifle ammunition could be adapted to use it. A longer barrel than the carbine-length barrels currently favoured (350–400 mm) may prove more suitable for a general-purpose round. Some observers have also noted that the selection of a bullpup rifle layout would allow a long barrel to be used while the overall length of the weapon is kept within current norms,

Table 2 **Recoil impulse of selected small-calibre cartridges**

Cartridge	Recoil impulse (kg-m/s[31])
5.45 × 39 mm	~5.0
5.56 × 45 mm	~6.0
7.62 × 39 mm	~7.5
6.8 × 43 mm	~8.0
7.62 × 51 mm	~11.5

Source: Daniau (2015)

since such a layout 'saves' around 200 mm in overall length (Williams, 2014b). The use of a bullpup layout introduces other challenges, however.

Advantages and disadvantages of a general-purpose calibre

The introduction of a general-purpose cartridge, intermediate in calibre and with a muzzle energy between that of the 5.56 × 45 mm and 7.62 × 51 mm rounds, could offer a number of advantages over the in-service ammunition mix. Such a cartridge would be developed to be able to use longer, low-drag projectiles with a high BC. As a result, the general-purpose cartridge would be endowed with **long-range ballistics** and an effective range equal to or greater than that of the 7.62 × 51 mm cartridge, despite the reduction in muzzle energy. As noted, some commentators have questioned the requirement for a longer-ranged cartridge for infantry personnel.

A larger projectile than that used with the 5.56 × 45 mm cartridge is likely to result in more reliable **terminal effectiveness**. While this effectiveness may be reduced for the limited numbers of 7.62 × 51 mm weapons in a squad, the net impact would be positive. In addition, a projectile with a high BC for an intermediate-calibre cartridge would be capable of delivering sufficient lethal energy at long ranges. It should be noted that lethality could be affected for projectiles of all calibres, should expanding projectile types be employed instead of those with full metal jackets.

Recoil impulse, which is primarily a function of bullet mass and muzzle velocity, would be midway between that of the 5.56 × 45 mm and 7.62 × 51 mm cartridges, providing greater controllability in rifles currently chambered for 7.62 × 51 mm. However, the increase in recoil for service rifles now chambered for 5.56 × 45 mm may pose a challenge.

Weight may prove one of the most significant challenges to overcome if a general-purpose calibre is to achieve military acceptance. While there are applications by which the adoption of a general-purpose calibre as a replacement for the 5.56 × 45 mm and 7.62 × 51 mm cartridges would result in net weight savings—such as in a weapons squad currently equipped with 7.62 × 51 mm general-purpose machine guns—an overall weight increase for an infantry platoon is likely (Devil CAAT, 2003; US Army, 2007). The most common argument against the introduction of a general-purpose calibre, on technical rather than logistic or economic grounds, suggests that the effective range of the 5.56 × 45 mm is adequate for the great majority of engagements, and that the increased ammunition weight and recoil of a general-purpose cartridge would result in little practical advantage. If the current ammunition load weight is considered acceptable, then the introduction of a general-purpose calibre—which would offer a significantly increased range and more reliable terminal effectiveness—in conjunction with a polymer and possibly telescoped cartridge case may be deemed advantageous.

It has been suggested that a general-purpose cartridge may offer an **advantage to suppression fire**[32] from the overall increase in average calibre. It is widely acknowledged that the overwhelming majority of bullets fired in combat fail to hit a target, and that they are frequently fired in the general direction of an unseen enemy. The practical function of small arms fire, especially at long range, is suppression. Two important factors in suppression are the volume of the sonic boom as a bullet passes nearby (a function of bullet size and shape) and how close the bullet passes (a function of long-range accuracy). Both bullet size and long-range accuracy favour a general-purpose cartridge, rather than the 5.56 × 45 mm round; however, the shape of such projectiles may mitigate these advantages (Daniau, 2015; Williams, 2015b). Further modelling and study are required.

Ammunition sharing and sustainment would be simplified by the introduction of a general-purpose calibre. **Maintenance**, particularly if one family of weapons were selected, could also be streamlined.

Quite apart from the technical merits of a general-purpose calibre, and the arguments against these, the introduction of such a cartridge would also be tempered by significant economic and logistic challenges (see Section IV).

Candidates for a general-purpose cartridge

Given the wide range of commercially available rifle-calibre ammunition, one might assume that several cartridges could fulfil the requirements that are outlined above. This is currently not the case. While a number of cartridges fall within the 6.35–6.8 mm-calibre range, most of these can be separated into two

Photo 5 **Left to right: 7.62 × 51 mm NATO, 6.8 × 43 mm Remington SPC, 6.5 × 39 mm Grendel, and 5.56 × 45 mm NATO**

Source: Anthony G. Williams

groups: relatively low-powered cartridges based on the diameter of the 5.56 × 45 mm case (9.5 mm) and significantly higher-powered ones based on the 7.62 × 51 mm case (12 mm). A cartridge of general-purpose calibre, intermediate in proportion to the 5.56 × 45 mm and 7.62 × 51 mm cartridges, would have a case diameter of some 10.5 to 11.3 mm. There are only a handful of modern cartridges in this range, most notably the 6.8 × 43 mm Remington Special Purpose Cartridge (SPC), the 6.5 × 39 mm Grendel, the 6.5 × 40 mm, and the .264 USA (see Photo 5).[33] Annexe 1 on page 66 examines these candidates in further detail.

III. Modern advancements in cartridge case technology

The development of modern cartridge case technology

In the mid-1800s, the advent of metallic cartridge cases allowed for a single round of ammunition to be packaged in a self-contained format (Smith and Smith, 1948; Wilson, 1934). While the metallic cartridge case increased the overall weight of a round and necessitated mechanisms such as extractors and ejectors within a weapon, it allowed for the introduction of the self-loading weapons that form the backbone of modern militaries, such as self-loading rifles and machine guns (Jenzen-Jones, 2016).

The cartridge case is an essential component, providing the housing for the propellant and projectile, and withstanding gas pressures that can easily exceed 379 MPa (55,000 psi) when fired.[34] The case also serves as durable packaging for the other key components, including the primer, propellant, and projectile, allowing the cartridge to survive varied environmental conditions and the mechanical action of self-loading firearms. Finally, the modern cartridge case is responsible for rearward obturation, a process by which the cartridge case wall expands under gas pressure to form an airtight seal against the chamber behind the projectile, resulting in the reliable and safe functioning of the firearm (Goad and Halsey, 1982). The structural integrity and strength of the cartridge case is critical to these functions and has presented the greatest obstacle for its would-be successors to date.

During World War II, the German military sought to reduce its strategic reliance on copper and zinc used in the manufacture of brass cartridge cases. Instead, German designers developed a thin-walled steel cartridge case, which saw widespread issue with positive results.[35] Depending on the calibre, steel cartridge cases weighed 3–5 per cent less than brass cases and were produced at a lower cost per unit (Schatz, 2015b). Two other non-traditional cartridge case materials bear mention: aluminium and thin-walled stainless steel (TWSS). While aluminium cartridge cases are used in a number of training rounds and are available as a low-cost alternative to brass-based cartridges for low-pressure handguns and rimfire weapons, they are generally considered unsuitable for high-velocity rifle cartridges. The incompatibility is largely due to 'burn-through' failures, as well as extraction issues that result in torn case rims (Squire and Donnard, 1972). More recently, ATK Small Caliber Systems[36] explored TWSS ammunition with a view to reducing the weight of standard .50 BMG (12.7 × 99 mm) cartridges by some 15 per cent. This effort met with little success, due to a combination of technical obstacles and the emergence of successful polymer cases that lower weight by 25 per cent at a lower cost (Hunt and Stoll, 2012; Westbrook, 2012).

Conventional brass-cased and, to a lesser extent, steel-cased ammunition has been perfected to the limits of technology and manufacturing (Schatz, 2015b). While heavy and relatively costly, brass cartridge cases perform very well in small-calibre applications, even under harsh environmental and mechanical stresses. Brass remains the most common cartridge case material in the Western world, and brass and steel are the dominant case materials worldwide.

The development of lightweight cartridge case designs

The development of small arms technology during and after World War II has yielded man-portable firearms capable of firing up to 1,200 rounds per minute for extended periods of time.[37] With the widespread issue of firearms capable of automatic fire, the volume of ammunition carried by modern infantry personnel has increased dramatically. For example, in several modern militaries, it was not uncommon for machine gunners armed with the MAG (or M240B) GPMG to carry 400 to 600 rounds of brass-cased 7.62 × 51 mm ammunition in metal-linked belts.[38] With each 100-round belt weighing just under 3 kg, the total ammunition weight carried by the combatant could be heavier than the 12.5 kg weapon. Similarly, a US soldier equipped with an M4 carbine generally carries 210 rounds of 5.56 × 45 mm ammunition in a combat load, which weighs some 2.5 kg[39] (Devil CAAT, 2003). The manoeuvrability of the infantry remains a primary consideration for many developed countries' armed forces, and hence developing technical solutions that achieve weight reduction in ammunition is a sought-after goal.

Brass cartridge cases often account for a significant portion of the total weight of a given cartridge. Table 3 shows the approximate weight distribution of a 7.62 × 51 mm M80 ball cartridge. The brass cartridge case, accounting for 48 per cent of the total weight, offers significant potential for total cartridge weight reduction, as well as possible cost savings and further technical developments.

Table 3 **Weight distribution of a 7.62 × 51 mm M80 ball cartridge**

Component	Weight (%)
Cartridge case (brass)	48
Projectile	38
Propellant	12
Primer and sealants	2

Source: Schatz (2015b)

Most NATO and Western countries continue to employ brass-cased small-calibre ammunition, with cost and availability of materials not generally considered significant limitations. Many former Warsaw Pact states, and a great many developing militaries supplied by these states, continue to employ steel-cased ammunition. This is due in part to longstanding production processes and significant capital equipment investments, first established for the manufacturing of steel-cased ammunition in Warsaw Pact countries in the 1950s. Small-calibre ammunition that was intentionally designed to be lightweight sees little use among armed forces around the world, with the exception of some cartridges used in limited, country-specific training roles. In view of the direct interaction between the proper functioning of modern firearms and the material of the cartridge cases they chamber, steel-cased ammunition is often less attractive for use with firearms designed primarily for brass-cased ammunition. This is primarily a result of the subtle differences in hardness and pliability during obturation between brass-cased and steel-cased ammunition (Schatz, 2015b).

The first low-cost, commercially viable polymer cartridge cases were introduced for training purposes. Adopted in limited numbers by some Western law enforcement agencies and military units from the early 1960s onwards, these make use of a full-polymer case, a lightweight plastic projectile, and metallic primer with no propellant required (see Photo 6).[40] The polymer materials of the era were significantly less advanced than those available today, and there were numerous reports of failures due to heat or violent extraction forces, particularly on the rim of the cartridge (Schatz, 2015b). Nonetheless, cartridges of this type remain available today (Speer Bullets, n.d.).

Photo 6 **Speer .38 Special plastic training cartridge. Note the all-plastic rim, which is generally unsuitable for use in self-loading weapons**

Source: Speer

Photo 7 **German Dynamit Nobel 7.62 × 51 mm *Übung* (practice) cartridge. Note the steel base and rim and lightweight plastic projectile**

Source: Bud's Gun Shop

More advanced designs, using a metal case head (often made of aluminium or steel) with a polymer 'caselet', along with propellant, a primer, and a lightweight plastic training projectile, were introduced in the 1980s (see Photo 7). These found favour with several European militaries for training purposes, although there were issues with some self-loading firearms due to the reduced propellant load, and the resulting decrease in the amount of gas pressure generated. Attempts to scale the concept were not successful. The significantly heavier projectiles required for lethal effects[41] called for increased propellant loads and resulted in much higher chamber pressures, which caused failures in the polymer cases. For reliable function in self-loading weapons, these lightweight rounds often necessitated the use of special, lightened 'plastic training' bolt groups.

End-user requirements

Following are some of the most important aims and requirements of modern cartridge case design, in descending order of priority. Depending on the end user and intended use, some of these requirements may prove more or less important. The main aims are to:

- reduce ammunition weight;
- reduce ammunition volume;
- increase the number of rounds that can be carried;
- improve hit probability;
- improve general performance and function;
- enable special applications;
- allow for the enhancement of legacy weapon systems and the development of new weapon systems;
- reduce ammunition cost in terms of production and procurement; and
- reduce ammunition transport costs.

Emergent cartridge case technologies

Polymer cartridge cases

Polymer cartridge cases face a number of design challenges. The material selected must be able to withstand the various mechanical, thermal, and chemical stresses to which cartridge cases are subjected. The cases must be low-friction, feeding and loading in a weapon as a finished brass case would. Polymer cartridge cases used in current weapon designs must be produced from a material with elastic properties that match those of brass, so as to allow for consistent obturation and extraction. Some manufacturers have claimed that their polymer materials obturate better than brass cases (Western Shooter, 2011). Consistency in manufacturing is essential, as it ensures not only accuracy, but also safety and quality.

The primary advantage of polymer-cased ammunition is a reduction in overall cartridge weight. According to one manufacturer, pistol cartridges typically weigh 11.5–20 per cent less, while rifle-calibre cartridges are 23–60 per cent lighter (PolyCase Ammunition, n.d.). Polymer cartridge cases typically require a thicker case wall than brass, which results in a slightly reduced cartridge case capacity. As a result, the amount or type of propellant used may vary from those used in their brass counterparts.[42]

Polymer-cased conventional ammunition is currently available from a small number of manufacturers. Other manufacturers previously offered similar products, or are intending to do so in future. Commercially successful designs, or those expected to gain widespread military acceptance, will need to function correctly in existing firearm designs. Certain issues have reportedly emerged in relation to available ammunition that uses polymer cases, including catastrophic failures (C., 2014). Some manufacturers of polymer cartridges have indicated that their ammunition should not be used in firearms with fluted chambers,[43] such as the Heckler & Koch G3 series of rifles (PCP Ammunition, n.d.).

The most successful designs of polymer cartridge case ammunition used with unmodified self-loading firearms employ metallic cartridge case heads (see Photos 8 and 9). Such heads provide sufficient strength to the thin rim of the case for the relatively violent extraction and ejection forces commonplace in the regular functioning of a firearm; they may also assist in providing adequate rearward obturation. Rim and base strength is critical to ensuring safe, reliable operation in firearms, particularly with aged or fouled weapons. At least one manufacturer intends to offer cartridges with a metallic case rim only (PolyCase Ammunition, 2015).

Photo 8 (left) **A MK323 Mod 0 polymer-cased .50 BMG (12.7 × 99 mm) cartridge**

Source: MAC LLC

Photo 9 (below) **This recent graphical representation of a conventional-configuration lightweight 5.56 × 45 mm cartridge from MAC LLC shows the metallic cartridge head (base) at left, and the moulded polymer cartridge case 'caselet' with projectile at right. Note the join towards the base of the caselet**

Source: Naval Surface Warfare Center Crane Division

Cased telescoped ammunition

Emergent cased telescoped (CT) ammunition[44] offers a significant reduction in cartridge weight and volume. In telescoped cases, the projectile is seated fully within the length of the cartridge case, reducing a cartridge's overall length (see Photo 10). This configuration obviates the need for metal cartridge case heads while maintaining a functional level of case strength and integrity. A rim or extractor groove is typically not required because the mechanism of the weapon forces the fired case forward using a rammer, rather than extracting it towards the rear, as with most conventional firearms. The weapon mechanism must be purpose-built to allow for the use of CT ammunition, making it incompatible with conventional firearms and thus costly, as a complete replacement of both the ammunition and the weapon system is required.

Telescoped cartridge designs have been under development since the 1950s, using various materials, including light metals, and polymer; some even employ fully combustible caseless technology. Early iterations of telescoped ammunition were designed around medium-calibre projectiles, including examples in 20, 30, 40, and 75 mm configurations. Technological limitations meant that early CT cartridges were typically heavier and larger than their conventionally configured counterparts, and that they suffered from ballistic inefficiencies (DoD, 1996). Some successful employments of telescoped cartridge technology were developmental weapons, including the Heckler & Koch G11 caseless self-loading rifle candidate for the US Army's Advanced Combat Rifle programme[45] (Johnston and Nelson, 2010).

Some specific technical challenges with telescoped case designs include controlling the 'jump' of the projectile into the barrel, ensuring the correct orientation of ammunition when filling magazines, and ensuring proper sealing for the chamber in order to achieve correct function. The most significant effort examining CT ammunition to date is the US Army's Lightweight

Photo 10 **CT cartridges in comparison to conventional brass-cased cartridges. From left to right: 5.56 mm LSAT, 5.56 × 45 mm M855, 7.62 mm LSAT, 7.62 × 51 mm M80**

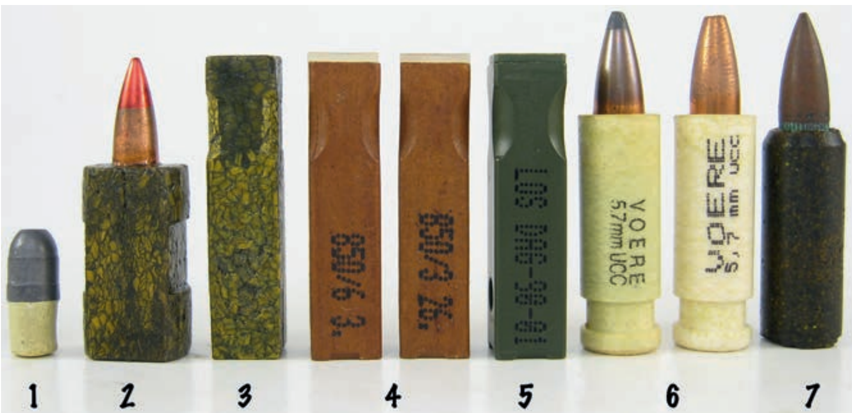
Source: Textron Systems

Small Arms Technologies (LSAT) programme (Shipley and Spiegel, 2005). The LSAT programme has also examined other emergent ammunition technologies, as discussed in Section IV.

Caseless ammunition

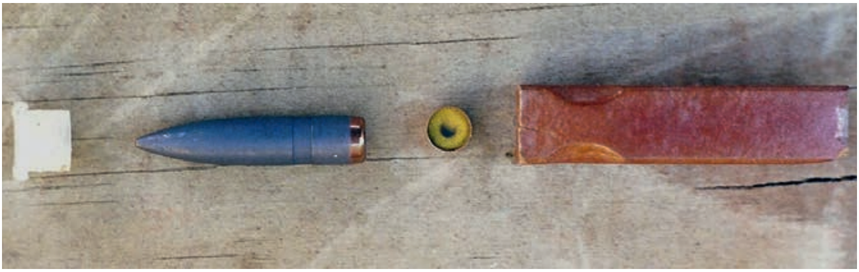
Currently, the greatest reduction in cartridge weight and volume can be achieved through the use of caseless ammunition. In this configuration, the cartridge body is comprised of the propellant, leaving no case to be discarded once fired. Certain iterations of this technology, using a 5.56 mm projectile, have achieved a reduction in weight of nearly 50 per cent as well as a 40 per cent reduction in overall cartridge volume (Phillips, 2010). This can only be achieved with a significant increase in the complexity of the weapon system used to employ the ammunition, which imposes additional reliability challenges. As a result, there are no small arms in military service that use caseless ammunition, despite attempts to perfect these systems for more than seven decades (Schatz, 2015b).

Photo 11 **A side-by-side comparison of conventional caseless (1, 2, 6, 7) and telescoped caseless rounds (3, 4, 5).**[46] **The cartridges pictured make use of different propellants, including nitrocellulose (2, 3, 7) and high-ignition-temperature propellant (4). Two of the caseless rounds visible at right (6) are the electrically fired 1994-era Voere caseless cartridge that saw limited commercial success in bolt-action sporting rifles**



Source: DrakeGmbH

Photo 12 **German 4.73 × 33 mm high-ignition-temperature propellant G11 caseless cartridge components. From left to right: plastic cap, projectile, booster cup, and propellant body (the primer is not visible). The propellant and primer are both combustible, while the plastic cap and booster cup are post-firing remnants, discarded from the muzzle**



Source: Schatz (2012a)

Long-term development of caseless ammunition has given rise to both conventional configurations, in which the projectile is visible above the cartridge body (sometimes called 'shouldered caseless'), and telescoped configurations, in which the projectile is fully contained within the block of propellant (see Photo 11). Telescoped caseless designs have been the most successful, providing the necessary strength to secure all cartridge components—including the projectile—within the relatively brittle block of propellant. The term 'fully caseless' broadly applies if the entire cartridge, barring the projectile, is consumed during the firing process, leaving nothing in the chamber of the weapon, although this term is also applied to some cartridges that expel post-firing remnants through the muzzle of the weapon after the projectile (see Photo 12). Once fired, nothing but residual gases and typical minor fouling remain within the weapon's chamber (Schatz, 2015b).

'Semi-caseless' cartridges have also been developed. These are frequently described as rocket-propelled, as they a function in similar manner. Propellant is placed in a hollow cavity to the rear of the projectile warhead, with a restricted opening to the rear. When the charge is ignited, the entire projectile is driven forward, leaving nothing else within the weapon system. The Russian 40 mm VOG-25 grenade is one example of an in-service cartridge that utilizes this design.[47]

Technical advantages and disadvantages of emergent cartridge case technologies

The primary advantages of emergent cartridge case technologies may be the weight and volume savings they offer. The most commonly perceived advantage of lighter cartridges is the corresponding reduction of combat loads that are regularly carried by modern infantry personnel.[48] The direct, tactically desirable result of this is increased mobility. This weight reduction, which ranges from some 15 per cent to nearly 50 per cent depending on the technology, could permit combatants to carry a significant amount of additional ammunition beyond their current-day standards, allowing for overall increased unit 'firepower' (Phillips, 2012; Shipley, 2015). An increase in total ammunition carriage, which is sometimes referred to as 'stowed rounds', could have further tactical effects. Machine gunners, for example, may become more independent, able to carry more ammunition for their weapons. Combined with a general-purpose calibre, reduced weight may entail additional benefits (see Section IV). In general, the larger the calibre of the cartridge, the greater the weight savings generated through the use of emergent cartridge case technologies. That is, there is a greater potential to save weight in larger calibres, such as .50 BMG (12.7 × 99 mm), than in smaller calibres, such as 5.56 × 45 mm (Schatz, 2015b).

Advanced lightweight cartridge cases also offer significant advantages for mobile weapon platforms, in particular helicopters and fixed-wing aircraft. A reduction in overall ammunition weight may allow for more stowed rounds, depending on platform configuration, or for longer loiter times—more 'time on target'. The advantage of carrying more ammunition is even more pronounced when employing weapon systems with a high rate of fire, such as the US GAU-19 and GAU-21 machine guns.[49] Ground platforms, often overloaded with equipment, may also benefit from speed and mobility advantages while using lightweight ammunition.[50]

The significant weight savings possible through the adoption of advanced technologies could allow certain weapon systems to be employed in various non-traditional roles, whereas the weight or volume of conventional brass-cased ammunition previously disallowed its use, transport, or availability in given scenarios.[51] Weight reduction is also a technology enabler, as it opens doors to completely new and unorthodox weapon systems that could utilize reduced-weight designs to achieve unique capabilities or applications beyond legacy systems.

An increase in stowed rounds is also likely to result in an increase in overall hit probability (often expressed as P_H). Primarily a function of the marksmanship of the firer, hit probability is directly affected by the number of rounds fired at a target, which is often influenced by the total quantity of ammunition carried (Tolk, 2012). For caseless ammunition, the absence of a need to extract and eject a fired cartridge case often allows for an overall increase in the weapon's rate of fire.[52] This also enables the inclusion of specific 'salvo' or burst-fire features in a weapon's design, as in the Heckler & Koch G11 (Johnston and Nelson, 2010).

Photo 13 **The volume of 4.73 × 33 mm high-ignition-temperature propellant caseless ammunition[53] (right) is about 37 per cent smaller than that of brass-cased US M855 5.56 × 45 mm ammunition (left)**

Source: Schatz (2012a)

A significant reduction in overall cartridge weight and volume also offers an important logistic advantage in packaging, transport, and storage cost reductions. In particular, shipping costs are likely to drop substantially, with estimates of a 10–20 per cent reduction reported for conventionally configured polymer-cased ammunition compared to brass-cased ammunition of the same calibre (Schatz, 2012a; 2015b). Photo 13 shows that the overall volume of 4.73 × 33 mm caseless cartridges is significantly smaller than that of 5.56 × 45 mm M855 cartridges; a reduction of some 37 per cent in volume is achieved.

Polymer ammunition in both conventional and telescoped configurations saves an estimated 10–20 per cent in manufacturing costs when compared to brass-cased equivalents (Schatz, 2015b). These are very rough estimates, however, and savings are directly dependant on production volume, case material, manufacturing and assembly equipment, amortization of plant costs, and other factors that are subject to variation. Caseless and telescoped ammunition could prove more costly overall, due to the cartridge-specific weapon systems needed to fire them, as well as logistic costs associated with producing and issuing these weapons. In terms of overall cost savings, conventional polymer-cased cartridges represent the greatest opportunity, as unmodified legacy weapons are likely to prove suitable for this ammunition.

Modern cartridge case developments, materials, and manufacturing methods (particularly moulding processes) may provide new opportunities to develop special ammunition variants, or to change the way in which special-purpose cartridges are produced. Since precision moulding allows for custom case thickness and capacity, polymer cartridge designs pave the way for ammunition that is not as sensitive to the position of the propellant within the case. The positioning of propellant directly affects the generation of propellant gases, which determines interior and exterior ballistics—and, in turn, accuracy—of the projectile (Hogdon, 2008). Specially moulded interiors of polymer cases would allow propellant to be repeatedly positioned with great precision and consistency; as a consequence, burn rates could be controlled with enhanced precision and deviations in muzzle velocity could be minimized, thus ensuring increased accuracy. This would be especially true in subsonic applications for precision shooting and would also reduce weapon signature, aiding concealment.

Industry developers in the United States are actively researching this application (Schatz, 2015b).

Polymer cartridge cases may offer safety advantages, as they help to reduce the heat transferred to the chamber and barrel of a weapon during the deflagration of propellant. This confers two main benefits. First, weapon failure from overheating occurs at a slower rate, allowing for a higher sustained rate of fire. As a result, there is an increased likelihood that infantry personnel will be able to 'outlast' opponents in a firefight. Second, polymer cases conduct heat less readily, meaning that cook-offs[54] due to excess heat in the chamber of the weapon are likely to occur less often (Schatz, 2015b). Another, minor safety benefit lies in the manufacture of coloured polymers for cases. Various colours can correspond to different variants of ammunition, rendering it more difficult to mistake one ammunition type for another. This concept was adopted by Natec, Inc., at the introduction of their .223 Remington polymer-cased ammunition.

The introduction of polymer cartridge cases would reduce the reliance on strategically important materials such as copper and zinc (DoD, 2013). Viable caseless cartridges, such as those developed by Dynamit Nobel for the G11 rifle or the US Army's LSAT programme caseless ammunition, rely on certain materials for their special high-ignition-temperature propellant (HITP) that could prove more difficult to acquire.

Recent evaluations of polymer-cased ammunition have shown better accuracy than conventional brass-cased equivalents. In one example, US Marine Corps MK323 Mod .50 BMG (12.7 × 99 mm) ammunition displayed an extreme spread average of 1.1 minutes of angle (MOA), compared with 2.1 MOA for standard US M33 brass-cased ball rounds, under ideal test conditions. While the exact causal factors have yet to be determined, two possible explanations are likely. The first is that reduced ullage within the case probably results in more consistent burning of propellant.[55] Second, greater precision can be achieved in moulding polymer cases compared to drawn-brass cases. In particular, more precise interior dimensions, case wall thickness, and overall length are likely to be key factors. Other possible explanations could include the more predictable chemical adherence of the projectile to the mouth of the cartridge case (as compared with the mechanical adherence in brass cases), more consistent obturation of the case, heat reduction through the walls of the cartridge case, or a possible combination of any or all of these. With improved accuracy, lower weight, and potentially lower cost, polymer-cased cartridges present a very attractive option for future cartridge case design.

Caseless ammunition challenges

Caseless ammunition technology presents three unique and significant technical challenges that need to be overcome before such ammunition would be viable for military use:

- With no cartridge case to provide rearward obturation, weapons that fire caseless ammunition must include a mechanical function of the weapon to seal the chamber, firing pin, and other components as rounds are fired. Failures to seal during the firing process may result in the escape of high-pressure gases, which can form a high-pressure jet that can damage or destroy the operating parts of a weapon, or injure its operator.[56] Any openings for feeding unfired cartridges must also seal reliably; otherwise, the cartridge may fail to combust completely in the chamber.[57] Providing a fool-proof chamber seal in all environments and under all conditions is of utmost importance, but the complexity of the mechanical systems required to do so is often at odds with operational reliability.
- Caseless weapons may be more prone to thermally induced firing, or cooking off. Some types of caseless ammunition have proven more susceptible to cook-offs. An example of relatively modern caseless ammunition, 4.73 × 33 mm cartridges for the Heckler & Koch G11 rifle achieved a cook-off rate comparable to conventional brass-cased ammunition, but this required the use of non-standard propellants to form the cartridge body, as well as a special heat-resistant surface coating. Standard nitrocellulose propellant does not possess the resistance to heat-induced ignition required for current military firing rates.
- The body of caseless cartridges, formed by propellant, must be fragile enough to fully fracture and ignite when fired, but durable enough to withstand the mechanisms of the weapon, handling and manipulation, and operational

Photo 14 **A ruptured 4.73 × 33 mm caseless cartridge. Note the fragmentary nature of the propellant block and the absence of propellant fragments**

Source: Heckler & Koch USA

environments. If the cartridge body is fractured or cracked, then proper transport through the weapon's mechanism is likely to be compromised (see Photo 14). In addition, missing propellant results in lower chamber pressure when the weapon fires, which is likely to cause issues with weapon accuracy, dispersion, and terminal effectiveness.

Caseless ammunition designs must take a number of additional challenges into account. Environmental effects on the propellant block are likely, including damage from water, fuel, and other chemicals. The weight and shape of this propellant block must be precise in order to ensure consistent, intended ballistics, correct feeding, and nominal gas volume; as a result, it is practically impossible to adjust the charge load, as could be done with conventional ammunition for research or hand-loading. As with other telescoped ammunition, the caseless variety can potentially be inserted into the feed device incorrectly, as physical features or protrusions may not prevent improper loading or provide an easily discernible indication of the wrong orientation. This is of particular concern in low-light conditions. Other remnants from caseless ammunition, such as plastic projectile-sealing caps or booster cups, may become secondary missile hazards, being ejected forward of the muzzle. As with many other non-conventional ammunition types, caseless ammunition production typically requires new, purpose-built manufacturing machinery and processes, some of which present new challenges (such as the moulding and milling of propellant blocks).

Table 4 summarizes the advantages and disadvantages of conventional brass-cased cartridges compared to the emergent cartridge case technologies described above. The table compares like calibres and applications. It should be noted that the percentages included are necessarily generalized, and some values can vary depending on the level of material and developmental maturity, special application modifications, and other variables.

Table 4 **Conventional brass-cased ammunition vs. emergent cartridge case technologies**

Characteristic/attribute	Brass-cased (legacy)	Polymer-cased (conventional)	Polymer-cased (telescoped)	Caseless (HITP)	Sources
Currently fielded	Yes	First fielding 2015	No	No	Schatz (2015b)
Reduced weight[a]	No	15–28%	37%	50%	Phillips (2012); Shipley (2015)
Reduced volume	No	0%	12%	40%	Phillips (2012); Shipley (2015)
Increased stowed rounds	No	Yes	Yes	Yes	
Proven ballistic performance and reliability	Yes	Yes	Underway	No	
Reduced production cost[b]	No	Yes (up to 20%)	Undetermined[c]	Undetermined	Schatz (2015b)
Reduced transport cost[d]	No	Yes (estimated at 10–20%)	Yes	Yes	Schatz (2015b)
Reduced reliance on strategic materials	No	Yes	Yes	Undetermined[e]	
Improved safety (resistance to cook-off)	No	Yes	Undetermined	Equal to or better than brass-cased ammunition	Schatz (2015b)
Can be produced using current production tools	Yes	Partial[f]	No	No	
Reliant on new technologies	No	Partial	Yes	Yes	

Notes: The table reflects findings of a comparison between emergent cartridge cases and current brass-cased standard-issue of the same calibre, as determined by the author and supported by cited sources. Green represents a net gain, yellow consistency or unknown change, and red a net loss in terms of attaining the selected characteristics or attributes.

[a] Weight is dependent on calibre.

[b] Production costs depend on production volume and amortization of tooling.

[c] Some information on capital costs is discussed in Hopkins, Perhala, and Tolbert (2012).

[d] There is a direct relationship between reduced weight and volume and packaging and shipping costs.

[e] HITP caseless propellant availability and costs have not yet been fully determined in comparison to brass material.

[f] Current assembly tooling can be used.

IV. Synergies of emergent ammunition technologies

The likelihood of large-scale adoption of emergent ammunition technologies

Plans for a general-purpose calibre between the current 5.56 × 45 mm and 7.62 × 51 mm cartridges are most often challenged on the grounds of weight. On average, the overall weight of ammunition would increase if the same number of rounds were to be carried by a unit or squad. While the adoption of a general-purpose calibre would no doubt provide infantry with a ballistically superior cartridge, the success of the concept hinges on whether this increase in capability is necessary and, more importantly, whether it is worth the trade-off in terms of weight. The weight reduction offered by advanced case technologies may reduce or neutralize this disadvantage and allow for greater performance to be built into smaller-calibre cartridges, which could prove a key enabler for the adoption of a general-purpose calibre. The viability of a widely issued general-purpose calibre may thus be tied to the success of programmes that examine other emergent ammunition technologies, including polymer cartridge cases, advanced propellants, and telescoped cartridge configurations.

As a result of significant technological challenges, caseless ammunition is unlikely to be adopted by a world power in the near or medium term. Other emergent ammunition technologies are much more likely to be successfully implemented, especially while the weight and volume savings offered by caseless ammunition—even in a telescoped configuration—fail to offer a substantial advantage over their CT counterparts. A number of failed attempts to develop fully combustible caseless ammunition since the 1960s have resulted in modern programmes that favour CT and other technologies (Schatz, 2012a; 2015b).

In recent years, CTA International has successfully introduced telescoped medium-calibre cartridge designs. The 40 mm Cased Telescoped Armament System is intended to provide firepower superior to other medium-calibre systems in compact package. Six different varieties of ammunition are available—for anti-armour, general-purpose, anti-air, and training purposes—offering a 30 per cent reduction in volume over traditionally configured rounds (Duckworth, 2005). While the UK and French militaries have adopted the system, sources familiar with the programme acknowledge that the technology may be expensive and technically challenging to transition to small-calibre applications.[58]

The adoption of polymer-cased conventional ammunition—while likely to have a lesser economic and logistic impact than the introduction of either a general-purpose calibre or more radical changes in cartridge case technology, such as caseless or telescoped rounds—would still pose a significant economic and logistic challenge. Manufacturing plants and techniques would need to be replaced or adjusted at major manufacturing centres in order to produce such ammunition on a large scale. Polymer ammunition that is used for army testing has been produced on a comparatively small scale—by manufacturers other than those that traditionally produce cartridges and cartridge cases for military service (Hunt and Stoll, 2012). Given that the introduction of any of the abovementioned emergent ammunition technologies would require significant changes to the manufacturing process, it is likely to prove substantially more cost-efficient to adopt a combination of technologies at the same time, potentially in ways that may include technologies not covered in detail in this report (see Box 1).

A new cartridge that requires a significant adjustment to production infrastructure or weapon systems will not be acquired and fielded unless it offers a substantial advantage over the current calibre mix, or unless such an acquisition is conducted in conjunction with the adoption of other new technology that requires the replacement of available ammunition. Given past acquisition trends, it is highly improbable that NATO would adopt a new cartridge unless the US armed forces, and the US Army in particular, intend to field it in significant quantities.[59] US Army requirements are thus the most critical factor in determining whether a general-purpose calibre is likely to be adopted by major Western militaries.

At this writing, no new family of small arms was expected to enter US service prior to 2025 (Williams, 2015b). Requirements for these systems are still being developed and are likely to draw on a number of concluded, ongoing, and

Box 1 **Other emergent ammunition technologies**

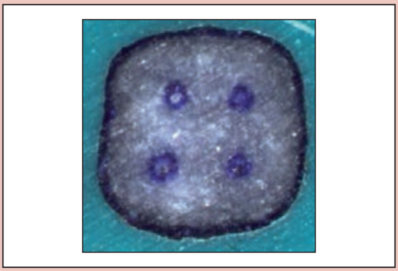
Advanced propellants

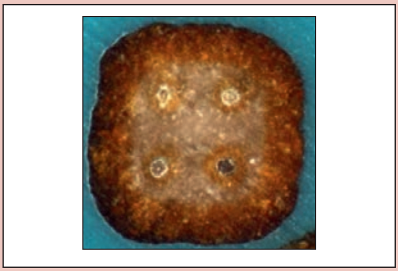
According to some specialists, the performance potential of current nitrocellulose-based propellants is almost fully exploited.[60] Other chemical formulations have been developed, including 'semi-double base propellants' that contain nitroglycerine, such as Rheinmetall Nitrochemie's Extruded Impregnated (EI) propellants. While the addition of nitroglycerine to a propellant composition provides greater energetic output, it reduces the chemical stability of the finished product by a factor of about three (Vogelsanger et al., 2013).

Newer chemical formulations and changes in propellant grain geometry are likely to be necessary to enhance the performance of small-calibre ammunition. Nitrochemie has introduced non-classical grain geometry, almost cubic in form, designated 'C4' (see Photo 15). When combined with their EI formulation, the resultant propellant has achieved a 30–50 m/s velocity increase at the muzzle, with the same chamber pressure and erosion values as legacy composition (Antenen et al., 2013).

For applications with cartridges of 12.7 mm calibre or greater, Nitrochemie has introduced Extruded Composite Low Sensitivity propellants, which feature a cylindrical grain geometry with seven perforations. This propellant type is at the cutting edge, with a formulation that achieves enhanced performance over traditional nitrocellulose-based propellants without the addition of nitroglycerine. As a result, chemical and ballistic stability and consistency are retained. This formulation also complies with European Union Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulations, which restricts the manufacture

Photo 15 **Rheinmetall 'C4' propellant geometry in both single base and Extruded Impregnated formulations**





Rheinmetall C4 Single Base (C4-SB)

- Nitroglycerine-free resulting in outstanding stability.
- Improved progressivity as a result of C4 geometry.
- Performance in the range of ball or EI single-perforation propellants.

Rheinmetall C4 Extruded Impregnated (C4-EI)

- Contains nitroglycerine and has good stability.
- Improved progressivity as a result of C4 geometry.
- V0 increase of 30-50 m/s at the same pressure when compared to traditional spherical propellant geometry.

Source: Rheinmetall Nitrochemie

Photo 16 **The OWL tracer technology concept**

Source: PDW Defense

of propellants that contain chemical compounds of concern, such as dinitrotoluene (DNT), and phthalate esters such as dibutylphthalate (DBP), diethylhexylphthalat (DEHP), and diisobutylphthalat (DIBP) (Penny, Somerville, and Wilton, 2012; Vogelsanger et al., 2013). A less-toxic propellant is an essential step on the path to what would be considered truly 'green' ammunition.

One-way luminescence projectiles

Non-pyrotechnic tracer technology has been examined for some time, as developers seek to produce a projectile that allows for a 'tracer-like'[61] effect that is only visible towards the rear of the projectile. This one-way luminescence (OWL) would allow the shooter to observe the projectile's trajectory with the naked eye and make point-of-aim corrections, without targets in the impact zone being able to determine their position (see Photo 16). In addition, OWL projectiles are being developed using a chemical tracer technology (Kent, 2014).[62] As the vast majority of traditional tracer projectiles have employed a pyrotechnic compound to achieve visibility, these so-called 'cold' tracers will obviate the fire hazard posed by conventional tracers. The US Army intends to examine OWL tracers as potential replacements for 5.56 × 45 M856A1, 7.62 × 51 mm M62/M62A1, and .50 BMG (12.7 × 99 mm) M17 conventional tracer ammunition.

Laser-initiated cartridges

In its current stage, the development of laser-initiated cartridges involves replacing the primer of conventional brass-cased ammunition with an industrial sapphire crystal that is integrated into the base of the cartridge. The propellant is then ignited by a laser beam focused through this crystal. The firing pin mechanism typical of a conventional bolt-action rifle is replaced with a laser beam emitter housed inside the weapon's bolt (Voere Präzisionstechnik, 2015). This technology was first shown in 2015 by the Austrian precision rifle manufacturer Voere Präzisionstechnik, which patented it in 2007 (Obergantschnig and Ruhland, 2007). The technology appears to have been integrated into .308 Winchester, .338 Lapua Magnum, and possibly other cartridges.

The technical advantages of the Voere system are advertised as a reduction in vibrations during ignition of the cartridge, enhanced safety controls through the presence of an electronic firing mechanism, and the removal of toxic elements common in most small-calibre ammunition primers (Voere Präzisionstechnik, 2015). A similar concept aimed at using laser-ignited propellant to fire a projectile was patented as early as 1972 but did not integrate the requisite technologies into a self-contained cartridge (Platt, 1972). It remains to be seen whether the application of this technology can provide a practical advantage over conventional ammunition, especially with the substantially higher cost incurred in the production of the sapphire crystal-based ammunition.

planned programmes and studies. In 2013, the US Army announced the Calibre Configuration Study (CCS) to support two new small arms programmes—the Combat Lightweight Automatic Weapon System (CLAWS) and the Lightweight Dismounted Automatic Machinegun (LDAM). Since then, the former has been replaced by Next Generation Squad Weapon (NGSW) and the CCS by the Small Arms Ammunition Configuration (SAAC) study, whose results are due in 2016 (Alessio, 2014; Dawson, 2014). An indication of the possible priorities was already outlined in a 2011 report from the US Army Program Executive Office Soldier, entitled 'Soldier Battlefield Effectiveness'. In outlining future goals for US Army service rifles, the report finds that:

> *Ultimately, Army service rifles must be general purpose in nature and embody a series of tradeoffs that balance optimum performance for a wide range of possible missions in a range of operating environments. With global missions taking Soldiers from islands to mountains and jungles to deserts, the Army can't buy 1.1 million new service rifles every time it's called upon to operate in a different environment* (PEO Soldier, 2011, p. 6).
>
> *'A Soldier must be able to engage the threat he's faced with—whether it's at eight meters or 800'* (p. 5).
>
> *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* (p. 7).
>
> *Weapons [. . .] must be accurate and capable of engaging the enemy at overmatch distances* (p. 16).

The horizon for emergent cartridge case technologies is outlined in Table 5. Polymer cartridge cases in a conventional configuration for the .50 BMG (12.7 × 99 mm) calibre were expected to enter service in 2015, with other calibres to follow. Polymer cartridge cases in both CT and conventional configurations are to be further developed in 2016–18, and a general-purpose-calibre CT cartridge may be expected in 2018–20. Caseless ammunition technology, while remaining fraught with technical risk, could be viable for fielding by then as well, according to some analysts (Schatz, 2015b). However, given the lack of programmatic attention this technology is receiving, this author does not expect caseless ammunition to be fielded in the near future.

Table 5 **Emergent cartridge case technology maturity**

Current status (horizon)	Conventional configuration (polymer-cased)	Polymer-cased telescoped cartridge	Caseless
Nearing fielding (by 2016–18)	MK323 Mod 0 .50 BMG (12.7 × 99 mm)[a] 5.56 × 45 mm .338 NM (8.6 × 63 mm)		
Advanced development (potential for fielding in 2017–19)	.264 USA (6.5 × 48 mm) .300 BLK (7.62 × 35 mm) 7.62 × 51 mm .300 Win. Mag. (8.6 × 64 mm) .338 LM (8.6 × 70 mm) Subsonic cartridges	LSAT[b] 5.56 mm CT 7.62 mm CT	
Early development (earliest fielding in 2018–20)	Other general-purpose rifle calibres	General-purpose calibres 7.62 mm CT (France)	LSAT caseless ammunition[c]

Notes: Unless otherwise specified, all cartridges in this table are being developed in the United States.

[a] First fielding is expected in the short term.

[b] Canada and the UK are also involved.

[c] High technical risk applies; see Section III.

Source: Schatz (2015b)

Outside of the United States, other NATO countries have expressed interest in emergent ammunition technologies; in particular, Canada and the United Kingdom are participating in US LSAT programme trials (Williams, 2015b; Schatz, 2015b). France and the Russian Federation are also working on general-purpose calibres, and France is further developing CT ammunition. Some analysts interpreted China's introduction of the 5.8 × 42 mm cartridge as an early step towards a general-purpose calibre. According to some commentators, the Chinese 5.8 × 42 mm DBP 87 loading does not perform effectively at long ranges, due to its poor BC and light projectile weight for its calibre (Andrew, 2015). The 7.62 × 54R mm cartridge has been retained in service.[63]

Operational and logistic considerations

The LSAT programme

If the US Army decides to adopt a new general-purpose calibre under the Next Generation Squad Weapon programme, it will be either a conventionally configured brass-cased cartridge, or a cartridge that incorporates emergent cartridge case technologies, such as a polymer–metal hybrid, or variants investigated under the LSAT programme.[64] The Lightweight Machine Gun and Ammunition programme, which began in 2004, had the goal of reducing the weight of weapons and ammunition carried by combatants, while maintaining capability, cost, and maintenance requirements (Shipley and Spiegel, 2005). Funded by the Joint Service Small Arms Program, contracts were awarded in April 2004 to two teams, led by AAI Corporation[65] and General Dynamics Armament and Technical Products.[66] The core goal was to develop a new lightweight LMG platform (dubbed the LSAT LMG) and lightweight ammunition, both in 5.56 mm calibre.

Critically, the programme focused on further development of the enabling technologies, rather than just specific weapon systems (Shipley and Spiegel, 2008). It was consolidated as the LSAT programme in 2005, with the intent to develop caseless and CT ammunition in parallel (Shipley and Spiegel, 2005). By 2010, the LSAT programme had achieved a 50 per cent weight reduction and 38 per cent size reduction in Spiral 2[67] caseless ammunition, as well as a 41 per cent weight reduction and 13 per cent volume reduction in Spiral 3 CT ammunition—as compared with standard M855 brass-cased 5.56 × 45 mm cartridges (Phillips, 2010).

By 2012 the LSAT programme as originally outlined had concluded, having produced the CT Light Machine Gun[68] and a 5.56 mm caseless telescoped cartridge rated at technology readiness level (TRL) 7.[69] LSAT programme research into caseless technologies was abandoned. Final figures showed an overall weight reduction of 37 per cent and a volume reduction of 12 per cent as compared to 5.56 mm CT ammunition with its M855 brass-cased equivalent,[70] and a significant 48 per cent weight reduction compared to the CT LMG with the M249 squad automatic weapon (SAW).[71] Testing of eight CT LMG systems and approximately 23,000 rounds of 5.56 mm CT ammunition conducted over two weeks in 2011 at Fort Benning, Georgia, resulted in a significant user-evaluated preference for the CT LMG over the M249 SAW. The assessment was conducted across categories such as accuracy, engagement time, and preference for use in combat; another category was the 'foot march', in which users expressed a unanimous preference for the CT LMG (Phillips, 2012).

Under the LSAT programme, Textron also applied CT ammunition technologies to other calibres, including 7.62 × 51 mm, .338 Lapua Magnum (8.6 × 70 mm), .50 BMG (12.7 × 99 mm), and an unspecified 6.5 mm general-purpose calibre.[72] The stated design goal was to match the existing values of the brass-cased equivalent cartridges for muzzle velocity and chamber pressure. Weight savings ranged from 29.4 per cent (for the .50 calibre) to 42.8 per cent (for the 6.5 mm), with a reduction in overall length of 20–30 per cent.[73]

Weapon system considerations

CT ammunition developed under the LSAT programme has generated unique options for the acquisition of new weapon systems. The gun and ammunition designs are entirely different from legacy systems, and would require significant adjustments to existing development, production, and logistic mechanisms and systems. As a result, there would be less impetus to select an existing service calibre than if a conventional weapon were to be acquired. Selecting a general-purpose CT calibre for one family of weapons might result in cost savings over designing, developing, manufacturing, and maintaining two new weapon families in two new, different CT calibres. New weapon systems acquired in a CT general-purpose calibre are likely to offer end users greater effective range, along with improved penetration and terminal effectiveness; they may also enable infantry to carry more ammunition (on the weapon, the operator, and the mobility platform), while offering overall combat weight reduction and a substantial reduction in feed system volume.

Development of polymer-cased, conventionally configured ammunition is primarily focused on meeting the functional standards of legacy brass or steel-cased ammunition in unmodified issued weapons. The most successful of these designs, such as those produced by MAC LLC, are able to function interchangeably in available weapons. This provides benefits such as lighter weight and lower costs, with minimal disturbance to current logistic arrangements. An investment in this capability would also lend itself to manufacturing geared towards the commercial market, which should help to offset development and production plant costs. Many analysts believe that polymer cartridge cases that have passed government testing will become popular in the law enforcement and civilian markets in the near future (Schatz, 2015b).

If a general-purpose cartridge were to be adopted in a conventional configuration (with either a brass or polymer case), current weapon systems would probably be modified to be compatible. Due to its overall length, an optimized general-purpose cartridge would probably preclude adaptions of existing 5.56 × 45 mm weapons, meaning that 7.62 × 51 mm weapons would make the most likely candidates. While a number of 7.62 × 51 mm machine guns are in service with NATO armies, far fewer full-power self-loading rifles are in use. In addition, these weapons are often heavier than necessary and, ultimately, lighter weapons will probably be developed to take advantage of the reduced recoil of a general-purpose calibre.[74] Some weapons, such as the M4- and M16-series self-loading rifles, could be partially repurposed through an exchange of the upper receiver (see Annexe 1).

While the general-purpose calibre concept describes a cartridge that is intended to replace infantry weapons chambered for SCHV and full-power rifle cartridges, such as 5.56 × 45 mm and 7.62 × 51 mm, another possibility with similar impacts is the adoption of an intermediate calibre between 7.62 × 51 mm and .50 BMG (12.7 × 99 mm).[75] A current example of a weapon system that builds on this concept is General Dynamics Ordnance and Tactical Systems' Lightweight Medium Machine Gun (LWMMG), chambered for .338 Norma Magnum (8.6 × 63 mm). At 1,000 m, a .338 Norma Magnum is capable of delivering some 2,576 J—more than four times that of a 7.62 × 51 mm projectile. The LWMMG weighs less than 24 lbs (10.9 kg), compared to 84 lbs (38.1 kg) for an M2HB heavy machine gun (GD–OTS, n.d.b). A full loadout[76] for the LWMMG, with 500 linked polymer-cased rounds, weighs 103 lbs (46.7 kg), compared to 288 lbs (130.6 kg) for the equivalent M2HB arrangement (Schatz, 2015b). As a result, a single M2HB atop a ground vehicle could feasibly be replaced with three LWMMG, and each would also be capable of being dismounted and used in a ground role.

Logistic and economic considerations

Introducing a new cartridge, particularly a cartridge in CT configuration, has considerable logistic and financial implications. Such a move calls for the acquisition of new or modified weapons; the establishment of training programmes for users and armourers; the phased programming of the introduction of the weapons into service; and the gradual conversion of ammunition production to the new calibre and, potentially, configuration.

Three closely linked administrative obstacles to the widespread adoption of any emergent ammunition technology are programmatic, logistic, and cost-related. Military small arms acquisitions have historically been considered resistant to change at an institutional level, reflecting the general lack of agility in large government acquisition programmes. Any change would first involve the modification of formal technical requirements for any new weapon platform or ammunition, in order to reflect the desired performance gains.

With new requirements come new programmes to research, develop, test, acquire, and sustain new ammunition, as well as any new or modified weapons that are chambered for that ammunition. Other necessary changes would occur as a result of widespread adoption of a new platform and ammunition, all with associated costs. These changes would occur in areas including production, packaging and storage, inventory and stockpile management, training and education, and sustainment and maintenance.

The broader commercial success of technologies such as conventionally configured polymer cartridge cases or a general-purpose calibre (probably for hunting and target shooting applications) may help to drive government acquisitions. For more advanced technologies, such as CT and caseless, governments are likely to be the primary enablers. Government production of ammunition or weapons may be supplemented by private industry, which can help to subsidize some of the capital costs involved in retooling and other expenses.

One study, conducted in 2012 to determine capitalization cost estimates for CT ammunition, presents three different capitalization scenarios to the US government: vendor-owned production of all components (low cost to government), government-owned moulds and vendor production, and a government-owned, contractor-operated model (high cost to government) (Hopkins, Perhala, and Tolbert, 2012). In the first two scenarios, vendors would amortize the mould

Table 6 **Capitalization cost estimates for CT ammunition production, USD millions**

Capitalization cost category	Production model	Cost (USD millions) per production rate		
		Low production (200 million rounds per year)	Medium production (400 million rounds per year)	High production (1 billion rounds per year)
Low	Vendor-owned	20	25	45
Medium	Government moulds, vendor production	30	50	125
High	Government-owned, contractor-operated	40–75	125–210	295–500

Source: Hopkins, Perhala, and Tolbert (2012)

and equipment costs over production runs—which could include commercial sales, particularly in the first scenario—resulting in a higher per-cartridge cost for government purchases. The latter scenario, most similar to the current production of brass-cased ammunition in the United States, would see the government establish a dedicated production facility for polymer part production. The total costs as determined by this study are presented in Table 6.

These significant financial costs could prove difficult to overcome given current constrained budgetary conditions that face many Western and NATO militaries. Despite the technical merits of many of these technologies, the considerable risk involved in the adoption of any radical design may temper acquisition appetites and count against the more radical designs available. Globally, adoption by one major world power is likely to result in at least a limited knock-on effect. Several countries are likely to follow in the wake of developments made by their military opponents, as they attempt to match capability.

V. Policy implications and proliferation concerns

International treaties and norms

As with any new development in the arms and munitions field, the advent of emergent ammunition technologies is likely to raise a number of legal, normative, and law enforcement questions. Yet, these technologies have not received the same level of media attention and state scrutiny as other emergent technologies, such as 3D printing. Whereas this latter technology has been discussed by national, regional, and international bodies—including the United Nations, the Organization for Security and Co-operation in Europe, and NATO—emergent ammunition technologies have received little normative and legal scrutiny (Jenzen-Jones, 2015). While emergent ammunition technologies offer significant advantages in many cases, a thorough understanding of the technical and policy issues at hand is essential for stakeholders.

Broadly speaking, national and international controls apply to general-purpose calibre cartridges, as well as caseless, polymer-cased, and telescoped ammunition in much the same way as they do to conventional, brass-cased ammunition that is currently available. Nonetheless, specific considerations for some of these technologies need to be examined. In particular, ammunition that uses polymer cartridge cases without a metallic cartridge head (such as polymer CT cartridges) and caseless ammunition both pose challenges to marking, record-keeping, and tracing as required under certain national and regional instruments.

Marking of ammunition

While no standardized international requirements exist for marking ammunition, varying national, sub-regional, and regional policies are in place. These often apply differently to civilian and military ammunition. In fact, military forces often have their own format (or formal 'standards') for marking cartridges for military use.[77] NATO standardization agreements, for example, require that certain calibres of ammunition that are intended for military use by NATO member countries be marked with the NATO design mark,[78] manufacturer's identification, and last two digits of the year of production (Kirkman and Pellegrino, 2011).

The majority of small-calibre ammunition is marked at the time of manufacture with information varying by country, manufacturer, ammunition type, and intended use. Generally, military ammunition bears markings that indicate the manufacturer and, often, the year of manufacture. These markings most commonly take the form of a 'headstamp': markings stamped on to the case head of a cartridge (Diehl and Jenzen-Jones, 2014; Persi Paoli, 2011). The purpose of marking ammunition is primarily for identification (generally of the manufacturer and the calibre), stockpile management, and quality control. As individual cartridges are not typically marked with unique identifying information, they cannot be traced in the same way as firearms marked with a unique serial number. Nonetheless, the information currently marked on most cartridge cases can prove important to identifying patterns of procurement and transfer (Persi Paoli, 2011).

Polymer cartridge cases without a metallic cartridge head (including polymer CT cartridges) and caseless ammunition may prove difficult to mark with these identifying markings in a durable, cost-effective manner. Unlike firearms, which require a unique serial number, the current marking practices for most cartridges could allow for polymer cartridge cases and caseless ammunition produced by moulding processes to have a manufacturer's identifier code and year of production code directly incorporated into the relevant mould. Alternatively, markings may be printed in weatherproof ink on to the side walls of the cartridge case. This method was used with caseless ammunition produced for the Heckler & Koch G11 rifle. Cases marked in such a way may not retain their markings under adverse circumstances, however, in which case they may lose their 'identity'. The low durability of this method means that markings may be abraded during the mechanical function of a weapon or during handling or transport; they could also be affected by exposure to heat, water, solvents, and other chemicals common in the military environment. Photo 17 shows a caseless cartridge that was abraded by the slide of a weapon during an unloading procedure.

Photo 17 **An abraded 4.73 × 33 mm caseless cartridge**

Source: Heckler & Koch USA

Markings are destroyed when caseless cartridges are fired, rendering the issue of tracing them moot. While it may be feasible to mark post-firing remnants in an identifiable manner, the author is not aware of any meaningful examination of this concept. Moreover, such marking would only apply to caseless cartridges and weapons that expel post-firing remnants, and may not be broadly applicable to all caseless ammunition.

Law enforcement challenges

In addition to the difficulties inherent in marking cartridges that employ certain emergent technologies, there may be other challenges for law enforcement. Forensic assessment techniques for metallic cartridge cases are now very advanced. It is not clear how these would apply to polymer cartridge cases without metallic case heads, and particularly to CT ammunition, as the mechanism of the weapon itself differs markedly from current systems. Caseless ammunition offers further challenges. Current caseless ammunition leaves only a few post-firing remnants, and no forensic processes have yet been developed specifically to address this type of ammunition. The absence of fired cartridge cases may require markings on other parts of the cartridge.

The weight and volume reductions associated with some advanced ammunition technologies offer commensurate benefits to illicit traffickers of ammunition. For a given weight or size restriction, more cartridges of the same calibre could be transported illegally. While the technology remains nascent, training and education of law enforcement personnel will be important. CT and telescoped caseless ammunition, in particular, look significantly different from conventionally configured cartridges and may not be immediately identified as ammunition at security screening checkpoints. Without adequate training in the identification and handling of new ammunition types, law enforcement efforts risk being ineffective and error-prone.

Surplus created by the adoption of new technologies

Perhaps the most significant concern to policy-makers is the potentially significant surplus that could be created by the adoption of new technologies. The scale of this surplus is directly dependent on which technology or combination of technologies is adopted. If, for example, conventionally configured cartridges with a polymer case are adopted, the resultant surplus is likely to be very limited. Yet if a CT or caseless cartridge were to be adopted—along with the requisite new weapon systems—then a much larger surplus may be created, comprised of both legacy weapon systems and their ammunition.

A number of other factors will influence any such event, including the speed and scope of adoption (a limited, phased acquisition of such weapons having an appreciably smaller impact than a rapid replacement programme), military policies with regard to disposal of surplus, and the country in which this takes place. The speed of adoption may initially be limited; several observers have noted that the initial scope for the US Army, for example, may be limited to some 140,000 frontline combatants, rather than the total of more than 3.6 million soldiers. This last consideration would directly influence the fate of any such surplus; some states hold significant small arms stockpiles, well in excess of their national requirements. Surplus may be made available to foreign allies, disposed of, or sold on the international or domestic markets, depending on a given state's policies for surplus arms.

VI. Conclusion

The next five to ten years will prove critical for emergent ammunition technologies. Many of these have reached technological maturity already, while many others are expected to hit this milestone in the next two to five years. Polymer cartridge cases in a conventional configuration were due to be fielded from 2015 onwards and offer a notable reduction in overall weight. Other emergent ammunition technologies represent more of a challenge to the status quo. If a radical change from conventionally configured, brass-cased ammunition is to occur on a large scale, it is likely to be led by the US Army, and may be expected to occur in 2025 or thereafter. The US Army's 'Army Soldier Weapons Strategy 2014', released in December 2013, notes:

> *Near-peer threats are moving towards a common, intermediate caliber to maximize fire-power and efficiencies for the squad in an attempt to increase lethality at close range and accuracy at long-range [. . .]. Potential adversaries have begun to field common intermediate caliber, advanced performance ammunition with a max effective range (MER) of 600m for the improved rifle; 800m for the light machine gun* (Schatz, 2015c).

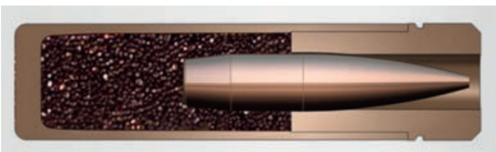
Recent conflicts in places such as Afghanistan have placed a renewed emphasis on the small arms carried and employed by individual combatants, at ranges exceeding those traditionally accepted and accounted for. The current calibre mix of Western militaries (5.56 × 45 mm and 7.62 × 51 mm) has been called into question by many observers, primarily on the grounds of long-range accuracy and lethality.[79] While the 7.62 × 51 mm cartridge has proven effective in mitigating these issues, it is unnecessarily heavy and generates too much recoil impulse for general use in individual weapons. Proponents of the general-purpose calibre concept have pointed out that the introduction of a 6.35 to 6.8 mm cartridge of optimized design could resolve the criticisms levelled against the 5.56 × 45 mm cartridge, while also offering tactical, logistic, and possibly even longer-term financial advantages.

Developments in cartridge technology over the past decade have been significant, and have built on technologies developed in the 1950s and 1960s. Decades of unsuccessful and frequently costly attempts have led to emergent small-calibre ammunition technologies that are ready, or nearing readiness, for large-scale adoption and field use. This significant technical progress has been enabled by advanced polymer materials, combined with modern projectile and case modelling as well as design tools and assembly methods.

Since 2003, at least 15 government studies around the world have examined the introduction of a general-purpose calibre. The US Army Small Arms Ammunition Configuration study is due to be delivered in late 2016 and may prove critical in determining the next steps for emergent ammunition technologies. In 2014–15, Textron Systems carried out a study entitled *Intermediate-calibre Cased Telescoped Small Arms Systems: Benefits and Trade-offs*, which involved the examination of three projectile shapes for each of ten different calibres. The outcome indicates that a 6.5 mm-calibre cartridge with a relatively long, high-BC projectile offered the best balance between lethality at short and long ranges, time of flight, system weight, and recoil impulse.[80]

Infantry personnel would be able to carry approximately 170 rounds of .264 USA (a conventional cartridge configuration) with a polymer case at the same weight as 210 rounds of brass-cased 5.56 × 45 mm M855A1 (Schatz, 2015a). The .264 USA projectile loaded into a polymer-cased CT configuration is likely to be lighter still, and would confer notable overall length and volume reductions as well. Textron Systems' belt-fed machine gun chambered for a CT cartridge with a 6.5 mm-calibre projectile offers a 10 per cent weight reduction over the existing US Army M249/M855 5.56 × 45 mm combination, and a 43 per cent weight reduction over the M240B/M80 7.62 × 51 mm combination (Schatz, 2015c; see Photo 18).

Photo 18 **6.5 mm CT configuration cartridge cutaway diagram**



Source: Textron Systems–Unmanned Systems

At the time of writing, some programmes showed promise for the imminent adoption, production, and fielding of lightweight and conventionally configured polymer-cased ammunition. More advanced ammunition technologies are on the near-term horizon. According to some analysts, the current range of field-ready lightweight ammunition—including those in a general-purpose calibre—represents the single biggest increase in overall weapon system performance since the advent of brass-cased ammunition in the 19th century (Schatz, 2015a). It remains to be seen whether the advent of emergent small-calibre ammunition technologies will result in a significant or sudden shift towards polymer cases or a general-purpose calibre, or whether such advances will simply continue to drive the design and development of weapon systems incrementally.

Annexe 1: Candidates for a general-purpose cartridge[81]

6.8 × 43 mm Remington SPC

The 6.8 × 43 mm Remington Special Purpose Cartridge was brought to market by Remington Arms as a further development of a 'wildcat' round first conceived by members of the US Special Operations Command (USSOCOM) and the US Army Marksmanship Unit (AMU) under the Enhanced Rifle Cartridge (ERC) programme. It emerged in 2002 and was made available to civilians in 2004 (Sadowski, 2014). The cartridge was developed to provide increased terminal effectiveness and a more robust long-range capability than the 5.56 × 45 mm and 7.62 × 39 mm cartridges. At 600 yd (550 m), the 6.8 SPC cartridge projectile delivers 180 per cent of the energy of the M855 5.56 × 45 mm and approximately 86 per cent of the energy of the 7.62 × 51 mm.[82]

The diameter (10.7 mm) of the cartridge case, which is based on the .30 Remington case first introduced in 1906, is greater than that of the 5.56 × 45 mm round (9.5 mm), but smaller than that of the 7.62 × 39 mm (11.3 mm). During development, different projectile diameters of 6, 6.5, 6.8, 7, and 7.62 mm were tested, along with a range of projectile shapes, types, and weights from 90 to 140 grains (see Photo 19). The 6.8 mm projectile provided the best balance of accuracy, lethality, and reliability in a cartridge designed for engagements out to 500 yd (457 m) and fired from an M4-type platform (Roberts, 2008).

Photo 19 **Developmental 6.8 SPC cartridges, showing different tested projectile calibres**

Source: Roberts (2008)

The cartridge was designed to function in M16/M4-type self-loading rifles with the use of a dedicated upper receiver and magazine. The cartridge case design was thus constrained by the maximum cartridge case length of the 5.56 × 45 mm round[83] (Dennison, 2014). As a result, the projectiles are necessarily short and their shape insufficiently aerodynamic, and the cartridge may not have the long-range performance to be able to serve as a viable general-purpose round (F., 2015a; Williams, 2015a). Nonetheless, military units in both Jordan and Saudi Arabia have adopted the cartridge (Johnson, 2010a; Sadowski, 2014).

6.5 × 39 mm Grendel

Another commercial cartridge in the 6.35 to 6.8 mm-calibre range is the 6.5 × 39 mm Grendel. Like the 6.8 SPC, this cartridge was designed for use in lightly modified 5.56 × 45 mm rifles and is subject to the same overall length limitation. The 6.5 Grendel, however, has been optimized for longer ranges, and features larger projectiles with a better BC than the 6.8 SPC. It makes for a very good long-range cartridge. At 1,000 m the 6.5 Grendel delivers more energy than the 7.62 × 51 mm M80 (Williams, 2015c). However, it only generates significant energy (2,500 J) from a relatively long barrel of more than 500 mm in length (Williams, 2015a). Given the current trend in modern militaries towards shorter carbine barrels of 350–400 mm in length, this limitation may pose an obstacle to the adoption of a Grendel-type cartridge design. In addition, in order to conform to the length requirements of the design while still developing the requisite muzzle energy, the cartridge case is necessarily shorter and broader. This case shape is not optimal for military purposes due to its extreme shoulder angle and a lack of case taper; it may also prove difficult to package efficiently.

6.5 × 40 mm

The 6.5 × 40 mm cartridge was developed by Mitch Shoffner, a former US Army Special Forces weapons specialist, with the intent of greatly improving long-range performance from existing AR-15-type rifles. It has a case diameter similar to that of the 6.8 SPC, with a case taper and shoulder angle similar to those of the 7.62 × 51 mm cartridge. Early testing has shown positive results. Despite a modest initial velocity of some 707 m/s, when paired with the 140-grain

Photo 20 **Two .264 USA cartridges in brass- and polymer-cased configurations**

Source: Rebekah Ehrich

Berger Very Low Drag, match-grade target bullet, the projectile remains supersonic to 1,000 m when fired from a 14.5-inch carbine barrel (Williams, 2014c). The relatively low initial velocity means a steeper trajectory at medium ranges, however.

.264 USA

The .264 USA (6.5 × 48 mm) cartridge was developed by the AMU following extensive testing of the 6.5-284 Norma wildcat[84] cartridge.[85] It also appears to share design similarities with the 7 × 46 mm Universal Intermediate Assault Cartridge (UIAC). The latter was designed by former AMU member Cris Murray, who also helped design the 6.8 SPC for USSOCOM (Johnson, 2010b). The .264 is said to be capable of delivering a ballistic performance similar to the 6.5 Grendel from a shorter barrel (Williams, 2015c). MAC LLC is producing a polymer case for a variant of the .264 USA (see Photo 20); the cartridge is believed to be 28–31 per cent lighter than the brass-cased alternative (Schatz, 2015c). There has been some speculation that the cartridge was designed from the outset for production with both polymer and brass cases, although this has not yet been substantiated (F., 2015b). Textron Systems has tested a CT cartridge based around a projectile that is very similar to the one used in the .264 USA in a belt-fed machine gun that was originally developed under the US Army LSAT programme (see Section IV).

Endnotes

1 This extrapolation could be taken further: such innovation could bring about a polymer-cased telescoped intermediate-calibre cartridge loaded with advanced propellant and featuring one-way luminescence, for example (see Box 1).
2 A projectile is not always present (as in blank cartridges, for example).
3 In addition, the expansion of the cartridge case during firing provides rearward obturation, which protects the mechanism of the firearm.
4 Rifling is the internal geometry (typically spiral grooves) inside the bore that engage the projectile and cause it to rotate as it accelerates along the barrel. This rotation imparts gyroscopic stability to the projectile, ensuring that it flies accurately and point first (Ferguson et al., 2015). In some cases, projectile rotation is achieved by the use of a barrel with a polygonal cross-section.
5 The .303 British cartridge, for example, actually uses a .311-inch projectile when measured across the grooves (7.7 mm vs. 7.9 mm) (ARES, 2014).
6 The groove depth for any given cartridge may vary slightly from one barrel design to another. The diameter between grooves is normally very close to, but certainly not less than, the bullet diameter. Military cartridges are most often described using the smaller measurement, taken across the lands. Notable exceptions include the 9 × 19 mm and .338 Lapua Magnum cartridges.
7 In addition, the term 'intermediate calibre' is sometimes used to refer to a calibre between 7.62 × 51 mm and .50 BMG (12.7 × 99 mm), such as the .338 Norma Magnum (8.6 × 64 mm) cartridge.
8 That cartridge was often in service with many other components of their armed forces as well.
9 Early intermediate calibres, developed in many cases for so-called 'proto-assault rifles', were first introduced in the 1920s. Examples include the 7.65 × 33 mm Furrer (1921), 7.35 × 32 mm Terni (1921), and 7 × 41 mm BSA (1925). For more information, see Labbett (2000).
10 The StG 44 is also known as the MP 43 and MP 44. StG stands for *Sturmgewehr*, understood as 'assault rifle'.
11 It was derived from the German 7.92 × 33 mm cartridge and destined to become the most widespread of all intermediate-calibre cartridges.
12 Some of the earliest US designs were tested in 1923, with the development of a series of .276-calibre cartridges for the prototype Pedersen, Garand, and lesser-known self-loading rifle designs.
13 An alternative, though less common, term is 'small-bore, high-velocity'.
14 A 1947 British military report titled *The Choice of a Standard Round for Small Arms* suggests a cartridge of 6.35 to 6.9 mm in calibre (Ministry of Supply, 1947). British experiments led to the development of the EM.2 self-loading rifle, chambered for a .280 (7 × 43 mm) calibre

cartridge. The UK government requested a competitive test of the British rifle and cartridge against recent US prototype models. The United States submitted a rifle derived largely from the M1 Garand, designated the T25, chambered for what would become the 7.62 × 51 mm NATO cartridge. Based on these trials, the British .280 cartridge was found to be superior. See Jenzen-Jones (2016) for a fuller discussion of the developmental history of the self-loading rifle, including the development of SCHV cartridges.

15 A combatant's primary arms, such as rifles and machine guns, are sometimes referred to as 'individual weapons'. Pistols and, when issued, sub-machine guns are chambered for handgun-calibre cartridges. Historically, such pistol-calibre weapons have tended to be chambered for the 9 × 19 mm cartridge in NATO and allied countries, and the 9 × 18 mm cartridge in former Warsaw Pact countries.

16 Specialist rifles include designated marksman rifles (DMRs).

17 For a detailed examination of the global development and production of self-loading service rifles, see Jenzen-Jones (2016).

18 Organizational units of this size are known as 'sections' in some nations' military forces, such as the United Kingdom.

19 The expression 'terminal effectiveness' can be interpreted broadly in the ballistics field. It is generally taken to indicate 'the speed with which human targets can be expected to be put out of action by a hit in the torso' (Williams, n.d.). Such effectiveness is most commonly determined based on testing methodologies in which projectiles are fired into a tissue simulant, such as ballistic gelatine or ballistic soap. The term is related to, but not synonymous with, 'wound ballistics', 'lethality', and 'stopping power'. For a fuller discussion of the mechanisms of wound ballistics, see Coupland, Rothschild, and Thali (2011).

20 The US Army sets the maximum effective range of an M4 carbine when it is used to engage point targets at 500 m (US Army, 2008).

21 Author interviews with current and recently active ISAF personnel, March 2014 to July 2015.

22 In 1957, ArmaLite improved this round by designing the .222 Remington Special. For further information, see Hughes (1990).

23 A projectile's 'yaw' is its oscillation around the vertical axis.

24 Increased accuracy depends not only on reduced muzzle yaw and increased stability, but also on uniformity of manufacture (Goad and Halsey, 1982).

25 In addition, emergent cartridge case technologies—such as a lightweight polymer case, the application of telescoped cartridge design, or caseless technology—could serve to attain further reductions in weight or volume. See Section III for details.

26 BC is calculated by dividing the sectional density of a projectile by its form factor. Sectional density describes the relationship between mass and calibre; the form factor of a projectile is used to describe its deviation from a standard drag model (often one known as G1), which is derived from a 'standard' projectile used in ballistics calculations (Litz, 2011).

27 Having carried out tests, the US Army Armament Research, Development and Engineering Center identified the optimum assault rifle cartridges as falling within the 6.5–6.8 mm range (Schatz, 2012b). Interestingly, a UK calibre study carried out in 1947 suggests a cartridge of 6.35–6.9 mm in calibre (Ministry of Supply, 1947).

28 Modern advancements in other components of the cartridge would also play a key role in achieving the desired objectives of a general-purpose calibre.

29 Truly 'green' ammunition will require changes to primer and propellant compounds that are currently commonplace (see Box 1).

30 While tungsten alloys with higher density have been tested, they are expensive and several are not considered 'green' alternatives (Plaster, 2014). Recently, Nammo of Norway, in conjunction with Kennametal in the United States, developed a cobalt-free tungsten carbide alloy for use in 'green' small-calibre ammunition. Testing is ongoing (Erninge, 2015).

31 Recoil impulse can also be expressed in Newton seconds (N.s). It is calculated using a nominal 4 kg weight for an individual weapon (self-loading rifle).

32 Sometimes called 'covering fire', 'suppressing fire', or 'suppressive fire', suppression fire is defined by NATO as: 'Fire that degrades the performance of a target below the level needed to fulfil its mission. Suppression is usually only effective for the duration of the fire' (NATO, 2015).

33 A number of other cartridges in a similar calibre range have been developed or proposed, including the .260 Remington, 6.5 × 45 mm Lapua/HK, 6.5 Creedmoor, 7 mm Raptor, .275 Raptor, .277 USA, 6.8 × 45 mm Urban Combat Cartridge, and 7 × 46 mm Universal Intermediate Assault Cartridge.

34 The example is based on the 5.56 × 45 mm M855A1.

35 Caseless ammunition was also tested, although not adopted (Schatz, 2012a).

36 The company has since changed its name to Orbital ATK Small Caliber Systems.

37 In the case of many machine guns, this capability is enabled by the changing of barrels, which reduces the thermal stresses on a weapon.

38 In addition, machine gun ammunition is commonly carried by most or all members in a squad or section.

39 The weight is calculated based on M855 ball ammunition.

40 The cases are reusable and the projectile is propelled under the gas pressure provided by the primer alone. These cartridges were primarily intended for use in revolvers and saw limited use with pump-action, lever-action, and bolt-action repeating rifles. They were typically employed for indoor training scenarios. Popular calibres included .38/.357, .44, and .45 cartridges.

41 For example, the lightweight training projectile for the Dynamit Nobel 7.62 × 51 mm Übung ('practice') cartridge weighs 11 grains, compared to some 147 grains for a 7.62 × 51 mm M80 cartridge (Brandt et al., 1977). Grains are an important unit of measurement used in conjunction with ammunition and ordnance. One grain is defined as exactly 64.79891 mg (Butcher et al., 2011).

42 Depending on the specific cartridge type, calibre, propellant, and application, any variation in propellant composition, quantity, or arrangement could affect external and terminal ballistics.

43 Fluted chambers are found in a number of firearms, including several models manufactured by the German company Heckler & Koch. Fluted chambers help to equalize the pressure between the interior and exterior of the forward portion of a cartridge case immediately after the projectile is fired, aiding in extraction of the fired case by providing for 'gas lubrication' to overcome friction between the cartridge case and the chamber (Agnelli, 1915).

44 CT ammunition is sometimes referred to as 'cased telescoping ammunition' or using the acronym 'CTA'.

45 The Steyr weapon used telescoped flechette ammunition.

46 Note that cartridge 5 is actually a plastic dummy cartridge, designated the DM10.

47 In the case of the VOG-25, combustion continues during and after the round has left the chamber of the weapon.

48 Other advances in recent decades have added significantly to the weight carried by infantry personnel. Body armour, including ballistic plates, often weighs more than 10 kg, and helmets, personal communications devices, advanced optical sights, and personal medical equipment may also contribute to increased weight. While modern militaries are focused on reducing the overall combat load, ammunition does not contribute as significantly as it once did.

49 These have rates of fire of 1,000–2,000 and 950–1,100 rounds per minute, respectively (FNH USA, n.d.; GD–OTS, n.d.a).

50 Cartridge-based ammunition is likely to represent a lesser portion of the total overall weight carried by these platforms, however, when compared to water, fuel, personal equipment, and other weapon systems, such as anti-tank guided weapons and disposable anti-armour systems.

51 See Section IV for a discussion of the General Dynamics Ordnance and Tactical Systems' Lightweight Medium Machine Gun.

52 Such an increase may cause more wear and place additional strain on the weapon system, resulting in reduced barrel life, overheating, and so on.

53 Note that the original designation for this cartridge was 4.73 × 33 mm, from when the US Army awarded an early contract to Heckler & Koch. When the G11 rifle entered the Advanced Combat Rifle programme in 1984, the designation 4.92 × 34 mm was used. The German military designated the cartridge the DM11.

54 In conventional firearms, a 'cook-off' is the spontaneous ignition of the cartridge due to residual heat in the chamber of a weapon (Acharya and Kuan-yun Kuo, 2012). It is one of the most dangerous weapon malfunctions as it causes the unintended firing of a round, potentially in an unsafe direction.

55 US-based experiments compared brass-cased .50 BMG cartridges with differing ullages: at the bottom (above the primer) vs. at the top (under the bullet) of the case. The differences in chamber pressure and muzzle velocity were considerable. Confidential author interview, May 2015.

56 In some early caseless firearm designs, manufacturers recorded instances in which rearward gas leakages resulted in the ignition of rounds in the weapon's magazine (Josserand and Stevenson, 1972).

57 A failure to combust completely can result in total weapon failure from unburnt propellant remnants in the chamber or bore, which cannot be easily removed by the operator.

58 Confidential author interview, November 2015.

59 Both the 5.56 × 45 mm and the 7.62 × 51 mm cartridge were developed for the US Army, before being adopted by NATO.

60 Confidential interview with a specialist in the development of propellants.

61 Tracer ammunition allows the weapon operator and observers to see the trajectory of a projectile with the naked eye. This permits the operator to make corrections to the point of aim without needing to observe the impact of the projectiles fired. Tracer ammunition is commonly used in automatic weapons in the support role, such as machine guns.

62 While various manufacturers, such as Fiocchi (in partnership with Cyalume) and Glow Ammo, have introduced products using chemical tracer technology, these have often been restricted to use in low-light conditions, have been expensive, and have not enjoyed substantial commercial success.

63 For details on the limitations of the Chinese approach, see Section II.

64 Many US Army programmes, such as the Advanced Combat Rifle and Special Purpose Individual Weapon programmes, have been primarily focused on developing new small arms technologies, with limited degrees of success.

65 The company was later acquired by Textron Systems (DID, 2007).

66 The division is now part of General Dynamics Ordnance and Tactical Systems.

67 Each technology has a series of design iterations that are known as 'spirals'.

68 The weapon evolved from the earlier 'LSAT LMG', designed for use with the CT ammunition produced.

69 The US Department of Defense and several other organizations use TRLs as a series of indicators of technological maturity. The scale ranges from 1 ('basic principles observed and reported') to 9 ('actual system proven through successful mission operations'). TRL 7 is 'system prototype demonstration in an operational environment' (DoD, 2011).

70 The savings amount to 13 lbs (nearly 6 kg) per 1,000 rounds (including ammunition links).

71 The total weight savings amount to 8.5 lbs (3.9 kg).

72 Preliminary tests were also carried out on CT integration with the M855A1 enhanced performance round projectile, with initial results proving positive (Phillips, 2012).

73 Testing also began in 2011 on the action for a CT-compatible carbine. Another key achievement of the LSAT programme was the establishment of a pilot plant for 5.56 mm CT ammunition in Warrensburg, Missouri, with an initial production capacity of 15,000 cartridges per day (Phillips, 2012).

Following the primary LSAT programme, in August 2013, a USD 2 million contract was awarded to Textron Systems; it was followed by a further two-year, USD 5.7 million contract under the Joint Service Small Arms Program to further develop CT ammunition technologies, with initial proposals indicating the development of 7.62 mm-calibre CT ammunition and a GPMG, as well as a 5.56 mm CT carbine (Cox, 2014; Cole, Phillips, and Shipley, 2014). These proposals were reportedly merged for the contract, but they include an additional design optimization study, noting that the carbine development will not necessarily be limited to 5.56 mm and that an unspecified 6.5 mm calibre CT cartridge and carbine action will also be developed. These are expected to be demonstrated at TRL 5 by mid-2016 (Cole, Phillips, and Shipley, 2014; Williams, 2015a).

In May 2015, Textron unveiled a polymer mock-up of the new 7.62 mm CT GPMG at the 2015 Special Operations Forces Industry Conference and announced that a firing prototype was expected to be ready by the third quarter of 2016 (Cox, 2015). A 2015 release from Textron Systems indicates that 7.62 mm CT ammunition is approximately 39 per cent lighter than its brass-cased equivalent, based on 800 rounds of linked ammunition (Textron Systems, 2015).

74 It is important to note, however, that several modern rifles and machine guns developed for full-power cartridges are not that much heavier than their counterparts chambered for SCHV ammunition. For example, the FN Herstal SCAR-L self-loading rifle (chambered for 5.56 × 45 mm) weighs 3.5 kg, while the SCAR-H (7.62 × 51 mm) weighs 3.9 kg. Similarly, the

FN Herstal Minimi Mk 3 light machine gun chambered for 5.56 × 45 mm weighs 8 kg, compared to 8.8 kg for the 7.62 × 51 mm model (FN Herstal, n.d.a; n.d.b).

75 China is also believed to have begun development of an intermediate-calibre cartridge between 7.62 × 54R and 12.7 × 108 mm. The calibre is understood to be 10.5 mm; the case length is not currently known, however.

76 A full loadout includes weapon sight, spare barrel, and tripod.

77 The German armed forces, for example, require a manufacturer code, year and month of manufacture, and lot number of a cartridge to be incorporated into a standardized format in the headstamp (Diehl and Jenzen-Jones, 2014).

78 This is often incorrectly referred to as the 'NATO standardization' or 'NATO standard' mark. The NATO design mark has no official significance for small-calibre ammunition standardization. There are separate NATO Symbols of Interchangeability (Kirkman and Pellegrino, 2011).

79 See, for example, Avery (2012); Ehrhart (2009); Roberts (2008); Schatz (2015a); Williams (2015c).

80 Confidential author briefing, April 2015.

81 This annexe provides a limited list; other cartridges have been developed and may prove potential candidates for a general-purpose calibre.

82 This assumes 465 ft/lbs (approximately 630 J) for the 115-grain Hornady Open Tip Match 6.8 SPC, compared with 540 ft/lbs (732 J) for the 150-grain FMJ 7.62 × 51 mm, and 258 ft/lbs (350 J) for the M855 62-grain FMJ 5.56 × 45 mm.

83 The 5.56 × 45 mm cartridge has a 44.6 mm case, while the 6.8 SPC cartridge has a 42.6 mm case (Sadowski, 2014).

84 A wildcat cartridge is one that is not produced in commercial quantities, and for which firearms are not readily chambered. The 6.5-284 Norma has since been produced commercially by Norma and is no longer considered a wildcat.

85 Confidential author interview, August 2015.

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