ARES

Cased Telescoped Ammunition

A technical & historical overview

December 2019

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RESEARCH REPORT No. 7

ARES Armament Research Services

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Published in Australia by Armament Research Services (ARES).

Published in December 2019.

ISBN 978-0-6485267-1-1

Credits

Authors:	N.R. Jenzen-Jones & Nathaniel Fitch
Editor:	N.R. Jenzen-Jones
Technical Reviewer:	Anthony G. Williams

Bibliographic Information

Jenzen-Jones, N.R. & Nathaniel Fitch. 2019. *Cased Telescoped Ammunition: A technical and historical overview*. Perth: Armament Research Services (ARES).

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Acknowledgements

The authors would like to express their sincere gratitude to those who assisted in making this report a reality. Special thanks are due to Kori Phillips, a Picatinny-based programme officer who led the LSAT and CTSAS programmes; to Anthony G. Williams, editor of the IHS Jane's Weapons: Ammunition series and long-time ARES contributor; and to the late Jim Schatz, who supported much of the earlier ARES work that informs this report. Thanks are also due to Peter de Coux, Jack Dutschke, Federico Graziano, Ian McCollum, Danny Michael, Matthew Moss, Drake Watkins, Daniel Watters, and the members of the IAA Forum.

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Cover image: *AAI CT Light Machine Gun, circa 2012 (Source: ARDEC).*

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Abbreviations & Acronyms

ACR	Advanced Combat Rifle
ADVAP	Advanced Armor Piercing
AICW	Advanced Individual Combat Weapon
AIWS	Advanced Individual Weapon System
ARDEC	U.S. Army Armament Research, Development and Engineering Center
CT	Cased telescoped (ammunition)
CTA	Cased Telescoped Ammunition
CTSAS	Cased Telescoped Small Arms System
EPR	Enhanced Performance Round
GP	General-purpose (calibre)
ICSR	Interim Combat Service Rifle
LCCA	Lightweight composite-cased ammunition
LSAT	Lightweight Small Arms Technologies
NGSAR	Next Generation Squad Automatic Rifle
NGSC	Next Generation Squad Automatic Carbine
NGSW	Next Generation Squad Weapon
OICW	Objective Individual Combat Weapon
ONR	Office of Naval Research
OTM	Open-tip match
PON	Program opportunity notice
PPC	Palmisano & Pindel Cartridge
S&W	Smith & Wesson
SAPI	Small Arms Protective Insert
SCHV	Small-calibre, high-velocity
SOST	Special Operations Science & Technology
TRL	Technology readiness level
Tround	(Dardick) Triangular round

Introduction

The age of the all-metal-cased small arms cartridge is coming to a close. Refinements in materials technology and ammunition design have opened the way for new ammunition construction techniques utilising lightweight and inexpensive polymers in place of traditional brass or steel. Conventionally configured cartridges are far from optimal in terms of overall length, weight, and volume (Hoppman Corporation, c. 1975). Cased telescoped (CT)[1] ammunition offers the potential for significant reduction in all of these areas. With a much lower specific gravity—between 1.00-2.00 g/cm^3 for most formulations, versus 7.85-8.00 g for steel and ~8.50 for ordnance brass—and without relying on iron or copper supply for production, a workable polymer-cased round has the potential to significantly benefit the front-line soldier and rear-line logistician alike (Jenzen-Jones, 2016).

Emergent ammunition technologies are likely to prove key in future firearms designs (Jenzen-Jones, 2016). If the next movement in small arms ammunition technology is towards polymer, it stands to reason that a new ammunition configuration could be developed that maximises the advantages and minimises the pitfalls of the new case material. CT ammunition is currently being explored by the U.S. Army and others, and promises to combine the benefits of both lightweight polymer cases and optimised geometry to create small arms ammunition that is significantly more efficient and effective pound-for-pound.

Figure 1.1 *A suite of (L–R) 5.56 mm, 6 mm, and 6.5 mm cartridges each in (back to front) conventional brass cased, hybrid composite cased, and cased telescoped configurations (source: Nathaniel Fitch/ARES).*

Although CT technology has been applied to medium- and large-calibre cartridges, this report will focus primarily on small-calibre cartridges. Almost all modern small arms use small-calibre cartridges as ammunition. For a general introduction to small-calibre ammunition, see Jenzen-Jones, 2018. In the field of small-calibre ammunition, the terms 'cartridge' and 'round' are synonymous: both refer to a single complete unit of ammunition. Modern, conventionally configured small-calibre cartridges are generally comprised of:

1. A **projectile**, or bullet, which is fired from the gun. It typically consists of a 'core' and 'jacket'.
2. A **propellant**, which, when ignited, generates the gas pressure that propels the projectile out of the barrel.
3. A **primer**, which consists of chemicals designed to be initiated by a firing pin.[2] The primer then, in turn, ignites the propellant.
4. A **cartridge case**, which contains the components of a complete round of ammunition and, when the weapon is fired, blocks the escape of gases in a way that causes pressure to build up behind the projectile (Goad and Halsey, 1982; Jenzen-Jones, 2016a).[3]

[1] In some literature, cased telescoped ammunition is referred to by the acronym 'CTA'.
[2] Or another method.
[3] Caseless ammunition is the exception. For more information, see Jenzen-Jones, 2016.

Figures 1.2 & 1.3 compare these four primary components between a conventionally configured small-calibre cartridge and a CT equivalent.

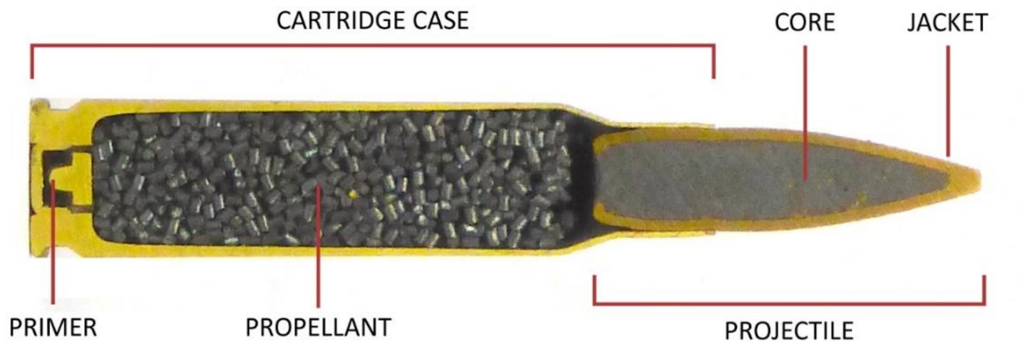

Figure 1.2 *Labelled cross-section of a conventionally configured 7.62 × 51 mm cartridge (source: Anthony G. Williams/ARES).*

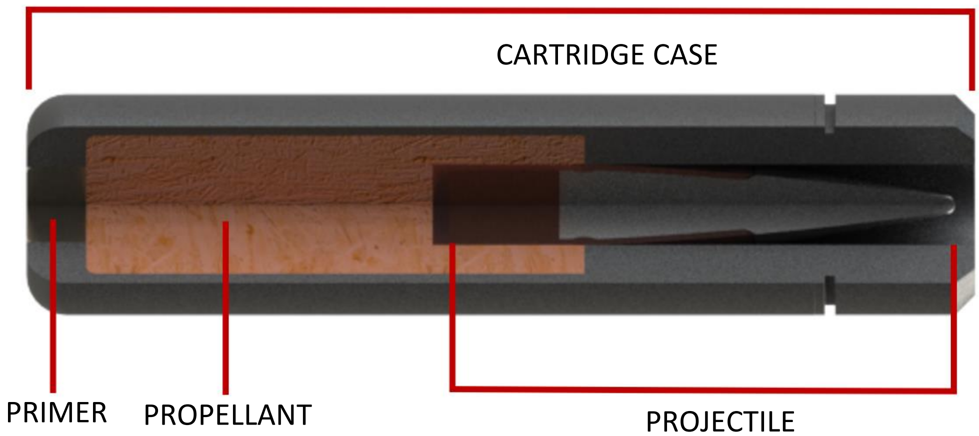

Figure 1.3 *Labelled cross-section of a nominal cased telescoped cartridge. Note the projectile buried deep in the case, rather than protruding as in a conventionally configured cartridge (source: Nathaniel Fitch/ARES).*

In a cased telescoped cartridge, the projectile is seated fully within the length of the cartridge case[4], with the goal of reducing a cartridge's overall length. In order to achieve this, it is also generally understood that the projectile must be embedded within the propellant in some way. In early 'semi-telescoped'[5] designs, such as the 1895 7.62 × 38R Nagant cartridge, the projectile sits atop the propellant within the cartridge[6], whereas in 'true' telescoped designs the base of the projectile sits notably below the propellant level within the case (Jenzen-Jones et al., 2020). This distinction rules out cartridges such as the 7.62 Nagant, and, indeed, modern shotgun cartridges, which could otherwise be considered CT ammunition due to the projectile(s) being fully enclosed by the case.

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[4] In addition to some small-calibre ammunition, this would rule out numerous medium- and large-calibre cartridges, including most APFSDS rounds, which are mostly—but not entirely—seated within the cartridge case.
[5] Sometimes known as 'partially telescoped' (Hackley, Woodin & Scranton, 2015).
[6] There are medium-calibre cartridges, such as 50 × 228 mm cartridge developed for the Rheinmetall Rh 503 autocannon, in which the projectile is almost entirely seated within the cartridge case (i.e. it protrudes only slightly) and is also embedded within the propellant (Rheinmetall, 1999). These could be considered semi-telescoped designs.

Terminology has not yet been standardised for cased telescoped ammunition. The second figure in a cartridge case designation (e.g. the '51' in 7.62 × 51 mm) typically refers to the cartridge case length. For some CT rounds, this figure includes the overall cartridge length (including the end-cap or similar), whilst in some usages it has excluded the end-cap, and represented only the cartridge case length (Jenzen-Jones, 2016). In the case of CT ammunition, ARES suggests the overall cartridge length be given in the cartridge designation.

Technical Characteristics of CT Ammunition

Polymer cartridge cases have long been understood to offer significant advantages in terms of weight, production cost, and a lack of reliance on strategic metals (Jenzen-Jones, 2016). The basis of the cased telescoped ammunition concept originates in the understanding that an all-polymer cartridge case cannot have a thin extraction rim with the same shear strength as a metallic cartridge. CT ammunition circumvents this limitation by having a round with a uniform external cross-section from back to front, and using a firearm with a separate moving chamber, from which the cartridge can be extracted via the 'push through' method. In this method, the fresh, incoming cartridge case is used as a rammer to push the empty, fired case out of the chamber; either in a back-to-front or front-to-back motion (Jenzen-Jones, 2016). As a result, firearms using CT ammunition do not have traditional extractors, and cartridge cases designed for this extraction method do not need a conventional case rim and can be made mostly or entirely of polymer (see Figure 2.1). It is important to note that the cased telescoped ammunition concept is not the same as caseless ammunition[7], which has no cartridge case to extract at all. Although the method of extraction is different and requires novel firearms actions, the polymer case of the CT cartridge must still be extracted from the action after firing, and the CT concept is therefore still considered a 'cased' ammunition configuration.

Figure 2.1 *Sectioned polymer case heads compared. The cased telescoped configuration (left) lacks the substantial extractor groove cut of the conventional cartridge case (right) and is thereby stronger (source: Nathaniel Fitch/ARES).*

At first blush, the need to have the cartridge case with uniform external cross-section may seem like a limitation of the CT cartridge concept—and, to a certain extent, it is. However, the layout brings with it several key benefits that make the cased telescoped ammunition concept highly competitive with the alternatives, including the increasingly mature lightweight composite-cased ammunition (LCCA) configuration which uses a hybrid cartridge case made with a metallic head and a polymer body (Beckstrand, 2018). The first advantage is that the nature of the CT cartridge has the bullet seated completely within the cartridge case itself. This means

[7] Note that caseless ammunition has been produced in both semi-telescoped and telescoped formats (Jenzen-Jones, 2016; Hackley, Wooding & Scranton, 2015). These are not considered in this report.

that the exterior of the bullet need not make contact with the interior surfaces of the weapon's action, and can therefore be made of exceptionally hard material. Given that the U.S. Army's otherwise-excellent 5.56 mm M855A1 round produced the phenomenon of quickly-wearing feed ramps in the M4 and M27 self-loading rifles due to its exposed hardened steel penetrator, and the U.S. Army is determined to move to a tungsten-tipped variant of that same style of projectile, this advantage is significant (Aberdeen, 2014; Calloway, 2018; Schogol, 2017). With conventional cartridges, the wear issue due to hard-tipped small arms rounds can be mitigated through carefully designed magazines and feedways, but the use of cased telescoped ammunition would circumvent this issue entirely (Calloway, 2018).

Figure 2.2 *CT cartridges in comparison to conventional brass-cased cartridges. L–R: 5.56 mm LSAT, 5.56 × 45 mm M855, 7.62 mm LSAT, 7.62 × 51 mm M80 (source: Textron Systems).*

Due to the projectile's depth within the cartridge case, most CT rounds have a squat profile with a low length-to-diameter ratio (Phillips & Shipley, 2016) (see Figure 2.2). As noted by Palmisano and Pindell in their landmark paper describing the design of the excellent 6 mm PPC cartridge, this 'short and fat' aspect ratio produces a highly efficient and consistent ignition, allowing the use of less propellant for a given amount of utilised energy and producing less variance shot-to-shot (Palmisano, 1992). The short-fat 6mm PPC is currently regarded by many benchrest shooting competition champions as the most inherently accurate conventional cartridge in the world in part due to this property (Accurate Shooter, 2019).

In traditional ammunition, significant distance (often called 'jump') between the engraving surface of the projectile at its starting point in the chamber, and the lands of the barrel's rifling, is closely associated with inaccuracy. Cased telescoped ammunition has considerable jump by design—because of the necessity for uniform external cross-section and due to the fully enclosed nature of the projectile. However, U.S. Army experimentation with the CT cartridge design at ARDEC showed that the polymer end-cap of their CT cartridge design actually stabilised and centred the projectile during travel to the barrel's throat, thereby *increasing*, rather than decreasing, the consistency and accuracy of the ammunition. In addition, this jump allows a significant decrease in peak pressure (other things being equal), as the projectile does not start engraving on the barrel's rifling until it has accelerated considerably. A related effect is the compression of the propellant due to the deep seating position of the projectile. This compression effect was discovered to significantly improve the consistency of the propellant burn of otherwise fairly typical ball propellant (Fitch 2017b). Both of these factors also contribute to the accuracy and efficiency of cased telescoped ammunition.

Cased telescoped ammunition is also capable of withstanding higher pressures than conventional metallic cased ammunition. Because it abandons both the rimless case design and the brass material of conventional ammunition, cased telescoped ammunition has fewer weaknesses when under pressure, and lacks one or more of the failure modes of conventional ammunition. With a standard brass-cased, rimless cartridge, part of the case head is unsupported at the extractor groove. Because of this, and due to the mechanical properties of brass, pressures higher than 70,000 psi can cause cartridge brass to enter a plastic state, and flow into the recesses near the case head. At extreme pressures, this plastic flow effectively brazes the case to the weapon's bolt, destroying the weapon's operating group and putting the weapon out of commission. Because of this brass-cased ammunition is effectively limited to approximately 65,000 psi. Military ammunition is additionally restricted, as pressures must be limited further to prevent peak pressure from rising during extended strings of fire (Marsh, 2006).[8] Occasionally, brass-cased weapons will experience failures due to heat and pressure in combat due to extreme heat build-up in the chamber, as happened to one M249 during the infamous Battle of Wanat (Cubbison, 2009). Not only is the high-strength, temperature-resistant polymer that CT cartridges can be made of more resistant to these extreme conditions, but the chamber can be fully supported—as there is no extractor groove in the case. This means that, when paired with an appropriately designed action, even if there *is* plastic flow of the cartridge case, there is nowhere for the case material to flow to, and it retains its shape.

Additionally, the push-through extraction method of a weapon chambered for CT ammunition acts by pushing on the expended cartridge case itself, rather than by pulling against a potentially weakened rim, and the cartridge's chamber is fully swept by the incoming round. This means the threshold for a fired case ‘sticking’ in the chamber is much higher, as it must resist and stop the entire feeding force, rather than just overcome the strength of the case body at its weakest point as in conventional ammunition. Without these limitations, cased telescoped ammunition can be safely tailored for much higher peak pressures than legacy brass-cased ammunition, with U.S. Army officials citing the CT test weapons within the Next Generation Squad Weapon programme as having pressures close to those of 120 mm tank ammunition—between 75,000 and 100,000 psi (Singleton, 2016). For this same reason, cased telescoped ammunition also synergises well with electronic ignition, as proposed for the NGSW, allowing for an even stronger and more pressure-tolerant case design, by removing another point potential of mechanical failure (Singleton, 2016).

[8] This is one of the reasons SIG Sauer Inc. has developed multiple-piece composite cartridge cases, allowing for much higher peak pressures (Imhoff & Burczunski, 2019).

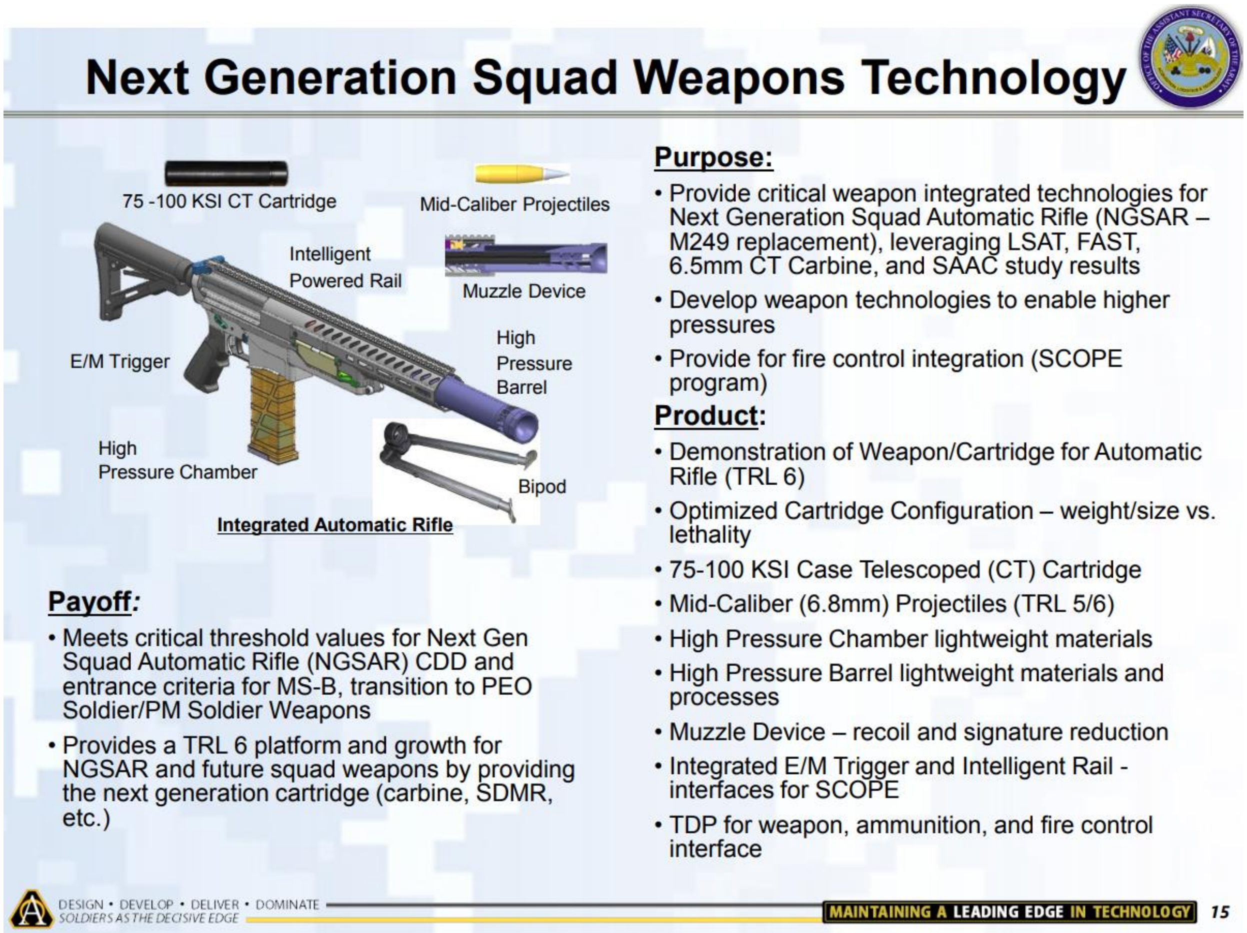

Figure 2.3 *A presentation panel from the Office Assistant Secretary of the Army, illustrating the NGSW weapon concept. Notably, the weapon is represented by Textron's CT Carbine (source: U.S. Army).*

Unlike brass, the medical-grade polymers used in cased telescoped ammunition are insulators rather than conductors. Since the CT round is fully enclosed by insulating polymer, there is no direct heat transfer from the barrel to the primer pocket or propellant, meaning that the propellant and primers of CT rounds remain much cooler than conventional brass-cased ammunition when sitting in a relatively hot chamber. Not only that, but due to the separate chamber, the chamber and barrel of a CT weapon can be isolated from one another, meaning that the chamber unit *itself* can also remain much cooler even during extreme strings of firing. ARDEC testing indicated that due to these two properties, the cook-off[9] limit of their CT machine gun was effectively non-existent. Auto-ignition was described as being almost impossible. (Fitch, 2017d; Phillips, 2011).

Cased telescoped ammunition is not without its flaws, of course. The format intrinsically presents a challenge to the weapons designer, as the case cannot be extracted through conventional means (i.e. via an extractor operating on a cartridge rim). The novel push-through feed mechanism means that a fresh round or some kind of additional rammer is necessary to extract the round. In the case of lightweight carbines in particular, this can cause difficulties. For example, AAI's (Textron's) initial CT carbine design for the Lightweight Small Arms Technologies (LSAT) programme could not be unloaded until the magazine had been emptied. This design flaw was corrected, however, in the second Textron design.

[9] In conventional firearms, a 'cook-off' is the spontaneous ignition of the cartridge due to residual heat in the chamber of a weapon. It is one of the most dangerous weapon malfunctions as it causes the unintended firing of a round, potentially in an unsafe direction (Acharya & Kuan-yun Kuo, 2012; Jenzen-Jones, 2016).

An additional concern in CT weapon design is achieving a reliable gas seal, both in terms of rearward and forward obturation. The term 'obturation' most often refers to rearward obturation—the process by which a weapon's breech is sealed to prevent the escape of gasses and ensure that sufficient (and consistent) pressure builds up in order to propel a projectile (Goad & Halsey, 1982).[10] With modern cartridges, rearward obturation is achieved by the expansion of the (commonly metallic) cartridge case walls when a round is fired. Different materials have different properties which determine how well they form a gas-tight seal in this manner (Schatz, 2015). Whilst brass has historically been preferred over steel and other materials, some polymer manufacturers have claimed their formulations obturate better and current CT ammunition and weapon design seems to have solved the problem of rearward obturation[11] (Jenzen-Jones, 2016). Weapons must also achieve forward obturation, which is primarily accomplished by the snug fit of a projectile into a weapon's chamber and bore.[12] Forward obturation is complicated by a telescoped projectile, which takes longer to engage a weapon's rifling than in conventional designs. Telescoped ammunition designs therefore require the projectile to be expelled quickly, before gas or unburned propellant can escape ahead of it. This operation must also be consistent and reproducible between cartridges (Fisher, 1977). Solving these challenges requires some engineering finesse, but it can be done.

Figure 2.4 *Textron's early cased telescoped carbine design, from a 2010 presentation (source: U.S. Army).*

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10 Rearward obturation also protects a firearms working parts (Jenzen-Jones, 2016)

11 Polymer cases also offer the use of a non-strategic material, something that has been a selling point for their manufacturers and proponents for decades (Hughes, 1970b; Jenzen-Jones, 2016).

12 In larger-calibre munitions, forward obturation may be enhanced by the presence of obturating bands or 'gas check' grooves (Goad & Halsey, 1982; U.S. Army, 1996).

A Brief History of CT Ammunition

Although widely considered an emergent or horizon small arms technology, cased telescoped ammunition has an extensive history. One might consider self-contained paper cartridges—such as the 15.4 mm Dreyse and 11 mm Chassepot[13]—to be of a 'semi-telescoped' design, for example. Even if the term is restricted to ammunition with modern, rigid cartridge cases, the huge variety of obscure ammunition configurations introduced in the 19th Century, make it difficult to definitively establish the origins of the cased telescoped cartridge. In fact, there are several cartridge designs introduced in the first fifty years of the modern metallic cartridge case that could also be considered semi-telescoped[14].

The early and mid-1800s gave rise to a wide range of self-contained metallic cartridge designs. Two semi-telescoped designs were introduced as a result of revolved designs which were specifically intended to avoid infringing on the famous Rollin White patent (White, 1855). This was the first US patent to protect the design of a revolver with a fully-bored-through cylinder, intended to be loaded from the rear with self-contained metallic cartridges.[15] White and Smith & Wesson fiercely defended this patent, which resulted in the development of front-loading cylinders firing novel cartridges. In 1859, a patent was granted to Willard C. Ellis and John N. White for a revolver design using a front-loading cylinder and a unique 'cupfire' cartridge design with a concave base containing the primer compound (Ellis & White, 1859). The hammer of the revolver would act on the inside rim of the concave base, in a similar fashion to a rimfire design (McCollum, 2015a).[16] In 1863, Daniel Moore was granted a patent for his 'teatfire' revolver design and proprietary cartridge. The cartridge is convex at the rear, with the ogive terminating in a nipple which contains the priming compound. The teatfire revolver design circumvents the Rollin White patent by loading from the front of the cylinder, allowing the nipple of the cartridge to protrude through a smaller opening in the rear, where it is struck by the hammer upon firing (McCollum, 2015b). A patent for a slightly refined cartridge design was granted to David Williamson of Moore's Patent Fire Arms Company in 1864 (Williamson, 1864).

Figure 3.1 *L–R: .28 Ellis & White cupfire; .42 Ellis & White cupfire; .32 Moore teatfire; .32 Moore-Williamson teatfire. Note the mouths of the cartridges are toward the bottom of the image (source: Drake Watkins/ARES).*

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[13] Much like modern cartridge designs, these combined a projectile, propellant, and primer with a paper case, often reinforced with silk gauze or other materials. The paper case was partially combusted and expelled upon firing (McCollum, 2019).

[14] As noted previously, designs in which the projectile sits atop the propellant (i.e. where the level of the propellant in a cartridge cases is below the base of the projectile) should properly be considered semi-telescoped.

[15] Such an invention had previous been patented in France—and subsequently elsewhere in Europe—by Eugène Lefaucheux (Lefaucheux, 1854).

[16] The design was refined somewhat in an 1863 reissue (Ellis & White, 1863).

Figure 3.2 *L–R: .28 Ellis & White cupfire; .42 Ellis & White cupfire; .32 Moore teatfire; .32 Moore-Williamson teatfire. Note that the projectiles are visible, recessed into their cases (source: Drake Watkins/ARES).*

Another design of this period was the .28 Wood cartridge, subject of an 1865 British patent. Stephen Wells Wood of Cornwall, New York, designed a cartridge that looked like a simple cylinder, but featured a priming compound sandwiched between the cartridge case walls and an inner foil liner. Wood designed these to work with a front-loading cylinder revolver in which the hammer reached down through a slot in the side of the cylinder in line with each chamber (Wood, 1865). The cartridge and weapon were not widely adopted. In all of these front-loading revolver cartridge designs, the projectile was fully seated within the cartridge case, but atop the propellant. This was presumably to aid in grasping the cartridge and loading it, although this was not strictly necessary. Indeed, front-loading metallic cartridges with exposed projectiles (i.e. of comparatively conventional configuration) were also developed, including those of the Thuer design. Colt also sought to circumvent the Rollin White patent and Smith & Wesson's monopoly on the rear-loading revolver cylinder. Colt employee F. Alexander Thuer patented his front-loading, centrefire metallic cartridge design in 1868, and the company performed some 5,000 conversions of colt percussion pistols to the new round (Kinard, 2003, p. 124; Thuer, 1868).

Figure 3.3 S*emi-telescoped cartridges of the 19th century. L–R: .32-44 S&W Target; .38-44 S&W Target; .32 S&W Rifle; 7.62 × 38R mm Nagant (military production); 7.62 × 38R mm Nagant (commercial production); 8 × 41R mm Pieper (source: Drake Watkins/ARES).*

A variety of other semi-telescoped designs were introduced for revolving arms during the latter half of the 19th century. Many were target and gallery loadings. Some, such as the .32 S&W Gallery, .32 S&W Long Gallery, .32 S&W Rifle, .32-44 S&W, .38-44 S&W,.44 S&W Russian Gallery, and .45 Colt Gallery were available from major retailers for several years or more, whilst others were flashes in the pan (UMC, 1887; 1889, pp. 87, 89, 92; 1910, pp. 80–81). In 1893, Mexico adopted both a revolver and a revolver carbine produced by Henri Pieper of Belgium (Hughes, 1968). These were chambered for proprietary cartridges of 8 × 41R mm and 8 × 50R mm, respectively. The 8 mm Pieper cartridges[17] feature a projectile seated deeply within the case, with significant empty space at the case mouth. The case protrudes slightly from the front of the revolver cylinder when loaded. When the trigger of the weapon is pulled[18], the cylinder cams forward, allowing the forcing cone to mate with the cylinder recess, and pushing the mouth of the cartridge case into the forcing cone (*C&Rsenal*, 2019; *Revue d'Artillerie*, 1901, pp. 383–388). The result of this arrangement is an effective gas seal.[19] This was particularly desirable in the carbine configuration, as gas and 'shaved' lead could sometimes strike the users of similar weapons in their support arm or hand (Hughes, 1968; Boorman, 2002).

Figure 3.4 *The Steyr (left) and Steyr-Pieper (right) revolvers as submitted to the 1897 Austrian military trials. Both are fitted with gas-seal mechanisms and are chambered for semi-telescoped cartridges, however the Steyr-Pieper has other improvements, including a swing-out cylinder and ejector rod (source: Rock Island Auction Company).*

In the early 1890s, Steyr Waffenfabrik of Austria were working on a new *gasdichter* ('gas-tight') revolver for planned Austrian military trials, which resulted in their model of 1893. Pieper and Steyr appear to have had a continuing relationship, and the first Steyr designs was no doubt influenced by Pieper's work. Indeed, several models of the gas-seal revolver were then developed for the 1897 trials: the latter of which directly incorporated the Pieper system (HGM, 2018; Hunnicutt, 1988, p. 67). These made use of a proprietary 8 mm cartridge, very similar to Pieper's own design. Ultimately the Steyr design was not adopted. Despite Pieper's earlier innovations, the most widespread semi-telescoped cartridge design of the 19th and early 20th centuries was to be the 7.62 × 38R mm Nagant cartridge of 1895, used with the widely-issued Russian Nagant revolver of the same year. The revolver and its proprietary cartridge were developed by Belgian designer Léon Nagant—

[17] These were also made in other lengths, including 8 × 30R mm and 8 × 37R mm.
[18] The Nagant, by contrast, cams the cylinder forward when the hammer is cocked (including when the trigger is pulled in double-action operation) (Kinard, 2003, p. 161).
[19] In most conventional revolver designs, a certain amount of gas will escape from the 'cylinder gap', reducing the gas pressure available to propel a projectile (BBTI, n.d.; Downey, 2011). Pieper's system was by no means the first gas-seal type. An early example of a gas-seal mechanism for a revolver is seen in the Collier flintlock system, first patented in 1818 (The Met, n.d.). Later guns, such as the North-Savage 1861 Navy revolver and the H. Genhart turret rifles, also incorporated similar mechanisms (McCollum, 2016; RIA, 2019).

brother of Émile Nagant, who had contributed to the design of the Mosin-Nagant rifle adopted for Russian service in 1891. The Nagant revolver's gas seal design and its cartridge are substantively similar to that of the earlier Pieper designs.[20] Although not the original design intent of the weapon, this gas seal means that the revolver can be effectively suppressed—unlike most conventional revolvers (SilencerCo, 2017). The Nagant action was also resurrected in the Soviet Khaidurov TOZ-36 target revolver, introduced in 1961, and its successors (DOSAAF, 1968, pp. 189-192).

The semi-telescoped cartridge design of the Pieper and Nagant was emulated in modern, highly specialised revolver cartridges. In the early 1990s Knight's Armament Company of Vero Beach[21], Florida introduced a suppressed revolver pistol and a suppressed revolver rifle. These made use of novel, proprietary semi-telescoped cartridges featuring an aluminium piston sleeved inside the cartridge case and over a sub-calibre projectile. The front face of this piston incorporated a polymer O-ring. Upon firing, the piston projects forward a very short distance, sealing the cylinder gap (Kokalis, 1992). This innovative cartridge design meant a Pieper-type gas-seal mechanism was not required for the revolver itself.[22] Two cartridges were developed; the revolver rifle fired a .30 calibre projectile contained within a cut-down .44 Magnum cartridge case, whilst the revolver pistol fired a .22 calibre projectile contained within a cut-down .38 Special case. The latter cartridge was simpler in design, with a polymer case-mouth insert and no piston.[23]

The Knight's designs were based on developments patented by Charles Robert "Bob" Olsen in his earlier 'INVICTA' series of cartridges from the 1980s. The INVICTA series also used reduced-calibre projectiles, and were designed with the primary aim of achieving higher velocities from revolver cartridges in non-bottlenecked cases[24], both by using a smaller projectile and by sealing the cylinder gap. Olsen's patent documents mention configurations of .224/.357, .257/.357, .358/.44, and .358/.45, using cartridge cases from .357 Magnum, .44 Magnum, and .45 Long Colt cartridges, respectively. All were sealed with polymer case extensions/end caps that bridged the cylinder gap, and these cartridges were designed to be used with unmodified cylinders (Olsen, 1980; 1983). The INVICTA designs saw only very limited use.[25]

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[20] Some sources indicate that Pieper allowed the patent to lapse in 1890, leading to the incorporation of a gas-seal mechanism in the Nagant revolver (Hunnicutt, 1988, p. 67), whilst others suggest the Nagants simply borrowed or copied what they could (*C&Rsenal, 2019*).
[21] Now Titusville.
[22] Alternative designs which retained the ability to fire conventional cartridges included the use of a clamshell enclosure to contain gasses escaping from the cylinder gap. German gunsmith Franz-Josef "Joe" Peters manufactured a small number of PSDR III suppressed revolvers in 1993, incorporating this concept into modified Smith & Wesson Model 625 revolvers (Popenker, n.d.).
[23] Author interview with industry source.
[24] Bottlenecked are not generally used in revolving firearms. As Olsen writes, "The bottleneck form is not suitable for use in revolving cylinder firearms as the case sets back against the frame, preventing the subsequent rotation of the cylinder, a condition known as cylinder freezeup" (Olsen, 1980).
[25] Smith & Wesson filed a patent for a revolver cartridge design which shares similarities with both the Olsen and KAC designs in 2005 (Mochak, 2005).

Figure 3.5 *A variety of Dardick Tround cartridges, L–R: .38 Dardick (three variations); 5.6 mm Triplex; .30 HIVAP; .310 Rock Drilling; .50 Dardick (source: Drake Watkins/ARES).*

The first semi-telescoped design of note in the modern era was probably the Dardick design of 1958. Known as 'Trounds' (an contraction of 'triangular round'), this ammunition used a projectile seated entirely within in an oddly shaped polymer case of uniform cross-section, very similar to how modern cased telescoped ammunition is laid out, albeit with propellant entirely below the projectile. Unlike the current generation of cased telescoped ammunition, however, the case was not a cylinder, but an elongate shape with the cross-section of a Reuleaux triangle, featuring three curved convex sides (Dardick, 1959; Lyles, 2016). This shape allows the ammunition to form a segment of an open-sided cylinder, facilitating loading and unloading of ammunition from the sides of a revolving cylinder set of chambers, rather than conventional front-to-back insertion and extraction. Side-loading ammunition in this way can be accomplished very quickly and with a simple mechanism, facilitating extremely high rates of fire, up to or exceeding 2,000 rounds per minute for a single-barrelled weapon. Because of their shape, Trounds also have better stacking efficiency for a given propellant volume than cylindrical ammunition (Office of Naval Research, 1989). For all of these reasons, some still believe the general geometry of the Tround is worthy of consideration as a next-generation ammunition configuration for infantry weapons.[26] Tround-firing weapons in small- and medium-calibres underwent development throughout the latter half of the 20th Century and into the 1990s (Office of Naval Research, 1989).

[26] Author interviews with industry sources.

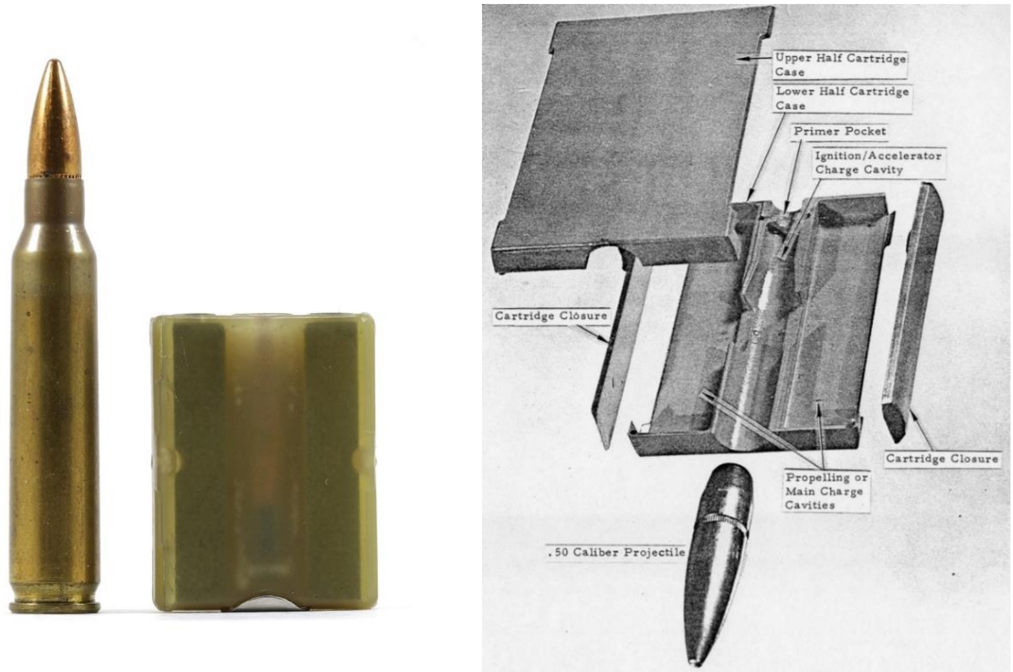

Figure 3.6 *L: 5.56 × 30 mm Hughes Lockless cartridge shown next to a conventional 5.56 × 45 mm NATO cartridge. Note the projectile seated in the polymer case (source: Jack Dutschke/ARES) R:* Diagram showing the components of a *.50 calibre Hughes Lockless cartridge (source: Hughes, c. 1980).*

Other telescoped and semi-telescoped ammunition designs were developed in the 20th century. So-called 'Lockless' ammunition, developed by Hughes from 1967, consisted of a flat 'chiclet'-shaped cartridge which could be fed into a slot-chamber via a compact and simple mechanism, similar in design concept to the Tround (Hackley et al. 2015; see Figure 3.6). Originating from a 27 mm design and later developed in various small- and medium-calibre configurations[27], the lockless cartridge design offered solutions to problems arising from earlier caseless ammunition programmes, whilst retaining many of the benefits and perceived benefits of caseless cartridges (Hughes, c. 1980). These were primarily perceived as a reduction in weight and volume; the 30 mm version, for example, gave a 25% reduction in weight and volume compared to conventional cartridges (*Military Review*, 1974).

Perhaps the most visually unusual semi-telescoped designs from the mid-20th century are the 'folded' cartridges of the 1970s (see Figure 3.7). Beginning in April 1969[28], Frankford Arsenal in the United States developed a novel cartridge design in which the propellant charge was relocated from behind the projectile to beside it (Grandy & Horchler, 1971). The weight and volume savings were notable. Indeed, it was indicated that even a steel-cased folded configuration of the 30 mm GAU-8 cartridge would be lighter than the conventionally configured aluminium-cased service cartridge. The packing volume reduction for the 5.56 mm Folded cartridge versus a conventional 5.56 × 45 mm cartridge was determined to be approximately 29 per cent. (Donnard, Rhodes & Hennessy, 1976, pp. 3–7) A mid-1970s report indicated that telescoped and folded configurations were considered comparable in terms of reducing packing volume and overall cartridge length, with folded cartridges having a slight advantage in optimising the former, and telescoped ammunition a slight advantage in the latter. In terms of packing volume, however, the geometry of folded cartridge (or, indeed, the Hughes Lockless design) was superior. The primary perceived advantages of folded versus telescoped designs were the use of conventional projectile seating, propellant types, and ignition (Hoppmann Corporation, c.1975).

[27] Hughes developed cartridges with 5.56, 7.62, 12.7, 25, 27, 30, and 40 mm projectiles (Hughes, c. 1980).
[28] Andrew Gandy patented the concept in 1972 and 1973 (Gandy, 1972; 1973)

Figure 3.7 *L–R: 5.56 mm Hughes Lockless; 5.56 mm Folded (ball); 5.56 mm Folded (practice); 5.56 mm folded (XM2) (source: Drake Watkins/ARES).*

The folded ammunition concept is best conceived of as a type of semi-telescoped design. The Dardick Tround and Hughes Lockless designs, however, can be considered 'true' telescoped cartridge configurations[29], as can the .50 calibre CT ammunition developed by ARES Inc. for their Telescoped Ammunition Revolver Gun (TARG) in the late 1980s (Willbanks, 2004; Williams, 2008; see figure 3.8). At 44 lbs (just under 20 kg), this gun design was substantially lighter than the in-service Browning M2 design (38 kg) and it made use of a belt-less feed mechanism (Willbanks, 2004, p. 146). The TARG was one of several weapons ARES developed to use telescoped ammunition, with CT cartridges also designed for a number of medium- and large-calibre guns, in 20, 25, 30, 45, 75, and 90 mm configurations (ARES, 2007).

Figure 3.8 *Experimental .50 calibre cartridges, L–R: Hughes Lockless, ARES TARG, Dardick Tround; .50 BMG (12.7 × 99 mm) for scale (source: Anthony G. Williams/SAR).*

[29] Indeed, Hughes marketing shoes the company was aware of the fact, describing their lockless cartridges as "fully telescoped" (Hughes, 1970a).

The ARES TARG program influenced their small-calibre ammunition development, too. Indeed, both the Steyr and ARES entrants into the Advanced Combat Rifle (ACR) programme of the late 1980s and early 1990s used cased telescoped ammunition (see Figure 3.9); the former fired a high-velocity flechette and the latter initially using a novel all-tracer sightless aiming technique. The ARES entrant into the ACR programme was the Advanced Individual Weapon System (AIWS), designed by a team led by Eugene Stoner—the famous engineer behind the AR-10 rifle that later evolved into the AR-15 (Bartocci, 2004). He was an early, but largely unsung pioneer of the cased telescoped ammunition concept, as evidenced by his patent of 1987 (Stoner, 1987). The current NGSW cased telescoped ammunition effort is a distant relative of Eugene Stoner's design, by way of ARES' position as a subcontractor on the Lightweight Small Arms Technologies programme (Phillips & Shipley, 2016). Mechanically, the 6.5 mm CT Carbine shares many similarities with the AIWS, and can be considered a spiritual descendant (Shipley et al., 2019).

Figure 3.9 *Cartridges of the ACR Phase III contenders, L–R: 5.56 × 45 mm Colt ACR Duplex (three variations); 5.56 × 45 mm AAI ACR flechette; 5.56 mm Steyr ACR flechette; 4.73 Heckler & Koch DM11 caseless (source: Drake Watkins/ARES).*

There are, of course, other small-calibre telescoped and semi-telescoped designs. Certain 'silent' piston cartridges may be considered semi-telescoped, for example. The Soviet 7.62 × 41 mm SP-4 cartridge, fired by the 6P28 PSS pistol and other weapons, is one of the better-known examples of this type. Adopted circa 1983, uses a bottlenecked rimless cartridge case with a very short neck. The cylindrical projectile is seated flush with the case mouth, and rests on a short piston inside the case. Upon firing, the piston is rapidly pushed forwards by expanding gasses, propelling the projectile. The piston is wider than the case mouth, and is jammed into the mouth by firing, sealing in the propellant gasses (Popenker, 2010). The Soviet Union produced several other designs operating on a similar principle, and analogous designs were also developed by other nations. The U.S., for example, developed several piston cartridges from the late 1950s onward, under Silent Weapon System, Project Whisper, and subsequent programmes. These resulted in the .30 XM76, 7.62 XM115, .38 XM202, Mk 59 Mod 0 Underwater Cartridge, and other models (Fulton, 1962; Dunham, 1966; Skochko & Greveris, 1967; Hackley et al., 2015). Other medium-calibre telescoped ammunition has also been developed. The 40 mm Cased Telescoped Armament System (CTAS), which was adopted by the UK in July of 2015 and received for fielding in early 2016, has been the most successful of these systems to date (BAE Systems, 2016; see Figure 3.10).[30] With the compact design of the gun and ammunition, the 40 mm CTAS can be integrated into turrets which were previously carrying 25 mm guns (CTAI, 2018). Medium-calibre semi-telescoped designs, such as the Soviet 23 × 260RB mm R-23 cartridge, have also been developed. Much like the R-23 round, these cartridges typically feature a projectile fully seated within the case, but atop the propellant (Koll, 2009).

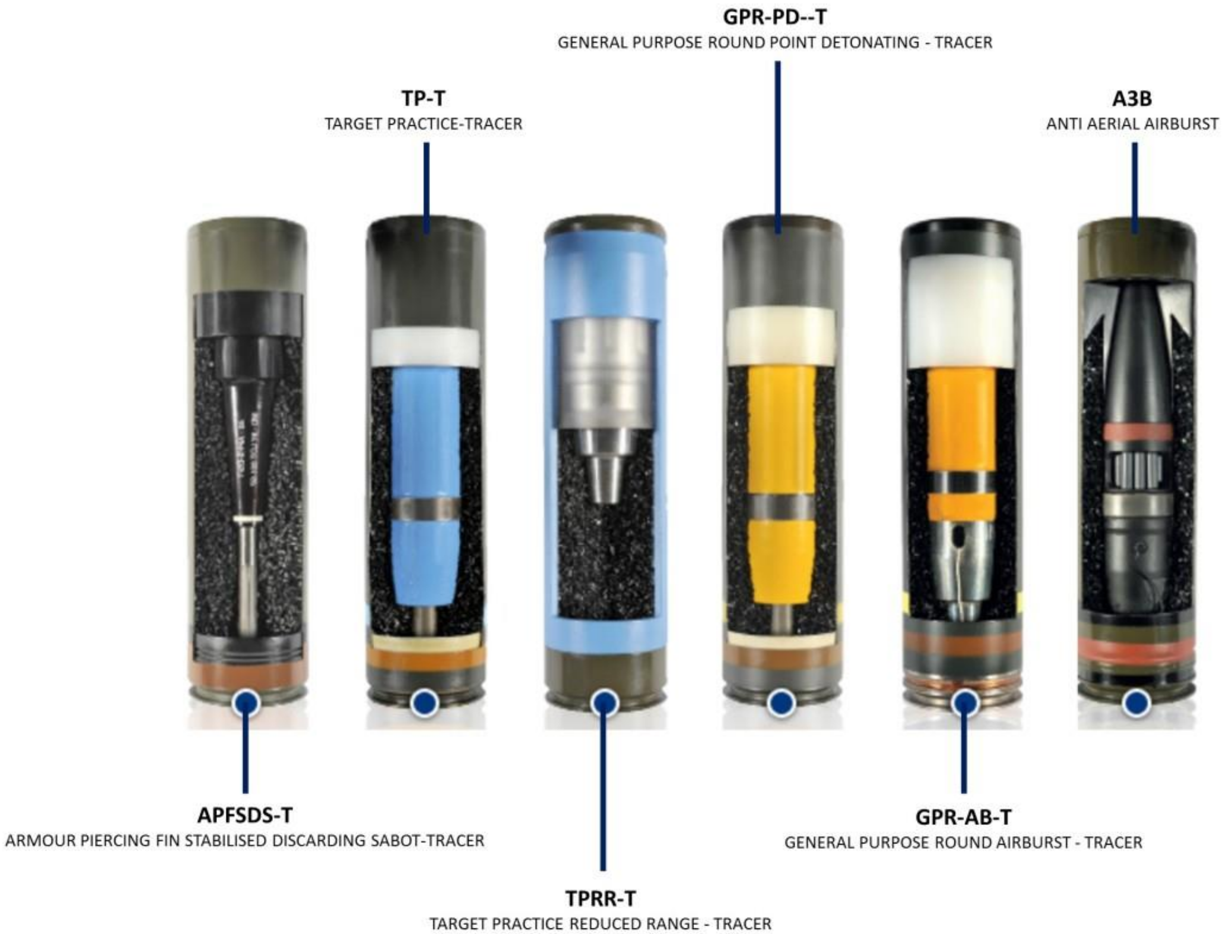

Figure 3.10 *The range of available 40 mm CT ammunition types for the CAI CTAS, shown as sectioned cartridges (source: BAE Systems).*

Development of cased telescoped small arms ammunition in the United States and the broader western world slowed to a near standstill after the conclusion of the Advanced Combat Rifle programme in 1990. U.S. Army efforts to find a next-generation rifle, informed by the results of ACR, shifted towards an area-effect approach with the highly advanced and ambitious Objective Individual Combat Weapon (OICW) programme. This sought to field a sophisticated individual weapon, combining a computer-controlled grenade launcher with a conventional 5.56 mm assault rifle. This combination weapon would later become known as the XM29. The abortive XM8 Carbine programme also stemmed from and was contained within the scope of OICW, and while neither of these novel weapons were adopted by the U.S. military, they did have downstream impacts.

[30] A range of other cartridges have been designed, including examples from US, Chinese, Japanese, European, and Russian developers.

US Programmatic Developments

Cased telescoped ammunition would not come to the forefront of U.S. thinking on next-generation small arms again until the advent of the Lightweight Machine Gun and Ammunition programme in 2004, which had grown out of a series of studies which followed a U.S. Army report on soldier load. This load study determined that the soldier was carrying a much greater weight and volume of gear, weapons, and ammunition than was ideal, especially following the issuance of advanced body armour like the Small Arms Protective Insert (SAPI) (Devil CAAT, 2003).

The Lightweight Machine Gun and Ammunition programme was commissioned to study the possibility of reducing the weight of ammunition carried by the soldier using lightweight ammunition technologies, such as cased telescoped and caseless ammunition (Spiegel, 2004)[31]. The effort, renamed the Lightweight Small Arms Technologies (LSAT) programme in 2005, was helmed by Picatinny-based programme officer Kori Phillips (née Spiegel) and initially included studies of both CT and caseless ammunition designs (Spiegel & Shipley, 2005). The caseless ammunition design was inherited from Dynamit Nobel's efforts in support of the West German G11 'hyperburst' rifle program. The exact formulation of the propellant used in these cartridges was lost following the end of the ACR programme and the reunification of Germany, but the LSAT programme was able to replicate the formula with some effort (Fitch, 2017a). The original formulation proved too expensive and hazardous to produce, but an alternate formulation was developed before the caseless effort was handed off to the Office of Naval Research (ONR), an LSAT partner, after 2010. During this time, prime contractor AAI[32]—led by engineer Paul Shipley—further developed the cased telescoped cartridge. The CT designs matured, eventually achieving Technology Readiness Level (TRL) 7[33] by 2012. At the same time, M855A1-equivalent cased telescoped ammunition using the same Enhanced Performance Round (EPR) projectiles was also being developed. The LSAT team was also conducting a calibre study to determine the best characteristics for a brand-new CT round, rather than simply matching projectiles and performance to existing 5.56 mm and 7.62 mm brass cased ammunition (Phillips & Shipley, 2016).

In 2013, Textron and the LSAT team were awarded an additional contract by the U.S. Army to pursue a scaled-up, 7.62 mm CT version of their 5.56 mm CT machine gun, as well as a matching 7.62 mm CT carbine. Critically, both of these weapons could be readily adapted for the new 6.5 mm CT, the round which had resulted from the aforementioned calibre study. This new cartridge delivered similar energy at long ranges as the conventional, commercially available 6.5 Creedmoor round, but weighed less than the ubiquitous Soviet steel-cased 7.62 × 39 mm cartridge of the famous Kalashnikov assault rifle (Phillips & Shipley, 2016). By June 2015, the programme name 'LSAT' had been retired and replaced by Cased Telescoped Small Arms Systems (CTSAS), which it would retain through the middle of 2017 until its absorption into the Next Generation Squad Automatic Rifle/Weapon (NGSAR/NGSW) programme. Through this name change and until its absorption into NGSAR, the programme organisation remained effectively the same, and Phillips remained the programme officer (Fitch, 2019).

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[31] The programme initially included two teams, one led by AAI and another by General Dynamics – Armament and Technical Products (Spiegel, 2004).

[32] Now part of Textron Systems Corporation. The LSAT team also included ARES Inc., MSC Software, and St. Marks Powder Inc. (Phillips & Shipley, 2016). The initial AAI Lightweight Machine Gun and Ammunition team also included Battelle, Omega Training Group Inc. and, for a time, ATK (Speigel, 2004; Spiegel & Shipley, 2005). Several of these partners remained part of Textron's CT team (Textron Systems, 2017).

[33] The US Department of Defense and 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).

Figure 4.1 *Textron 5.56 mm cased telescoped machine gun, serial number CT001 (source: U.S. Army).*

As interest in a cased telescoped configuration for next generation small arms ammunition grew, the CTSAS team endeavoured to produce a more mature and capable weapon. By combining a prototype 6.5 mm version of the 7.62 mm CT carbine design with an advanced computerized optic also developed at Picatinny, the team demonstrated a compelling system to U.S. Army officers, including Chief of Staff General Mark Milley, in mid-2017. The performance of this demonstration resulted in a change of course for U.S. Army small arms development (Fitch, 2019; U.S. Senate, 2017).

Figure 4.2 *Textron's 6.5 mm CT Carbine on display at AUSA 2017 (source: Nathaniel Fitch/ARES).*

At the time of the 6.5 mm CT Carbine's first demonstration in mid-2017, the U.S. Army was pursuing a conventional 7.62 × 51 mm calibre rifle for its next infantry weapon, under the Interim Combat Service Rifle (ICSR). This programme sought to leverage off-the-shelf industry 7.62 × 51 mm designs in conjunction with the Army's own 7.62 × 51 mm XM1158 Advanced Armor Piercing (ADVAP) round to counter near-peer body armour out to combat distances (Mizokami, 2017). However, with the demonstration of the 6.5 mm CT Carbine, which promised even greater range and performance with significantly less weight in both rifle and ammunition, the ICSR programme was cancelled by General Milley before any prototypes were submitted to the programme office (U.S. Senate, 2017). Simultaneously, the CTSAS programme was folded into a pre-existing technology programme intended to replace the M249 SAW—the Next Generation Squad Automatic Rifle (NGSAR) programme—and its scope expanded to cover both rifle and squad automatic weapon.

During this period, it seems Kori Phillips' tenure shepherding the cased telescoped programme came to an end, and instead the programme accelerated to an initial technology demonstration stage open to the industry at-large. The official announcement of the newly rechristened Next Generation Squad Weapon (NGSW)[34] programme was made in October of 2017 with a Prototype Opportunity Notice (PON) being issued in March 2018. Six contract awards were made under that PON to five different vendors: Textron, General Dynamics Ordnance and Tactical Systems, SIG Sauer, and PCP Ammunition, and two contracts to FNH USA[35]. In October of that year, a second draft PON was issued, which was widely speculated to be a programme reboot, but which the Army clarified was a planned follow-on programme for a more mature system to lead directly to a production contract. The Army expects to down-select to one NGSW candidate system in the first quarter of 2021, with production and fielding to follow by the end of that year.

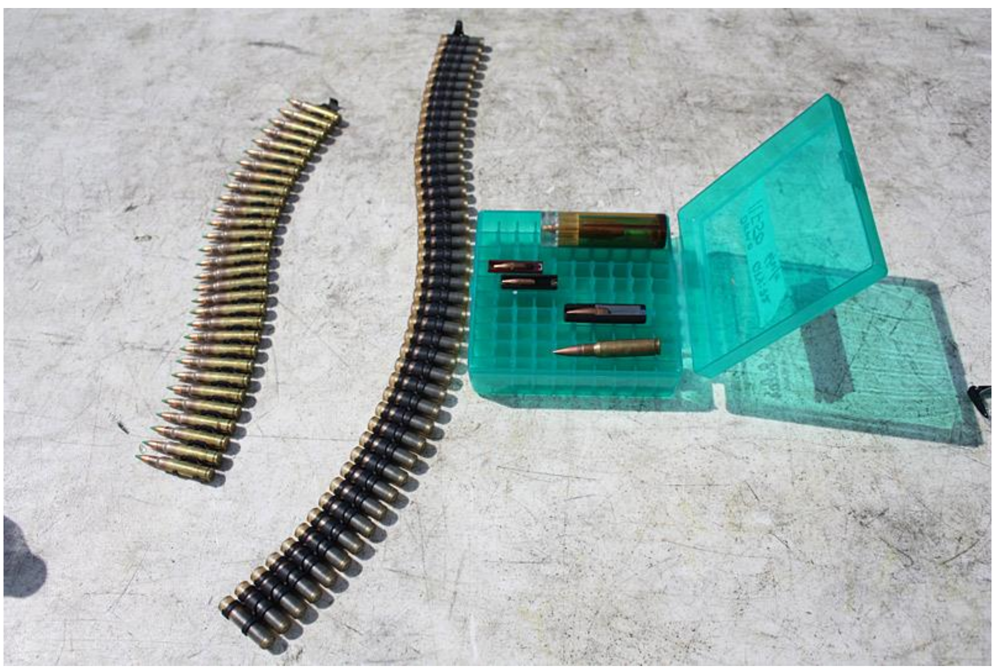

Figure 4.3 *A belt of Textron's 5.56 mm CT ammunition on display at a demonstration. Sectioned ammunition illustrates the buried projectile (source: U.S. Army).*

[34] Over the course of its life and to the present day, the NGSW program's names were changed several times, resulting in some confusion. The initial name of the technology programme focusing on the M249 replacement alone was NGSAR, with a sister programme called 'Next Generation Squad Carbine' (NGSC) being added after the cancellation of ICSR. Later, the umbrella programme was redubbed 'NGSW', with subprograms 'NGSW-AR' ('AR' for automatic rifle), and NGSW-R ('R' for rifle). As the programme has been accelerated in late 2018 and 2019, the U.S. Army has stuck with the NGSW label.
[35] Now FN America.

The core of the NGSW system is a 6.8 mm general-purpose (GP) calibre, and specifically a very high-performance round designed to penetrate current and future ceramic body armour. Projectile weight is reported to be 8.75 grams (135 gr), with a muzzle velocity “that far exceed[s] the velocity of bullets today”, speculated to be between 3,000 and 3,500 ft/s (Cox, 2018; Vranic, 2018). The NGSW programme team believes this can be facilitated using a high-pressure CT ammunition configuration, with operating pressures approximately equivalent to that of the M256 120 mm tank gun—about 520–690 MPa (75,000–100,000 PSI) (Singleton, 2016). Companies competing for the NGSW contract are required to come up with their own proprietary high-performance ammunition, but are to be provided with the same 6.8 mm government-designed projectiles to load in them (Moss, 2019). This ammunition configuration is highly ambitious, reaching energy levels as high as the commercial 7 mm Remington Ultra Magnum—effectively a .404 Jeffery dangerous game cartridge necked down to 7 mm, itself an example of one of the most overbore[36] cartridges made—but presumably fired from shorter barrel lengths. Even on the low end of speculated muzzle velocities for the 6.8 mm GP, it would be extremely difficult to create a practical conventional military round that met the requirements, due to the pressure limitations of conventional case designs. There is even some doubt that such results can be achieved with the high-pressure CT ammunition concept (Williams, 2018).

Implications of Cased Telescoped Ammunition

Military Requirements

The development of any new weapon or cartridge should be designed to meet a series of well-thought-out, sufficiently specific requirements. Such requirements will naturally set constraints on design. Small arms ammunition is subject to many constraints, and these are primarily driven by the use of such ammunition by the average infantryman. Infantry remain the most archaic engines of war in any army's inventory. The fundamental platform, the infantryman, has remained the same for thousands of years, despite being augmented during that time with ever more effective weapons, more resilient armour, and advanced communications devices. Any consideration of "where next" for small arms ammunition must maintain an understanding that it is not the *rifle* that is the host platform, but the infantryman himself—and that the fundamental truths governing his use are not likely to change any day soon. The soldier cannot shoot what he cannot carry. He cannot hit what he cannot see and acquire. He cannot match the enemy's volume of fire if his weapons overtax their platform (him!) with every shot. These and other factors are—at least for now—fixed and do not change.

Following are some of the most important aims and requirements of modern cartridge design:

- reduce ammunition weight;
- reduce ammunition volume;
- increase the number of rounds that can be carried;
- improve hit probability;
- improve terminal ballistics;
- improve general performance and function within a weapon;
- 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 (Jenzen-Jones, 2016).

[36] ‘Overbore’ cartridges are considered to be those with a relatively large case volume paired with a relatively small-diameter projectile (*Accurate Shooter*, n.d.).

The competing pressures of design choice are largely self-evident. It is difficult to develop a round that is both more powerful than another nominal cartridge, whilst at the same time being lighter in weight and smaller in volume. Even when a round is engineered to meet performance requirements that seem reasonable at the time, it can often end up too powerful or too heavy to be very useful as a dismounted infantry round. A real-life example of this is the 7.62 × 51 mm NATO cartridge, which, when it was envisioned in the 1940s, was designed around orthodox performance requirements. Yet, due to developments in automatic weapons and infantry tactics, it ended up being too heavy and generating too much felt recoil—it is considered by many historians to be a misstep in small arms ammunition (Williams, 2016).

The necessity for compromise is therefore clear. Changes to infantry weapons must be carefully considered and wrought within the well-established limitations which have been informed by centuries of infantry combat. Such limitations create substantial competition between individual requirements like range or recoil, and striking the best balance between them is difficult as a result. It may be useful therefore to adapt from the realm of armoured vehicles a hierarchy of needs, called the “survivability onion” (Hazell, 2016). This model describes the process of threat defeat in armour like so:

1. Do not be seen.
2. Do not be acquired.
3. Do not be hit.
4. Do not be penetrated.
5. Do not be killed.

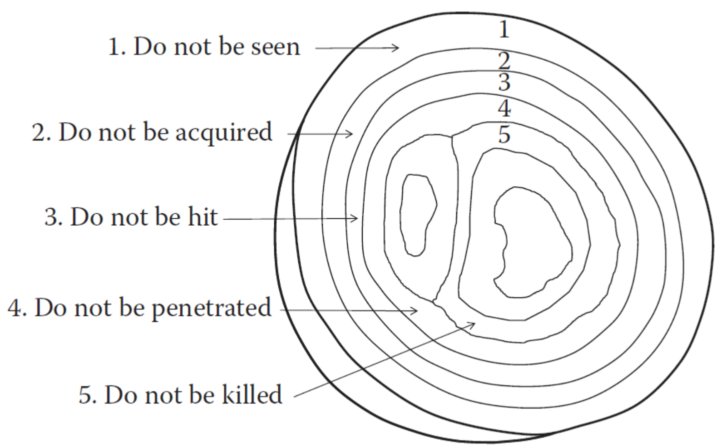

Figure 5.1 *The survivability onion (source: Hazell, 2016).*

For small arms, we can invert this to be a ‘lethality onion’:

1. See.
2. Acquire.
3. Hit.
4. Penetrate.
5. Kill.

This structure allows a designer to prioritise the competing pressures influencing cartridge design. For example, if using a larger cartridge case with more propellant better enables a soldier and his rifle to penetrate a target, but the muzzle blast is increased such that it interferes with the proper operation of thermal optics, it may be prudent to accept the reduced penetration in order to better see and acquire the enemy. Which priorities trump others is still ultimately subject to human judgment, but structures such as this can act as a useful guide in refining and visualising this decision-making process.

The General-purpose Calibre

The discussion regarding the hypothetical calibre and projectile design for a future cartridge is directly influenced by another critical decision in the development and issue of small arms: the number of calibres to be fielded. The world's major fighting forces currently employ a two-calibre system for their primary infantry arms. Self-loading service rifles and light machine guns are typically chambered for an intermediate[37] or small-calibre, high-velocity (SCHV)[38] cartridge, whilst a full-power rifle cartridge is retained for use with general-purpose machine guns and specialised precision rifles (Jenzen-Jones, 2017; 2018). In NATO nations and in the western world more broadly, the two primary calibre roles are fulfilled by the 5.56 × 45 mm and 7.62 × 51 mm cartridges. Former Warsaw Pact states have traditionally made use of the 7.62 × 39 mm and 7.62 × 54R mm cartridges, although a small number of states have since replaced or supplemented the former with the 5.45 × 39 mm cartridge or, less commonly, the 5.56 NATO cartridge. China took yet another path, having supplemented the standard Warsaw Pact cartridges with their indigenous 5.8 × 42 mm cartridge (Andrew, 2015; Jenzen-Jones, 2018; Williams, 2015). Table 6.1 shows the dominant worldwide infantry service rifle and machine gun calibres in modern usage.

Table 6.1 – Dominant Cartridges for Infantry Weapons Worldwide

Cartridge designation	Country of origin	Total cartridge weight (g)	Projectile weight (g)	Muzzle velocity (m/s)	Muzzle energy (J)
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 (PRC)	12.8	4.6	900	1,900
5.56 × 45 mm	United States	12.0	4.0	950	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 loading, and other factors.
Sources: Andrew, 2015; Williams, 2015.

This arrangement was arrived at organically, once the advantages of the much lighter SCHV 5.56 × 45 mm cartridge were made apparent in the late 1950s and early 1960s. Proven thereafter through American and Vietnamese experience in Southeast Asia during the Vietnam War, the 5.56 mm cartridge became a staple in the U.S. and in other countries. Its success set off a firestorm of copycats and competitors, leading directly to the second NATO calibre trials of the late 1970s, which expanded ammunition standardisation within the Organization by selecting the Belgian-designed SS109 5.56 × 45 mm round to join the 7.62 × 51 mm NATO cartridge.[39] This dual-calibre arrangement is not without its faults, but it has proven broadly satisfactory for more than 50 years, with the light weight and low recoil of the 5.56 mm cartridge improving marksmanship training and reducing the soldier's load for the majority of troops, whilst the 7.62 mm cartridge provides a

[37] That is, a cartridge intermediate in power between pistol-calibres and so-called 'full-power' rifle calibres (Jenzen-Jones, 2018).
[38] SCHV cartridges are considered a subset of intermediate calibre cartridges.
[39] The STANAG was ratified in the 1980s (Pellegrino & Kirkman, 2011). In the Soviet Union, 5.56 mm NATO ammunition obtained by Soviet intelligence was used as the basis for development of the USSR's own 5.45 × 39 mm SCHV cartridge (Popenker, Jenzen-Jones & Dutschke, 2019).

more traditional machine gun and marksman's rifle round. It is also worth noting that, at the time of writing, no major military has transitioned to a general-purpose calibre (Jenzen-Jones, 2017; 2018).

Nonetheless, proponents of a general-purpose calibre typically identify three key limitations to the current two-calibre system:

1. The 5.56 × 45 mm cartridge has a relatively short effective range, which has proven insufficient in recent conflicts according to some. Some observers also claim it has erratic terminal effectiveness.
2. 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.
3. 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 (Jenzen-Jones, 2016).

Whilst a general-purpose calibre cartridge could be introduced in a conventional configuration, the weight and volume reduction offered by CT ammunition technology—as well as the inherent requirement to radically alter both ammunition production facilities and small arms design to accommodate the new ammunition—would make the simultaneous adoption of a general-purpose calibre cartridge substantially more efficient in terms of both time and cost. In light of these synergies, armed forces must ask themselves: does this two-calibre paradigm still make sense? Is it better to have one CT round which approaches the weight of current SCHV cartridges and the performance of current full-power rifle cartridges, or two—one very lightweight round filling the same operational roles as the 5.56 × 45 mm cartridge does today, and one which fills the roles as the 7.62 × 51 mm cartridge?

Figure 6.1 L–R: 7.62 × 51 mm NATO, 7.62 mm CT, 6.5 mm CT, and 5.56 CT cartridges (source: ARDEC).

Proponents of a single-calibre system would argue the former. Because of the reduced ammunition weight, a round can be made which offers the weight benefits of SCHV cartridges but with obvious improvements to a round's range, precision, and terminal effect. In the most likely incarnation of a single-calibre system, essential performance characteristics of the 7.62 NATO cartridge (such as retained energy at distance) would be incorporated into a cartridge closer in weight to the 5.56 NATO round by using a lightweight CT configuration and very low drag projectiles. Such a round has been proposed as a general replacement not only for the 7.62 mm cartridge in the general-purpose machine gun and marksman's rifle, but also the 5.56 mm in the standard rifle and light machine gun as well (Williams, 2016). Such a system is also likely to have benefits in terms of standardisation, weapon interoperability, logistics, and manufacturing (Jenzen-Jones, 2016). The 6.5 mm CT round developed by the LSAT programme team broadly represents the kind of round called for under this paradigm. The chief downsides of this concept include increased ammunition bulk and recoil, and their unfavourable weight characteristics relative to *other* lightweight cased ammunition of smaller calibre (e.g., at least at present, 6.5 mm CT is still 85% heavier than 5.56 mm CT) (Phillips & Shipley, 2016).

Table 6.2 – Comparison of CT cartridges to 7.62 × 51 mm NATO cartridge

		7.62 × 51 NATO	7.62 CT	6.5 CT	5.56 CT
Size	Overall length (in)	2.8	2.032	2.032	1.556
	Case diameter (in)	0.487	0.504	0.504	0.419
Weight	Projectile weight (gr)	131	131	125	62
	Cartridge weight (gr)	362	240	237	127
	Cartridge weight savings	-	34%*	35%*	33%†
	Belted weight, 200 rounds (lb)	12.2	7.5	-	3.8
	Belted weight savings	-	38%*	-	39%†
Volume	Volume (in^3)	0.486	0.398	0.398	0.215
	Volume reduction	-	18%*	18%*	12%†

Notes: * Compared to 7.62 × 51 mm NATO.
† Compared to 5.56 × 45 mm NATO.
Source: Phillips & Shipley, 2016.

Although the single-calibre solution is the most intuitive way to leverage the benefits of lightweight cased ammunition, it is still well worth considering future dual-calibre solutions, including greatly improved SCHV rounds. High-performance .22 calibre ammunition is no longer restricted to the domain of hand-loaders and competition shooters. The release of Federal Ammunition's .224 Valkyrie cartridge (Fitch, 2017e) proves the viability of the high performance, low drag .22 calibre round concept, with many of the round's performance characteristics, such as bullet drop and wind drift, falling in-between the full size 7.62 NATO and high performance 6.5 Creedmoor rounds, even out to a kilometre (Fitch, 2017e). It's not difficult to imagine a calibre system that combined two CT rounds analogous in performance to .224 Valkyrie and 6.5 Creedmoor, respectively, and those each 1-for-1 replacing current brass-cased 5.56 mm and 7.62 mm ammunition within NATO. Such an arrangement would "split the difference" of CT benefits between reduced weight and improved performance, for each calibre of weapon. The increased flexibility of having two calibres for different missions and applications could more than compensate for the increased complexity of a two-calibre system (and, it should be noted, a 2-calibre system in the form of 5.56 mm and 7.62 mm has been supported by NATO forces for almost 40 years), and the benefits of a lower recoil round in training and combat accuracy would be maintained. Recoil, unlike weight, is not significantly reduced for CT rounds versus their conventional counterparts.

Figure 6.2 *The .224 Valkyrie (far left) uses a much finer projectile shape and a heavier bullet than the 5.56mm (centre-right) to retain more energy over longer distances, despite being the same calibre. It is closer, ballistically-speaking, to the larger 6.5 Grendel round (far right), and even superior in some respects, despite being smaller in calibre (source: Nathaniel Fitch/ARES).*

Core to the U.S. Army's NGSW programme is the very ambitious 6.8 mm high-velocity round. This round is almost unprecedented in performance, offering speculative muzzle velocities of 3,200–3,500 ft/s (975–1,067 m/s) (H., 2019; Williams, 2018). This would earn it the title of "most powerful infantry rifle cartridge ever proposed" with no close competition. Due to its great power, it does not neatly fit within any of the traditional categories proposed for small arms ammunition. In concept, it is most comparable to the high-performance rounds developed by several nations just before the First World War. These include the .276 Enfield (UK), 7 mm STA (France), .280-1000 Danger Space (US), and 6.5 × 57 mm Fedorov (Russia) (Fitch, 2016). However, even though today each of these could be considered a high-velocity cartridge, none of them reach the upper bound of the 6.8 mm GP's performance level. The justification for the 6.8 mm GP's high velocity is armour penetration. Advanced ceramic body armour plates such as the U.S. ESAPI are resistant to shots even from .30-

06 steel-core armour-piercing ammunition at the muzzle (Department of Justice, 2008); the 6.8 mm sacrifices potential weight savings, and creates potentially prodigious recoil energy, for the benefit of being able to penetrate this armour even out to several hundred meters. Whether these drawbacks can be mitigated enough to make the benefits worthwhile remains to be seen with the conclusion of the NGSW program, however. It is also important to note that achieving the very high performance required for NGSW will be made much easier with a longer barrel than a shorter one. This has implications for rifle design, and likely accounts for the selection of a bullpup configuration in the rifle design proposed by GD-OTS (Trevithick, 2019).[40]

Figure 6.3 *The GD-OTS entry into the U.S. military's NGSW programme, as of late-2019 (source: GD-OTS).*

Opportunities for Change

How best to satisfy the modern infantry's needs for a small-calibre cartridge has been discussed at great length in a variety of forums. Western opinions vary from general satisfaction with the existing two-calibre (5.56 mm and 7.62 mm) arrangement, to complete rejection of one of those calibre and promotion of the other, to the view that *both* were grave mistakes that have cost NATO forces significantly over the decades. However, few would argue that, if a new calibre system is to be adopted as part of a technological shift, *no* changes should be made to existing cartridge configurations and other technologies. Indeed, the 5.56 × 45 mm cartridge has been the subject of numerous ongoing development programmes since its introduction and rise to primacy in the west. In the U.S. alone, standard ball ammunition has seen three major iterations: M193, M855, and M855A1. It has also been supplemented by a wide range of additional functional types, from tracer to armour-piercing, and in more recent years, novel approaches to solving perceived issues with range, terminal ballistics, and intermediate barrier penetration have also gained military favour. The MK 318 SOST and MK 262 OTM[41] are examples of rounds which were developed and adopted by the U.S. military in response to such requirements (Williams & Jenzen-Jones, 2016).

[40] The bullpup rifle configuration, whilst having its own inherent drawbacks, allows for a longer barrel within the same overall length as a conventionally configured weapon (Ferguson, 2020).
[41] SOST for 'Special Operations Science & Technology' and OTM meaning 'open-tip match'.

As the LSAT team realized in the mid-2000s, the adoption of a brand-new cased telescoped round that merely *replicated* the characteristics of existing ammunition would be a waste of an opportunity to improve the efficiency and lethality of small arms. The ballistic characteristics of existing military ball projectiles are perhaps the most obvious area for improvement. Both the 7.62 mm and 5.56 mm NATO rounds were designed around ballistic shapes first developed for the American .30-06 calibre that preceded them, and this design dates back more than one hundred years, to 1906 (Stevens et al. 1987; Hackley et al. 2015). As a result, both NATO calibres feature projectiles still informed by the ballistic state-of-the-art as it was in the early 1900s—decades before the advent of modern supersonic drag theory, developed independently by Wolfgang Haack and William Sears in 1947 (Vos & Farokhi, 2015).

Critically, this means that the ogive space—that is, the space between the end of the projectile's cylindrical shank when it is seated in the cartridge case, and the maximum allowable overall length for the cartridge to reliably function in magazines—of both NATO standard rounds is short enough to preclude the use of the most modern low-drag projectile shapes. More efficient projectile shapes, designed around the modern theory of supersonic drag, now exist, and any new calibre that dispenses with the constraints of existing 5.56 mm and 7.62 mm ammunition could be designed to take advantage of this. These principles have been understood for many decades, evidenced by the fact that in the 1970s the U.S. Army Ballistic Research Laboratory and the now-defunct Frankford Arsenal developed a 5.56 × 38 mm round with a very fine ballistic shape (see Figure 7.1), which allowed that round to match the performance of then-standard 5.56 × 45 mm M193 ammunition, despite it generating just two-thirds as much muzzle energy (Hackley et al., 2015).

Figure 7.1 *5.56 × 45 mm M193 (left) compared with 5.56 × 38 mm FABRL (right) (source: Nathaniel Fitch/ARES).*

Modern ballistic design would allow for a new CT ammunition design in a general-purpose calibre to match the ballistics of legacy full-power rifle cartridges such as 7.62 × 51 mm in a more compact and lighter-weight package. This could mean soldiers carrying an ammunition loadout of the same or reduced weight, without sacrificing the number of rounds carried. However, this technology could alternatively enable reduced ammunition weight without a performance decrease, lowering the overall carriage weight and improving the soldier's mobility and battlefield endurance. Perhaps the most intuitive configuration is a middle ground: a compromise design resulting in both modest weight savings and a modest performance benefit, enabled by the intrinsically lighter weight of the new ammunition design.

Conclusion

There are substantial logistic, programmatic, and economic implications to the military adoption of any new widely-issued calibre. These would be magnified substantially by the adoption of a cartridge in a CT or other novel configuration. Such a step would require overcoming institutional inertia within the military acquisitions, logistics, and operational apparatuses. Ammunition is already a niche consumable within the system, being both intrinsically subject to strict limitations on interchangeability (e.g. 5.56 mm ammunition cannot be used in 7.62 mm weapons, and vice-versa) and being treated as a commodity, like fuel. The adoption of a CT cartridge would have significant impacts, and require the acquisition of new or substantially modified weapons; the establishment of training programmes for users and armourers; the phased introduction of the weapons into service; and the gradual conversion of ammunition production to the new calibre and configuration (Jenzen-Jones, 2016).

The costs of adopting new ammunition standards are invariably high, both in terms of dollars and risk. As a result, new ammunition developments that are refined through experience or research are not often incorporated into existing military service cartridges; the cost is simply too high relative to their perceived benefits. This is perhaps truest when such developments would necessitate a new, non-interchangeable cartridge and/or weapon to be introduced. For these reasons, new military service rifle calibres are very rarely adopted—in most western nations, this only happens once every 50 years or so. However, the introduction of cased telescoped ammunition would necessitate a new ammunition standard regardless of ballistic characteristics, creating a once-in-a-half-century opportunity to optimise those characteristics for the best possible result.

Cased telescoped ammunition offers numerous benefits, and the obstacles to adoption—though significant—are unlikely to outweigh those benefits for much longer. Although cased telescoped ammunition is not competing alone in the race to lightweight, cased ammunition (see Table 8.1), it seems unlikely that the future lies with traditional brass-cased designs. With new case technologies comes the opportunity to re-examine ammunition calibre configuration. The best balance for future infantry calibres can only be determined with strong doctrine, sound requirements, and informed analytics. Finding that balance will require significant institutional input, and may vary by country or service. Regardless of the specific needs or doctrine of the user, and whether or not a general-purpose calibre is adopted, the core benefits of lightweight, low-volume CT ammunition are obvious.

Table 8.1 – Conventional brass- and polymer-cased ammunition vs. emergent cartridge configurations

Characteristic	Brass-cased (legacy)	Polymer-cased (conventional)	Polymer-cased (telescoped)	Caseless (telescoped)
Currently fielded	Yes	Yes	No	No
Reduced weight [a]	No	15-28%	37% or more	50%
Reduced volume [b]	No	No	12%	40%
Increased stowed rounds	No	Yes	Yes	Yes
Proven ballistic performance and reliability	Yes	Yes	Underway	No
Reduced production cost [c]	No	Yes (up to 20%)	Likely [d]	Undetermined
Reduced transport cost [e]	No	Yes (10-20%)	Yes	Yes
Reduced reliance on strategic materials	No	Yes	Yes	Undetermined [f]
Improved safety (resistance to cook-off)	No	Yes	Likely	≥ brass-cased ammunition
Can be produced with current tooling	Yes	Partially [g]	No	No
Reliant on new technologies	No	Partially	Yes	Yes

Notes: The table reflects findings of a comparison between emergent cartridge cases and current brass-cased standard-issue rounds of the same calibre, as determined by the authors 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 positive outcome under each category.

[a] Weight (and weight saving) is dependent on calibre.
[b] Total packing volume will also be reduced.
[c] Production costs depend on production volume and amortization of tooling.
[d] Some information on capital costs is discussed in Hopkins, Perhala, and Tolbert (2012).
[e] There is a direct relationship between reduced weight and volume and packaging and shipping costs.
[f] HITP caseless propellant availability and costs have not yet been fully determined in comparison to brass.
[g] Current assembly tooling can be used.

Sources: Jenzen-Jones, 2016; Schatz, 2015; Phillips, 2012.

Bibliography

Aberdeen Proving Ground. 2014. ‘M855A1 Conformance Testing on Commercial Magazines.’ <https://static1.squarespace.com/static/597679b68419c2bc1f2f8ef1/t/5983944f414fb5bec61d2711/1501795423281/Tech+Report+ARWSE-TR-12012%2C+redacted.pdf>.

Accurate Shooter. 2019. ‘6MM PPC – The Benchmark of Accuracy.’ Digital Edition: 26 May 2019. <https://www.accurateshooter.com/cartridge-guides/6mmppc/>.

Acharya, Ragini and Kenneth Kuan-yun Kuo. 2012. *Applications of Turbulent and Multi-phase Combustion*. Hoboken, NJ: Wiley.

Accurate Shooter. n.d. ‘“Overbore” Cartridges Defined by Formula: Can a Formula Provide a Useful Index Ranking of Overbore Cartridges?’. <https://www.accurateshooter.com/technical-articles/overbore-cartridges-defined-by-formula/>.

Andrew, Martin. 2015. *How the PLA Fights: Weapons and Tactics of the People’s Liberation Army*, rev. edn. Self-published.

ARES Inc. 2007. ‘ARES Engineering Capabilities’. Website. Available via: <https://web.archive.org/web/20091101000000*/http://www.aresinc.net/engineering.htm>.

BAE Systems. 2016. ‘New 40mm cannon system handed over to British Army’. Press release. 21 March. <https://www.baesystems.com/en/article/new-40mm-cannon-system-handed-over-to-british-army>.

Ballistics by the Inch (BBTI). n.d. ‘Cylinder Gap’. Website. <https://www.ballisticsbytheinch.com/gaptests.html>.

Bartocci, Christoper R. 2004. *The Black Rifle II: The M16 into the 21st Century*. Cobourg, ON: Collector Grade Publications.

Beckstrand, Tom. 2018. 'True Velocity's New Polymer-cased Ammunition' *Guns & Ammo*. 21 June 2018. <https://www.gunsandammo.com/editorial/true-velocitys-new-polymer-cased-ammunition/247607>.

Boorman, Dean K. 2002. *The History of Smith & Wesson Firearms*. Guilford, CT: Lyons Press.

C&Rsenal. 2019. ‘Small Arms of WWI Primer 098: Russian Nagant 1895’. YouTube video. 7 May. < https://www.youtube.com/watch?v=_GTR5vR1rq8>.

Calloway, Audra. 2018. ‘Picatinny team wins DOD award for innovative manufacturing.’ *U.S. Army*. Digital Edition: 12 January 2018. <https://www.army.mil/article/199042/picatinny_team_wins_dod_award_for_innovative_manufacturing>.

Cox, Matthew. 2018. ‘Army Chief Offers New Details on 6.8 mm Next-Gen Squad Weapons’ *The Military.com*. 8 October 2018. <https://www.military.com/kitup/2018/10/08/army-chief-offers-new-details-68mm-next-gen-squad-weapons.html>.

CTAI (CTA International). 2018. *40 CTAS: Cased Telescoped Armament System*. Sales brochure. Bourges, France: CTAI.

Cubbison, Douglas R. 2009. 'Army Historian's Report: Wanat' *US Army Combat Studies Institute.* Retrieved from *The Washington Post* on 26 May, 2019. <http://www.washingtonpost.com/wp-srv/special/world/battle-of-wanat/correspondence/documents/2-Army-Historians-Report.pdf>.

Dardick, David. 1959. 'US3046890A: Ammunition for open chamber guns.' U.S. patent. <https://patents.google.com/patent/US3046890A/>.

Devil CAAT (Task Force Devil Combined Arms Assessment Team). 2003. *The Modern Warrior's Combat Load*. Forth Leavenworth, KS: U.S. Army Center for Army Lessons Learned.

DoD (United States Department of Defense). 2011. *Technology Readiness Assessment (TRA) Guidance*. Washington, DC: Office of the Assistant Secretary of Defense for Research and Engineering.

Donnard, Reed E., Richard R. Rhodes & Thomas J. Hennessy. 1976. *Feasibility Study of 5.56 mm Folded Ammunition/Weapon System.* Report FA-TR-76061. Philadelphia, PA: Frankford Arsenal.

DOSAAF (Volunteer Society for Cooperation with the Army, Aviation, and Navy). 1968. *Sovremennoye Sportivnoye Oruzhiye i Yego Otladka* ["Modern Sporting Weapons and Their Tuning"]. Moscow: DOSAAF Publishing.

Downey, Jim. 2011. 'Mind the Gap: Cylinder Gaps on Revolvers and Their Effects on Power (and Fingers)'. *Guns.com*. 7 May. <https://www.guns.com/news/2011/05/07/mind-the-gap-cylinder-gaps-in-revolvers-and-their-effect-on-power-and-fingers>.

Dunham, J. 1966. *Development of Cartridge, Caliber .30 XM76*. Report R-1794. Philadelphia, PA: Frankford Arsenal.

Edwards, Terry. 2018. 'Flipper Must Die!'. *Small Arms Defense Journal*. Vol. 10, No. 5.

Ellis, Willard C. & John N. White. 1859. *Improvement in Revolving Fire-arms.* US24726. Available via: <https://patentimages.storage.googleapis.com/57/9d/f3/96c37a7c560cfb/US24726.pdf>.

———. 1863. *Improvement in Metallic Cartridges*. USRE1529. Available via: <https://patentimages.storage.googleapis.com/63/1f/a2/296cf7fc648ee6/USRE1529.pdf>.

Fisher, Edward B. 1977. *Basic Design Analysis of GAU-7/A Telescoped Ammunition*. Eglin AFB, FL: Air Force Armament Laboratory.

Fitch, Nathaniel. 2016. 'A History of Military Rifle Calibers: The Infantry Magnums, 1902-1914' *The Firearm Blog*. 16 May 2016. <https://www.thefirearmblog.com/blog/2016/05/16/history-military-rifle-calibers-infantry-magnums-1902-1914/>.

———. 2017a. 'INTERVIEW with Kori Phillips, Program Officer for LSAT and CTSAS, Part 1: Program History and Ammunition Technical Discussion.' *The Firearm Blog*. 11 March 2017.

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———. 2017b. ‘INTERVIEW with Kori Phillips, Program Officer for LSAT and CTSAS, Part 2: Ammunition Technical Discussion, Cont'd.’ *The Firearm Blog*. 18 March 2017. <https://www.thefirearmblog.com/blog/2017/03/18/interview-kori-phillips-program-officer-lsat-ctsas-part-2-ammunition-technical-discussion-contd/>.

———. 2017c. ‘INTERVIEW with Kori Phillips, Program Officer for LSAT and CTSAS, Part 3: Development of 6.5mm CT.’ *The Firearm Blog*. 25 March 2017. <https://www.thefirearmblog.com/blog/2017/03/25/interview-kori-phillips-program-officer-lsat-ctsas-part-3-development-6-5mm-ct/>.

———. 2017d. ‘LSAT Cased Telescoped Ammunition, and the Problem of Cookoff (Brief Thoughts 002 Follow Up).’ *The Firearm Blog*. 18 November 2017. <https://www.thefirearmblog.com/blog/2017/11/28/lsat-cased-telescoped-ammunition-problem-cookoff-brief-thougts-002-follow/>.

———. 2017e. 'The AR-15's Creedmoor? .224 Valkyrie vs. .22 Nosler and 6.5 Grendel (Modern Intermediate Calibers 025)' *The Firearm Blog*. 6 October 2017. <https://www.thefirearmblog.com/blog/2017/10/06/ar-15s-creedmoor-224-valkyrie-vs-22-nosler-6-5-grendel-modern-intermediate-calibers-025/>.

———. 2019. *Cased Telescoped Ammunition Technology*. Unpublished background paper. Perth: Armament Research Services (ARES).

Fulton, Charles L. 1962. *Silent Weapon System Cartridge Design and Development*. Report R-1654. Philadelphia, PA: Frankford Arsenal.

Goad, K.J.W. and D.H.J. Halsey. 1982. *Ammunition (Including Grenades & Mines)*. Brassey’s Battlefield Weapons Systems & Technology, Vol. III. Oxford, UK: Brassey’s Publishers.

Grandy, Andrew J. 1972. *Ammunition and Weapon Systems*. US3857339A. Available via: <https://patents.google.com/patent/US3857339A/>.

———. 1973. *Ammunition and Weapon Systems*. US3913446A. Available via: < https://patents.google.com/patent/US3913446>.

Grandy, Andrew J. & Martin H. Horchler. 1971. *The Encapsulated Folded Ammunition Concept*. Technical note TN-1161. Philadelphia, PA: Frankford Arsenal.

H., Hrachya. 2019. ‘MARS Inc. and Cobalt Kinetics Submit NEW Carbine, LMG and 6.8mm Cartridge for US Army NGSW Program’. *The Firearm Blog*. 28 August. <https://www.thefirearmblog.com/blog/2019/08/28/mars-inc-and-cobalt-kinetics-submit-new-carbine-and-lmg-for-us-army-ngsw-program/>.

Hackley, F.W., Woodin, W.H., and Scranton, E.L. 2015. *History of Modern U.S. Military Small Arms Ammunition, Volume III: 1946-1977*. Orange Park, FL: MRC3 Publishing.

Hazell, Paul J. 2016. *Armor: Materials, Theory, and Design*, page 2-3. Boca Raton, FL: CRC Press.

HGM (Heeresgeschichtliches Museum). 2018. ‘Gasdichter Revolver – System Steyr und Steyr Pieper’. YouTube video. 9 October. <https://www.youtube.com/watch?v=MELNe0-zTu0>.

Hopkins, Martin, Christopher Perhala, and C. Byron Tolbert. 2012. 'Engineering Study for Polymer Cased Telescoped Ammunition.' *NDIA 2006 Armament Systems Forum*.

Hoppmann Corporation. c. 1975. *Comparison of Folded and Telescoped Ammunition.* Springfield, VA: Hoppmann Corporation.

Hughes, James B. 1968. *Mexican Military Arms: The Cartridge Period, 1866-1967*. Houston, TX: Deep River Armory.

Hughes (Hughes Helicopter & Ordnance Systems). 1970a. *5.56mm Lockless Rifle/Machine Gun*. Culver City, CA: Hughes Helicopter & Ordnance Systems.

———. 1970b. *30mm Lockless Gun System*. Culver City, CA: Hughes Helicopter & Ordnance Systems.

———. c. 1980. *Hughes Lockless*. Culver City, CA: Hughes Helicopter & Ordnance Systems.

Hunnicutt, R.W. 1988. '8 mm Pieper Cartridge'. *American Rifleman*. April.

Imhoff, Jason W. & Thomas J. Burczynski. 2019. *Multiple-piece Cartridge Casing and Method of Making*. US20190226817A1. Available via: <https://patentimages.storage.googleapis.com/6f/9b/14/98c76b58a4a209/US20190226817A1.pdf>.

Jenzen-Jones, N.R. 2016. *Chambering the Next Round: Emergent Small-calibre Cartridge Technologies.* Working Paper 23. Geneva, Switzerland: Small Arms Survey. <http://www.smallarmssurvey.org/fileadmin/docs/F-Working-papers/SAS-WP23-cartridge-technologies.pdf>.

———. 2017. *Global Development and Production of Self-loading Service Rifles: 1896 to Present Day*. Working Paper No. 25. Geneva, Switzerland: Small Arms Survey. <http://www.smallarmssurvey.org/fileadmin/docs/F-Working-papers/SAS-WP25-Self-loading-rifles.pdf>.

———. 2018. 'Weapons Identification: Small-calibre Ammunition' in *An Introductory Guide to the Identification of Small Arms, Light Weapons, and Associated Ammunition* (Jenzen-Jones & Schroeder, eds.). Geneva, Switzerland: Small Arms Survey. <http://www.smallarmssurvey.org/resources/publications/by-type/handbooks/weapons-id-handbook.html>.

Jenzen-Jones, N.R., Jonathan Ferguson, Anthony G. Williams & Ian McCollum. 2020 (forthcoming). *ARES Arms & Munitions Classification System (ARCS)*. Perth, Australia: ARES.

Kinard, Jeff. 2003. *Pistols: An Illustrated History of Their Impact*. Santa Barbara, California: ABC Clio.

Kokalis, Peter G. 1992. 'Knight's .30 Cal. Revolver Rifle'. *Soldier of Fortune Magazine*. September.

Koll, Christian. 2009. *Soviet Cannon*. Self-published.

Lefaucheux, Eugène Gabriel. 1854. *Perfectionnements Apportés Dans les Armes à Feu* ['Improvements Made to Firearms']. 1BB19380. Available via: <http://bases-brevets19e.inpi.fr/>.

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Lyles, Ernest. 2016. ‘A brief history of the peculiar Dardick revolver and 'tround''. *NRA Blog*. 26 September. <https://www.nrablog.com/articles/2016/9/a-brief-history-of-the-peculiar-dardick-revolver-and-tround/>.

Marsh, Charles. 2006. 'Cased Telescoped Small Arms Systems.' NAVSEA Warfare Centers, Crane. *NDIA 2006 Armament Systems Forum*. <https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2006/smallarms/marsh.pdf>.

McCollum, Ian. 2015a. ‘Merwin & Bray .42 Caliber Cupfire Revolver at RIA’. *Forgotten Weapons*. 6 April. <https://www.forgottenweapons.com/merwin-bray-42-caliber-cupfire-revolver-at-ria/>.

———. 2015b. ‘Moore Teatfire Revolver at RIA’. *Forgotten Weapons*. 22 June. <https://www.forgottenweapons.com/moore-teatfire-revolver-at-ria/>.

———. 2016. ‘RIA: Savage Navy Revolver: Almost Double Action!’. *Forgotten Weapons*. 18 June. <https://www.forgottenweapons.com/ria-savage-navy-revolver/>.

———. 2019. *Chassepot to FAMAS: French Military Rifles 1866–2016*. Nashville, TN: Headstamp Publishing.

Military Review. 1974. ‘Lockless Gun’. Vol. 54, No. 7.

Mochak, Richard. *High velocity ammunition system and firearm*. US20060011092A1. Available via: < https://patents.google.com/patent/US20060011092>.

Moss, Matthew. 2018. 'British Army Set to Drop Light Machine Guns' *Overt Defense*. 21 March 2018. <https://www.overtdefense.com/2018/03/21/british-army-set-drop-light-machine-guns/>.

———. 2019a. 'BREAKING: Army Issues Call for New Next Generation Squad Weapons Prototypes.' *The Firearm Blog*. 31 January 2019. <https://www.thefirearmblog.com/blog/2019/01/31/breaking-army-issues-call-for-new-next-generation-squad-weapons-prototypes/>.

Office of Naval Research European Office. 1989. ‘Lucas Turreted Tround Gun System.’ <https://apps.dtic.mil/dtic/tr/fulltext/u2/a270684.pdf>.

Olsen, Charles R. 1980. *Revolving firearms and ammunition therefor*. US4393782A. Available via: <https://patents.google.com/patent/US4393782A/en>.

———. 1983. *Revolving Firearms*. US4457093A. Available via: <https://patentimages.storage.googleapis.com/0c/52/f1/19fc242c289e01/US4457093.pdf>.

Palmisano, Lou 1992. *PPC Cartridge Design*. Unpublished.

Pellegrino, Dominic & Charles Kirkman. 2011. ‘NATO Small Arms Ammunition Interchangeability via Direct Evidence Testing’. *NDIA 2011 Armament Systems Forum*. <https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2011/smallarms/WednesdayInter12315Pellegrino.pdf>.

Phillips, Kori. 2011. ‘Lightweight Small Arms Technologies “The Final Installment” (or is it?)'. *NDIA 2011 Armament Systems Forum*. <https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2011/smallarms/Tuesday12170Phillips.pdf>.

Phillips, Kori & Paul Shipley. 2016. 'Cased Telescoped Small Arms Systems'. *NDIA 2016 Armament Systems Forum*. <https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2016/armament/18325_Phillips.pdf>.

Popenker, Maxim. n.d. 'Peters PSDR III suppressed / silenced revolver (Germany / USA)'. *Modern Firearms*. <https://modernfirearms.net/en/handguns/psdr-suppressed-silenced-iii-2/>.

———. 2010. 'The Guns of Spetsnaz: Internally Silenced Handgun Ammunition'. *Small Arms Review*. Vol. 14, No. 2.

Popenker, Maxim, N.R. Jenzen-Jones & Jack Dutschke. 'Soviet 5.45 Ammunition Development' in *Vickers Guide: Kalashnikov, Volume II.* Nashville, TN: Mott Lake Publishing.

Revue d'Artillerie. 1901. 'Revolver Système Pieper'. Volume 58 (April–September). Paris, France: Berger-Levrault & Cie.

Rheinmetall. 1999. 'Technische Daten MK 35/50 mm Rh 503'. Data sheet. Düsseldorf, Germany: Rheinmetall.

RIA (Rock Island Auction Company). 2019. 'Lot 307: H. Genhart Brevet Turret Gun'. <https://www.rockislandauction.com/detail/76/307/h-genhart-brevet-turret-gun>.

Schatz, Jim. 2015. *Modern Advancements in Cartridge Case Technology*. Unpublished background paper. Geneva: Small Arms Survey.

Schogol, Jeff. 2017. 'New in 2018: Corps adopts M855A1 round'. *Marine Corps Times*. 11 December. <https://www.marinecorpstimes.com/news/your-marine-corps/2017/12/11/new-in-2018-corps-adopts-m855a1-round/>.

Shipley, Paul A., Gregory P. Habiak, Benjamin T. Cole & Joshua S. Ruck. *Cased telescoped ammunition firearm with headspace reduction.* US20190049199A1. Available via: <https://patents.google.com/patent/US20190049199A1/en>.

SilencerCo. 2017. 'Arsenal Blog 008: Nagant M1895'. SilencerCo company blog. 14 May. <https://silencerco.com/2017/05/14/arsenal-blog-008-nagant-m1895/>.

Singleton, Jeffery D. 2016. 'The Army Science & Technology Program.' Office of the Deputy Assistant Secretary of the Army. *NDIA 2018 Armament Systems Forum*. <https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2018/science/Singleton.pdf>.

Skochko, Leonard W. & Harry A. Greveris. 1967. *A Source of Small Arm Muzzle Noise*. Report R-1860. Philadelphia, PA: Frankford Arsenal.

Spiegel, Kori. 2004. 'Lightweight Machine Gun and Ammunition: The "Clean Slate" Approach'. *NDIA Joint Service Small Arms Symposium*.

Spiegel, Kori & Paul Shipley. 2005. 'Lightweight Small Arms Technologies (Formerly known as…Lightweight Machine Gun and Ammunition)'. *NDIA International Infantry & Joint Service Small Arms Systems Annual Symposium*. <https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2005/smallarms/wednesday/spiegel.pdf>.

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Stevens, R. Blake and Ezell, Edward C. 1987. *The Black Rifle: M16 Retrospective*, page 60. Cobourg, ON: Collector Grade Publications.

Stoner, Eugene M. 1987. *Telescoped ammunition round*. US4770098A. Available via: <https://patents.google.com/patent/US4770098>.

Textron Systems. 2017. *Cased Telescoped (CT) Weapons and Ammunition*. Sales brochure. Hunt Valley, MD: Textron Systems.

The Met (The Metropolitan Museum of Art). n.d. 'Collier Second Model Five-Shot Flintlock Revolver'. <https://www.metmuseum.org/art/collection/search/27563>.

Thuer, F. Alexander. 1868. *Improvement in Revolving Fire-arms.* US82258A. Available via: <https://patents.google.com/patent/US82258A>.

Trevithick, Joseph. 2019. 'This Exotic Bullpup Rifle Is Competing To Replace The Army's M4 Carbines And M249 SAWs'. *The Warzone*. 17 October. <https://www.thedrive.com/the-war-zone/30472/this-exotic-bullpup-rifle-is-competing-to-replace-the-armys-m4-carbines-and-m249-saws>.

UMC (Union Metallic Cartridge Company). 1887. *Price-list of Metallic Cartridges, Paper and Brass Shot Shells, Gun Wads, Primers, Percussion Caps, etc.* Bridgeport, CT: Union Metallic Cartridge Company.

———. 1889. *Metallic Cartridges, Paper and Brass Shot Shells, Wads, Percussion Caps, Primers, etc. Manufactured by The Union Metallic Cartridge Company*. Bridgeport, CT: Union Metallic Cartridge Company.

———. 1910. *1910 Illustrated Catalogue*. Bridgeport, CT: Union Metallic Cartridge Company & Ilion, NY: Remington Arms Company.

U.S. Army. 1996. *Tactics, Techniques, and Procedures for Field Artillery Manual Cannon Gunnery*. FM 6-40. Washington, D.C.: Headquarters, Department of the Army.

U.S. Department of Justice. 2008. 'Ballistic Resistance of Body armour NIJ Standard-0101.06' <https://www.ncjrs.gov/pdffiles1/nij/223054.pdf>.

U.S. Senate (U.S. Senate Committee on Armed Services). 2017. 'Army Modernization'. Subcomittee on Airland. 22 March. <https://www.armed-services.senate.gov/imo/media/doc/18-10_02-07-18.pdf>.

Vos, Roelof & Saeed Farokhi. 2015. *Introduction to Transonic Aerodynamics*. Dordrecht, The Netherlands: Springer.

Vranic, Miko. 2018 'AUSA 2018: New details emerge on 6.8 mm Textron Systems NGSWs' *The Jane's 360*. 11 October 2018. <https://www.janes.com/article/83753/ausa-2018-new-details-emerge-on-6-8-mm-textron-systems-ngsws>.

White, Rollin. 1855. *Improvement in Repeating Firearms*. US12648. Available via: <https://patentimages.storage.googleapis.com/d6/74/2a/f745697026ec64/US12648.pdf>

Willbanks, James H. 2004. *Machine Guns: An Illustrated History of Their Impact*. Santa Barbara, CA: ABC CLIO.

Williams, Anthony G. 2008. ‘The Heavy Machine Gun Cartridge: Postwar Efforts”. *Small Arms Review*. Vol. 11, No. 5.

———. 2015. *Introduction to Modern General-purpose Calibres*. Unpublished background paper. Perth, Australia: ARES.

———. 2016. 'The Case for a General Purpose Rifle and Machine Gun Cartridge (GPC).' *Military Guns & Ammunition*. <http://quarryhs.co.uk/TNG2.pdf>.

———. 2018 'The US Army’s Next Generation Squad Weapon programme' *UK Land Power*. 19 October 2018. <https://uklandpower.com/2018/10/19/the-us-armys-next-generation-squad-weapon-programme/>.

Williams, Anthony G. & N.R. Jenzen-Jones. 2016. *Open-tip & Expanding Projectiles: Development, acquisition, and use history*. Perth, Australia: Armament Research Services (ARES).

Williamson, David. 1864. *Improvement in Cartridges for Revolving Fire-arms*. US41183. Available via: <https://patentimages.storage.googleapis.com/5e/5d/f2/33487ac912fe7e/US41183.pdf>.

Wood, William W. 1865. *Fire-arms and Cartridges*. GB186500309A.

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