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Desktop Firearms:

Emergent Small Arms Craft Production Technologies

G. Hays & Ivan T.
with N.R. Jenzen-Jones

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Authors:	G. Hays & Ivan T. with N.R. Jenzen-Jones
Editor:	N.R. Jenzen-Jones
Technical reviewers:	Jonathan Ferguson & Bruce Koffler
Layout & Design:	Justin Baird

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About the Authors

G. Hays

G. Hays is a firearms researcher with a specific interest in improvised and craft-produced weapons. He has documented hundreds of different designs and examined methods of manufacture, design influences, and user types. He has produced original research for ARES and other organizations, mostly focusing on the design, development, and employment of improvised and craft-produced small arms and light weapons. Together with N.R. Jenzen-Jones he authored one of the foundational works on craft-produced weapons, *Beyond State Control: Improvised and Craft-produced Small Arms and Light Weapons*, published by the Small Arms Survey in 2018.

Ivan T.

Ivan T. is a firearms enthusiast with a particular interest in manufacturing technologies and techniques. They have worked to develop '3D-printable' magazines and receivers; electrochemical machining systems and methods; and other tools and techniques useful to the home gunsmith. In addition to working as a developer for Deterrence Dispensed, Ivan has conducted original research into the recent history of craft-produced firearms in both the United States and globally, with a particular focus on the application of advanced and emergent technologies to small-scale home production.

N.R. Jenzen-Jones

N.R. Jenzen-Jones is an arms and munitions intelligence specialist focusing on current and recent conflicts and weapons technologies. He is the Director of Armament Research Services (ARES), the Director of Research for Headstamp Publishing, and holds Visiting Fellowships at the Centre for the Reduction of Firearms Crime, Trafficking and Terrorism at the University of Northampton, and in the School of Law, Policing and Forensics at the University of Staffordshire. He serves in consultancy roles with a number of prominent organisations in the field, and has produced extensive research and analysis on a range of small arms and light weapons (SALW) and small- and medium-calibre ammunition issues. Mr. Jenzen-Jones maintains a broad focus on how weapon systems are selected, acquired, stockpiled, and employed.

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AVOID the area

RECORD all relevant information

MARK the area to warn others

SEEK assistance from the relevant authorities

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Cover image: *A member of Deterrence Dispensed test-fires the FGC-9 self-loading carbine (source: JStark1809).*

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Abbreviations & Acronyms

ACP	Automatic Colt Pistol (cartridges)
AM	Additive manufacturing
AP	Armour-piercing
BJP	Binder jet printing
CAD	Computer-aided design
CNC	Computer numerical control
CP Ti	Commercially pure Titanium
DD	Defense Distributed
det_disp	Deterrence Dispensed
DIAS	Drop-in auto[matic] sear
DIY	Do-it-yourself
DMLS	Direct metal laser sintering
EBF	Electron beam freeform fabrication
EBM	Electron beam melting
ECM	Electrochemical machining
ECR	Electrochemical rifling
EDM	Electrical discharge machining
F3DP	Fully 3D-printed
FCG	Fire control group
FDM	Fused deposition modelling (also ‘fused deposition of material’)
FFF	Fused filament fabrication
FGC-9	F**k Gun Control 9
Fosscad	Free Open Source Software – Computer Aided Design (also ‘FOSSCAD’)
IRC	Internet Relay Chat
ITAR	International Traffic in Arms Regulations
PKC	Parts kit conversion (also ‘parts kit completion’)
PLA	Polylactic acid polymer
SMG	Sub-machine gun
SLM	Selective laser melting
SLS	Selective laser sintering
STL	Stereolithography

Introduction

Fundamentally, firearms are a simple technology. In their most primitive form, a firearm may consist of no more than a tube sealed at one end and open at the other, with small a hole through which a charge of propellant is ignited. Historically, this was the same propellant which is still packed into fireworks enjoyed every year around the world. Up until the Industrial Revolution—and its attendant advances such as the production line—firearms were made entirely by hand, usually by a single gunsmith, perhaps with an assistant or apprentice. Today, individuals in much of the world have unfettered access to an extensive virtual library containing the accumulation of more than 700 years of gun-making knowledge. Whereas once a firearm's barrel had to be skilfully and laboriously forged around a mandrel from a solid piece of iron, for example, suitable thick-walled precision steel tubing—a ready-made barrel save for a breech/chamber or breech-plug— may now be purchased online or from a local hardware store.[1] Early firearms makers were often forced to develop and produce their own specialised tooling, whereas today advanced tools can be readily acquired by individuals. Inevitably, the production of firearms has continued to incorporate new technologies, of which those found to be readily replicated with less demanding input from the maker have tended to prove successful (Hays & Jenzen-Jones, 2018). Whilst the firearms industry has historically tended toward conservatism, relatively new technologies such as 3D printing (also known as 'additive manufacturing'; AM) offer sufficient advantages to even major manufacturers that they have found acceptance in commercial design and manufacture as well (Jenzen-Jones, 2015).

Craft-produced firearms are generally understood to be those which are fabricated primarily by hand in relatively small quantities. Often as simple as improvised 'zip guns'[2], they are recovered daily by police forces across the world, frequently in countries where local laws restrict the legal acquisition of firearms (Hays & Jenzen-Jones, 2018). In more recent years, there has been an uptick in the legal craft production or home-assembly of weapons in nations where firearms are more easily obtained, such as the United States (ARES, 2019). Partially homemade weapons assembled using un-serialised components are increasingly seized from criminal groups in other countries, such as Canada and Mexico. In cases of both legal and illegal acquisition, these weapons are often hybrid designs combining available firearm components with substituted non-firearms or craft-produced parts (ImproGuns, 2018a).

The increasing affordability of hobbyist machines and tooling, such as small desktop lathes and computer numerical control (CNC) mills[3], as well as the proliferation of (and improvement in) consumer-grade 3D printers, has led to significant advances in home manufacturing techniques (Federico, 2019). These allow for greater ease in the production of certain otherwise-unavailable or regulated firearm components. Designs may be both created and shared by skilled individuals in the form of computer-aided design (CAD) files or in other digital formats. The process for producing fairly complex parts now requires significantly fewer skills and less experience on the part of an individual craft-producer than at any other time in history. Although not quite a case of hitting 'Ctrl-P', these new technologies do significantly reduce the barriers to entry for those wishing to attempt manufacture of a firearm. As such, they increasingly represent a realistic method by which an individual may easily acquire a firearm. Accordingly, such methods also represent a challenge to the governmental control and regulation of firearms manufacturing.

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[1] Also written 'C90' or 'C-90-CR' etc. Both formats have been observed on official paperwork and packaging. For this report, we will use 'C-90' and 'C90-CR', consistent with the most recent marketing material and training manuals available. This is the basis of the so-called 'slam gun'. See Hays & Jenzen-Jones, 2018, pp. 65– 67.

[2] Zip guns are generally understood to be improvised, single-shot, small-calibre firearms that lack a conventional trigger mechanism (Hays & Jenzen-Jones, 2018, p. 64; Koffler, 1969, pp. 520–521).

[3] CNC mills are, in essence, the opposite approach to additive manufacturing and represents a modern take on earlier machining and hand-crafting methods. A piece of material is gradually machined away in a series of precise, computer-controlled operations until the final shape is achieved.

The vanguard of 'home gunsmith' development has largely been located in the U.S., however there are a number of notable and active European contributors. Most designs continue to utilise 3D-printed components wherever possible, due to their low cost and ease of production, and supplement these with metal components obtained in varying ways. Whilst a range of new technologies may be employed to craft-produce firearms, the focus of this report will be on technologies that scale down to the individual level—that is, those technologies accessible to the average hobbyist in a developed country on the basis of legal status, commercial availability, price, and ease of use. As of early 2020, the entire receiver (or frame)[4] of certain semi-automatic firearms as well as their magazines may be produced on a commercial-grade 3D printer costing no more than 200 USD[5]. Furthermore, a firearm's barrel may be fashioned from a piece of steel tubing, chambered, and rifled using an electrochemical machining (ECM) method, with the aid of a 3D-printable jig (ImproGuns, 2017; 2019). Many of the remaining metal components such as the bolt, firing pin, and trigger mechanism may in some cases be produced by combining less-durable 3D-printed parts with off-the-shelf metal components for increased structural strength. Hybrid firearms designs—that is, those most often combining a combination of production technologies, such as 3D printing, desktop CNC mills, and ECM—are increasingly the norm for modern craft production in the developed world. These processes and the associated designs are being rapidly refined and improved by 'home gunsmiths' and enthusiasts, mostly in the United States. In the near future, it will be possible to assemble a semi-automatic or automatic pistol-calibre firearm—comparable to a factory-made weapon in all respects—from 90 per cent 3D-printed parts. The remaining metal components may be discreetly obtained either online or from a hardware store almost anywhere in the world, and finished in the home (C., 2019).

Figure 1.1 *A Glock 17 pistol with a 3D-printed (pink) polymer frame (source: Ivan T./ARES).*

[4] The 'receiver' (frame in the case of handguns) is the main body of the firearm which accepts or 'receives' all other components.

[5] See for example the 'Creality Ender 3' (Creality, n.d.).

A Brief History of 3D-printed Firearms

On 5 May 2013, Defense Distributed (DD)—a self-described "…private defense contractor in service of the general public", based in Austin, Texas—released the data for an almost entirely 3D-printed firearm (see Figure 2.1) (Defense Distributed, 2019). Christened the 'Liberator' after the small, disposable, single-shot .45 ACP pistol developed during the Second World War, it could be printed on a relatively inexpensive consumer-grade 3D printer, the only additional part being a nail to act as a firing pin.[6] A video released by the group showed spokesman Cody Wilson firing a single .380 ACP round using the pistol, proving the concept of an entirely plastic firearm as at least viable for a small number of shots (Defense Distributed, 2013; Greenberg, 2013a). The ensuing publicity leading up to and following the release resulted in a letter from the U.S. Department of State to the company, advising them of an apparent International Traffic in Arms Regulations (ITAR) violation, and requesting the company remove download links to the Liberator design files (Greenberg, 2013b). More than 100,000 people downloaded the Liberator stereolithography (STL) design files in the two days they were hosted on Defense Distributed's website (Neal, 2013). Prior to the release of the design, a lease between DD and Stratasys, the US-based manufacture of the 3D printer used in producing many of DD's firearms designs, was cancelled by the latter company (Beckhusen, 2012). From this point onwards, and largely as a direct result of the publicity surrounding the work of Defense Distributed, 3D printing of firearms and firearm components began to proliferate (Fey, 2017, pp. 21 – 30).[7]

Figure 2.1 *The Liberator single-shot pistol released by Defense Distributed in 2013 (source: Michael Carter/Forbes).*

[6] Like its modern namesake, the original FP-45 Liberator was designed to make use of the then-state-of-the-art in expedient firearms manufacturing technology. In the 1940s, this was stamped, folded and welded sheet steel. See (Canfield, 2012, pp. 48–51; 83–84).

[7] For a wider assessment of the viability and potential security risks associated with 3D printing and other consumer-level additive manufacturing technologies see Jenzen-Jones, 2015; Shaw et al, 2017.

Later in 2013, Austin, Texas-based 3D printing company Solid Concepts[8] made public their success with printing an all-metal copy of the well-known M1911 self-loading pistol called the 1911 DMLS. Production of this design used a direct metal laser sintering (DMLS), a high-end AM method in which powdered metal is fused using a high-powered laser. A combination of Inconel 625 (a nickel-chromium alloy)[9] and stainless steel was used to print the gun using a German made German EOSINT M270 Direct Metal 3D Printer—a machine costing in the region of 600,000 USD at the time. The grip panels were manufactured from a carbon-filled nylon 12 powder, using selective laser sintering (SLS), a process equivalent to DMLS but using polymer powders (Farago, 2013). Not only was the production equipment expensive, the finished product was offered for sale at the remarkably high price of 11,900 USD per handgun. Nonetheless, the finished pistol was reportedly both accurate and reliable, having fired more than 4,500 rounds with no damage to the gun or replacement parts required, and represented an important step in 'mainstreaming' 3D printing technology for firearms use (Hollingsworth, 2013; SMC, 2013; Jenzen-Jones, 2015).

Following the U.S. State Department's effective shutdown of Defense Distributed's freely available downloads, followers of DD re-hosted the restricted files via a variety of online hosting services. Some of those followers subsequently banded together under the name 'FOSSCAD' (Free Open Source Software – Computer Aided Design; usually rendered in lower case as 'Fosscad'). Fosscad members made significant progress in furthering the use of 3D printing for firearms development, both in improving Defense Distributed's designs, and in pioneering new designs. Printed AR-15 lowers were further perfected as seen in the 'V5.1' and 'Vanguard' lowers (amongst others) shared by Fosscad (ARES, 2019). One user who went by the pseudonym of 'Derwood' designed a platform known as the 'Shuty', named for (if not substantially derived from) the sub-machine gun design developed in the 1990s by Englishman Philip A. Luty. The Shuty uses a printed structure—comprised of upper and lower receivers, bolt housing, and receiver extension—paired with a bolt made from steel rods, a factory-made Glock 17 barrel, and an AR-15 lower parts kit (ARES, 2016). The platform was initially released in 2016 as the Shuty MP-1 and it continues to be improved to this day.

As Defense Distributed remained entangled in multiple legal battles over the years, several people active in online discussion forums decided to band together under the banner of 'Deterrence Dispensed' (a not-so-subtle nod to Defense Distributed) in February 2019 (Deterrence Dispensed, n.d.). Like Fosscad, the group (known as sometimes by the shorthand 'det_disp') operates as a decentralised collective of designers and publishers who use a variety of platforms to communicate and to improve upon designs, often sharing pre-release (or 'beta') files for peer review and testing to ensure quality upon final release. So far, the group have released more than 30 original files for the creation of 'printable' receivers, magazines, and even entire firearms. They remain at the forefront in the development of 3D-printable firearm designs and adoption of emergent manufacturing technologies (ARES, 2019).

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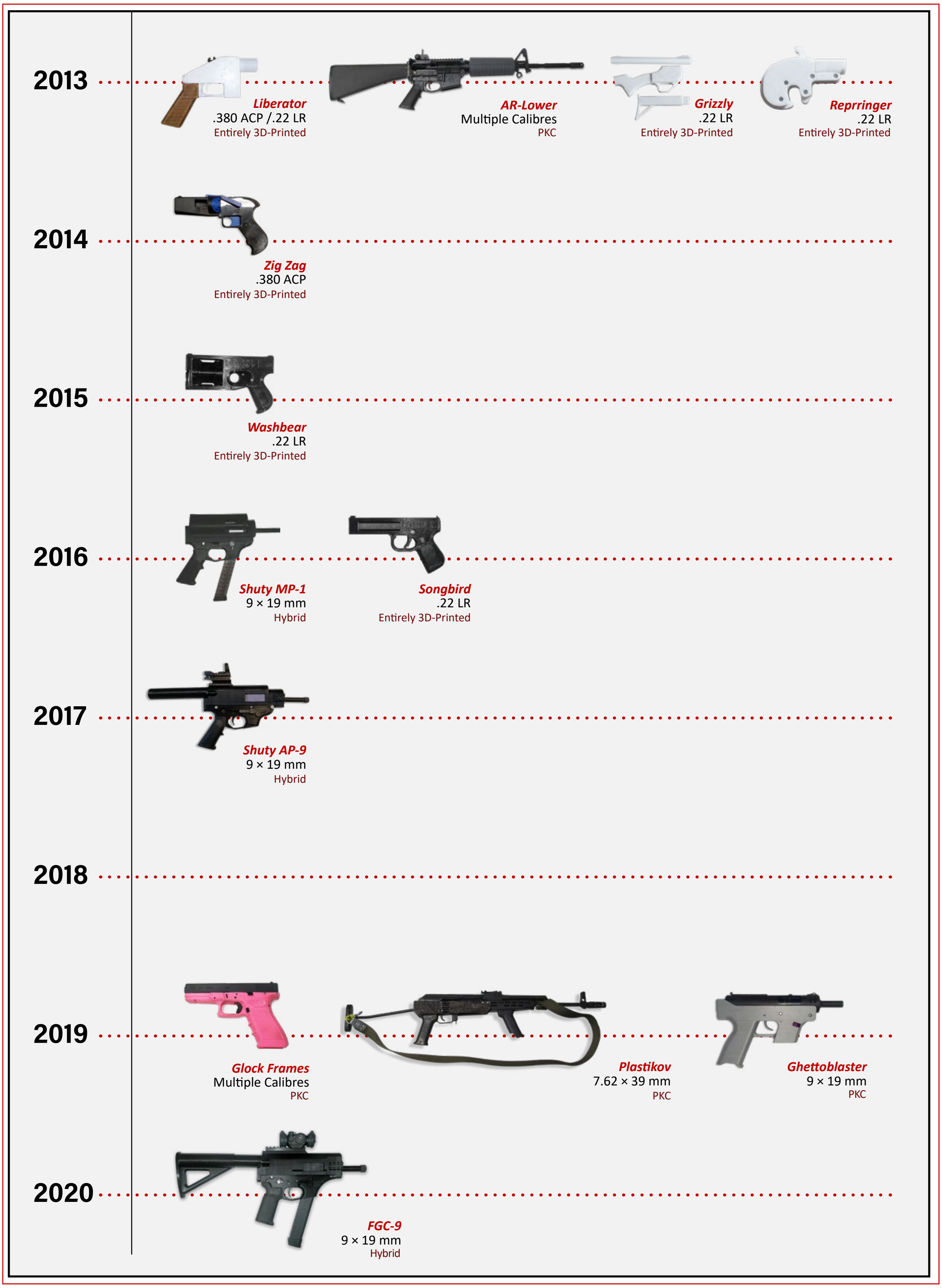
[8] Solid Concepts was later acquired by Stratasys.

[9] SpaceX has also used 3D-printed Inconel alloy in its 'SuperDraco' thruster system (SpaceX, 2014).

Timeline of Selected 3D-printed Firearms



Notes: *Non-exhaustive. See text for further details.*

Categorising 3D-printed Firearms

While some 3D-printed firearm designs such as the famed 'Liberator' are indeed almost entirely constructed from polymers (and therefore subject to some unforgiving material limitations), recent developments have involved the integration of critical metal components such as steel barrels and breech faces. Just as in factory-made designs, these components are able to adequately contain the pressures subjected upon them from the rapid deflagration of propellant that takes place inside a modern cartridge.[10] The reliance on printed parts and incorporation of typically regulated components is perhaps the best determining factor when categorising 3D-printed firearms. All 3D-printed firearm designs in circulation fall into one of the three categories outlined below, which are summarised in Table 3.1.

Table 2.1 — Relative characteristics of the three categories of 3D-printed firearms

	F3DP	HYBRID	PKC
Durability	Low to Moderate	Moderate to High	Moderate to High
Capability	Low	Moderate to High	High
Ease of Production	Moderate to High	Moderate	Moderate
Accessibility of Parts	High	Moderate	Low to Moderate
Cost of Production	Low	Low to Moderate	Low to High

Notes: *These are necessarily generalisations, and depend on numerous factors. See more detailed descriptions below. There are edge cases which could be considered either Hybrid or PKC designs. The assumptions regarding durability and capability depend largely on the builder's ability to follow the specifications and instructions that accompany the CAD files. When the these are not followed, the firearms produced can be significantly less capable or less durable, and may be more dangerous to operate.*

Fully 3D-printed firearms

3D-printed small arms in this category require no pressure-bearing non-printed components, but may contain minor non-printed parts, such as a nail to act as a firing pin or an elastic band to power a hammer. Because of the near-total absence of metal components, designs such as these have become the focus of many sensationalist media reports. 'True' or 'Fully' 3D-printed (F3DP) firearms are in most cases only usable for a limited number of shots before parts become either too distorted or structurally unsafe to use. The vast majority of firearms in this category are either single-shot pistols or combine multiple barrels in a 'pepperbox' arrangement to allow for multiple shots.[11] The most widely publicised firearm which fits into this category is the Liberator pistol released by Defense Distributed in 2013. Others include the Songbird single-shot pistol, and the Washbear PM522 and Hexan (.22 LR) revolvers (see Figure 3.1) (ARES, 2019). To increase longevity, sections of steel tubing are sometimes inserted into the barrels and/or chambers of such firearms, providing a level of capability and robustness that is at least equal to, and frequently better than, traditional craft-produced firearms in the zip gun category. These would then constitute hybrid designs, as outlined below, although it is accepted that there is some blurring of the line between the two categories.

[10] These pressure- or stress-bearing components include the barrel, slide or bolt, and the trigger mechanism (as opposed to the lower receiver or housing that contains it). In many jurisdictions around the world, all pressure-bearing components are legally controlled.

[11] 'Pepperbox' is a term coined in the antique firearms collecting world for a simplified form of revolving firearm lacking a fixed barrel. These elongated the chambers to act as both chamber and barrel, lending the weapon the same many-holed appearance as the traditional cylindrical household ground pepper dispenser. The term is still in use for any revolving pistol with this multi-barrelled design (ARES, 2017; Hays & Jenzen-Jones, 2018, p. 71).

Figure 3.1 *The Washbear PM522 (top) and Hexan .22 LR (bottom) pepperbox-type pistols are examples of entirely 3D-printed firearms (source: Metropolitan Police).*

Hybrid 3D-printed firearms

Hybrid 3D-printed firearm designs rely on readily available components that are globally unregulated, such as steel tubing, metal bar stock, and springs. Such designs are primarily 3D-printed but utilise non-restricted metal parts primarily for strengthening major assemblies or to serve as barrels and chambers. Most of these parts are so innocuous as to ordinarily attract little attention from law enforcement or intelligence agencies. Despite not using purpose-made firearms parts, hybrid designs can still offer broadly comparable performance to some types of conventional weapons. Where available, unregulated firearms components (such as magazines) may be incorporated.

The 'Liberator 12k' is a six-shot 12-gauge hybrid shotgun design which is primarily constructed of 3D-printed parts, supplemented by lengths of steel tubing, available either online or from a local hardware store or supplier (see Figure 3.2). The main frame of the gun is structurally supported by two long steel bolts which run through the length of the upper body and provide rigidity and strength. Such methods, especially when paired with lower-pressure cartridges, negate the requirement for a solid metal frame. They are analogous, in conceptual terms, to some commercial firearms designs with metal-reinforced polymer receivers. The cylinder is fitted with six inserts of steel tubing which are affixed with a strong epoxy. After the fashion of the early 20th century Webley-Fosbery revolver, each chamber is 'indexed' into firing position through mechanical means via contact between the cylinder stop and a series of external grooves incorporated into the design of the cylinder. This method provides for a reasonably robust and reliable system that avoids reliance on the many small and high-stress parts needed when copying a conventional revolver design indexed by means of a 'hand' or pawl.[12]

[12] I.e. the system used in all modern revolvers since the Colt patents of the early 19th century, in which the pawl is driven up into a ratchet on the rear of the cylinder, rotating it. This system requires a robust and relatively complex locking system to prevent misalignment.

Hybrid designs presently represent the most viable 3D-printed firearms in countries with strict legal controls on small arms, such as many European nations. The FGC-9, for example, is widely regarded as being the most capable 3D-printed firearm currently designed, and can be constructed without any firearms parts (see Pushing the Envelope: The FGC-9, below). Unlike those of the previous category, hybrid 3D-printed designs are often self-loading, have a large magazine capacity, and may be capable of firing one of many different modern centrefire cartridges.

Figure 3.2 *The 'Liberator12k' is a hybrid 3D-printed six-shot pump-action revolver shotgun. This design relies on thick-walled steel tube inserts and uses no original-purpose firearms components (source: Rodriguez, 2019).*

Firearms with 3D-printed receivers

The final category includes firearms which have been assembled using a 3D-printed receiver (or frame), but in which most or all of the pressure-bearing components (e.g. the barrel, slide, and bolt) are commercial, factory-made parts. These designs, sometimes referred to broadly as 'parts kit conversions' or 'parts kit completions' (PKC), are generally the most reliable of those firearms that utilise 3D-printed parts—often just as capable as factory-made guns. However, these designs typically incur the highest material cost and may be more difficult to build if certain components are restricted by law.

Figure 3.3 *The 'Low Point' 9 mm pistol frame, designed by Ctrl+Pew and released in December 2019 (source: Ctrl+Pew).*

In the U.S. context, and in jurisdictions with similar firearms laws, designs in this category are often assembled around legally obtained firearms parts supplied as complete kits, save for a receiver or frame (or part thereof) due to the legal control of that component. In some cases, parts may be acquired very cheaply. The 'Lo-Point' printed frame design, for example, takes advantage of the very low price of parts kits for a particular firearm (see Figure 3.3). Designed by developer 'Ctrl+Pew' in November 2019, the design is based around the Hi-Point series of 9 × 19 mm self-loading pistols (KARVER, 2019). The Hi-Point firearms typically retail for less than 200 USD, and the parts available for them are correspondingly economical. Entire parts kits are often auctioned off in large numbers by companies tasked with destroying guns seized by U.S. police departments. These kits include all components except the legally controlled frame, and can sometimes be purchased for less than 30 USD.

In some cases, controlled firearms parts are acquired illegally. Broadly speaking, firearms components are easier to smuggle across national borders than complete weapons, which has led to some individuals ordering such components online, including via the dark web.[13] In many cases, such parts may lack unique or group identifiers, such as serial, lot, or batch numbers. This provides little intelligence as to potential sources, making interdiction more difficult.

Figure 3.4 *A 3D-printable lower receiver assembly capable of accepting a Cobray M11-9 upper receiver, AR-type fire control group, and Glock magazines (either factory-made or printed), designed by a Deterrence Dispensed contributor who goes by the pseudonym 'FreeMenDontAsk' (source: FreeMenDontAsk).*

[13] ARES interviews with confidential sources.

Obtaining a Craft-produced Firearm

Concepts and requirements

Craft-produced firearms are most often made by individuals for personal use, usually the result of experimentation as part of a hobby. This is, of course, either licit or illicit activity depending upon the jurisdiction. For example, it is quite legal in the USA for an individual to manufacture a firearm provided they do not then sell it, whereas any successful manufacture of a 'component part' in English or Scottish law represents a serious crime (ATF, 2020; CPS, 2019). Although many makers have no intention of profiting from their activities, adequately skilled individuals may be incentivised to manufacture and supply craft-produced or modified firearms for profit both on a small or large scale. Again, this activity can be legal or illegal. Skilled individuals employed in relevant trades may be approached by criminals or criminal groups to produce firearms for them, being supplied either blueprints or an original weapon to reverse-engineer. In other cases, the traditional craft is passed on through family within local communities where the trade often provides necessary income (Hays & Jenzen-Jones, 2018; Hills, 2017).

Craft-produced firearms have long been produced by hand, using traditional manufacturing techniques and technologies. Increasingly, these may be augmented or supplanted by emergent methods, such as 3D printing, miniaturised ('desktop') CNC machines, and small-scale ECM. The production of entirely 3D-printed or hybrid firearms—and even the assembly of 'parts kit' firearms, depending on jurisdiction—offers an easy way for an individual assemble a viable firearm which is difficult for law enforcement to trace through conventional means.

There are a variety of reasons an individual may choose to produce a firearm, which may range from the simple enjoyment gained in completing a technical challenge, to an urgent need for a self-defence tool, or even for criminal or warfighting purposes. In some cases, the choice to attempt craft-production may be influenced by an inability to acquire firearms legally, or through conventional black-market routes. Some criminal elements may be attracted to the low cost and disposability of craft-produced weapons, something reflected in the success of the early zip guns of 1950s and 1960s America, or the tumberas of modern Latin American street gangs (Koffler, 1969; Hays & Jenzen-Jones, 2018). At SHOT Show 2020, the annual U.S. firearms and outdoor industry trade show held in Las Vegas, the Liberator 12K was featured at the Serbu Firearms booth, highlighting a growing interest in 3D-printed firearms technology from both consumers and manufacturers (see Figure 4.1).

As with traditional craft production, the primary 'barrier to entry' for a prospective craft-producer of 3D-printed firearms is their level of interest and determination. The largely automated nature of 3D printing has significantly lowered this barrier when compared to traditional craft production methods—the layperson with access to a 3D printer is now able to print out the receiver for an AR-15 rifle or Glock pistol at home, with relatively little manual work involved, in less than a day of printing time.[14] representing a huge shift in the nature of craft production. For example, according to one active developer, a new user to the det_disp Keybase group went from purchasing a 3D printer online to printing a Glock frame within just one week (ARES, 2019).

[14] For example, the stated print time for one AR-15 lower receiver in 2019 was 17 hours (Potatosociety, 2019).

Table 4.1 — Users and producers of improvised and craft-produced weapons, their motivations, and associated risks.

USERS AND PRODUCERS	PRIMARY MOTIVATIONS FOR ACQUISITION OR PRODUCTION	ASSOCIATED RISKS
Tribal groups and families	Cultural reasons, limited availability of conventional firearms, hunting, deterrence, self-defence	A decline in access to or production of craft weapons may lead to an increased use of commercial weapons. Craft weapons may be used in conflict.
Hobbyists and collectors	Interest	Minimal direct threat to others, although the sharing of know-how online may facilitate production by and proliferation among criminals and non-state armed groups. If poorly designed, the weapons may harm users if fired.
Gunsmiths and engravers	Livelihood or supplemental income (see Section III)	Production is unregulated and contributes to illicit proliferation, including of semi-professional copies of commercially-available weapons.
Subsistence poachers	Limited availability of conventional firearms, livelihood	Possession facilitates crime. Safety issues may threaten users and bystanders.
Traffickers	Limited availability of conventional firearms, profit (see Box 3)	Trafficking exacerbates illicit proliferation and the arming of non-state armed groups.
Individual criminals	Limited availability of conventional firearms, low cost, limited traceability, easy concealment	Possession facilitates crime. Safety issues may threaten users and bystanders
Criminal organizations	Limited availability of conventional firearms, low cost, limited traceability, easy concealment	Possession facilitates crime. Safety issues may threaten users and bystanders
Insurgent groups and militias	Limited availability of conventional firearms, filling capability gaps, supplementing holdings or facilitating capture of industriallyproduced weapons	Acquisition facilitates armed conflict, including attacks on civilians and security and military personnel.
States	Limited availability of conventional firearms, circumventing sanctions or embargoes	Acquisition or production may entail the misuse of international aid and can facilitate armed conflict.

Source: *Hays & Jenzen-Jones, 2018*

Figure 4.1 *The Liberator 12K featured at the Serbu Firearms booth at SHOT Show 2020 in Las Vegas (source: Jeff Rodriguez).*

Information Accessibility

Construction plans, original machinist's drawings, video tutorials, and detailed CAD models for craft-produced firearms have been widely available—in both amateur and professional formats—for decades (see Figure 4.2) (Colvin, 1917; Luty, 1998; Hays & Jenzen-Jones, 2018). Increasingly, such plans have been made available online. This trend, coupled with the rapidly increasing availability of consumer-grade 3D printing technologies and other production methods, has given rise to a growing network of hobbyists dedicated to digitising all types of physical objects. Computer-aided design (CAD) files for firearms and various components have been available since the early 2000s (Snider, 2003; Guslik, 2012). Whereas once detailed 3D models would have had limited application outside of the commercial engineering and manufacturing industry, the advent of affordable consumer-grade 3D printers has spurred the interests of many, allowing individuals the ability to readily create physical models from downloaded files. User-submitted CAD files for entire firearms now proliferate; both amateur attempts exhibiting dubious accuracy (and therefore dubious production viability) as well as highly accurate models reverse-engineered from original examples or translated from original blueprints (ARES, 2019). Certain firearm accessories are particularly suitable for creating on a consumer-grade printer due to their size and relative lack of complexity, such as grips, stocks, and rail attachments.[15]

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[15] See, for example, search results on the Thingiverse site for 'AR15'; https://www.thingiverse.com/search?q=ar15&type=things&sort=popular

Figure 4.2 *A .22 LR calibre revolver, made using traditional craft production techniques and based upon widely available construction plans. The skill level required to produce this sort of craft-produced firearm is higher than for some 3D-printed designs (source: ImproGuns).*

Discussion groups dedicated to firearm manufacture have existed for a long time, evolving from trade groups and in-person meetings into online message boards and mailing lists. Websites followed. Two long-running websites—both operating for more than a decade—are Homegunsmith.com and Weaponsguild.com. With the advent of social media platforms and mobile devices, exposure to online groups and the media released by their participants has increased. Videos may easily be sought out or even stumbled upon in the course of related internet searches. Those posts or, especially, videos accruing high view counts (sometimes into the millions) and positive comments lend instant credibility to a design, where once books, pictures, or written instructions in text files or forum posts may have left feasibility in question. Additionally, technical questions may be easily asked and are often quickly and helpfully answered via comment instantly accessible to a large and willing pool of discussion participants. In this way, knowledge may be both readily obtained and affirmed.

[16] It is important to note that a variety of groups, pages, and other fora intended for professional gunsmiths are available online, and there is significant overlap between amateur and professional outlets.

Both open and closed groups dedicated to 'home gunsmithing'[16] exist on large sites such as Facebook with hundreds of members. Other platforms such as the Russian based social media site VK also host many active groups. High profile platforms such as Reddit and Facebook have attempted to restrict this activity. In 2018, Facebook amended its policy to prohibit the sharing of files and instructions for gun making, but exempted 'legitimate' gun shops and online vendors from marketing said files and instructions (Garcia, 2018). Reddit followed suit in 2019 with a ban on "...3D printed files to produce firearms...[including]...torrent links" (Reddit.com, 2020) and most firearms-related subreddits have attempted to follow this guidance. Users are nevertheless still free link to other sites and share the results of their 3D printing efforts, growing and enabling interest in the technology as it pertains to firearms. Since 2018, YouTube policy ('community guidelines') on firearm-related content has prohibited videos which are "intended to sell firearms, instruct viewers on how to make firearms, ammunition, and certain accessories, or instruct viewers on how to install those accessories". Specifically prohibited are "accessories that convert a firearm to automatic fire, such as: bump stocks, gatling triggers, drop-in auto sears, or conversion kits" (YouTube, n.d.). A large number of firearms and history channels have reported that their videos have been 'demonetised' (making them ineligible to earn advertising revenue for creators, and making them less likely to be returned in search results), or have suffered harsher consequences, such as 'community guideline strikes' (essentially written warnings), being marked 'not family friendly' (all but eliminating advertising revenue), and even channel suspension or deletion. Several of these channels reported not publishing any content that, to the best of their knowledge, violated YouTube's guidelines. The opaque nature of YouTube's enforcement mechanism and a perceived lack of accountability led the popular channel InRangeTV to say that YouTube's "vague and one-sided firearms policy makes it abundantly clear that YouTube cannot be counted upon to be a safe harbor for a wide variety of views and subject matter" (InRange TV, 2018). According to a VICE News interview InRange TV "view[s] these new rules as a dangerous slippery slope away from freedom of speech on the internet's largest public square of video content" (Turton, 2018).

With restrictive policies and selective enforcement on the sharing of information on larger platforms, groups dedicated to developing designs using emergent technologies have thrived on encrypted chat applications and older generation chat protocols like Internet Relay Chat (IRC). Fosscad operate an active IRC channel and, until its removal in early 2019, had one of the most active 3D-printed firearm news feeds on Twitter.[17] Formed in February 2019, Deterrence Dispensed (also known as 'det_disp') remains the most active group dedicated to 3D-printed firearms online (T, 2019). It currently operates the third largest group or 'team' on the encrypted chat platform Keybase[18], where developers exchange files, originate and workshop new ideas, and scout for individuals who may possess certain skillsets to further projects worked on by the community (see Figure 4.3) (Barton, 2019; det_disp, 2020)[19]. Files are hosted via blockchain-based service[20]—such as LBRY—which, unlike many larger platforms, offer a commitment to censorship-free hosting (LBRY, n.d.).

[17] Fosscad still maintain an active website and IRC channel at https://fosscad.org

[18] Keybase is an online platform that allows for easy-to-use encrypted chats between users, in a format similar to the more popular Discord. Users can create teams and sub-teams to focus discussions, and the 3D-printed firearms development community uses these as meeting rooms virtual workshop spaces.

[19] At the time of publication, the det_disp Keybase team had 6,682 members, including well-known developers such as 'IvanTheTroll', 'jstark1809', 'incarbonite', and 'ctrlpew' (det_disdp, 2020).

[20] Blockchains are cryptographically linked data records that are openly accessible, but resistant to unauthorised tampering. Some blockchains can be accessed and modified anonymously. Blockchains allow for a decentralised network to operate under the same set of conditions; it "allows disparate entities to all agree on a rivalrous set of affairs" (LBRY, n.d.; Iansiti & Lakhani, 2017).

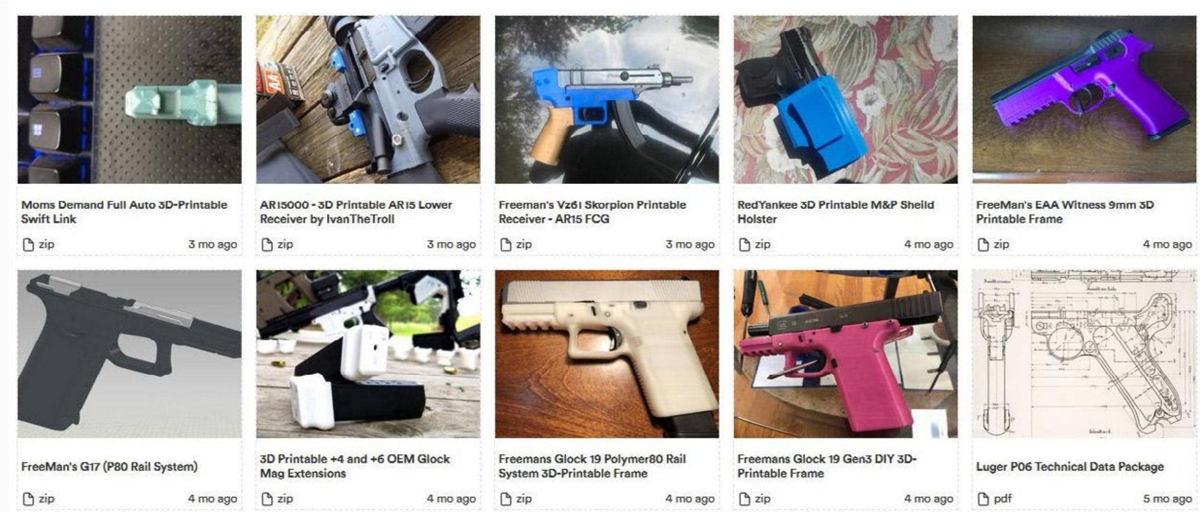

Figure 4.3 *A snapshot from January 2020 showing part of a new generation of 3D-printable DIY firearm files hosted in an extensive file repository maintained by det_disp (source: Deterrence Dispensed).*

Development and Peer-testing of Designs

Several groups have begun to implement semi-formalised methods to ensure the quality and viability of the designs they make publicly available. As part of the process of verifying files before release, Deterrence Dispensed forms a 'beta' group of willing individuals who test files prior to their being posted.[21] The testing process examines both the production and use of the firearm, accessory, or component in question, and generally involves use of different printers and polymers, as well as ergonomic and live-fire testing under a range of conditions (varying temperatures, ammunition types, and magazines, for example). In testing its latest release, the FGC-9, which incorporates an ECM barrel-making process, det_disp and its associates conducted testing over an extended three-month period. During this time, multiple different models of printer using different filament types were each used for multiple prints of the same parts. This was done to ensure dimensional compatibility and greatly increase chances of first-print success for a wide range of users (ARES, 2019). The peer-review system has proven very effective in incentivising testers by providing early access to designs, and has resulted in improved, more reliable releases since its introduction. This stands in stark contrast to the early days of 3D-printed firearms—the Liberator, for example, was released a day after its first successful shot, having been printed on just one model of printer and in only one type of material. Those wishing to make their own had to work on a range of issues just to get the gun to function reliably, mainly related to the fragility of the available material. One journalist who attempted to replicate the weapon was unable to do so, going so far as to state that "…as of right now, printing your own gun is not a feasible enterprise" and noting that Defense Distributed themselves had stated the weapon might only fire a single shot before failure (Bump, 2013). Destructive testing carried out by the New South Wales Police in Australia and by the U.S. Bureau of Alcohol, Tobacco, Firearms and Explosives showed, in both cases, that the catastrophic failure and injury to the user was possible, depending on the polymer used to produce the firearm (NSW Police, 2013; ATF, 2013; Jenzen-Jones, 2015).

[21] 'Beta' testing is a concept borrowed from the world of computer software, which operates using initial in-house 'Alpha' testing, followed by secondary 'Beta' testing. The latter involves developers and users outside the development team. See Ince, 2019.

Emergent Firearms Craft Production Technologies

Additive Manufacturing

Additive manufacturing (AM), otherwise known as '3D printing', is a computer-controlled process by which a physical object is created from a virtual 3D computer model in the form of a CAD file. This file provides information to a 3D printer which creates the item through a physical process most often involving the depositing and fusing together of layers of material (Jenzen-Jones, 2015). The term '3D Printer' alludes to the creation of 2D images on paper by means of ink deposition in the traditional desktop printer. Additive manufacturing first emerged in the 1980s when a techniques known as Stereolithography (SLA)—which used an ultraviolet beam to selectively cure photosensitive polymer layer by layer—was developed by Chuck Hull (Bártolo 2011; Jenzen-Jones, 2015).

One of the most valuable characteristics of 3D printers for firearms developers (both craft producers and commercial manufacturers) is their ability to rapidly produce prototypes. As useful as CAD models and digital assets are, a cheap physical model of a part can provide exceptional tactile and visual feedback for gunsmiths and enthusiasts alike. Prototype parts can often be reused in dry-fire or live-fire testing, cutting down on total tooling costs and development time, and reducing the number of complex parts that must be made. 3D printers are also increasingly easy to operate, and learning to use a 3D printer is significantly more straightforward than learning to run a manual mill. The lower machine and tooling cost and reduced skill requirements make one-off projects more feasible—should someone want to dabble in home gunsmithing in their spare time, they can do so by making an FGC-9 or Songbird with a significantly reduced investment in time and money when compared with conventional craft-production methods.

The most popular process for consumer-level additive manufacturing today is known as fused deposition modelling (FDM)[22], where the CAD file is built through depositing and fusing together melted layers of thermoplastic material through a heated nozzle (Jenzen-Jones, 2015). Selective laser sintering (SLS), selective laser melting (SLM), and direct metal laser sintering (DMLS) fuse together polymer or metal powders, and are much more advanced than almost all FDM processes. This is reflected in a considerably higher price per printer, which are often orders of magnitude more expensive than consumer-grade FDM machines. Other technologies, such as binder jet printing (BJP), electron beam freeform fabrication (EBF), and electron beam melting (EBM), also exist (Jenzen-Jones, 2015). FDM is the most recognisable 3D printing technology to the layperson, and is the primary technology used by craft-producers of 3D-printed firearms (ARES, 2019).

Perhaps the most prevalent printer in the DIY gun community in 2020 is the Creality Ender 3, a 200 USD printer made in China (see Figure 5.1) (Pete, 2019). This lacks many features of commercial-grade printers such as automatic bed levelling, a heated build chamber, and high-temperature polymer capability. Despite these limitations, this model is able to produce a range of different parts for firearms, ranging from frames for Glock handguns to AR-15 lower receivers, and from barrel rifling jigs to suppressor baffles. FDM printers

[22] Also known as fused filament fabrication (FFF) and fused deposition of material (also FDM).

can be used to work with a variety of polymers, which are typically fed from a spool of filament (see Figure 5.2) and vary by printer model (see Table 5.1). Certain polymers may also be more suitable for the application of other production techniques, such as conventional machining or chemical welding.[23] Whilst the Creality Ender 3 is somewhat limited in terms of the polymers it can print, another popular printer—the Prusa i3 family—can handle higher temperature nylons and comes with automatic bed levelling to ensure printing is performed on a level surface. Automatic levelling aids accuracy, which becomes significant when printing more complex components (ARES, 2019).

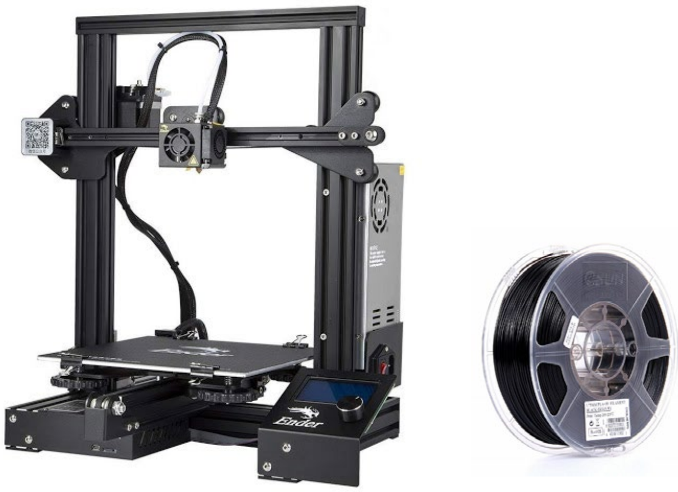

Figure 5.1 *A Creality Ender 3 desktop FDM 3D-printer; Right: a representative spool of polymer for an FDM 3D-printer, in this case eSun PLA+. Not to scale (sources: Amazon; eSun).*

Table 5.1 — *Physical Properties of Selected 3D-printer polymers.*

Polymer	Rigidity	Strength	Failure Mode	Ease of Printing	Cost (USD)	Chemically welded easily?
PLA/PLA+	Very High	Low	Shatter	Very Easy	Very Low ($20/kg)	Yes
PETG	High	Low	Shatter	Easy	Low ($25/kg)	Yes
ABS	Moderate	Moderate	Gradual/crack	Hard	Low ($25/kg)	Yes
Nylon alloy (Taulman 910)	Low	High	Gradual/crack	Moderate	Medium ($50/kg)	No
DuPont Zytel	Very Low	High	Gradual/crack	Easy	High ($90/kg)	No
DuPont Zytel (33% glass fill)	Very High	Very High	Gradual/crack	Very Easy	Very High ($100/kg)	No

Source: *IvanTheTroll, 2020.*

Notes: *Suitability for a given application will depend on a wide range of factors, such as the mechanical and thermal stresses a part may be subject to, the operating conditions of the finished component, and any weight, flexibility, or thickness requirements.*

[23] Chemical welding involves coating the mating surfaces of two or more parts you wish to join together in a chemical that dissolves a layer of polymer on each surface, and then pressing those parts together. Once the chemical binder evaporates or solidifies, the two parts have been welded together as one contiguous part.

On the surface, the applications of FDM printing seem limited for gunsmithing. The polymer used by cheap printers is much weaker than aluminium, and FDM parts are weaker than injection-moulded polymer parts (Agarwala et al., 1996). However, if the craft-producer takes full advantage of an FDM printer, it can become a tool just as valuable as a lathe or mill. FDM printers are capable of producing a wide range of gun parts not required to bear extreme pressure, including the receivers of certain firearms (such as the lower receiver of an AR-15), magazines, grips, stocks, receiver extensions, and accessory rails. Whilst the strength of these parts is not high in comparative terms, the low cost of FDM printers and the relative ease of adding reinforcing elements to polymer components allow users to produce parts which will still function reliably over extended use, but at a fraction of the tooling cost of conventional manufacturing set-ups or more advanced 3D-printing technologies. FDM printers are also able to produce specialised tooling and workholding aids (for holding components in place during work) for use with traditional machine and hand tools. As maker 'JStark' puts it:

> *"One can 3D-print the parts that are not directly impacted by the forces of the discharge of the cartridge. Complex shaped parts of firearms such as the main receiver or other secondary parts and assemblies of a firearm can be made by a 3D printer as well. By increasing the proportion of parts on a firearm design that can be 3D-printed one needs less labor and less specialized tools" (ARES, 2019).*

Depending on a range of factors including printer, polymer, and design, some 3D-printed components may be formed with more porosity than desired. Whilst metal reinforcements are preferred for many applications, plastic components can be strengthened in other ways. Parts printed in thermoplastics can be re-melted with a soldering iron to better fuse together the layers within the part, greatly increasing their lifespan. Another method of strengthening involving re-melting printed polymers is fiberglass patch reinforcement, a technique in which a sheet of fiberglass is held against the printed part and melted 'into' it by a soldering iron. Because the heat is localised, components are unlikely to warp, and will gain the stiffness of fiberglass over the applied area. Yet another re-melting technique used on PLA is referred to as 'annealing', although this is not a technically accurate term in this context. In PLA 'annealing', a part printed in PLA is left in a conventional oven for a period of time (usually around an hour) at a temperature which is held just above PLA's glass transition temperature (around 60–65 °C). This causes individual layers of PLA to better fuse together. However, because heat is applied to the whole part, it will often warp as it cools (ARES, 2019).

A variety of different parts and components can be produced using FDM printers, but these do have their limitations. It can be challenging to print pressure-bearing components such as bolts and barrels, or parts that need to be harder than cartridge cases, such as firing pins. Printing such components is difficult whilst maintaining cost-effectiveness and/or the ergonomics and function of the firearm. As a result, hybrid and PKC builds have become increasingly popular; frames, receivers, and magazines are now believed to be the most-printed firearms-related objects (ARES, 2019).

Receivers & Frames

Perhaps the most prolific use of 3D printing in the craft production of firearms to date has been the design of 3D-printable lower receivers. The lower receiver or frame of some firearms designs—including most handguns and the ubiquitous AR-15 self-loading rifle—is not a component which is subject to significant stresses. Accordingly, receivers for these weapons, or portions thereof, may be made from non-metallic materials such as polylactic acid polymer (PLA), the standard filament type used in consumer-grade 3D printers. In many cases, the original design of a receiver is strengthened in printed models through increasing the thickness of material in certain areas. For example, the use of a polymer replacement receiver for the sheet steel AKM pattern weapon is believed to increase its overall resistance to mechanical stress (ARES, 2019). One reason makers have focused on the design and production of receivers and frames is their legal status within the United States. As previously discussed, these components may be the only legally controlled part of a firearm; as a result, an unregistered, difficult-to-trace firearm may be acquired in some jurisdictions by simply combining a 3D-printed receiver or frame with readily available components (see Figures 5.3 & 5.4).

Figure 5.2 *A 3D-printed AR receiver with reinforced rear section (source: Ivan T./ARES).*

Figure 5.3 *Commercially available FCG parts fitted to a 3D-printed AR-15 lower receiver (source: Ivan T./ARES).*

In some cases, 3D-printed polymer receivers may e xperience some wear from the reciprocating parts of the firearm (such as the bolt carrier on an AKM). In such cases, simple metal parts can be incorporated into the design to reduce wear. These are typically produced by using commercially available tube or bent angle stock, and provide a durable receiver with minimal additional effort (see Figures 5.4–5.6). This requires more skill than simply printing the polymer parts, but is easily achievable by anyone with basic craftworking experience or aptitude. Designers are increasingly simplifying this process for producers; for the Glock 17 receiver, for example, a series of 3D-printable jigs have been released to aid in the accurate removable of material where hand tools are to be used.

Figure 5.4 *A Glock 17 frame printed in DuPont 'Zytel' glass-filled nylon. Factory Glock pistols use a near-identical polyamide 66 type material. Note the visible metal rails at right (source: Ivan T./ARES).*

Figure 5.5 *CAD diagram showing the placement of metal rail inserts (red) in the 3D-printable Glock 17 receiver (source: Ivan T./ARES).*

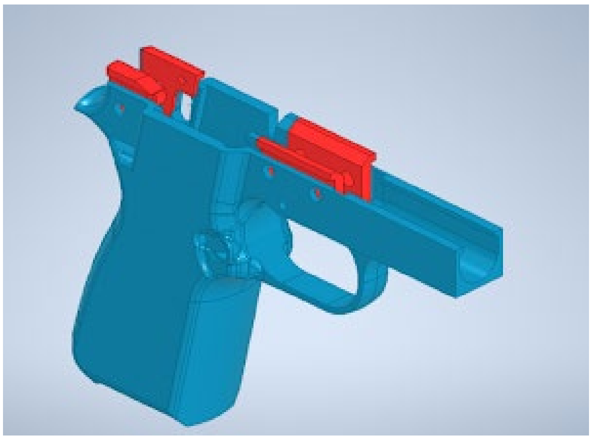

Figure 5.6 *CAD diagram showing placement of metal rail inserts (red) in the 3D-printable Browning Hi-Power receiver (source: Ivan T./ARES).*

Figure 5.7 *The 'Plastikov', a 3D-printable AKM pattern receiver recently developed by IvanTheTroll. The example pictured is assembled using Hungarian AMD parts (source: Ivan T./ARES).*

Figure 5.8 *Fibreglass-reinforced rear section of the Plastikov receiver (source: Ivan T./ARES)*

3D-printed receivers and frames have been developed for a wide range of commercially produced small arms, ranging from pistols and sub-machine guns to self-loading rifles (See Figures 5.7–5.11). At the time of publication, the frames and receivers compatible with commercial firearm part kits which have been successfully printed in PLA include:

- AR-15 self-loading rifle (.223 Remington/5.56 × 45 mm)
- AR9 self-loading rifle ('pistol') (9 × 19 mm)
- AKM ('Plastikov') self-loading rifle (7.62 × 39 mm)
- Ruger 10/22 rifle (.22 LR)
- VZ61 Škorpion sub-machine gun/pistol (7.65 × 17SR mm)
- TEC-9 (AB10 'Ghetto Blaster') self-loading pistol (9 × 19 mm)
- MAC Model 10 and 11 sub-machine guns ('Mac Daddy') (9 × 19 mm)
- Glock models 17, 19, and 26 self-loading pistols (9 × 19 mm)
- M&P Shield self-loading pistol (9 × 19 mm)
- Ruger SR9 self-loading pistol (9 × 19 mm)
- EAA SAR K2P self-loading pistol (9 × 19mm)
- EAA Witness self-loading pistol (9 × 19 mm)
- G43 SS80 self-loading pistol (9 × 19 mm)
- S&W SD9 self-loading pistol (9 × 19 mm)
- Diamondback DB380 self-loading pistol (.380 ACP)
- Hi-Point C9 ('Lo-Point') self-loading pistol (9 × 19 mm)
- Browning Hi-Power self-loading pistol (9 × 19 mm)

Figure 5.9 *A Browning Hi-Power self-loading pistol with a 3D-printed frame (source: Ivan T./ARES).*

Figure 5.10 *A vz. 61 Skorpion .32 ACP pistol (the civilian-legal semi-automatic version of the original sub-machine gun) with a 3D-printed receiver, based on a design developed by FreeMenDontAsk (source: Ivan T./ARES).*

Figure 5.11 *A 9 mm Tec-9 type (AB-10) pistol assembled using the 'Ghetto Blaster' 3D-printed receiver designed by FreeMenDontAsk (source: AustinQuemist).*

Magazines

Depending on a craft-producer's location, firearms magazines may also be regulated. This varies by jurisdiction, even within a country. In the United Kingdom, for example, magazines are unrestricted in England, Scotland, and Wales, but constitute a legally-controlled 'component part' under Northern Irish law (Northern Ireland Office, 2005; PSNI; n.d.). This is partially due to their use in craft-produced designs, as producing reliable magazines has traditionally been difficult. (Jenzen-Jones, 2018).

Being not much more than a box housing a spring, magazines were some of the first firearm parts to be produced using a 3D printer (Johnson, 2011). Early results proved less than adequate, however. Producing reliable magazines has always been a challenge for the craft-producer, as the geometry of the feed lips must be precise and strong enough to enable consistent reliable feeding of rounds from the magazine into the chamber. Designer IvanTheTroll recounts:

> *"3D-printed mags have been a valid concept since at least 2013, when Defense Distributed demoed a printed AR15 magazine. They employed SLA printing – a process more expensive than FDM. The DIY community never managed to match what Defense Distributed had shown in their promotional videos for their AR15 magazine – partly because of the lack of documentation from DD, partly because the printer DD used was superior to anything that the average DIY-er had access to. Users had issues with the lips on the top of the mag splitting, or the mags simply feeding poorly. This is where I came in, in the Summer of 2018. I took the DD AR15 mag, tweaked its internal geometry to better match a PMAG, and developed documentation on how to make a working magazine (detailing material and post-processing specs). I also developed a 3D-printable jig used to wind magazine springs into their rough shape – when using spring wire, the jig holds the spring in the shape needed for stress relief, which nets a spring in the proper shape without requiring a furnace, as an ordinary oven is able to stress relief spring wire. This made the AR15 30 round magazine an item that could be made entirely from scratch – body, peripherals, and spring" (ARES, 2019).*

With a reliable AR-15 magazine completed (see Figure 5.12), Ivan set his sights on what he considered the next-most widely-used magazine—that of the Glock 17 pistol (see Figure 5.13).

> *"My next project in this sphere was much more ambitious – at the very beginning of the FGC-9, it was realized that there were no proper models of Glock mags out there – even the outside dimensions of ones on Grabcad were wrong. I was asked to help by generating a new Glock mag model from scratch. I started by going for as close to a blueprint copy of a G17 mag as possible by reverse engineering a mag. This mag model was used to design the magwell of the FGC-9 around – but after putting in the time to model the mag, I figured I'd print it. It didn't work well at all, but I saw promise.*
>
> *I figured that with proper reinforcement, Glock mags could be printed in PLA – a cheap, easy to print polymer. After 6 months of working on the Glock mags, I finally got a design that works reliably, costs under 1 dollar to print (plus two bucks for the spring, but springs can be reused), and can be printed on virtually any printer (anything that can do PLA or PLA-level strength). Professor Parabellum saw the promise of the printed mags as a new standard to design guns around – gone are the days of relying on shoddy STEN mags or trying to do Luty-style DIY mags. You can print 30 G17 mags on a single build plate and have all the mags you need" (ARES, 2019).*

At this time Ivan's activities came to the attention of U.S. Senator Bob Menendez of New Jersey who upon becoming notified of a newly released technical data package for the AR-15 rifle compiled by Deterrence Dispensed, sought to pressure Twitter to remove Ivan's account (Campbell, 2019; Richer 2019). This led Ivan to name the 3D-printable Glock magazine the 'Menendez Magazine' when it was officially released. A 30-round high-capacity version, the 'Extendez' was later released (ARES, 2019).

3D-printable magazines have so far been released for weapons compatible with 7.62 AKM magazines, 5.56 AR-15 magazines, and 9 mm Glock series magazines. Most new 3D-printed designs and receiver releases have been standardized around the existing 3D-printed 9mm Glock 17 and AR-15 magazine designs, dramatically reducing the need for further development of magazines for each individual model or reliance upon factory magazines. The latest release of a 3D-printable Browning Hi-Power pistol frame accepts Glock 17 magazines rather than Hi-Power pattern magazines. The increasing range of functional so-called 'high-capacity' or 'large-capacity' 3D-printed magazines has the potential to significantly foreshorten repeated legal efforts to restrict magazine capacity.[24] As with other 3D-printed components, detection of these feed devices is likely to prove extremely difficult.

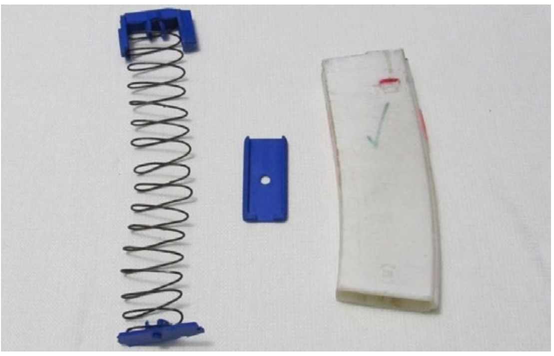

Figure 5.12 *A 3D-printed AR-15 magazine disassembled (source: Ivan T./ARES).*

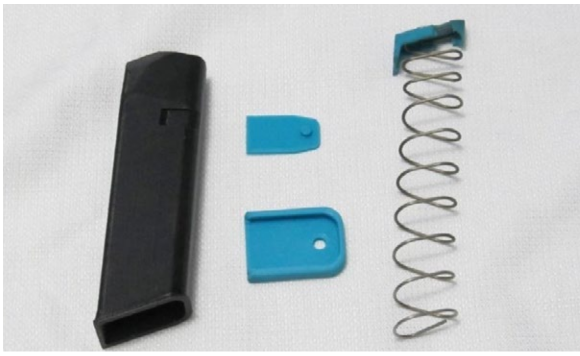

Figure 5.13 *The 'Menendez Mag' is a 3D-printable Glock 17 magazine developed and released by IvanTheTroll in July 2019 (source: Ivan T./ARES).*

[24] Bans on 'high-capacity' magazines in the U.S. and worldwide are too numerous to list. However, for example, the U.S. state of California has effectively banned magazines of greater than 10 rounds capacity since 2000; see Duncan et al. vs The State of California, 2019.

Drop-in Auto Sears (DIAS)

Firearms capable of automatic fire cannot be legally owned by civilians in much of the world, and are heavily restricted in other countries, such as the United States and Switzerland. Lower receiver designs that may be readily converted from semi-automatic only to automatic fire are widely prohibited for commercial sale, even in permissive countries.[25] A semi-automatic AR-15 self-loading rifle may be adapted to be capable of automatic fire by the addition of a device known as a drop-in auto sear (DIAS). This simple device, usually taking the form of a single strip of bent metal, is in the USA itself regulated as a 'machine gun' under the 1934 National Firearm Act (ATF, 1981)[26]. Improvised solutions to create DIY versions exist and have been shared online, including steps to fashion one from a piece of coat hanger wire simply by bending the wire (Chen, 2019). In December 2019, files for a 3D-printable DIAS named the 'Yankee Boogle' were released along with a video demonstrating it functioning in an AR-15 rifle (see Figure 5.14) (YankeeBoogle, 2019). Another switch device capable of making a Glock pistol fire automatically is also soon to be released (Incarbonite1, 2019).

Figure 5.14 *The 'Yankee Boogle' is a 3D-printable AR-15 DIAS which was released in December 2019 (source: CarnikCon).*

Desktop CNC

Desktop computer numerical control (CNC) machines are generally subtractive manufacturing tools such as mills, which utilise an automated computer-controlled process to precisely machine a variety of materials including metal, plastic, and wood. This process enables a computer model to be loaded for automated manufacture instead of a user manually operating machinery or using hand-tools to remove material according to a set of drawings. Traditionally, CNC milling machines are large, heavy pieces of equipment and comparatively expensive investments for commercial operations to make. In recent years, smaller, relatively affordable 'desktop' CNC mills have emerged that allow the machining of small components for the home machinist. Micro CNC mills, as the name would imply, are even smaller-scale CNC devices akin to desktop 3D printers in scale. These can carry out machining operations on small workpieces—often less than 200 mm square.[27] Firearms craft-producer 'BoostWillis' explains:

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[25] Despite the confusion caused by the differences in legal and technical use, some nations use the term 'machine gun' to refer to any weapon capable of automatic fire. In the United States, for example, the law defines a 'machine gun' as "...any weapon which shoots, is designed to shoot, or can be readily restored to shoot, automatically more than one shot, without manual reloading, by a single function of the trigger. The term shall also include the frame or receiver of any such weapon, any part designed and intended solely and exclusively, or combination of parts designed and intended, for use in converting a weapon into a machinegun, and any combination of parts from which a machinegun can be assembled if such parts are in the possession or under the control of a person" (26 U.S.C. 5845 (b)).

[26] In the wording of the ruling: "The AR15 auto sear is a machinegun as defined by 26 U.S.C. 5845(b)".

[27] Some, however, may have user-defined ways, allowing for much larger work envelopes.

"I use it to make light cuts in aluminum for things like DIY pistol rails, but it can be used for any number of other materials like wood, plastics, carbon fiber, and even some mild steel. Aluminum reinforcements in printed parts (like buffer towers in AR-15 lowers or FGC-9 trunnions) become pretty simple with a machine like this. Also designs based on layers of sheet metal, like JStark's Protector pistol, become much easier to design, iterate, and reproduce.

It can't operate at nearly the Material Removal Rate of professional CNC mills. These inexpensive CNC routers sacrifice a lot of rigidity in order to hit a price point. But with modern adaptive/trochoidal CAM strategies, it's possible to maintain decent tool life (Rauch, Duc & Hascoet, 2009). Instead of using only the very tip of the tool, making shallow cuts with 100% of the cross section of the endmill, you make deep cuts with ~10% of the tool's cross section, spreading the tool wear along a much larger area. Cycle time suffers, but that's ok. This isn't a production machine. Capability is more important than volume.

My experiments on this topic have focused around the Mostly Printed CNC from V1Engineering.[28] *It can be built for about $350, assuming you already have a printer. This is an inexpensive general-purpose CNC machine made from printed parts, EMT conduit, and skateboard bearings that can be used with various tools like routers, lasers, plasma cutters, extruders, drag knives, reciprocating needle cutters, and maybe even things like ECM toolheads in the future. This is the project that got me interested in 3D printing in the first place, because I wanted to be able to work with "real" materials and push the envelope of the democratization of manufacturing. Small and "rigid" machines can do important things like milling aluminum, while larger variants can cut 4'x8' sheets of plywood for important human-scale objects like furniture (opendesk.cc) or even housing (wikihouse.cc). Eventually, other higher quality routers will be available from Chinese manufacturers, further expanding access and the capabilities of this class of machines" (ARES, 2019).*

Some desktop/micro CNC units have even been marketed specifically for manufacturing firearm components. The 'Ghost Gunner' is a small CNC milling machine built specifically to complete 80% lower receivers for AR-15 rifles, Polymer80 Glock pistol frames, and Colt 1911 pattern handguns. While micro-CNC milling machines currently offer a cheap, versatile way to machine aluminium, these types of mills lack the rigidity and weight required to cut steel. As a result, they can't yet be used to make parts like barrels or slides that are generally made from steels. The upcoming Ghost Gunner 3 will expand the capability of the Ghost Gunner series to include 80% AKM receivers, and to provide a general steel-cutting capability.[29] The ability to cut steels (including stainless steel) will allow the Ghost Gunner 3 to complete gunsmithing tasks such as making cuts for optics in pistol slides, as well as milling rail blocks for 3D-printed Glock frames out of stainless or mild steels (ARES, 2019).

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[28] See: https://shop.v1engineering.com/collections/parts

[29] In the words of the manufacturer: "Ghost Gunner 3 is a general purpose CNC mill that gives you the ability to finish 80% receivers and frames with ease, in the comfort of your own home" (Defense Distributed, 2018).

Electrochemical Machining (ECM)

The most significant development in home craft-production technology in recent years has been the successful employment of simple electrochemical machining (ECM) set-ups to produce rifling grooves in barrels made from steel tubing. Historically, rifling has been often overlooked in craft-produced firearms as it is difficult to achieve and non-essential to function. It is however vital for proper spin-stabilisation of a bullet if the intent is to hit a target at any kind of range. ECM is a process that works, in practical terms, in the opposite manner to electroplating—removing material from the anode via electrochemical dissolution, rather than adding material through electrodeposition. ECM set-ups consist of an electrically conductive workpiece, an electrically conductive cathode (which will act as the cutting tool), and an electrically conductive liquid electrolyte, which fills the dual purpose of completing the circuit between the workpiece and electrode, and flushing away dissolved metal (see Figure 5.15) (Ghosh & Mallik, 2010).

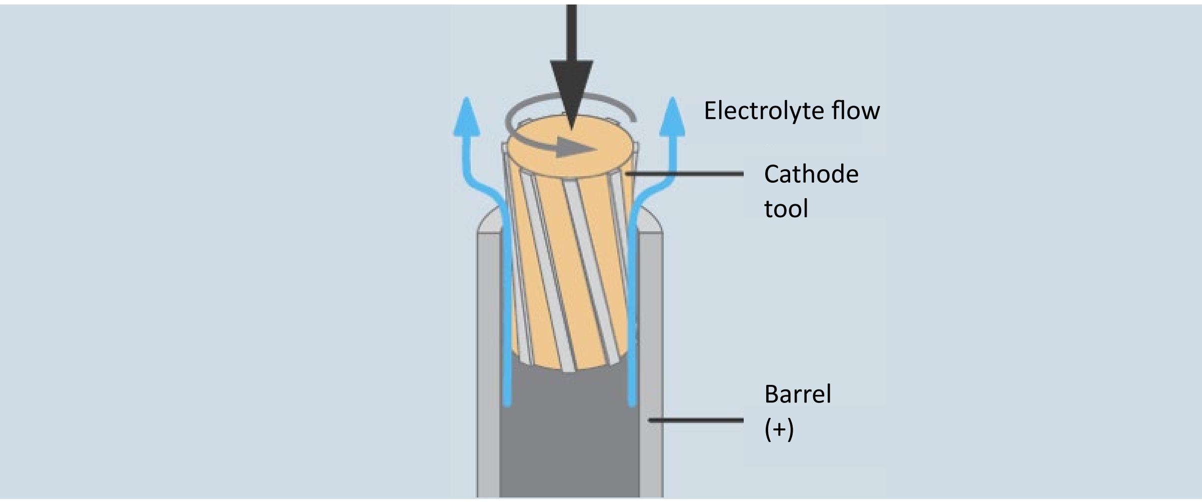


Figure 5.15 *An Illustration showing the basic ECM rifling process (source: Extrudehone).*

ECM is an interesting process for craft-producers for several reasons. Perhaps most importantly, it is useful in low-cost DIY set-ups because it can be employed as a static process, as opposed to most other forms of machining. In order to increase the bore diameter of a tube using a lathe, mill, or electrical discharge machining (EDM) process, at least one moving part is involved—be it the spindle on the lathe or mill, or the ways[30] of an EDM machine. In a home ECM set-up, both the workpiece and tool are static. As a result, there are no wear forces involved, and no need for a high-rigidity machine. Another of the most attractive benefit of ECM is that it cuts independent of workpiece hardness. In traditional machining, material removal rates—and, in some cases, whether a material can be machined at all—is governed by the material's hardness. In ECM, removal rate is governed by a particular metal's valency and its ability to conduct electricity (Mukherjee et al., 2008; Khan et al., 2019). As such, very hard steels—such as 40Cr hardened chrome alloy steel—can be cut with an incredibly cheap and simple set-up (see Figure 5.16 (ARES, 2019). This ability to machine hardened steel at a low cost is the primary reason ECM is being increasingly employed by craft-producers in barrel making.

[30] The rails/flats a 3-axis machine travels along are known as 'ways.'

Figure 5.16 *A simple DIY ECM barrel-making set-up (source: Ivan T./ARES).*

The process of rifling a firearm's bore is traditionally achieved by cut rifling, broach rifling, button rifling, or cold hammer forging. Cut rifling is the oldest form of rifling, and uses a cutter to remove material inside the barrel in the desired pattern. Broach rifling uses a 'broach, a tool with a series of integral cutting bits that cut the bore to progressively greater depth as the tool is passed through it. The button rifling method uses extreme hydraulic pressure to form the rifling in the bore by pulling a 'button' with rifling negatives on its exterior surface through the bore. The second swaging method is so-called 'cold hammer forging' in which the rifling is formed along with the bore itself by forging the barrel around a blank form or 'mandrel'. This is both akin to how smoothbore barrels were once forged by hand with hammers and the heat of a forge, and indeed to ECM, which uses a similar mandrel albeit a very different means of 'cutting' (Heard, 2011; Vortakt, n.d.).

Button rifling is the modern industry-standard way of mass-producing rifled barrels, as it can be done quickly, and finished barrels are fairly consistent from one barrel to the next (Kolbe, 2000). Button rifling may be suitable for craft-producers working with softer steels—indeed, leaded steels and tempered or annealed low-alloy steels can generally be rifled with something as simple as a bottle jack press (ARES, 2019). However, some materials are too hard for the technique to produce good results with simple equipment. Hardened steels, when button rifled, require immense force to press the button through the barrel—often not achievable by the home gunsmith, and leading to damaged tools and barrels.[31] Should one succeed in button-rifling a hardened steel barrel, they will be left with a barrel that is subject to unpredictable internal stresses as a result of the process. As a result, the barrel may wear prematurely, be subject to creep over time, warp unevenly as it heats when firing, or fail and crack along an area of stress concentration (ARES, 2019).

[31] Industry tackles the issue of button rifling hardened steels by using a rifle furnace. They will 'bake' a barrel until it is softer before they button rifle, and then anneal the barrel after rifling to relieve internal stresses afterwards. In some cases, a barrel may be hardened again to maximise strength and wear resistance (Gurklis, 1965; Sassen, n.d.). With commercial furnaces priced around 20,000 USD—and homemade examples still costing approximately 2,000 USD to produce and leaving some question of efficacy—such equipment is not readily available to most craft-producers (ARES, 2019).

ECM does not disturb the heat treat of a metal, avoiding subjecting the barrel to significant internal stresses (Gurklis, 1965). The method does have some drawbacks, however. Waste material from cut barrels needs to be disposed of responsibly, especially if the steel contains chrome. ECM cannot cut some metals, such as commercially pure titanium (CP Ti), due to a phenomenon known as hydrogen embrittlement. CP Ti cut using ECM will result in a porous, 'spongy' structure, rather than a clean machined finish.[32] Nickel-based superalloys should not be cut with ECM as the techniques cuts at inconsistent rates, often causing cracks in the microstructure of the metal, which can lead to unpredictable material qualities and premature failures (Kozak, 2011).

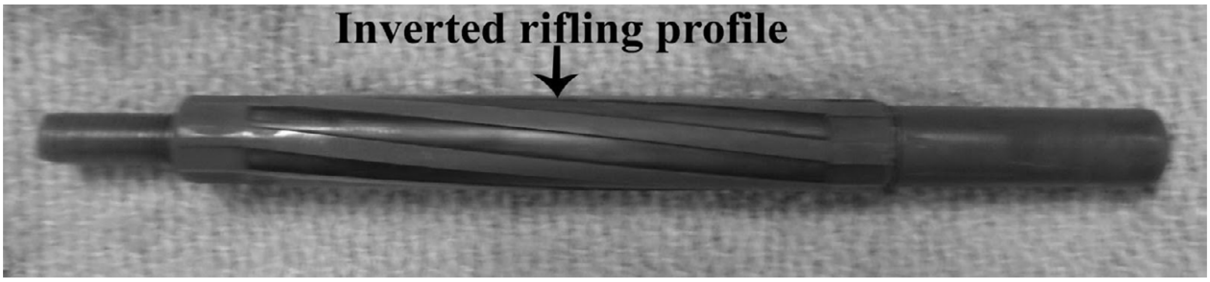


Figure 5.17 *An industrial rifling cathode used in the production of SIG Sauer pistol barrels in Germany (source: Bolton-King et al., 2012).*

The concept of using ECM to produce rifling grooves, or electrochemical rifling (ECR) as it is specifically known, is not new, having been used in the firearm industry to produce barrels commercially for many years (Vishnitsky, 1987). Patents for the technology date back over 60 years (Hartley, 1958). Notably the German firm SIG Sauer employed ECR in the production of barrels from 2002 onwards in an effort to reduce costs (see Figure 5.17) (Bolton-King et al., 2012). Whilst ECM has been used for a considerable length of time, there is only limited information regarding the manufacture of firearms parts using this technology in the literature. What discussion exists is almost entirely confined to large-scale, high-amperage commercial applications, and holds little value to the home gunsmith.

A viable home-manufactured method however has only recently been realised, however—enabled, and made all the more useful, by recent advances in 3D printing. The first proof-of concept experiment to demonstrate the basic home-ECM method was posted online in March 2017 by designer Jeff Rodriguez (ImproGuns, 2017).

This quickly led to further improvements on the design resulting in a near-commercial-quality 9 mm barrel being tested in 2019 by amateur firearms designer 'IvanTheTroll'. ECM allows craft-producers to work with hardened steels and produce viable rifle barrels cheaply. Pressure-bearing parts of an acceptable quality can be made with a substantially lower tooling cost compared to conventional machining methods. Pre-hardened, pre-drilled hydraulic tubing has proven a reliable starting point for an ECM process, which can be used to bore the tube to the desired diameter, rifle the bore, and create a chamber in the barrel. A 3D-printed mandrel with exposed copper wires acts as the cathode, making the tooling remarkably cheap. The process as it currently stands provides a viable barrel made from a hardened steel for under 100 USD (ARES, 2019). The basic process is described by 'IvanTheTroll', below (see Figures 5.18 & 5.19):

[32] Methods to machine these 'difficult' materials with ECM have been developed but are presently beyond the home gunsmith, and are often proprietary or experimental in nature (see, for example, Dhobe, Doloi & Bhattacharyya, 2014).

"The electrochemical machining (ECM) barrel cutting process starts with initial setup – the tooling is taken from raw stock and cut to size, and the fixtures and mandrels are printed and prepared. The supplies are then taken to the ECM setup, and the first operation is prepared – the boring operation. This operation is used to increase the bore diameter of the barrel – because off-the-shelf steel tubing doesn't have the 8.82 mm inside-diameter bore that 9 × 19 mm barrels require, 8 mm inside-diameter stock is taken and bore out to 8.82mm using ECM. This operation is the slowest of the ECM operations (as the most material is removed during it) but is easy to set up and measure. The second operation is rifling – the rifling mandrel is mounted and indexed to the barrel (so that the mandrel and barrel can be properly re-installed to the ECM setup between inspections of the rifling after cutting). This operation goes quickly and can be a little tricky to measure due to the polygonal-shaped rifling profile that the simple ECM rifling mandrel cuts into the barrel. For the final cutting operation, the barrel has a throat and chamber cut. This operation takes a bit longer than rifling but is the operation that takes the most precision – the depth of the throat and chamber needs to be quite accurate in order to ensure reliable feeding and extraction." (ARES, 2019).

Figure 5.18 *Two finished FGC-9 barrels (left) and the 3D-printed cathodes, jigs, and materials used (right) (source: Ivan T./ARES).*

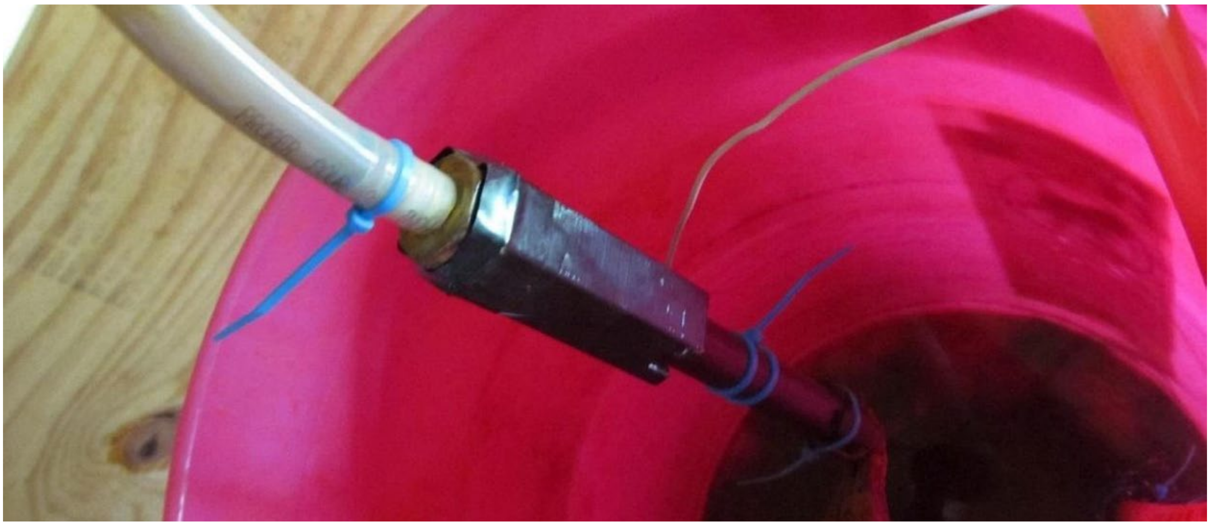


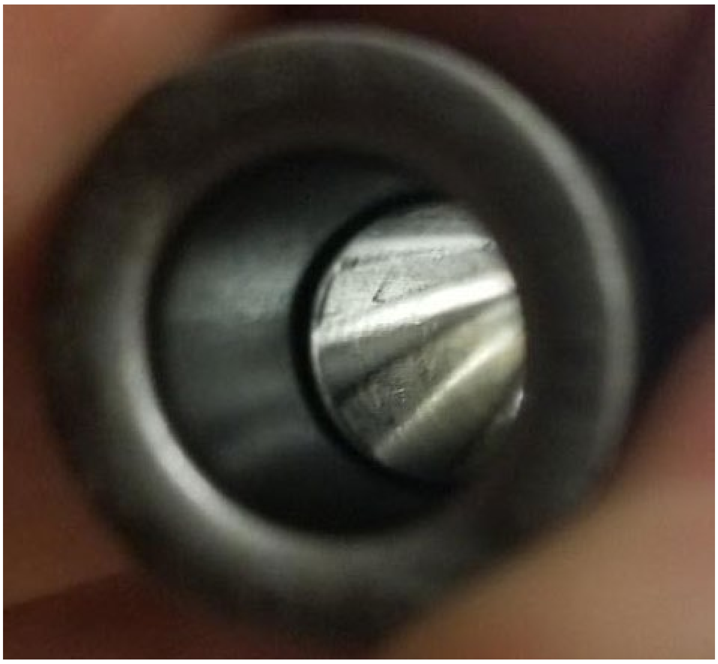
Figure 5.19 *The ECM boring process in action (source: Ivan T./ARES).*

IvanTheTroll's work has resulted in a near-factory-quality barrel capable of firing 9 × 19 mm projectiles relatively accurately. In August 2019, test shots having "achieved 2.5 in groups at 25 yards, with no signs of tumbling or unstable flight" (see Figure 5.20) (ARES, 2019). As the tools and techniques improve, so too will the accuracy of the barrels produced using this method.

Figure 5.20 *The ECM boring process in action (source: Ivan T./ARES).*

After the final cutting operation, the barrel is ready for us. At this stage, however, it can be tested to ensure a good rifling profile has been cut by 'slugging' a projectile through the barrel. Slugging the bore is done by taking the correct calibre projectile and tapping it down the length of the barrel using a punch or dowel rod. This process helps determine whether there are any portions of the barrel where the bore is either too tight or too loose, ensuring consistency and accuracy. It also allows the craft producer to assess the rifling engagement on the projectile. The ECM technique described above, as used by many producers, imparts a polygonal (hexagonal) rifling profile, which leaves a distinctive pattern on fired projectiles (see Figure 5.21). This provides around 50% rifling engagement on the bullet, and leaves striations where the imperfect surface finish of the ECM-cut bore of the barrel contacts the projectile (ARES, 2019).[33] This pattern is distinctive, and forensic techniques will be able to match barrels and fired projectiles, with many existing techniques being broadly applicable.

[33] The horizontal striations are particularly characteristic of the 3D-printed mandrels used in this particular ECM process, which are printed upright.



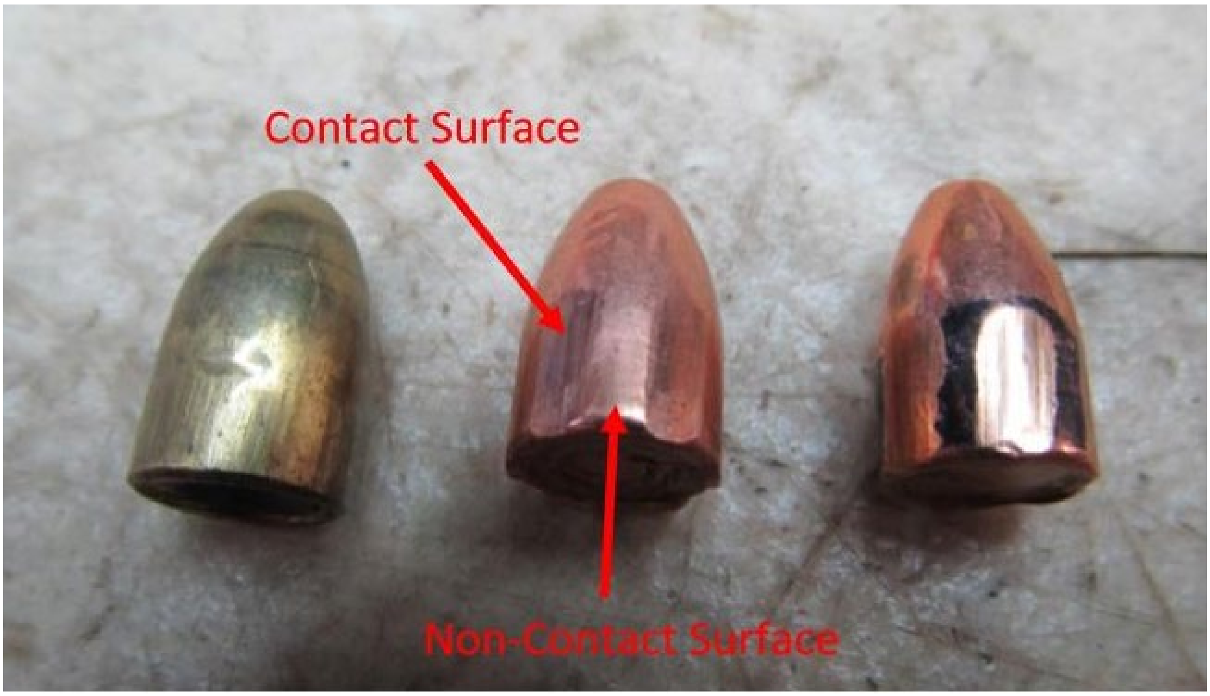


Figure 5.21 *Left: the resulting rifling grooves produced inside the bore of the barrel are the inverse of those of the 3D-printed ECM guide. Note the horizontal striations, characteristic of the 3D-printed mandrels used in the ECM process. Right: Distinctive rifling marks on a 'slugged' bullet indicate a successfully produced barrel (source: Ivan T./ARES).*

Additive Manufacturing and Ammunition Production

Whereas several of the major challenges facing the home gunsmith have been significantly aided by emerging technology (3D-printed magazines, barrels by ECM), home manufacture of ammunition remains problematic. There are several 'legacy' techniques available, such as the conversion of blank ammunition, reloading fired cartridge casings, or even craft-producing ammunition entirely from scratch (Jenzen-Jones & Hays, 2018; Jenzen-Jones & Ferguson, 2018b). However, there are emergent technologies applied in this area, too. Developer 'Jefford', has demonstrated 3D-printed 12-gauge shotgun cartridge cases for a variety of loadings, including slugs, buckshot, and multiple types and birdshot. Shotgun cartridges are relatively low-pressure and suitable for polymer cases (indeed, most commercial shotgun cartridges use polymer cases), yet they can provide a powerful firearm for home builders. As a result, being able to easily create a primary component the shotgun cartridge enhances the viability of homemade shotguns. Another idea in its infancy is to 3D-print polymer cartridge cases that can be sleeved over nail gun cartridges to accept a variety of projectiles (ARES, 2019). Nail gun cartridges are unregulated in much of the world, and are already used as the basis of craft-produced ammunition in some countries (Jenzen-Jones & Ferguson, 2018b). The end result would bear similarities to the Dardick 'Tround' cartridges. Thanks to the relative precision of a 3D printer, much of the human error involved in mating a projectile to a blank or nail gun cartridge could be avoided. As ammunition technology continues to develop—with the increased introduction of conventionally produced polymer cartridge cases, as well as less-developed technologies such as cased telescoped ammunition[34]—it is likely that craft-producers will experiment with a range of novel approaches to this perennial DIY firearms challenge.

Figure 6.3 *3D-printed shotgun cartridges in a variety of loadings, including slugs at left (source: Jeff Rodriguez).*

[34] See Jenzen-Jones & Fitch, 2019; Jenzen-Jones, 2016).

Craft-produced Sound Suppressors

Sound suppressors (or 'silencers') can be produced using machine shop tools such as a lathe or may be improvised by assembling a combination of hardware store components. For example, steel tubing may be fitted with a threaded connector and baffles[35] made from something as simple as screen wire (Hollenback, 1999). The challenge with such low-tech, DIY solutions lies in ensuring accurate alignment—both the internal alignment of the baffles and the external alignment of the suppressor to the muzzle of the weapon—so that a bullet may pass through unobstructed. In recent years incomplete tubes with threaded endcaps marketed as 'solvent traps' or kit type units designed to use flashlight bodies (typically 'MagLite' brand) have catered to the market demand for inexpensive but durable DIY solutions.[36] Such items offer a convenient body in which to house a baffle alignment system, and these are often usually purchased along with incomplete (undrilled) baffles or automotive freeze plugs. In the USA, the possession and sale of suppressors, defined as "any device which diminishes the report of a portable firearm"), is regulated by the National Firearms Act 1934 (18 U.S.C 921).

Commercial 3D-printed suppressors were introduced several years ago, notably by Norwegian company Tronrud Engineering. Their Te-Titan suppressor is produced by DMLS from Ti64 titanium alloy in a single piece, but still commands a premium price (Jenzen-Jones, 2015). Craft-produced 3D-printed suppressors have taken some time to catch up, with sporadic and problematic development. Files for a viable, 3D-printable set of baffles were released on Thanksgiving Day 2019 by designer 'KadeCAD'. These may be inserted into a standard model of Chinese-made automotive fuel filter, creating a usable suppressor which may be mounted to a firearm via a commercially available adapter (see Figure 5.22). 'KadeCAD' described his design as follows:

> *"DIY and 3D-printed suppressors aren't completely new in the world of firearms. People have been making suppressors out of PVC pipe and oil filters for decades, and print files for fully 3D-printed suppressors have been around for years. So why did I bother to design a whole new, partially 3D-printed suppressor? Because there were many problems with the DIY and fully 3D-printed suppressor designs available. Homemade suppressors take a lot of time and tools to build and are often poorly designed.*
>
> *Fully 3D-printed suppressors [produced via FDM using typical polymers] are weak and can't handle the pressures of higher calibers, plus fully 3D-printed suppressors have to be fully reprinted after they melt and wear out. By combining 3D-printed baffles with higher strength metal fuel filters you get a suppressor that is cheap, easy to make, durable and very effective. This new suppressor design is strong enough to handle all handgun ammunition as well as all subsonic ammo no matter the caliber. The baffles are small enough to be printed on almost any 3D printer and once they wear out you can print new ones in a fraction of the time that you would need to reprint a fully 3D-printed suppressor.*

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[35] A series of chambers, often conical or approximately conical in shape, which serve to disrupt and slow the passage of hot gasses exiting the muzzle of a firearm, reducing the audible report.

[36] 'MagLite suppressors' are relatively commonplace in the illicit black and grey firearms markets of Venezuela, for example (Pérez & Ferguson, 2020).

3D Printers offer the ability to easily create concentric baffles (the tolerances required for baffle concentricity can be held by cheap hobby printers). When these baffles are inserted into commercial fuel filter housings such as those sold by Napa and Wix, they can be affixed to a firearm and function as an effective sound suppressor. Calibres from .22 LR to .308 Winchester have been tested with these printed suppressor baffles - the weak point in the design ends up being the housing itself. The housings feature soft aluminium threads to affix the housing to a firearm, and when supersonic rifle calibre ammunition is fired through the suppressor, the threads will yield and the housing will come loose. When used with pistol ammo and subsonic rifle ammo, the printed baffles can last several hundred rounds when printed in PLA, a material that is suboptimal for this application. In a more suitable material, the baffles last longer and can endure more rapid firing without overheating" (ARES, 2019).

Craft-producers continue to design suppressors for a range of applications and weapons, and for a range of calibres. Existing 3D-printed firearms designs are likely to be increasingly modified to accept 3D-printed suppressors (see Figure 5.23).

Figure 5.22 *Printed baffles subjected to 150 rounds of continuous fire using .223 Remington ammunition (source: KadeCAD).*

Figure 5.23 *A modified .22 LR version of the Defense Distributed Liberator fitted with an experimental printed barrel and removeable suppressor unit (source: KadeCAD).*

3D-printed Tooling & Jigs

There is no shortage of dedicated gunmaking and gunsmithing tooling available on the market. Typical modern tools available include chamber reamers, dies for accurately threading barrels[37], and rifling 'buttons'. Commercially made jigs to aid in the completion of unfinished receivers (so-called '80% lowers', as they are commonly known) have been available for more than a decade (ARES, 2019). These usually provide pilot holes at the correct positions for drilling as well as rectangular pockets and depth stops to aid in the milling out of correctly sized pockets for installation of trigger components, reducing the chance of human error. Commercially available versions of these jigs—whether made from plastic or metal—can be relatively expensive, especially as they may often be needed only once. In contrast, 3D-printed tooling and jigs offer low-cost, make-at-home options for craft-producers. Plans for 3D-printed jigs have been developed over the previous years and have been steadily updated. One of the most popular at present is the AR-15 jig released by Ctrl+Pew (see Figure 5.24) (Ctrl+Pew, 2019). 3D-printable jigs will also enable builders of the upcoming FGC-9 to easily locate positions to machine holes in the metal components without the need to accurately measure, as well as facilitate operations such as 'turning down' and threading a barrel for a suppressor.[38]

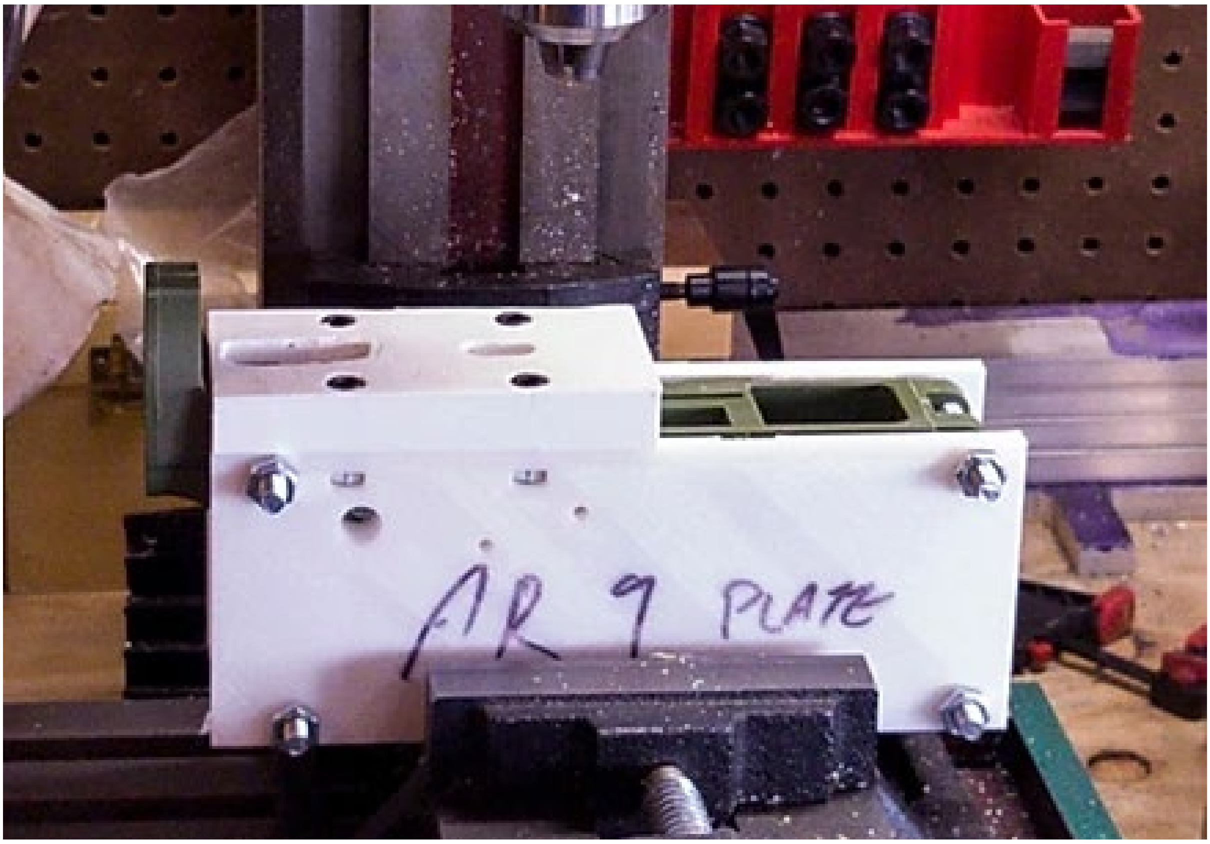

Figure 5.24 *A 3D-printed receiver milling jig for AR-15-type '80% lowers' (source: Ctrl+Pew).*

[37] To mount flash hiders, suppressors, and other muzzle devices.

[38] Turning is a manufacturing method used to reduce the diameter of a workpiece. In this context it is used to reduce the diameter of the barrel at the muzzle.

Perhaps the most important development in 3D-printed tooling has been the emergence of 3D-printable jigs designed for ECM operations. The combination of these two technologies has enabled the successful creation of near-factory-quality rifled barrels from off-the-shelf steel tubing without requiring the use of expensive tooling. Such jigs were first documented in December 2016, when a user by the name of 'Jeffrod' shared his successful results at producing deep helical grooves in a length of steel tubing by running salt water combined with an electric current through a specially designed 3D-printed jig inserted into the bore of the tube. 'IvanTheTroll' further improved upon the tooling used in the process (see Figure 5.25). Because of their ability to print custom jigs on demand, 3D-printers can be just as useful for the creation of gunsmithing tools as they can be for making firearms components. Using a novel process like ECM to take advantage of the complex geometry printers can produce with ease, is a significant step towards simplifying the craft-production of firearms.

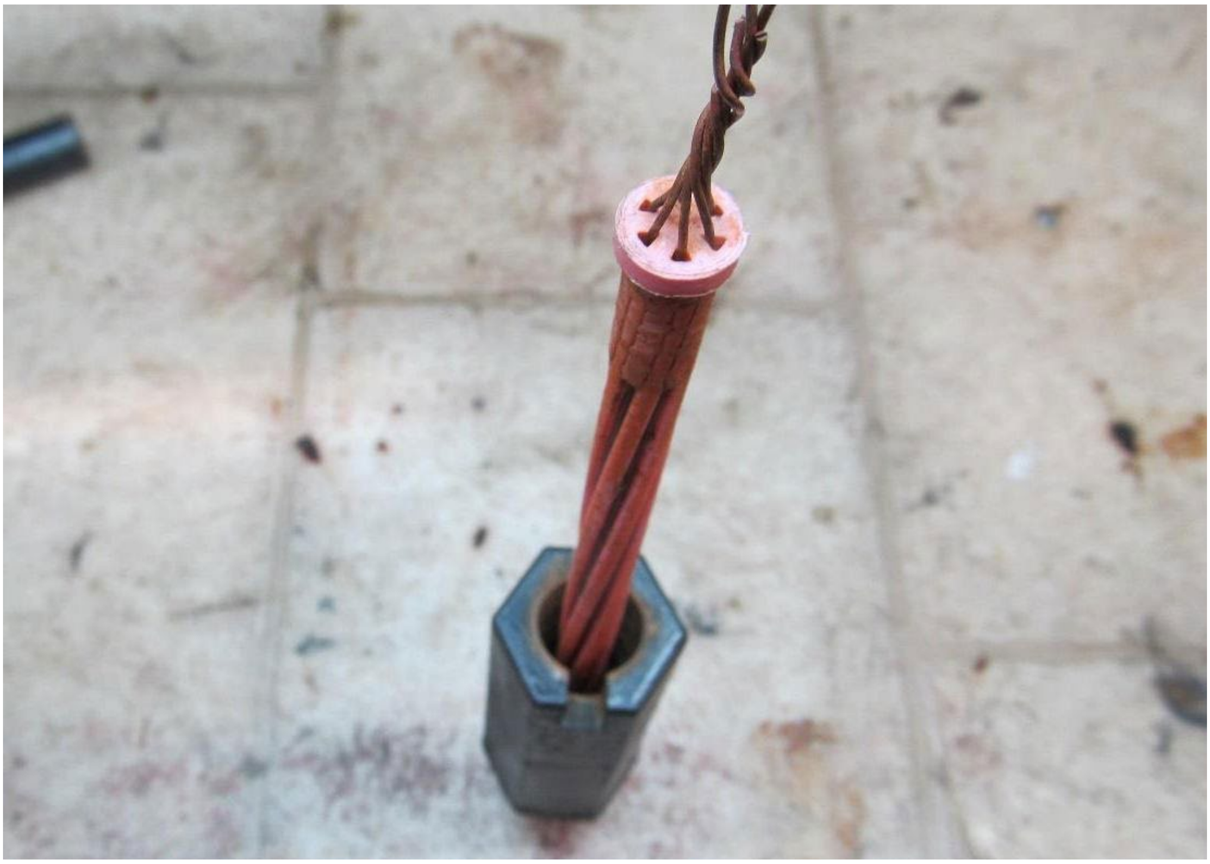

Figure 5.25 *A 3D-printed ECM rifling cutting tool being inserted into a barrel which is held in place by a 3D-printed collar (source: Ivan T./ARES).*

The Future of Craft-Produced Firearms

Pushing the Envelope: The FGC-9

According to numerous industry sources and outside observers, the FGC-9 ('F**k Gun Control 9mm') represents the pinnacle achievement of 3D-printable firearms technology at the current time (C., 2019; ARES, 2019). Designed by a Deterrence Dispensed team lead by JStark1809, the FGC-9 is a semi-automatic 9 × 19 mm hybrid[39] 3D-printed pistol-calibre carbine[40] which does not rely on firearms components that are typically regulated, such as barrels and bolts, and can theoretically be assembled with relative ease in most of the world (see Figure 6.1). While the infamous fully 3D-printed 'Liberator' pistol was a largely unsafe proof-of concept single-shot weapon capable of being reloaded and fired only a handful of times at best, the FGC-9 is broadly comparable to a commercial 9 mm semi-automatic pistol or carbine in terms of firepower and, potentially, in terms of durability. According to Deterrence Dispensed, who released plans for the FGC-9 on 27 March 2020, the design has been thoroughly peer-tested and is "their most ambitious project to date, combining 3D-printed magazines with an ECM barrel and a 3D-printed receiver".[41] When compared with the Liberator of 2013, the FGC-9 is a firearm which offers an-order-of-magnitude improvement in capability and durability (see Table 6.1).

Table 6.1 — Comparison of Liberator (2013) & FGC-9 (2020)

Metric	Liberator	FGC-9
Type	Single-Shot	Self-Loading
Calibre	.380 ACP	9 × 19 mm
Overall Length	8.5 in (215 mm)	20.47 in (520 mm)
Barrel Length	2.5 in (63.5 mm)	4.5 in (114 mm)
Weight (unloaded)	0.7 lb (0.32 kg)	4.6 lb (2.1 kg)
Capacity	1	10-33 (+ 1)
Capability	Low	High
Durability	Very Low	Moderate to High

Notes: *Physical characteristics may vary according to construction materials and methods. For example, polymers can vary notably in weight and required thickness. In the case of the Liberator, total weight excludes extraneous metal components which may be required to comply with US law.*

At the time of release the FGC-9 is a semi-automatic-only firearm; automatic operation is planned for a future release.

[39] The FGC-9 uses FCG components that are regulated in some parts of the world, but includes an option to use parts that are generally unregulated (see below).

[40] Plans are in the works for an automatic version (a sub-machine gun).

[41] Author interviews with det_disp members.

Figure 6.1 *The FGC-9 is a hybrid 3D-printed semi-automatic 9 mm pistol-calibre carbine which uses an ECM-produced barrel and no regulated firearm components (source: JStark1809).*

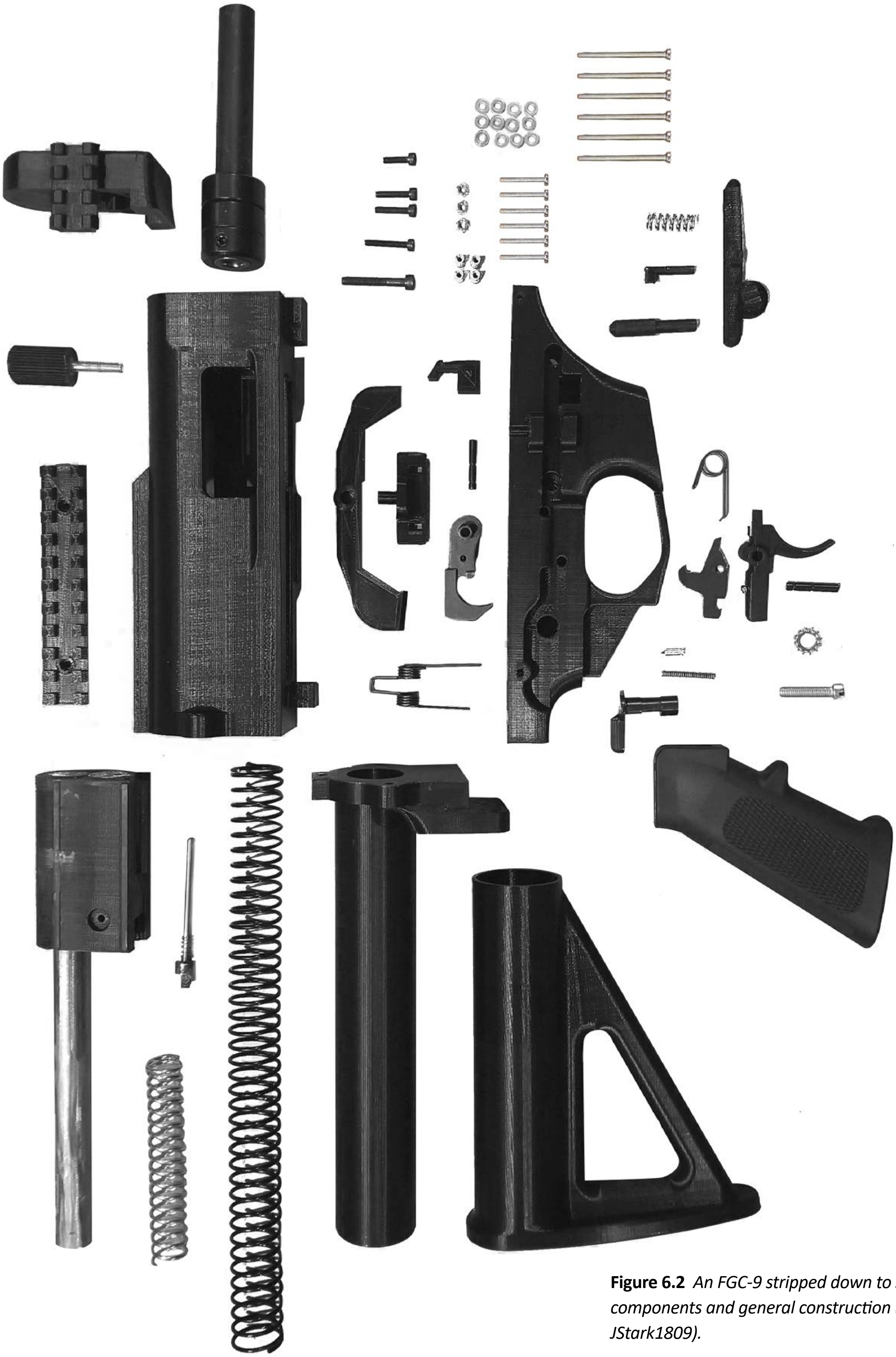

Figure 6.2 *An FGC-9 stripped down to show the components and general construction (source: JStark1809).*

One of the stated goals of the FGC-9 developers is circumventing European firearms regulations by avoiding the use of regulated component parts. The FGC-9's progenitor, the Shuty AP9, relied upon a factory-made Glock barrel, making it substantially more difficult to produce within the European Union. The authors interviewed 'JStark', the primary developer behind the project, who explained some of the history and rationale behind certain key aspects of the design:

> *"The FGC-9 is a non-commercial 9 × 19 mm caliber closed blowback action pistol caliber carbine design that utilizes 3D-printed parts quite extensively. I have based the design of it on the Shuty AP9 by Derwood and modified the original design extensively in order to improve the mechanics, ergonomics, assembly process and most importantly allow you to use a homemade barrel instead of relying on a Glock 17 barrel.*
>
> *The core mechanics of the pistol caliber carbine have been proven by the Shuty AP9 quite extensively. The main driver for the design of the FGC-9 is the goal of circumventing European gun regulations. It doesn't rely on pressure bearing EU regulated firearm parts that you have to acquire, whether it be the receiver parts or the barrel and bolt. Compared to other contemporary homemade 9 × 19 mm blowback designs it doesn't require particular metalworking skills and experience.*
>
> *A pre hardened 16mm OD hydraulic tubing can be used as the barrel and two 18mm OD round steel pieces are welded together to serve as the bolt. With the help of ECM rifling as demonstrated by IvanTheTroll one can rifle the 16mm OD hydraulic tubing and make the firearm significantly more effective over distance."*

The FGC-9 will make use of an AR-15 FCG, which provides a reliable set of components that are unregulated in the United States and cheap to acquire. In order to make the design accessible in more restrictive environments such as the European Union, the FGC-9 plans will include instructions for modifying a trigger group taken from gas-powered 'airsoft' toy rifles. This technique has been tested by det_disp members in both 3D-printed and conventionally produced AR-15 receivers, as well as the FGC-9 (see Figure 6.3). 'Jstark' explains:

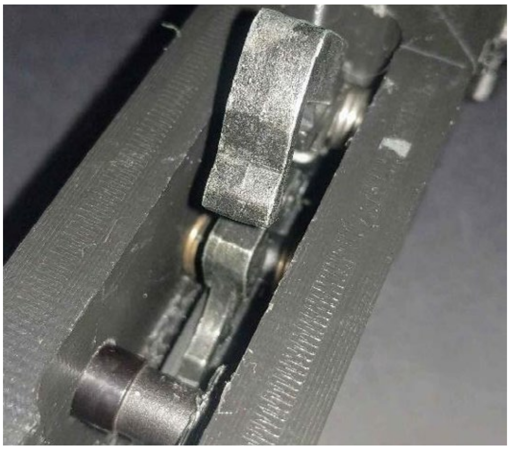

Figure 6.3 *An airsoft trigger group fitted to a 3D-printed FGC-9 lower receiver (source: Ivan T./ARES).*

> *To reduce the amount of work needed to construct the firearm an AR-15 rounded hammer fire control group serves as the trigger group (this can be substituted with a slightly modified spare trigger group used by gas powered airsoft toy guns).*[42] *As with the Ap9 9 × 19 mm double stack Glock magazines are used. As of recently thanks to the work of IvanTheTroll one can 3D-print all parts of the Glock magazine with the exception of the spring. Without a doubt the FGC-9 is currently the easiest to construct semi-automatic homemade firearm and at the same time one of the most practical homemade firearm designs there are" (ARES, 2019).*

[42] The 'rounded hammer' was a modification to the 'notched' hammer of the original AR-15 design; a redundant safety feature for centrefire automatic variants that is not needed or desirable in .22 LR variants or conversions.

Conclusion

The primary way in which 3D-printed designs depart from the traditional methods of craft-producing automatic and semi-automatic firearms—such as those described in established DIY publications such as Expedient Homemade Firearms (Luty, 1998) and The DIY STEN Gun (Anon, n.d.)—is by dramatically lowering the barriers to entry for the layperson. The time, level of skill, and requirements for hand fitting are reduced, and the rapid assembly of viable firearms becomes a possibility for the average person, particularly when operating with access to the data repositories, designs, and shared knowledge available via the Internet. The cost of producing capable 3D-printed small arms is rapidly decreasing, in-line with the reduction in price for 3D printers and other technologies. These technologies also allow users to obtain firearms without having to access criminal networks or legally controlled firearms distribution channels, maintaining anonymity and independence.

At present, the material limitations of consumer-grade 3D printers, and the high cost of those small number of industry-grade printers capable of producing objects in metals, means that certain essential pressure-bearing components must either be fabricated from metals using alternative methods or substituted for commercially made parts. In the case of a Glock-series handgun, for example, the frame and magazine body may be printed from PLA while the slide, barrel and trigger would usually be original, factory-made parts. The emergence of other technologies such as ECM and desktop/micro-CNC milling machines have bridged the technological gap, and now mean that viable, capable self-loading hybrid firearms such as the FGC-9 can be produced by the home gunsmith without using any regulated components. Other areas for development, such as the production of 3D-printed ammunition, remain in their infancy.

The advent of these increasingly capable, digitised technologies is rapidly turning the layperson into a de facto gunsmith or gunmaker.[43] It is highly likely that the FGC-9 is simply the first of a new wave of cheap, nearly-entirely-homemade 3D-printable firearm designs which solve material limitations by incorporating readily available metal components and unregulated firearms parts. This new breed of hybrid design offers adopters a cheap and effective firearm that is very difficult to trace, and may have the potential to rival or outstrip previous trends in the acquisition of illegal firearms modified from replica and deactivated firearms—themselves subject to increasing legislation (EU, 1991; EU, 2008; Warlow, 2007). There are very limited control options for restricting access to the materials or design files used in craft-producing such weapons, and progressively more affordable machines and tools—as well as ongoing refinement of techniques—are likely to make their continued development and acquisition increasingly commonplace.

It is also crucial to note that ECM is still a nascent technology within the craft-produced firearms community, and the outputs will only improve as techniques and tooling are refined. In much the same way the FGC-9 has now demonstrated the potential for craft production of viable, durable pistol-calibre carbines and sub-machine guns, new technologies and techniques will make increasingly durable and capable firearms available to the home gunsmith. On the horizon for the home gunsmith, static ECM set-ups could be used to machine locking actions, more complex trunnions, and other high-strength components. A dynamic ECM machine—essentially a 3-axis CNC with an ECM cutting head—could provide the home gunsmith with a cheap yet powerful way to machine more complex parts out of metal. Advanced tooling and jigs will allow for the desktop machining of increasingly complex high-strength machined components such as bolts, locking lugs, and slides from combinations of high-strength raw bar steel bar stock and tubing. Once this next technical hurdle has been overcome, rifle-calibre firearms requiring strong locking actions—previously the preserve of factories—may be produced in the same low-tech manner as the FGC-9.

[43] In modern vernacular, a 'gunsmith' is akin to a military armourer; a technically skilled individual able to maintain, repair, and modify firearms and their accessories. Although there has traditionally been little overlap of skillset between gunsmiths and gunmakers—able to fabricate an entire firearm from scratch—modern technology is increasingly blurring this gap and permitting those without any gunmaking or gunsmithing experience to not only modify, but actually build, entire weapons from scratch.

Annexe 1: Digital Data Types

SourceCAD

SourceCAD files are generally proprietary filetypes tied to a specific CAD studio; examples include .sldprt for Solidworks, .f3d for Fusion 360, and .ipt for Inventor. These files usually include a history of edits to the file, detailing how the part was made from first edit to last. They are the most valuable files to a designer because of this edit history, as edits can be undone and modified easily. Source CAD can often be opened and converted to a solid model if opened in a CAD studio that isn't native to them—e.g. Inventor can open .sldprt files and convert them to a solid model, but it will not retain the edit history.

Solid Models

Solid models are files generally found in the .step, .stp, and .igs formats. Solid models can be edited, but have no edit history attached to them. This means that a designer can edit the file, but past edits must be manually undone, and the order edits were made in is not recorded. The advantage to solid models is that they are used as exchange standard; all modern CAD studios can open common solid model formats and allow a designer to make new edits to the model. These files are the most important for designers to share because of their standard compatibility and ability to be edited. In addition, solid models can be converted to point clouds, a filetype useful to production.

Point Cloud/Mesh

Point cloud files are types of files usually used in the physical production of a CAD model. Common filetypes include .obj and .stl. Point clouds are different from solid models in that point cloud files exist to simply sketch out the outer boundaries of the part—the interior volume of a part isn't present—and thus point clouds are not solid models. Point clouds are useful in production of physical parts because the points that they consist of each have discrete coordinates. With enough of these points, toolpaths for CNC operations (like on a 3D printer) can be generated. The downside to point cloud files is that they cannot be edited like solid models or source files can be. Additionally, point cloud files cannot be converted back into solid models— making point clouds less-than-ideal for sharing, unless they are shared alongside solid models.

Renders

Renders come in two forms: physical items and CAD screenshots. They are common image filetypes (.jpg, .png, .bmp), and depict a part. They are useful in showing how a physical item looks after production, as well as helping people browsing repositories to understand what a part looks like without having to load it up in CAD.

Readmes/Tutorials

Readmes and Tutorials come in many formats, but the filetypes .txt, .pdf, and .md are the most common amongst the craft-produced firearms community. These files are text-based instructions on how to make use of the CAD they accompany. They include information on what sort of settings to use, what parts are needed to finish a build, where to source parts, how to troubleshoot reliability issues, as well as information about who designed the part in question and how to get into contact with them.

Source: *ARES, 2019.*

Bibliography

Agarwala, Mukesh K. et al. 1996. 'Structural quality of parts processed by fused deposition'. Rapid Prototyping Journal. Vol. 2 No. 4, pp. 4–19.

Anon. n.d. The DIY Sten Gun (Practical Scrap Metal Small Arms Vol. 3). Self-Published.

ARES (Armament Research Services). 2019. Home-built Firearms Technical Report. Unpublished background paper. Perth: Armament Research Services.

ATF (Bureau of Alcohol, Tobacco, Firearms and Explosives). 1981. '27 CFR 179.11: MEANING OF TERMS - The AR15 auto sear is a machinegun as defined by 26 U.S.C. 5845(b). ATF Rul. 81-4'. <https://www.atf.gov/file/11236/download>.

————. 2013. 'ATF Test of 3-D Printed Firearm Using VisiJet material (Side View).' YouTube video. 13 November. <https://www.youtube.com/watch?v=ZL7y3YNUbiY>.

————. 2020. 'Does an individual need a license to make a firearm for personal use?'. 17 March. Available at <https://www.atf.gov/firearms/qa/does-individual-need-license-make-firearm-personal-use>.

Bártolo, P.J. 2011. Stereolithography: Materials, Processes and Applications. New York, New York: Springer Science+Business.

Barton, Champe. 2019. 'As Social Networks Crack Down, 3D-Printed Gun Community Moves to New Platforms'. The Trace. Digital edition: 25 July. <https://www.thetrace.org/2019/07/3d-printed-guns-social-media-ban/>.

Beckhusen, Robert. 2012. '3-D Printer Company Seizes Machine From Desktop Gunsmith'. Wired. Digital edition: 1 October. <https://www.wired.com/2012/10/3d-gun-blocked/>.

Bolton-King, Rachel et al. 2012. 'Manufacturing of SIG Sauer 9 x 19 mm Pistols'. Association of Firearm Tool Mark Examiners Journal, Vol. 44, No. 1, pp. 19–28.

Bump, Philip. 2013. 'It's Not So Easy to 3D Print a Gun'. The Atlantic. Digital edition: 7 May. <https://www.theatlantic.com/national/archive/2013/05/its-not-so-easy-3-d-print-gun/315520/>.

C., Luke. 2019. 'DIY Guns: The New Improved FGC9.' The Firearm Blog. 14 August. <https://www.thefirearmblog.com/blog/2019/08/14/fgc-9-3d-printed-gun/>.

Campbell, Sean. 'Plans for 3D-Printed Guns Are Still Accessible on Twitter and YouTube'. The Trace. 17 May. <https://www.thetrace.org/2019/05/3d-printed-guns-twitter-youtube-social-media-platforms/>.

Canfield, Bruce N. 2012. 'Desperate Times: The Liberator Pistol.' American Rifleman. August.

Chacón, J.M., M.A. Caminero, E.García-Plaza & P.J.Núñez. 2017. 'Additive manufacturing of PLA structures using fused deposition modelling: Effect of process parameters on mechanical properties and their optimal selection'. Materials & Design, Vol. 124, pp. 143–157.

Chen, Nicholas. 2019. 'Coat Hanger Machine Gun DIAS (Drop In Auto Sear).' The Firearm Blog. 4 January. <https://www.thefirearmblog.com/blog/2019/01/04/coat-hanger-machine-gun-dias-drop-in-auto-sear/>.

Colvin, Fred H. 1917. United States rifles And Machine Guns. New York, New York: McGraw Hill. Available at: <https://archive.org/details/unitedstatesrifl00colvrich/page/n5>.

Coteaţă, Margareta, Hans-Peter Schulze & Laurenţiu Slătineanu. 2010. 'Drilling of Difficult-to-Cut Steel by Electrochemical Discharge Machining'. Materials and Manufacturing Processes, Vol. 26, No. 12, pp. 1466–1472.

CPS (Crown Prosecution Service). 2019. 'Legal Guidance: Firearms. Definitions of Firearms and Air Weapons'. The Code for Crown Prosecutors. <https://www.cps.gov.uk/legal-guidance/firearms>.

Creality. n.d. 'Creality Ender 3 3D Printer'. <https://creality.com/creality-ender-3-3D printer-p00244p1.html>.

Ctrl+Pew. 2019. '3D Printable AR15/AR9 80% Receiver Milling Jigs by CTRLPew'. Ctrl+Pew. 8 December. <https://www.ctrlpew.com/post/3d-printable-ar15-ar9-80-receiver-milling-jigs-by-ctrlpew>.

Defense Distributed. 2013. 'Liberator—Dawn of the Wiki Weapons'. Posted on YouTube 5 May 2013. <https://www.youtube.com/watch?v=drPz6n6UXQY>.

————. 2018. 'Ghost Gunner'. <https://ghostgunner.net/product/ghost-gunner-3-deposit/>.

————. 2019. 'Defense Distributed – Private Defense Tech Development in the Public Interest'. <https://defdist.org/>.

det_disp. 2020. 'det_disp' (Keybase team). <https://keybase.io/team/Det_Disp>.

Deterrence Dispensed. n.d. '@Deterrence-Dispensed:2'. <https://spee.ch/@Deterrence-Dispensed:2>.

Dhobe, Shirish D., B. Doloi & B. Bhattacharyya. 2014. 'Optimisation of ECM process during machining of titanium using quality loss function'. International Journal of Manufacturing Technology and Management, Vol. 28, Nos. 1–3, pp. 19–38.

Duncan et al v. The State of California. 2019. United States Court of Appeals Case. No. 19-55376. 15 July. Available at: <https://oag.ca.gov/system/files/attachments/press-docs/Duncan%20-%20Appellant%27s%20Opening%20Brief.pdf>.

EMAG. 2020. 'PECM for the machining of blisks.' <https://www.emag.com/workpieces/blisk.html>.

EU (European Union). 2008. Directive 2008/51/EC of the European Parliament and of the Council of 21 May 2008 amending Council Directive 91/477/EEC on control of the acquisition and possession of weapons. EU Directive 2008/51/EC.

EU (European Union). 1991. Council Directive 91/477/EEC on control of the acquisition and possession of weapons. EU Directive 91/477/EEC.

Extrude Hone. 2016. 'Extrude Hone Coolpulse™ Process Provides Solutions to Unlock 3D Printed Parts with Demanding Surface Finishing'. <https://extrudehone.com/coolpulse-technology-extrude-hone>.

Federico, Dan. 2019. 'What Is CNC? – Simply Explained.' All3dp. <https://all3dp.com/2/what-is-cnc-simply-explained/>.

Farago, Robert. 2013. 'Gun Review: Solid Concepts 1911 DMLS.' The Truth About Guns. 10 December. <http://www.thetruthaboutguns.com/2013/12/robert-farago/gun-review-solid-concepts-1911-dmls-direct-metal-laser-sintering/>.

Fey, Marco. 2017. 3D printing and International Security: Risks and Challenges of an Emerging Technology. Frankfurt: Peace Research Institute.

Garcia, Azrah. 2018. 'Facebook bars users from sharing blueprints for 3D-printed guns'. CNN. Digital edition: 9 August. <https://money.cnn.com/2018/08/09/technology/facebook-3d-printed-gun/index.html>.

Ghosh, A. & A.K. Mallik. 2010. Manufacturing Science (2nd edn.). New Delhi, India: Affiliated East West Press.

Greenberg, Andy. 2013a. 'Meet The 'Liberator': Test-Firing The World's First Fully 3D-Printed Gun. Forbes. Digital edition: 5 May. <https://www.forbes.com/sites/andygreenberg/2013/05/05/meet-the-liberator-test-firing-the-worlds-first-fully-3d-printed-gun/#749a7cd852d7>.

———. 2013. 'State Department Demands Takedown Of 3D-Printable Gun Files For Possible Export Control Violations'. Forbes. Digital edition: 9 May. <https://www.forbes.com/sites/andygreenberg/2013/05/09/state-department-demands-takedown-of-3d-printable-gun-for-possible-export-control-violation/#6d729904375f>.

Gurklis, John A. 1965. Metal Removal by Electrochemical Methods and its Effects on Mechanical Properties of Metals. DMIC Report 213. Columbus, OH: Defense Metals Information Center.

Guslik, Michael. 2012. 'Gunsmithing with a 3D Printer—Part 2.' Have Blue. 1 July. <http://haveblue.org/?p=1321>.

Hartley, J.C. 1958. 'Method of electrolytically rifling gun barrels'. United States patent US2848401A. Available at: <https://patents.google.com/patent/US2848401A/en>.

Hays, G. & N.R. Jenzen-Jones. 2018. Beyond State Control: Improvised and Craft-produced Small Arms and Light Weapons. Geneva: Small Arms Survey. <http://www.smallarmssurvey.org/fileadmin/docs/U-Reports/SAS-improvised-craft-weapons-report.pdf>.

Heard, Brian J. 2011. Handbook of Firearms and Ballistics: Examining and Interpreting Forensic Evidence (2nd edn.). Chichester, UK: John Wiley & Sons.

Hills, Brenden. 2017. 'Hardware Store DIY Machine Guns'. Sydney Sunday Telegraph. Digital edition: 19 November. Available at: <https://www.pressreader.com/australia/the-sunday-telegraph-sydney/20171119/281973197951042>.

Hollenback, G.M. 1999. Workbench Silencers: The Art of Improvised Designs. Boulder, Colorado: Paladin Press.

Hollingsworth, Barbara. 2013. 'World's First 3D-printed Metal Gun Successfully Fires 600+ Rounds'. CNS News. Digital edition: 13 November. <https://www.cnsnews.com/news/article/barbara-hollingsworth/world-s-first-3d-printed-metal-gun-successfully-fires-600-rounds>.

Iansati, Marco & Karim R. Lakhani. 'The Truth About Blockchain'. Harvard Business Review, Jan-Feb 2017, pp. 118–127.

ImproGuns. 2016. 'Semi-automatic firearm produced using 3D printer'. The Hoplite. 10 February. <https://

armamentresearch.com/semi-automatic-firearm-produced-using-3D printer/>.

————. 2017. 'DIY barrel rifling using salt water, electricity and a 3D-printed jig'. The Firearm Blog. 2 March. <https://www.thefirearmblog.com/blog/2017/03/02/diy-barrel-rifling-using-salt-water-electricity-3d-printed-jig/>.

————. 2018. 'Airsoft pistol combined with .22lr conversion kit'. Homemade Guns. <https://homemadeguns.wordpress.com/2018/12/12/airsoft-pistol-combined-with-22lr-conversion-kit/>.

————. 2019. 'Make a Factory Quality 9mm Rifled Barrel in your Kitchen Using Salt Water and Electricity (ECM)'. The Firearm Blog. 13 August. <https://www.thefirearmblog.com/blog/2019/08/13/make-a-factory-quality-9mm-rifled-barrel-in-your-kitchen-using-salt-water-and-electricity-ecm/>.

Incarbonite1. 2019. 'First live fire test of the 3D-printed Glock auto switch, perfect for the Christmas season'. Reddit forum post. 8 December. <https://www.reddit.com/r/guns/comments/e84tql/first_live_fire_test_of_the_3d_printed_glock_auto/>.

Ince, Darrel (Ed.). 2019. A Dictionary of the Internet (4th ed.) Available at Oxford Reference: <https://www.oxfordreference.com/view/10.1093/acref/9780191884276.001.0001/acref-9780191884276-e-292?>.

InRange TV. 2018. Facebook post. 20 March 2018. <https://www.facebook.com/inrangetv/posts/2170113519682253>.

Jenzen-Jones, N.R. 2015. 'Small arms and additive manufacturing: An assessment of 3D-printed firearms, components, and accessories' in Behind the Curve: New Technologies, New Control Challenges (King & McDonald, eds.). Geneva: Small Arms Survey. <http://www.smallarmssurvey.org/fileadmin/docs/B-Occasional-papers/SAS-OP32-Behind-the-Curve.pdf>.

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

Jenzen-Jones, N.R. & Jonathan Ferguson. 2018a. 'Weapons Identification: Small Arms' 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. 2018a. 'Weapons Identification: Other Small Arms and Light Weapons' 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. & Nathaniel Fitch. Cased Telescoped Ammunition: A Technical & Historical Overview. Research Report 7. Perth: Armament Research Services (ARES). <http://armamentresearch.com/wp-content/uploads/2020/01/ARES-Research-Report-No.-7-Cased-Telescoped-Ammunition.pdf>.

Johnson, Steve. 2011. 'Welcome to the Future: Print Yourself an AR-15 Magazine at Home!'. The Firearm Blog. 21 September <https://www.thefirearmblog.com/blog/2011/09/21/welcome-to-the-future-print-yourself-an-ar-15-magazine-at-home/>.

KARVER. 2019. 'The FOSS Chapter in the Meme Status of a Cheap Handgun'. The Kommando Blog. 22 November. <https://www.kommandoblog.com/2019/11/22/the-lo-point-foss-chapter/>.

Khan, Iqbal Ahmed, Megha Rani, Rupak Kumar Deb, & B.R. Bundel. 2019. 'Effect on Material Removal Rate and Surface Finish in ECM Process When Machining Stainless Steel-316 with Cu Electrode'. International Journal of Recent Technology and Engineering, Vol. 8, No. 4, pp. 2933–2941.

Koffler, Bruce. 1969. 'Zip Guns and Crude Conversions: Identifying Characteristics and Problems.' Journal of Criminal Law, Vol. 60, No. 4, pp. 520–531.

Kolbe, G. 2000. 'Making of a Rifled Barrel'. FirearmsID.com. July. <www.firearmsid.com/Feature%20Articles/RifledBarrelManuf/BarrelManufacture.htm>.

Kozak, Jerzy. 2011. 'The Effect of Electrochemical Machining on the Fatigue Strength of Heat Resistance Alloys'. Fatigue of Aircraft Structures, Vol. 1 (2011), pp. 57–63.

LBRY. n.d. 'Art in the Internet Age: An introduction to LBRY'. <https://lbry.com/what>.

Luty, P.A. 1998. Expedient Homemade Firearms: The 9mm Submachine Gun. Boulder, Colorado: Paladin Press. Available via: <https://archive.org/details/Expedient_Homemade_Firearms_9mm_Submachine_Gun_P_A_Luty_Paladin_Press>.

Mukherjee, S.K., S. Kumar, P.K. Srivastava & Arbind Kumar. 2008. 'Effect of valency on material removal rate in electrochemical machining of aluminium'. Journal of Materials Processing Technology, Vol. 202, No. 1–3, pp. 398–401.

Neal, Ryan. 2013. 'Blueprints For "Liberator", World's First 3D Printed Gun, Downloaded 100,000 Times in Two Days.' International Business Times. 9 May. <https://www.ibtimes.com/blueprints-liberator-worlds-first-3d-printed-gun-downloaded-100000-times-two-days-1248979>.

Northern Ireland Office. 2005. Guidance on Northern Ireland Firearms Controls.

NSW Police (New South Wales Police Force). 2013. 'NSW Police Commissioner Warns of Dangers of 3D Guns.' YouTube video. 23 May. <https://www.youtube.com/watch?v=9taL4svjH_g >.

Pérez, Pedro & Jonathan Ferguson. 2020. Black & Grey: The Illicit Online Trade in Small Arms, Ammunition, and Accessories in Venezuela. Perth: Armament Research Services (ARES). <http://armamentresearch.com/publications/>.

Pete. 2019. 'Can't Stop The Signal: DIY 3D Printed GLOCK Magazines'. The Firearm Blog. Digital edition: 19 July. <https://www.thefirearmblog.com/blog/2019/07/19/3d-printed-glock-magazines/>.

Potatosociety. 2019. 'Not named Beto but she will do'. Reddit forum post. Available at: <https://www.reddit.com/r/ar15/comments/d6kfg1/not_named_beto_but_she_will_do/>.

PSNI (Police Service of Northern Ireland). n.d. 'What is a Firearm?'. <https://www.psni.police.uk/advice_information/firearms/what-is-a-firearm/>.

Rauch, Matthieu, Emmanuel Duc & Jean-Yves Hascoet. 2009. 'Improving trochoidal tool paths generation and implementation using process constraints modelling'. International Journal of Machine Tools and Manufacture, Vol. 49, No. 5, pp. 375–383.

Reddit. 2020. 'Reddit's policy against transactions involving prohibited goods or services'. <https://www.reddithelp.com/en/categories/rules-reporting/account-and-community-restrictions/reddits-policy-against-transactions>.

Richer, J.D. 2019. 'I Talked with New Jersey's "Wanted" Ivan the Troll to Find Out if 3D-printed Guns Are a True Threat'. Foundation for Economic Education. 20 March. <https://fee.org/articles/i-talked-with-new-jersey-s-wanted-ivan-the-troll-to-find-out-if-3d-printed-guns-are-a-true-threat/>.

Rodriguez, Jeff. 2019. '#Liberator12k Music Video | Misirlou'. YouTube video: 6 March. <https://www.youtube.com/watch?v=EJKABc1vUEU>.

Sassen (Sassen Engineering). n.d. 'Button Rifling'. <http://www.sassenengineering.co.uk/products/rifle-barrels/button/>.

Shaw, Robert et al. 2017. Evaluating WMD Proliferation Risks at the Nexus of 3D printing and Do-It-Yourself (DIY) Communities. Middlebury, VT: James Martin Center for Nonproliferation Studies (CNS).

SMC. 2013. 'INCONEL® nickel-chromium alloy 625 (UNS N06625/W.Nr. 2.4856)'. <https://www.specialmetals.com/assets/smc/documents/alloys/inconel/inconel-alloy-625.pdf>.

Snider, Duke. 2003. 'AR15/M16 FAQs.' Bighammer. 4 March. <http://www.biggerhammer.net/ar15/cad/>.

SpaceX. 2014. 'SpaceX Completes Qualification Testing of SuperDraco Thruster.' SpaceX.com. 27 May. <https://www.spacex.com/press/2014/05/27/spacex-completes-qualification-testing-superdraco-thruster>.

Turton, William. 2018. 'Gun vloggers are flipping out at YouTube's crackdown on their videos'. VICE News. Digital edition: 23 April. <https://www.vice.com/en_us/article/9kg8v3/gun-vloggers-are-flipping-out-at-youtubes-crackdown-on-their-videos >.

U.S. (The United States of America). 18 U.S. Code§921. Definitions. Available at: <https://www.law.cornell.edu/uscode/text/18/921>.

Vishnitsky, A. 1987. 'Electrochemical rifling of gun barrels'. United States Patent US4690737A. Available at: <https://patents.google.com/patent/US4690737A/en>.

Vortakt. n.d. 'Barrel Blanks 101'. <https://vortakt.com/learn/barrel-blanks-101/>.

Warlow, T.A. 2007. 'The Criminal Use of Improvised and Re-activated Firearms in Great Britain and Northern Ireland.' Science & Justice, Vol. 47, No. 3, pp. 111–19.

Yankee Boogle. 2019. BitChute video. 27 December. <https://www.bitchute.com/video/BWWLfRW1j4hg/>.

www.armamentresearch.com
+ 61 8 6365 4401
contact@armamentresearch.com